Foreword

We are into the Sixth year of the formation of the Association for Cognitive Sciences, India and I am immensely honored to host the Annual Conference of Cognitive Science, 2019 at BITS Pilani, K. K. Birla Goa Campus. We have received participation in large numbers this year. Out of all submissions, the review committee has selected 33 submissions for oral presentation and 69 submissions for poster presentation. I would like to thank the Scientific Advisory Committee for reviewing the submissions.

Established in 2016 through the DST-CSRI project grant, the Cognitive Neuroscience Lab at BITS Pilani, K. K. Birla Goa Campus has a Philips EGI EEG Acquisition System with Net Station Acquisition Software and a Screen-Based Eye Tracker. Our research areas include Brain Computer Interface – Home Automation, Linguistics, study of Cognitive decline due to Neurodegeneration, Consumer Neuroscience. To know more, visit us at www.bitscogneuro.com.

I would like to thank the Department of Science and Technology, Cognitive Science Research Initiative, Government of India and Tobii for supporting this conference, and all the participants for showing rich enthusiasm towards Cognitive Science Research.

I would like to thank Prof. Harish Karnick and Prof. Narayanan Srinivasan for their unending support and guidance.

Finally, I would like to thank our Director, Prof. Raghurama G. for his continuous support and encouragement, The Department of Biological Sciences at BITS Pilani, K. K. Birla Goa Campus for their fervent enthusiasm and cooperation and the BITS administration for providing the beautiful infrastructure for this conference.

I welcome you to Goa and wish you a fruitful 3 days of learning and brainstorming.

Veeky Baths

Convenor, ACCS 2019

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Section I
Keynote Speeches

3D Processing and Cognition

Mr. Raghavendra Singh
Director of Computer Vision and Data Science
Oyla, Inc.

Our world is in 3D, however 99% of the deployed sensors are 2D. Stereo cameras give a limited depth perception, but 3D cameras that accurately measure depth continue to be expensive and also computationally difficult to process. In this talk, I will focus on different methods of sensing 3D, methods of processing 3D, and cognition of 3D data so as to make it more useful than the current 2D data paradigm.

WISER Neuromodulation of Brain Plasticity: Cognitive & Clinical Implications

Dr. Venkatasubramanian Ganesan
Department of Psychiatry
National Institute of Mental Health and Neurosciences (NIMHANS)

Brain plasticity plays a significant role in influencing cognition and clinical conditions. Contextually, there has been a recent re-emergent interest in plasticity modulation using a host of brain stimulation techniques that apply weak intensity electric current like transcranial Direct Current Stimulation (tDCS), transcranial Alternating Current Stimulation (tACS) and several others. This translationally relevant neuromodulatory paradigm may be conceptualized as “Weak Intensity Stimulation for Enhancement and Re-integration” or “WISER” paradigm. Modulation of brain plasticity using WISER neuromodulation techniques offers promising avenues to enhance cognition and thereby facilitating re-integration of disconnected brain in several neuropsychiatric disorders. Recent research advances strongly support immense potential for WISER neuromodulation techniques in adaptively modulating cognitive functions with significant clinical implications.

Componential Model of Reading (CMR): Implications for the Assessment of Instruction of Dyslexia and Related Reading Problems

Prof. R. Malatesha Joshi
Professor of Teaching, Learning and Culture
College of Education and Human Development
Texas A&M University

Literacy development may be influenced by various factors such as family background, classroom instruction, and type of orthography. Based on the findings, we developed a model called the Componential Model of Reading (CMR), which includes three components: cognitive component, which is based on the Simple View of Reading, psychological component, consisting of motivation and interest, and ecological component, which includes home environment, dialect, teacher knowledge, and orthography. In this talk, I shall present our research on literacy development based on CMR and how it can be applied to assess and instruct individuals with dyslexia and other related reading problems.

Gamma oscillations and SSVEPs as tools to investigate brain function in health and disease

Dr. Supratim Ray
Associate Professor
Center for Neuroscience
Indian Institute of Science, Bangalore

Brain signals often show intrinsic oscillations at “gamma” frequency range (30-80 Hz), which can be induced by presenting visual stimuli such as bars and gratings. Stimulus-induced gamma oscillations are modulated by high-level cognitive processes such as attention and memory and are abnormal in patients suffering from mental disorders such as Autism and Schizophrenia. An oscillatory signal can also be generated in the visual brain areas by presenting a flickering visual stimulus, which generates the well-known steady state visually evoked potential (SSVEP). Both gamma oscillations and SSVEPs provide ways to investigate neural processes underlying high-level cognition. In the first part, I will show that when two visual stimuli are presented at different flickering rates (a very common design in attention studies), the resulting SSVEPs interact in highly non-trivial ways. Using microelectrode recordings from awake monkeys, we try to understand the neural mechanisms underlying these interactions. In the second part, I will discuss how stimulus induced gamma oscillations and SSVEPs vary with healthy ageing in a large cohort of elderly subjects (>50 years), and in Alzheimer’s Disease.

Section II
Oral Presentation Papers

Revisiting the dual-process theory of cooperation: Intertemporal sensitivity interacts with time pressure to influence cooperation

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Abstract

The proximate mechanisms underlying cooperation have been recently studied extensively especially using the frame work of dual systems theory. One prominent question has been whether humans are intuitively cooperative, or if it is deliberate reflection that reins in our selfish impulses, thereby fostering cooperation. The Social Heuristics Hypothesis (SHH) proposed by Rand, Greene & Nowak (2012) posits that intuition promotes cooperation, but the evidence is inconsistent across studies. In the context of this variability in results across different labs and a failure to replicate (RRR, 2017) the study showing that intuition is linked to cooperation, we investigated cooperation under a time pressure manipulation in addition to exploring the effect of two other variables: global-local bias and temporal discounting. We hypothesized that individual differences might help explain the observed inconsistencies. The results once again failed to replicate the intuition-cooperation link but also showed a negative correlation between temporal discounting and donation amounts, especially in the time pressure condition. Our results highlight the importance of intertemporal impulsivity or self-control as a variable of interest in studying cooperation.

Keywords: cooperation, intuition, dual-process, public goods game, global-local bias, temporal discounting

Introduction

Cooperation has been conceptualised as a form of interaction characterized by shared undertaking for mutual gain, in which individuals incur personal cost for the benefit of others (Sigmund, 2010). Most psychological models have assumed, following the philosophical tradition of Hobbes epitomized as *Homo homini lupus* i.e "man is wolf to man", that humans are instinctively self-centered. It is deliberate, reflective control that is necessarily required to rein in these impulses, and thus realise cooperation and a peaceful community, which doesn't come naturally to us. In this view, rationality forms the source of morality.

However, decades of research in biology and psychology narrate a different story wherein sociality forms the natural core of human psyche. This impels prosocial acts and preferences which are routinely observed and are not even an aberration, thus demanding an investigation. Zaki & Mitchell (2013), argue that rather than a reflective model of prosociality, an intuitive model of prosociality is more plausible based on evidence from behavioural economics, cognitive neuroscience, and developmental psychology.

Rand, Greene, and Nowak (2012) tested the interplay of the dual processes: intuition and deliberation, on cooperative decision making by conducting a one-shot anonymous public goods game. Since they were one-shot and anonymous in nature, this meant concerns related to repeated interaction or reputation did not motivate preferences. They reported increased cooperation after forcing individuals in one condition to decide quickly (in less than 10sec) as opposed to the other condition (in greater than 10sec). Time pressure was thus used as a manipulation to induce intuitive decisions. They concluded that intuition promotes cooperation. The authors formulated the Social Heuristic Hypothesis (SHH) to explain this intuitive tendency to be more cooperative and the reflective tendency to make choices driven by self-interest. SHH suggests that social norms of cooperation are advantageous and adaptive in everyday interactions characterized by repetition and reputation. Thus, they are internalized in the form of automatic behavioral tendencies i.e as a social heuristic. The overgeneralization and misapplication of these adaptive intuitions is used to explain cooperative behavior in the laboratory even when there is no long-term strategic self-interest to cooperate.

However, the universality of intuitive prosociality is not undergirded by evidence. Tinghog and colleagues (2013), could not replicate an intuitive cooperation effect in three studies with samples of naive participants. Similar null results were reported by Verkoeijen and Bouwmeester (2014) calling for further detailed scrutiny of the theoretical relationship between intuition and cooperation.

The analyses in Rand et al's original study only included participants who complied with the time-condition instructions thereby excluding 50% of the participants (Verkoeijen and Bouwmeester, 2014). This can cause selection bias whereby systematic (individual) differences between participants rather than the random assignment to different experimental manipulation might cause artifactual significance in results (Bouwmeester et al., 2017). A replication study across 21 labs (Bouwmeester et al., 2017) sought to address this issue by adopting an intent-to-treat analysis in addition to compliant-only analysis. The former yielded almost a null or zero difference whereas a compliant-only analysis revealed a difference consonant with that found in Rand's original paper. The former null effect implies making causal interpretation imprudent, owing to selection bias (RRR, 2017).

In view of this variability in results across labs, our study sought to investigate if systematic individual differences could shed better light on the relationship between cognitive processes (intuition/deliberation) and choices in cooperation studies. We discuss two aspects that could be critical in influencing our decisions: global-local bias and temporal discounting.

Global-Local processing: Studies have shown that manipulating people's perceptual processing style to either a global or holistic processing style versus a local or analytic style can influence decisions (Mukherjee et al., 2018). They contextually changed attentional scope of participants either to broad or narrow processing through an unrelated perceptual task, and noted its effect on prosocial behaviour such as charity donations. They found that participants who performed a global processing perceptual task donated more than those who performed a local processing task. Thus, the authors suggested that scope of attention could be a plausible cognitive mechanism underlying prosocial behaviour. Thus we included global-local bias as one of the individual measures.

Temporal discounting: Curry et al (2008) found that individuals' rate of delay discounting (phenomenon that rewards decrease in subjective value as the delay associated with their receipt increases), hence self-control, are negatively associated (r = -0.27) with their contributions to the common resource in a one-time public goods interaction. They reasoned that people with preference for a future larger reward instead of immediate gratification would be more disposed to reciprocal altruism, or cooperation. Fehr and Leibbrandt (2011) found that those fishermen who demonstrated more impatience in the delay discounting tasks in the lab were more likely to over-exploit the common resource in a field-study.

Thus, in our study, we investigated whether measures on these attributes (global-local bias and intertemporal impulsivity) can potentially explain the inconsistent relationships between intuitive/deliberative processes underlying cooperation.

Methods

Participants

Participants were brought in to the lab in a group of eight at a time. Two hundred and one (97 males ; age range = 18 – 36 years) volunteers participated in the experiment. The study was approved the IERB of the University.

Stimuli and Procedure

Public Goods Game

Each participant was seated one of the eight personal computers on which they received the instructions for each task. Each participant was randomly assigned either to time-pressure or forced-delay experimental condition for a one-time interaction. Each subject was given Rs. 80 as an initial endowment (paid in actual money at the end) and was asked to choose how much to contribute to a common pool. The money contributed was doubled and split evenly among the four group members. To induce intuition, the instructions cued participants to decide quickly and choose within ten seconds in the time-pressure condition. To encourage greater reliance on reflective processes in the forced delay condition, the instructions prompted participants to wait and think for least ten seconds before making a decision.

Changes to RRR, 2017 paradigm: We followed the protocol developed for the multi-lab replication project of Bouwmeester et al., (2017) except that we made a few minor changes: (a) elaboration of instructions where calculations were involved, in the hope of increasing performance in comprehension checks; (b) with the aim of improving rates of compliance, we added a Compliance Incentivization Screen (before decision screen) of a fixed 15 second duration which informed the participants that they would not be eligible for payment if they did not follow the time-conditions (Isler et.al., 2017).

After their decision, participants answered two other questions to measure comprehension of the task. The *Qself* asked participants to indicate using a slider what level of contribution earned the highest payoff for them personally; whereas the *Qgroup* asked them what level of personal contribution earned the highest payoff for the group as a whole.

Intertemporal Choice Task

After finishing the first public goods task, participants did the Intertemporal Choice task, in which they had to make a choice between two monetary options. The options were between a smaller immediate monetary reward and another larger reward to be received after some delay period. There were 27 such options presented in a sequence and a choice had to be indicated at each option presented on screen to move to the next option. Kirby's 27-item Monetary Choice Questionnaires (Kirby et al., 1999) was used. The monetary choices were changed from dollars to rupees.

Global-Local Bias Task

An individual bias toward global or local information has often investigated with hierarchical stimuli, to adjudge whether a person takes sight of the trees or the forest as their default processing strategy (Dale and Arnell, 2009, 2013). Here, we used hierarchical shapes that each contained both a global and a local level. For the task, these hierarchical shapes were grouped into triads, such that each triad contained three of the hierarchical shapes. In each triad, one of the hierarchical shapes was designated the "standard" shape, and the other two were called the "comparison" shapes. Participants were required to select one of the bottom two figures in the triad that they believe best matches the top figure. Participants were encouraged to respond as fast as possible, and make instinctive choices.

Analysis and Results

Public Goods Game

In the main public goods task wherein participants were assigned in either of the two conditions, Forced Delay (N=101) and Time Pressure (N=100), an independent sample t-test (two-tailed) in the case of intent-to-treat analysis was done to find if the mean contributions differed in the Time Pressure (M=50.06, SD=25.30) and Forced Delay (M=50.11, SD=24.94) conditions. The difference did not reach significance, $t(199) = -0.01$, $p = 0.99$.

A compliant-only analysis (on 75.6 % of participants) was also done. Herein, those participants were excluded from analyses who did not follow the time prescriptions in the two conditions, i.e responded after 10 seconds in the Time pressure condition and responded within 10 seconds in the Forced Delay condition. This left us with 65 participants in the Time Pressure condition and 87 in Forced Delay for analysis. This was more than the number of participants in the Indian sample in the replication study (Bouwmeester et al., 2017). Again, an independent sample t-test (two-tailed) revealed no significant difference in the mean contribution in the Time Pressure (M=52.70, SD=25.42) and Forced Delay (M=49.85, SD=25.78) conditions: $t(150) = 0.68$, $p = 0.49$. Comprehension was 40% for personal payoff maximisation question (Qself) and 70% for group payoff maximisation question (Qgroup) indicating people appear to be significantly better at understanding the action required for group-payoff maximization. There was not any significant difference in the mean contributions of those participants who correctly answered the Qself comprehension check.

Global Local Bias

Correlational analysis of the amount of contribution and the global bias, independent sample t-test between the mean contribution of the two groups i.e locally (gl score <4) and globally biased (gl score ≥4), and two-way ANOVA with global-local bias and temporal discounting did not reveal any significant relationships between global-local bias, intuition-deliberation, and cooperation.

Intertemporal Discounting

Correlational analysis of the amount of contribution and the discounting rate irrespective of time condition (Time pressure/Forced Delay) yielded Pearson's correlation $r(199) = -.158$ ($p = 0.025$). Group-wise correlation revealed intertemporal discounting to be significantly negatively correlated with contribution only for people in time-pressure condition $r(99) = -0.213$, p=0.03. Independent sample t-tests and 2 x 2 ANOVA did not reveal any significant relationships between intertemporal impulsivity, intuition, and cooperation.

Discussion

Both compliant and intent-to treat analyses did not reveal a positive relationship between intuition/time-pressure and cooperation as initially posited by Rand's Social Heuristic Hypothesis (2012). This is evident from the lack of significant difference in mean contribution levels in the intuition and deliberation conditions, obtained from the t-test analyses. The intent-to-treat analyses results are consistent with those observed in the RRR(2017), wherein a difference of -0.37 percentage points (close to null) was reported. Additionally, even after addressing the time-prescription compliance issue, we still did not observe any significant results in favour of intuitive cooperation in compliant-only analysis too, contrary to Rand et al., 2012 and RRR, 2017.

However, poor comprehension levels (~40%) for personal payoff maximisation question and (~70%) for group payoff maximisation question is a cause of concern. Strømland et al. (2018) reported a time pressure effect only for participants who successfully answered the comprehension questions. Comprehension in Qself denotes an understanding of personal payoff maximisation in social dilemmas, required for deliberation to strategically override the intuitive prosociality in favour of rational self-interestedness in one-shot interaction, according to SHH. Thus accordingly, we compared mean contribution for those participants only, in both conditions, who answered correctly Qself. There was no significant difference between the mean contributions. Once again we find no evidence for intuitive cooperation. Thus, even after controlling for comprehension and compliance, our study did not find any evidence for a dual-process theory of cooperation. This is in line with emerging evidence that various intuition manipulations (time pressure, cognitive load, depletion, and induction) across multiple studies have failed to produce any statistically discernible effect of intuition on cooperation (Kvarven et al., 2019). The Social Heuristics Hypothesis stands unsupported by empirical evidence, thus far studied using the task used in current study.

One explanation could be that there is no internal conflict between intuition and reflection in the context of cooperation. Another important takeaway is the poor comprehension levels across studies including ours. 45.6% of participants in Rand et al's (2012) original study and 35.9% of participants in the multi-lab replication project failed the comprehension checks (Isler et.al., 2017). It could mean that economic games like prisoner's dilemma and public goods game are unsuitable or complicated paradigms to study social behavior like cooperation which occur in environments and social formats quite different from economic games in laboratories. Thus, future attempts to test the theory in more ecologically valid or simpler paradigms could provide a more resounding conclusion for the intuitive model of prosociality.

The registered replication report highlighted the possibility of systematic individual differences as a possible explanation for the variable relationship between cognitive processes (intuition/deliberation) and choices observed in cooperation studies across labs. In our study, we investigated measures on global-local bias and intertemporal impulsivity. In our analyses conducted so far, we have not found any result to suggest bias in perceptual processing style can influence cooperative choices. We did find a significant negative correlation between the discount rate and contribution regardless of time condition. This is consistent with previous studies (Curry et al., 2008, Fehr and Leibbrandt, 2011). The effect is present only in time pressure or intuition condition, and not deliberation condition. Future studies could investigate this relationship in other paradigms used to study prosocial behaviour.

To conclude, our study furthers the intuitive cooperation debate, by providing evidence in its disfavour. It also highlights the importance of intertemporal impulsivity or self-control as a variable of interest influencing cooperation among individuals.

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Effect of Perceived Control in Moral Dilemmas

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Abstract

Double-bind situations like the famous trolley problem have been extensively studied in moral psychology. According to the dual process theory, there are two types of dilemmas (impersonal and personal) which predominantly lead to different responses (utilitarian and deontological, respectively) elicited by the means of distinct processes (deliberative and intuitive process, respectively) (Greene et al., 2001). The objective of this study was to investigate the effect of perceptions of control associated with the permissible action in moral dilemmas. We examined whether the utilitarian action chosen over inaction was predicted by the level of perceived control and the type of dilemma (personal and impersonal). Forty nine participants participated in the experiment. Results of this experiment showed that both perceived control and the type of dilemma affect the decision to take a utilitarian action in dilemmas. Hence, we suggest that along with the type of dilemmas, the level of perceived control may be an important factor affecting responses in moral dilemmas.

Keywords: Perceived control; Moral decision making; Dual process theory

Introduction

In 2014,Dr.Kent Brantly caught the deadly and highly infectious virus Ebola when he was on a medical mission in Liberia. His chances of survival were extremely low unless he was returned to the hospice care back home in the United States. But returning him to his country posed a potential risk of starting an epidemic in the USA when there was no foolproof medicine to cure the disease. While some asserted returning the doctor was a moral duty of the government even though it would have risked spreading the infection, others argued that saving one while risking the lives of many to save one individual was a dangerous gamble.

Double-bind situations like this one have been extensively studied in moral psychology. In a typical moral dilemma paradigm, incidences like these are given to participants with two or more (but always limited) permissible actions with each action leading to some moral transgression. One such action is the deontological inaction, which endorses acting according to the irrevocable laws and duties that must be followed by all rational beings such as the no-harm principle This action is usually pitted against the utilitarian or consequentialist action, which is chosen when the goal is to maximize the total well-being resulted from it. Scientific inquiry in to which action is chosen when started with Joshua Greene's dual process theory model (Greene et al., 2001, 2004).

According to Greene et al.'s influential dual process theory, moral judgments are influenced by a rational, reflective process as well as a more intuitive, emotional process. Greene gave his participants moral dilemmas like the famous trolley problem and asked them to choose between a utilitarian action, and a deontic inaction. Utilitarian judgments were shown to follow deliberative reasoning while deontological responses were elicited by emotive reasoning. Another division has been proposed regarding the nature of utilitarian action permissible in the dilemma dividing them into two categories: personal and impersonal. Personal dilemmas involve serious bodily harm to a particular person or group, where the harm does not result from deflecting an existing threat. Impersonal dilemmas mean those problems in which harm is caused by the agent by means of something or someone (Greene, et al., 2009).

Though the personal-impersonal distinction has been defined and redefined over the years, Greene et al. showed that enhanced deontological reasoning is observed on personal dilemmas, supposedly as a result of increased emotional engagement. On the contrary, impersonal dilemmas elicit a utilitarian response as it is hypothesized to be evaluated by a more deliberative process. In summary, according to the dual process theory, there are two types of dilemmas (impersonal and personal) which predominantly lead to different responses (utilitarian and deontological, respectively) elicited by the means of distinct processes (deliberative and intuitive process, respectively). This was a remarkable and well-replicated finding (e.g., Greene et al., 2001; Starcke, et al.,2012).

However influential Greene's theory has been, this straightforward linking of a dilemma type to a distinct response has not gone unchallenged over the years (e.g., Bartels et al., 2011; Kahane et al., 2014). Research suggests that moral judgments are sensitive to factors outside as well as within the individual that can alter stereotypical responses on moral dilemmas. The objective of this study was to investigate one such important factor that can affect moral judgments: perceived control (PC). PC has been defined as the individual's belief in one's ability to exert control over situations or events(Lyet al., 2019). It is concerned with constraints that might facilitate or hinder an agent's understanding whether she can achieve an intended goal. We hypothesized that participants' tendency to take action as agents in such dilemmas will be sensitive to the level of control they perceive to have. We expected participants to take the action and demonstrate utilitarianism (like they would in an impersonal dilemma) when the perceived control is high. On the other hand, when perceived control is low, we hypothesized that participants will choose not to take the given action and be deontic, as would be expected in a personal dilemma.

Method

Forty nine participants (mean age: 22.4 years; 21 males) in the age group of 18-35 years Allahabad City participated in the study. The moral dilemmas were taken from the set used by Christensen et al. in their study (2014). Out of 46 dilemmas, 20 were used in the experiment and 2 were used in the practice session. (Refer to Appendix for sample dilemmas). Dilemmas were either personal or impersonal and had a permissible utilitarian action with either high or low PC associated with it. PC was manipulated by stating the chances of opposition associated with choosing to take that action. Participants were told to read the dilemmas carefully and respond as quickly as possible but no time constraint was set.

Results

The average number of actions taken per group are indicated in Table 1. As hypothesized, Impersonal+High PC recorded the maximum average of actions taken in 5 dilemmas (3.6122 out of a possible 5), while Personal+Low saw the least number average actions per person (2.4694 out of a possible 5). Interestingly, In the other two cases (Personal+High PC and Impersonal+Low PC), the former group recorded a higher average of actions.

Pair-wise comparison of Personal Dilemma+High PC and Impersonal Dilemma+Low PC was found to be significant (McNemar's Chi-squared = 17.082,p=3.579e-05001). Further, apart from responses on Personal Dilemma+High PC and Impersonal Dilemma+High PC there was a significant difference in number of responses recorded.

Table 1 Group Means (SD)

		Personal	Impersonal
Low PC	Mean (SD)	2.4694 (1.4734)	3.1224 (1.4088)
	Mean Percentage	49.39 %	66.53 %
High PC	Mean (SD)	3.3265 (1.5598)	3.6122 (1.4407)
	Mean Percentage	66.53 %	72.24 %

The RM logistic regression model showed significant main effects for both predictor variables, dilemma type (p=0.003699) and level of PC (p=0.000132). The odds of participant taking the action in impersonal dilemmas were 1.704275 or 70.43% more than in personal dilemmas. For high PC dilemmas, odds of taking an action were 2.037085 or 103.71% more than dilemmas with low PC.

Table 2 Odds Ratio and Percent Odds

	Coefficients	Odds ratio	Percent Odds
(Intercept)	-0.02449	0.97580745	-2.42 %
Dilemma	0.53314	1.70427534	70.43 %
PC	0.71152	2.03708528	103.71 %
Interaction	-0.26353	0.76833457	-23.17 %

Discussion

As suggested by the dual process theory, a preference for taking the given utilitarian action over inaction is observed when the given dilemma is impersonal. Interestingly, the odds of participants choosing to take the permissible action when the perceived control was high was 116.76% which is higher than when the dilemma was impersonal(7 7 . 0 3 %) .

Given that responses on Personal Dilemma+High PC and Impersonal Dilemma+High PC were not significantly different, but the difference was significant when Personal Dilemma+Low PC and Impersonal Dilemma+Low PC were compared suggests that personal-impersonal distinction may hold true only when the PC is low. Further, significant difference in responses on groups Personal+High and Impersonal+Low suggests that high perceived control is more likely to lead to choosing of the action than the dilemma being impersonal.

These findings are interesting as they cannot be explained easily by dual process models or theories (Greene et al., 2009). Further investigation into PC as a predictor variable of responses on sacrificial dilemmas is required along with other factors that may quantitatively influence moral decision making.

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APPENDIX

1. Impersonal Dilemma + Low PC

A runaway trolley is speeding down the tracks towards five workmen who will be killed if the trolley continues on its present course. You and a coworker are standing next to the tracks, but you are too far away to warn them. Next to you there is a control switch that can redirect the trolley onto a different track, where only one workman is working.

If you flip the control switch, it will divert the trolley onto the track with one workman and will not continue its course towards the five workmen. This will kill this workman, but it will save the other five. There is a HIGH CHANCE that your coworker will retaliate if you try to flip the switch.

Do you divert the trolley by flipping the control switch cause the trolley to run over one workman, so the trolley does not reach the five workmen?

2. Personal Dilemma + High PC

You are an inspector of a nuclear power plant. The plant foreman and you are visiting the facility when one of the supply conduits overheats. The emergency coolant system fails to activate, and a chain reaction which will result in a nuclear meltdown is about to start. This will release lethal radiation into the nearby town, killing thousands of people.

If you push the foreman onto the conduits it will release enough heat to prevent the nuclear chain reaction. This will kill him, but it will save you and the thousands of town inhabitants. There is a LOW CHANCE that the foreman will fight back if you try to push him.

Do you cool down the conduits by pushing the foreman down on them, so the nuclear chain reaction will be stopped in time for you and the thousands of people?

Affective Valuation of Gains and Losses of People's Lives under Risk

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Abstract: Many medical and policy decisions are based on affective valuation of other people's lives under risky situations. According to Prospect Theory, due to loss aversion, one would be risk-averse in the domain of gains (lives saved) and risk-seeking in the domain of losses (lives lost). Although medical trials have been ever increasing with advances in medical sciences, there is hardly any work on how lives of patients are valued under such risky trials. Using the structure of the 'Asian Disease' problem, two experiments were conducted on non-medical and medical populations. It was found that in the gain frame, risk-aversion is not always observed as suggested by Prospect Theory but is rather dependent on magnitude. In the loss domain, participants were always risk-seeking as per predictions from Prospect Theory. A more nuanced understanding of how lives are affectively valued will pave the way for future medical decisions, ethics and policy.

Keywords: Affective Valuation; Framing; Gains versus Losses; Risky choice; Loss Aversion; Risk-aversion; Utility of life; Medical decision making

Introduction

Contrary to the normative models in economics, cognitive psychological models based on reference dependence have significantly advanced the research in judgment and decision-making. One such instance is Prospect Theory (Kahneman & Tversky, 1979), which has been a hallmark development that changed the contours of decision research. It states that individuals depend on a reference point from which gains and losses are valued. The value function shows diminished sensitivity, and is concave for gains and convex for losses. The third, most important component is that the function gets steeper in the loss frame as individuals weigh losses more than gains because people are loss averse (Tversky & Kahneman, 1991). From these theoretical assumptions, Prospect Theory predicts that people should be risk-averse for gains and risk-seeking for losses. Extant research in the monetary domain has found evidences for these predictions, but some recent empirical evidences have also cast doubt because either loss aversion was absent or dependent on magnitude of stakes (Gal & Rucker, 2018; Harinck, Van Dijk, Van Beest & Mersmann, 2007; Mukherjee, Sahay, Pammi & Srinivasan, 2017). Clearing this confusion is vital as Prospect theory and its implications pan many areas like neuroeconomics, interface design, marketing, and policy among others.

We need to investigate other non-monetary domains to gauge the empirical evidence in light of recent confusions about existence of loss aversion. Beyond money, one immediately significant resource that is at the crux of our societies is lives of people. How do we affectively value other people's lives under risky situations? Do we show the same patterns with lives as with money when making affective valuations? Are these in accordance with what Prospect theory predicts?

For the first question, one of the early papers to examine how people value possible gains or losses of lives was by Tversky & Kahneman (1981). They used the context of an 'Asian Disease', where a cover story was about US preparing for the outbreak of an Asian disease that can claim many lives. Participants had to decide which program they wished to pick between two options where one had a sure outcome and the other was risky in terms of lives that could be saved or lost. The same information was presented to different groups of people after manipulating the frame (gains: possible lives saved versus losses: possible lives lost). They found that when the same information was framed with respect to gains, 72% of the participants favored the sure option but when framed with respect to losses, 78% opted for the risky option. The explanation for this observed data was due to the S-shaped affective value function in Prospect theory (or los aversion) as people would positively weigh a sure gain more than a risky gain prospect and negatively weigh a sure loss more than a risky loss prospect. This was one of the classic studies that started off a plethora of other studies on such gain-loss framing. Such framing effects had laid the foundation against the dominant utility models in economics and established Prospect Theory as a better explanatory theory of human decision-making. Note that Tversky & Kahneman (1981) did not vary the magnitude of lives at stake and plainly suggested that people would be risk-averse for gains and risk-seeking for losses. Diederich, Wyszynski & Ritov (2018) examined moderators to the Asian disease problem like disease type and need (magnitude of people affected). Though statistically insignificant, overall findings indicated that framing effects were stronger when more people's lives were involved. In the current study, we explicitly focus on magnitude given recent discrepancies about Prospect Theory in the monetary domain.

For the second question, a few studies in health economics (Bleichrodt & Pinto, 2000) have attempted to find affective value functions for one's own life and compared it with money. It was found that valuation of lives and money does not show the same affective function. Researchers found a concave pattern for lives when measuring disutility of losses, compared to a convex pattern for money. Further, the utility for gains of lives was almost linear as compared to a concave pattern in money (Attema, Brouwer & L'haridon, 2013). The study was however about valuation of own lives over time that is different from our question about valuation of other lives in general. Nevertheless, it suggests that the affective value function about health outcomes and monetary outcomes present themselves differently, thus further motivating more research.

For the third question, we need more evidence to reach a better conclusion. Either prediction from Prospect theory would be confirmed in this context or else the magnitude of lives at stake would induce differences in risk-aversion for both the domains of gains and losses against the standard predictions.

In the current study, the structure of the Asian disease problem was used but a new contemporary issue about prospective medical trials was used. In recent years, with the increasing number of diseases and advancement of science, we have seen a rise in the number of medical trials being conducted. Deciding about medical trials is a large issue that cuts across medical decision-making, public health, science policy and society at large. Relatives often need to decide about risks of patients who sign up for medical trials. Even common people have preferences of acceptable actions under these sensitive contexts. These decisions need to be seen from a strong sense of responsibility compared to monetary outcomes because risks with lives are indivisible and cannot be transferred. Two experiments were conducted on common people (non-medical students) and medical professionals (students at a medical school). The aim was to find empirical evidence to test whether people are always risk-averse for gain frames (lives saved) and risk-seeking for loss frames (lives lost) as predicted from loss aversion by Prospect Theory or are people's preferences flexible with respect to the number of lives at stake as predicted from the magnitude-dependent version of loss aversion.

Experiment 1

We first tested whether choices are consistent (risk-averse for gains and risk-seeking for losses) or dependent on magnitudes.

Method

The experiment was presented as a study on medical trials and was sent to random people who had studied in non-medical domains (e.g., engineering, sciences, arts) with a request to participate voluntarily. A total of 213 respondents (52.25% females, age range 18-35 years with 88.29% belonging to a range of 18-24 with some decent levels of self-reported proficiency in English: 30.63% expert, 62.96% comfortable, 4.50% intermediate, none at starter or low levels) completed the experiment. About half of them were presented with gain frames (n = 102) and others with loss frames (n = 111).

The instructions of the experiment entailed a cover story, in which the participants were told that different number of patients had signed up for various medical trials. They were further told that in such medical trials, there are two alternative medicines that have been developed to deal with diseases and has to be tested on different groups of people. The scientific estimates of the consequences are known and hence the outcomes of the trials can be predicted. Thus, the trials will be undertaken on different numbers of patients suffering from that disease and who have signed up for testing these two different alternative medicines at various kinds of hospitals. Both alternatives can cause serious side effects that can lead to death. Some groups of patients are more affected by side effects than others. For the sake of uniformity, the medical research committee kept a fixed probability of 1/3 for the efficiency of one drug. They were then presented with three different versions that varied on numbers of lives that are at stake along with the scientific estimates about its consequences. Their task was to decide which alternate between A and B they would have chosen to administer on the patients if you had to make a decision for the scenarios presented. This was very closely designed like the Asian disease problem used by Tversky & Kahneman (1981). Magnitude of lives was manipulated at three levels: 18, 402 and 912 and the order was randomly presented across participants. One group was presented a gain frame (people will be saved) while the other group was presented with the same information in a loss frame (people will die).

In the group presented with gain frames, the low magnitude version was for 18 people and presented as follows: "*About 18 people suffering from a disease signed up for a medical trial. Two alternative drugs have been developed to treat the disease. Assume that the exact scientific estimate of the consequences of the drugs is as follows: Drug A: 6 people will be saved and Drug B: 1/3 probability that 18 people will be saved and 2/3 probability that none will be saved*". The other version with a high magnitude of 402 people was similar except saying "*About 402 people suffering from a disease… Drug A: 134 people will be saved and Drug B: 1/3 probability that 402 people will be saved and 2/3 probability that none will be saved*". Finally, the highest magnitude version said "*About 912 people suffering from a disease… Drug A: 304 people will be saved and Drug B: 1/3 probability that 912 people will be saved and 2/3 probability that none will be saved*".

In the group presented with loss frames, the options given to choose were framed in terms of possible lives lost. For example, for 18 people, the options were *Drug A: 12 people will die and Drug B: 1/3 probability that none will die and 2/3 probability that 18 people will die*. Likewise for 402 people, *Drug A: 268 people will die and Drug B: 1/3 probability that none will die and 2/3 probability that 402 people will die*. For 912 people, the option were, *Drug A: 608 people will die and Drug B: 1/3 probability that none will die and 2/3 probability that 912 people will die*.

Participants had to choose between Drug A and Drug B. Note that the expected value was same between A and B in each but one was a sure option while the other was a risky option as in Tversky & Kahneman (1981). Further, the gain versus loss frames at each level of reference magnitude (18, 402, 912 people) presented participants with equivalent information as in previous studies.

Results

When data was condensed across all the three levels of magnitude, there was an overall pattern as predicted from Prospect theory with more number of choices for sure option compared to risky option in gain frames (202 vs 117) and less choices for sure compared to risky option in loss frames (111 vs 222); $\chi2 = 58.70$, $p < .001$. The same pattern was observed at each level of magnitude (For 18 people, $\chi2 = 15.02$, $p < .001$; for 402 people, $\chi2 = 17.344$, $p < .001$; for 912 people, $\chi2 = 27.39$, $p < .001$).

At the level of framing, for gain frames, risk-aversion was based on magnitude of lives at stake. At the low magnitude, there was no risk-aversion (18 lives: 55% sure vs 45% risky, $p = .496$), but there was risk-aversion at high magnitude (402 lives: 71% sure vs 35% risky, $p < .001$) and at the highest magnitude (912 lives: 68.87% sure vs 33.13% risky; $p < .001$). For loss frames, risk-seeking was observed at all levels: low ($p < .001$), high ($p = .022$) and highest ($p < .001$). A Stepwise logistic regression on choices with frames and magnitude as factors and participants as covariate found a model (Delta $\chi2 = 64.441$, $p < .001$) where frames was a predictor for choice (odds ratio = 3.714, 95% CI [2.673, 5.161], Z = 7.819, $p < .001$) and also another model (Delta $\chi2 = 8.313$, $p = .016$) where both frames and magnitude were predictors of choice (frames odd ratio = 3.784, 95% CI [2.715, 5.275], Z = 7.855, $p < .001$ and magnitude odds ratio = 1.740, 95% CI [1.158, 2.615], Z = 2.664, $p = .008$). This showed that there was an effect of magnitude in the gain frame (risk-aversion) such that no difference was observed for low magnitude but participants were risk-averse for high magnitudes. However, no effect of magnitude was observable in the loss frame (risk-seeking).

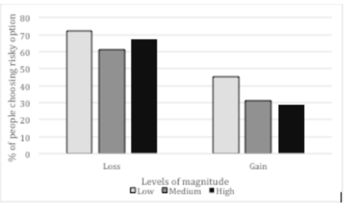

Figure 1: Proportion of choices showing risk-seeking in experiment 1 across frames and magnitude of lives

Experiment 2

Medical professionals need to consider various factors like the risk involved, probability of success and fatality of the disease when asking patients about volunteering for a medical trial. At times, medical professionals need to decide for patients and are hence empowered with the responsibility of making sound decisions. They need to be emotionally distant to act objectively, upholding the principles of their profession in accordance with their oath. We tested two kinds of diseases that varied on risk of fatality, which is a common concern for medical professionals during medical trials. Thus, we would assume such professionals would show limited gain-loss framing effects. Additionally, magnitude of lives at stake and the risk of the disease should play an even larger role. This implies: (a) we should not observe framing effect of gains versus losses among such professionals and (b) a magnitude dependent effect should be clearly observable.

Method

Both magnitude (low vs high) and fatality (low risk vs high risk) was manipulated within subjects by posing four questions that varied on both dimensions and was randomly presented to each participant. The experiment was posted online and requests to participate were sent to students of three medical and dental colleges. A total of 210 respondents (55.66% females, age range 18-24 years, medical students pursuing MBBS or BDS) participated voluntarily who were randomly allocated to the gain frame ($n = 105$) or loss frame ($n = 105$). The frames were similar to experiment 1. However, we specified the nature of the disease and also slightly modified the number of lives at stake because it had to be repeated. The four scenarios in both the gain and loss frames included the following: 18 people suffering from a disease with low rate of fatality (low magnitude & low fatality), 12 people suffering from a disease with high rate of fatality (low magnitude & high fatality) and 864 people suffering from a disease with low rate of fatality (high magnitude & low fatality), 870 people suffering from a disease with high rate of fatality (high magnitude & high fatality). High fatality would mean high stakes and hence this design also explicitly tested whether participants are sensitive specifically to magnitude or stake in general. As in experiment 1, one group was presented the information in gain frames (people will be saved) and another group in loss frames (people will die).

Results

Overall, participants were risk-averse in the gain domain (sure: 236 vs risky:184) and risk-seeking in the loss domain (sure: 154 vs risky:266), $\chi2 = 32.18$, $p < .001$. However, additionally, choices of medical professionals showed a specific magnitude-dependent effect along with sensitivity to the risk of fatality. Where the magnitude was low, no risk-aversion was observed and where the magnitude was high (and the fatality of the disease was high), participants showed risk-aversion. It was noticed that if overall stakes are low (for example, when the fatality was low but the magnitude of lives was high), no risk-aversion was observable. In the loss frame, more people preferred to be risk-seeking (although the pattern was marginally significant). While looking into why people might not have strongly preferred to be risk-seeking in the loss domain, it was noticed that some reasoned it is better to save as many lives as they could when the overall risk was very high (due to magnitude or nature of the disease).

Table 1: Proportion of choice (%) in experiment 2

Gain frame	Sure	Risky	Sign Test
Low mag, low fatality	45.71	54.29	$p = .435$
Low mag, high fatality	55.24	44.76	$p = .329$
High mag, low fatality	53.33	46.67	$p = .558$
High mag, high fatality	70.48	29.52	$p < .001$
Loss frame			
Low mag, low fatality	29.25	70.75	$p < .001$
Low mag, high fatality	39.62	60.38	$p = .031$
High mag, low fatality	38.68	61.32	$p = .025$
High mag, high fatality	42.45	57.55	$p = .078$

A stepwise logistic regression was done on choice (sure vs risky) with the predictors as frames (gain/loss), fatality (low/high) and magnitude (high/low) along with participants as a covariate. A significant effect was found for all the predictors (frames odd ratio: 2.242, 95% CI [1.696, 2.964], Z = 5.672, p < .001; fatality odd ratio: 0.683, 95% CI [0.516, 0.902], Z = -2.684, p = .007; magnitude odd ratio: 0.725, 95% CI [0.548, 0.958], Z = -2.264, p = .024.

We observed a clear framing effect of the same information being framed as gains versus losses. Critically, these results confirm those obtained in experiment 1 even among people being trained in medical sciences and show that we do not always observe risk-seeking for losses and risk-aversion for gains as predicted from Prospect Theory.

Discussion

Firstly, these results iterate some basic propositions forwarded by Prospect theory about valuations being subjected to framing of information in terms of gains versus losses. Given recent questions regarding the empirical evidence for loss aversion (Gal & Rucker, 2018), we need more evidence in various domains of valuation. The current results confirm the general prediction from Prospect Theory that stems from loss aversion: people are risk-averse in gain domains and risk-seeking in loss domains when lives are at stake. This adds support in favor of Prospect theory and the classic Asian disease problem (Tversky & Kahneman, 1981).

Secondly, the results also corroborate empirical evidences in favor of magnitude-dependent loss aversion that was studied in the monetary domain (Harinck et al., 2007; Mukherjee et al., 2017) highlighting some similarity between the affective utility of money and people's lives. Interestingly, when lives are at stake, the magnitude-dependence is observed in the gain frame (possible lives being saved) and not in the loss frame. This shows that the predictions from Prospect Theory are more consistent in the loss domain than gain frame. When possible gains are in sight, people are willing to take risks when stakes are low because possibly, losses do not always loom larger than gains; in contrast to what Prospect Theory would predict. This adds a much more nuanced understanding to the issue of valuing gains versus losses of lives. In addition, we also noticed in experiment 2 that the type of disease in question matters and people are sensitive to the risks while evaluating the stakes, supporting the results of Diederich et al. (2018). Overall, we need to revise the general idea that people are always risk-averse for gains and risk-seeking for losses (or even the idea that losses always loom larger than gains). Affective value functions are more contextual than thought earlier and hence requires a clearer prediction for future studies on this important aspect of valuing people's lives.

Thirdly, previous studies have shown that doctors use various heuristics that could limit their decisions (Blumenthal-Barby & Krieger, 2014; Slovic, Peters, Finucane & McGregor, 2005) and it is indeed worrisome that just like non-medical participants (college students in Tversky & Kahneman, 1981 and experiment1), future doctors also show such strong framing effects of the same information presented in terms of gains versus losses. At the same time, it is interesting to see that their preferences about prospective medical trials show magnitude-dependent risk-aversion depending on the lives involved which is a positive use of heuristic information processing by physicians (Marewski & Gigerenzer, 2012). On one hand, some more evidence was found contrary to standard prospect theory predictions about risk-aversion, and on the other hand, it showed critical thinking of future medical professionals. The reasoning and decisions of both common people and doctors about affective valuation of lives will influence medical decision-making, medical ethics, scientific innovation policies and public health.

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Testing a preference inference account of classic preference reversals

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Abstract

Different theories of decision making assume different sources of preferences for the choices we make. A recent theory has proposed that preferences are inferred from past choices in respective contexts, and that such preference inference offers a rational basis for the origin of classic preference reversals given certain sequences of observations. In this paper, we empirically test this theory for some of the classic preference reversals - the attraction effect and the compromise effect, through longitudinal preferential choice experiments. In this paradigm, participants provide their preferences for different choices occurring in different contexts throughout the experiment. Results indicate evidence in favour of a considerable attraction effect but are mixed for a compromise effect. We briefly discuss the theoretical implications of our findings and possible directions for future work.

Keywords: decision making; inference; preference reversals; attraction effect; compromise effect; longitudinal preferential choice experiment paradigm

Introduction

Decision making is a complex cognitive process that is inherently context dependent. As best described by Slovic (Slovic, 1995):

> "...decision making is a highly contingent form of information processing that is sensitive to task complexity, framing of the task, time pressure, response mode, reference points, and numerous other contextual factors..."

Different theories explain decision making from different perspectives and make different assumptions to explain the decision process. Descriptive theories such as the prospect theory (Kahneman & Tversky, 1979) explains how people make decisions under uncertain circumstances or under risk. Normative theories of decision making prescribes how people should make decisions (Hickson & Khemka, 2014) and posits that people choose options that maximizes their preferences. These preferences are often encoded as utility values, which are absolute numerical representations for preferences. Recently, it has been shown that living organisms, such as slime mold (*Physarum polycephalum*), use comparative valuation strategies rather than absolute valuation strategies, which require numerical value representations of preferences (Latty & Beekman, 2011). In any case, it is assumed that decision making is presupposed by existence of preferences. But the question of *where do these preferences come from?* has generally been avoided. Different models of decision making have their own set of assumptions that suggest different sources for preferences. The associative-value based model (Bhatia, 2013), a model influenced by MDFT(multi-alternative decision field theory), uses a feed-forward neural network, assumes associative connections between attributes and alternatives in a context and suggests that preferences are accumulated over the course of the decision time. The Bayesian model of context sensitive value (Rigoli, Mathys, Friston, & Dolan, 2017) assumes preferences are numerical values that arise from a precision-weighted prediction error and this naturally mandates feedback for the decisions made. Prior work (Srivastava & Schrater, 2012, 2015), has suggested that preferences are inferred from prior history of choices made in corresponding contexts and a model of decision making is proposed based on Bayesian learning that doesn't necessitate preferences being mapped onto numerical values. An immediate prediction of this theory is that preference reversals can be elicited by varying the frequency of comparison presentations of choices in appropriate contexts.

The aim of this paper is to obtain empirical evidence for the above prediction by testing for some of the classic preference reversals - the attraction effect and the compromise effect. The following sections describe the experiments done, their results and the scope for future work.

Methods

Different placements of decoy with respect to the target and competitor options result in different kinds of preference reversals (figure 5). In all the experiments, A was the target, B was the competitor and C was the decoy. A longitudinal preferential choice experiment paradigm was used (figure 1).

Attraction Effect

Phase 1 was divided into two blocks in experiment 1a and 1b. Participants were encouraged to take a short break between the blocks. They were asked for their baseline preferences after every five animations or trials.

Experiment 1a The attraction effect was first tested with stimuli having a single attribute. Each participant witnessed simulations of football matches between four teams - A, B, C and D. Block 1 consisted of sets of ten matches of A versus B and C versus D. Similarly, block 2 had sets of ten matches of A versus C and B versus D. The order of the sets within each block and the matches within each set were randomized. In phase 2, participants were asked for their final preferences in the form of the four choice sets containing two options each - {A or B} , {C or D}, {A or C}, {B or D}. The order of presentation of these four choice sets were also randomized. In the matches between A versus B, C versus D, and B versus D, both the teams win equal number of matches and the net

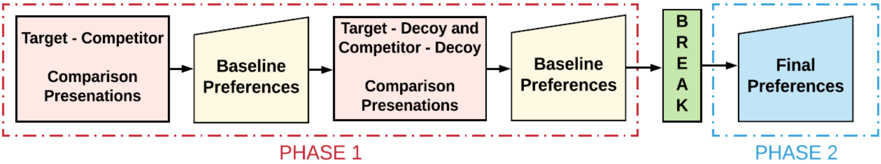

Figure 1: Longitudinal preferential choice experiment paradigm. In phase 1, subjects are shown all two-combination comparison presentations of target, competitor and decoy. Also, subjects are asked to enter their preferences frequently. These preference inputs constitute the baseline preferences or the initial preferences. Subjects are then asked for their final preferences in phase 2 with a compulsory break between phase 1 and phase 2.

goal difference is zero in total. A always wins against C in the matches between A and C, and A scores significantly more goals than C.

Experiment 1b Stimuli with two attributes were used. Each participant was shown animations of pair-wise horse races between four horses- A, B, C and D, along with food they consume after each race to get back the energy just spent. A frequency decoy was used. Block 1 consisted of sets of ten races of A versus B and C versus D. Block 2 had ten races of A versus C. The order of the sets within each block and the matches within these sets were randomized. Each participant was assigned randomly to one of the following two types of choice contexts: two option choice contexts or three option choice contexts. In either context, all possible combination of choices were presented and the order of presentation of the choice sets were also randomized. In all the blocks, the participants entered their preference in the form of bets on each of the horses involved in the choice set. For each bet, the participant could use a maximum amount of $100. In the pair-wise races of A and B, C and D, and B and D, both the horses win equal number of races and the net wins or losses are the same. A wins against C eighty percent of the time in the matches between A and C. In all of the races, the food stacks are either 4 or 6, but in any match, they are the same for both the horses involved. The speed difference between the winning horse and loosing horse was kept constant throughout the experiment.

Compromise Effect

Experiment 2 Participants were shown pairwise comparisons of performance in bench-marking tests of three computer configurations - A, B and C. The configurations varied with respect to two attributes - Graphics processing(GPU) performance and General purpose computing(CPU) performance. All the three types of phase 1 comparisons consisted of a set of ten tests of general purpose computing tasks and a set of ten tests of graphics processing tasks. The order of presentation of the sets of each of these comparisons and the tests within each set were randomized. After every set, participants were asked for their preference in form of preference points (instead of $) similar to experiment 1b. The participants were first shown bench-marking tests between A and B to determine the target and the competitor. A beats B six times and B beats A four times in the general purpose computing tasks. A beats B four times and B beats A six times in the graphics processing tasks. If a participant preferred A more than B, then B is the target, A is the competitor and C is the decoy. The dominant dimension would then be general computing task performance. Otherwise, A is the target, B is the competitor, C is the decoy and the dominant dimension is graphics processing task performance. Following this, the participants were shown target-decoy comparisons and competitor-decoy comparisons. In the target-decoy comparisons, the target wins seven times and the decoy wins three times in the dominant dimension. In the other dimension, the target wins four times and the decoy wins six times. In the competitor-decoy comparisons, the competitor wins eight times and the decoy wins two times in the dominant dimension. In the other dimension, the competitor wins 2 times and the decoy wins eight times. The order of presentation of the target-decoy comparisons and the competitor-decoy comparisons were randomized. In phase 2, the participants were asked for their final preference for A, B and C with the choice set containing all the three options.

Results

McNemar's test was performed with the counts of the number of participants choosing the target over the competitor before the introduction of the decoy and after the introduction of the decoy respectively as the discordant cells (see table 1).

Attraction Effect

Experiment 1a Fifty five students (graduate and undergraduate) participated in the experiment for course credit. A strong attraction effect was observed (figure 3).

Experiment 1b One hundred students (graduate and undergraduate) participated in the experiment for course credit. Forty two students were randomly assigned to two option final choice contexts and fifty eight students were assigned three option final choice context.

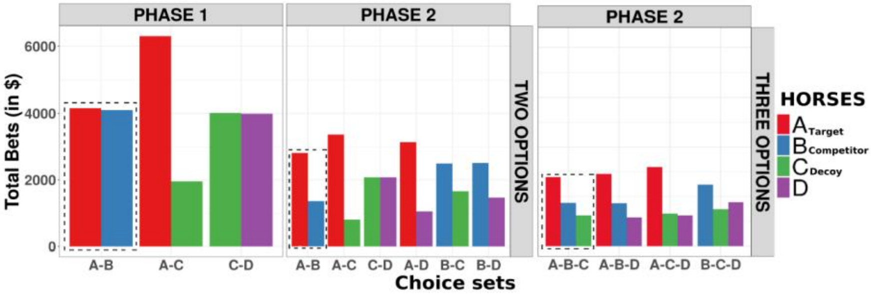

Figure 2: Results of experiment 1b. The first plot (from left) shows the participants' initial preference responses. The second and third plot shows their final preference responses when the choice context had two and three options each respectively. Note that initially, A and B are preferred almost equally. After the introduction of the decoy C in phase 1, A is preferred over B in the choice set containing $\{A, B\}$ or $\{A, B, C\}$ in phase 2, suggesting a considerable attraction effect.

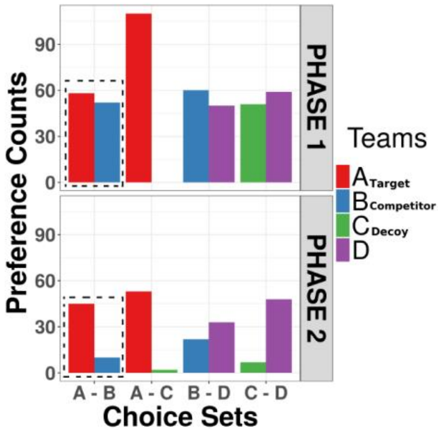

Figure 3: Results of experiment 1a. The first plot (from top) shows participants' initial preferences in block 1 and block 2. The second plot shows their final preferences. Note that initially, A and B are preferred almost equally. After the introduction of the decoy C in phase 1, A is significantly preferred over B in the choice set containing $\{A, B\}$ in phase 2, indicating a strong attraction effect.

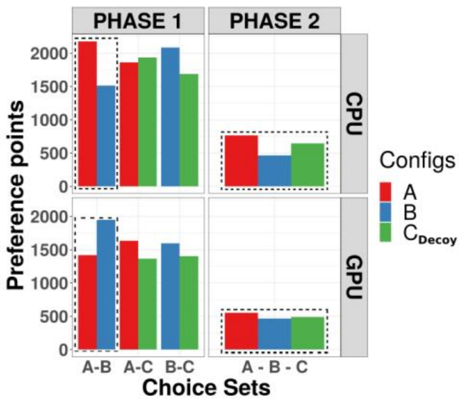

Figure 4: Results of experiment 2. The first row on the top corresponds to the case when CPU performance was the dominant dimension. The second row corresponds to the case when GPU performance was the dominant dimension. The first plot (from left) in each row shows the participants' initial preference responses. The second plot in each row shows their final preference responses when the choice context had three options.

Both the conditions failed to achieve statistical significance even though, the preference share for the target increased considerably compared to the competitor in phase 2 (figure 2).

Compromise Effect

Experiment 2 Thirty four students (graduate and undergraduate) participated in the experiment. A significant compromise effect was observed when the dominant dimension was graphics processing performance but the effect was not observed when the dominant dimension was general purpose computing performance (figure 4).

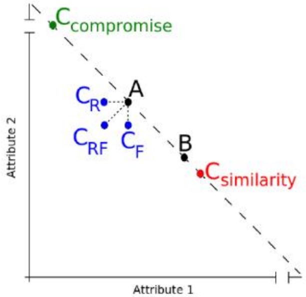

Figure 5: Different placements of decoy C, when A and B are the target and competitor options respectively. A is better in one attribute dimension, B is better in the other attribute dimension and there is no strong preference for either of them initially. In the case of the attraction effect, C could be a range decoy C_R or a frequency decoy C_F or a range-frequency decoy C_{RF}. In the case of the similarity effect, the decoy $C_{similarity}$ is slightly different from and is equally attractive as the competitor option. In the compromise effect, the decoy $C_{compromise}$ is an extreme option and it makes the target option appear as a compromise between $C_{compromise}$ and B. In all cases, the introduction of the decoy increases the preference share of A compared to B (Trueblood et al., 2013).

Discussion

While a substantial attraction effect was seen, the results were inconclusive for the compromise effect. Nevertheless, the direction of preference change towards the target option suggests that prior history of choices is one variable that can influence preferences. We note that the original model we are testing (Srivastava & Schrater, 2012, 2015) doesn't predict a compromise effect if the decoy is placed on the line (figure 5) and hence, it inherently requires such an asymmetry in the placement of decoy. The amount of decoy asymmetry and extremeness needed to elicit a strong compromise effect through this paradigm remains to be investigated. Also, the cover story of experiment 2 is from a very familiar domain for the participants. It remains to be seen whether the differential elicitation of the compromise effect might be because of participants' priors on the domain.

Experiment	Discordant Cells		p-value
	Before: T>C	After: T>C	
1a	11	45	5.38×10^{-6}
1b (Two)	18	26	0.2912
1b (Three)	25	36	0.2004
2 (CPU)	0	4	0.125
2 (GPU)	0	12	4.883×10^{-4}

Table 1: Columns 2 and 3 show the number of subjects who chose Target(T) over Competitor(C) before and after the introduction of the decoy respectively.

Typically, in the preference reversal literature, multi-attribute choices are presented to the participants with numerical values along the attribute dimensions and if the stimuli are perceptual, participants are asked for their preference on the same trial, thereby obviating any scope for inference from past choices. We demonstrated a novel experimental paradigm for preferential choice experiments. Participants were shown evidence of relative superiority of choices in different contexts along various attribute dimensions without resorting to presentation of numerical values along those dimensions. Based on the such a history, the participants supply their preferences for different choices frequently throughout the experiment. Our results suggest that preference inference is a realistic explanation for the occurrence of classic preference reversals.

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In Defense of Jñānalakṣaṇa Pratyakṣa

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Introduction:

This paper intends to present empirical evidence in favour of a particular form of perception named cognition-induced extraordinary perception (*jñānalakṣaṇa alaukika pratyakṣa*) admitted in Navya Nyāya tradition which is a realist Indian Philosophical school. They have analyzed such cognitive phenomenon through a series of psychological steps and used this mechanism as a hypothesis in order to explain illusion. The opponent Indian schools have rejected the possibility of such perception upon speculation. But cognitive neuroscience proved the existence of such a psychological and neurophysiological phenomenon that supports *jñānalakṣaṇa*.

Method and Implication:

The paper is a meta-level discussion regarding the plausibility of such hypothesis, hence is based on literature review. The implication of this discussion is that, once proved, the hypothesis of *jñānalakṣaṇa* can be used to design cognitive models for explaining several cognitive phenomena such as illusion, recognition and subsequent perception of cognition.

Cognition-induced Extraordinary Perception:

In Navya Nyāya tradition we find a reference of a special kind of perception named *jñānalakṣaṇa alaukika pratyakṣa* (cognition-induced or memory-driven extraordinary perception). Here the term '*alaukika*' does not mean something mysterious, but refers to a special psychological mechanism. The paradigmatic example of *jñānalakṣaṇa* is to 'see' fragrant sandal from non-smellable distance through eyes. Seeing a piece of sandal-wood from a distance, we may obtain a perceptual cognition in the form

'Here is a piece of fragrant sandal-wood' (*surabhi candanam*). The fragrance is neither smelt nor recollected here, since it is immediately felt to be seen. But there cannot be normal sensory connection between fragrance and the eyes. The Nyāya explains that through memory-driven non-physical contact we 'see' fragrance. Vision of sandalwood vividly revives the memory of previously smelt fragrance which presents its content to the visual sense-organ. This mechanism of sensory connection is adopted to explain four other epistemic situations – recognition, subsequent mental perception, perception of the negatum of an absence, and most importantly illusion. In the case of say rope-snake illusion the vision of rope revives the memory of snake so vividly that the memory lends its content to the visual sense-organ.

The opponents say that if we admit it then *pratyakṣa-pakṣa-anumiti* will become redundant where we infer an (unperceived) object, say fire, in a perceived locus, say hill, observing a sign, say smoke. The perception of smoke in a hill will energize the memory-trace of fire. And the memory, working as memory-driven extraordinary sensory connection, will connect its content to the operating sense-organ. In reply to this objection the Naiyāyikas would say that for such kind of perception the memory-content has to be revived at a certain level of vivacity. If not, inference will follow, where a logical implication in the form of 'this-therefore-that' is involved. So, causal condition for perception and that of inference are different from each other. Most importantly, such kind of perception is a psychological and empirical phenomenon which cannot be rejected upon speculation.

Empirical Evidence: Synaesthesia

We do have empirical evidence in support of the hypothesis of *jñānalakṣaṇa*. There is a clinically recognized psychological phenomenon, called synaesthesia, which proves the possibility of cross-modal perception. Synaesthesia is a curious condition in which an otherwise normal person experiences sensations in one modality when a second modality is stimulated, in the absence of any direct stimulation to this second modality. In such neurologically based condition, a particular tone, for example, may also evoke a vivid perception of a specific colour (C-Sharp may be blue) or the person may see any given number as always tinged with a certain colour ('5' may be green, '6' may be red). There are different forms of synaesthesia, such as number → form synaesthesia, sound → colour synaesthesia, lexical → gustatory synesthesia, taste → touch synaesthesia etc.

It has been proved through several experiments that synaesthesia is a genuine cognitive phenomenon. fMRI and PET scan results show that when the synaesthetes perceives achromatic alphaneumerals, the colour area of their brains, such as hV4, are activated. But even after extensive training, imagination of such experiences does not produce such scan results. Hence it is not an instance of hyperactive imagination. Colour actually is seen. Researches have shown that those special persons can associate specific grapheme with specific complex colours, and even after years, they report about the same associations accurately although they were not given any previous clue about the retest. So the phenomenon is not a confabulation with the help of memory. It is truly sensory. When presented a field of green dots with a shape made of red dots in it, everybody can instantly see the red shape. The grapheme-colour synaesthetes experience the same thing with numbers or letters. For this reason they can perform far better in finding specific numbers or letters in a matrix of other letters. For them those specific letters pop up as having specific colour. Stroop interference test, crowding effect, McCollough test etc. prove this phenomenon as a genuine one.

Cross-Activation Hypothesis:

There are several alternative theories which explain the phenomenon neurophysiologically. The most popular one is the Cross-Activation Hypothesis, which says that due to a defective pruning process, adjacent areas in the brain may be cross connected in such a way that activation in one module of the brain may stimulate other module resulting in a vivid experience of the second modality. The amazing finding in this matter is that the colour area in the brain (V4) is anatomically adjacent to the visual grapheme area in the brain. Recognition of visual numbers and visual words depends on the fusiform gyrus (especially left) and that this visual 'word-form area' lies directly adjacent to the 'colour area' V4.

Hence, grapheme → colour synaesthesia is caused by a cross-activation between these adjacent brain maps. Other types of synaesthesis have also been explained in similar ways.

In the immature brain, there are substantially more connections between and within areas than are present in the adult brain. Some of them are removed afterwards through a process of pruning. The presumption is that if this process (apoptosis) of slimming down is hampered due to some genetic mutation, connections may persist between areas such as between grapheme area and V4 leading to synaesthesia. Even for the non-synaesthetes, the walls between our senses are not as solid as they appear. It is possible to induce the sensation of taste simply by changing the temperature of small areas on palate. Warming front of the tongue 20-35ºC creates a mild but clear sweet sensation. Cooling the same area resulted salty taste.

Parallel between Jñānalakṣaṇa and Synaesthesia: A Conclusion

So far we have described synaesthesia as a purely sensory phenomenon but in we deploy abstract qualities or concepts or the contents of memory. Here we can say that in *jñānalakṣaṇa pratyakṣa* there occurs a conceptual association through memory and the degree of vividness of that concept is increased to that extent due to the operativeness of the sense-organ (i.e., due to the energization of the proximal sensory nerve stimulation) that it becomes a percept. In the experiment with Navon-type hierarchical figures it is proved that in synaesthesia there is top-down influence or the influence of the application of concepts. Besides sensory cross-activation, Ramachandran (2005) also found synaesthetic instances of conceptual cross-connection which he names 'higher synaesthesia'.

Secondly, synaesthetic experiences occur in a limited group of people whereas *jñānalakṣaṇa pratyakṣa* is a universal cognitive phenomenon. Here we can say that it has been neuroscientifically proved that multi-modal information processing is a universal phenomenon. Multisensory areas of the brain are those areas where two or more senses converge. Cross-modal object recognition exploits those multimodal areas.

That our perception in one modality is guided and modified by the other modality through multimodal area has proved by McGurk. And it is a universal phenomenon.

From the aforesaid observations, we can say that the basic claim of *jñānalakṣaṇa* is not an absurd one. It is possible that one sense-modality can stimulate another sense modality either through purely sensory association or through the content of memory. In the cases of higher synaesthesia there occurs abstract concept → percept bondage. More diffusedly there may be a percept → memory image bondage where memory images are energized through a hyper-connective cross activation to such a degree that reaches the vividness of percept. It happens in the cases of illusion and dream.

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It is true that our brain does not 'store' a particular concept in a particular region of brain. Although the content of memory is encrypted in ionic formation in the chemicals of nerve-cells, it is not the case that a particular memory is stored in a particular place of the brain. It has been found that they are stored in a network of neurons. The whole network is activated when we energize the memory or the concept. So, what was possible for sensory contents (because there are particular regions of brain devoted for specific brain-regions) may not be possible in the case of concepts. However, concept is produced as the result of abstraction - may be from sensory information received from different modalities. And in the multisensory areas in the brain such as superior temporal sulcus (STS), temporo-parietal occipital junction (TPO junction), Superior Colliculus (SC) etc. such multimodal concepts are formed. And through these areas concept → percept bondage, or percept → memory image bondage retains.

It is a fact that during object recognition we, the common people, often depend on multi-modality. The existence of such universal multi-modal task had been recognized even in Nyāya tradition. It is named '*pratisandhāna*' where seeing an object we recognize it as the same object that we previously touched (or simultaneously touch). The neuroscientists intend to seek the brain areas where such integration of multimodal information happens. Whatever may be the case, if there are such multi-modal concepts unifying different modal information then activation in one portion will energize the other portion of the concept.

The question is how information from different modalities combines to form a single multisensory representation of object. For this, the information must be encoded in a similar manner for all modalities – which assumes a functional equivalence among the modalities. For example vision and haptic information can both be seen as image processing systems – therefore amenable to similar functional descriptors. Loomis and others have shown when the spatial band-width of vision is reduced to that of haptics then letter identification performance is equivalent across both senses. To study these and other measures, we can use EEG, MEG, PET and fMRI techniques.

In humans, an area known as the lateral occipital complex (LOC) within the occipito-temporal part of the cortex has been found to respond to visual objects defined either by, motion or texture or luminance contrast using fMRI techniques. LOC is crucial for visual object recognition. Now, is it involved in multisensory object recognition? Amedi, Malach, Hendler, Peled and Zohary (2001) conducted a cross-modal recognition study using fMRI. Participants were presented with four different stimulus conditions, two visual (seeing objects or textures) and two haptic (touching objects or textures). The authors found significantly higher activation for object recognition relative to textures in the occipito-temporal areas and this effect was independent of sensory modality. Data suggests that LOC area is involved in cross-modal recognition, either by integrating information from the two senses or by representing haptic information about an object in a visual code for recognition.

Hadjikhani and Roland (1998) used PET to measure brain activation while participants performed a within-modality or cross-modality shape-matching test. In the conditions involving cross-modal transfer the authors found activation in the relevant sensory areas but also in the Claustrum. This area may play an important role in cross-modal matching because multisensory cross-modal projections stem from, and are projected to, the Claustrum. James et al. (2002) reported the effects of haptic priming on visual object recognition by measuring fMRI activation. They suggested that the ventral pathway is a generic object representational subsystem, such that, objects that are encoded haptically are then represented in terms of a visual or multisensory code. If higher visual areas are involved in multisensory object recognition, then damage or TMS to LOC should impair visual and haptic object recognition. Saetti, De Renzi and Comper (1999) described an individual with tactic agnosia whose performance was impaired on haptic recognition but was intact for tactile matching and tactile imagery. His right occipital lobe was damaged including lateral convexity and damage to the inferolateral part of the left occipital lobe extended to the posterior temporal cortex. His tactile discrimination of orientation also was impaired.

Active haptic exploration of an object makes different parts of the object visible. This way, through an interaction between haptic and visual processes, a rich view-independent representation is created in memory – thus solving constancy-problem. Convergence of information from complimentary sense-modalities makes a more complete representation about the object. Recent studies suggest that both the visual and haptic systems can create a representation of an object that allows common access across these modalities (Reales, Ballesteros, 1999; Easton, Srinivas, Grenne, 1997). The efficient interaction between different modalities depends on the fact that the same object is perceived. When there is ambiguity, one modality dominates. When visual information overrides, the effect is called ‘visual capture’. However, Heller (1992) says that vision is not always dominant. In the cases like judging ‘roughness’, touch dominates. Easton, Srinivas, et al. (1997) suggest that object representation across vision and haptics are not necessarily combined, but are mediated by imagery. But this is task-dependent: haptic exploration of weight and temperature require no ‘visual translation stage’ and ‘image-mediation’. In order for information to be shared across modalities, these different modalities should organize information using common principles and be functionally equivalent. These experiments suggest that multisensory areas of the brain are crucial for concept-percept or percept-memory bondages.

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Nonhuman Minds, Cognitive Epistemology, Cognitive Science

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This paper proposes to make arguments for the involvement of phenomenal consciousness in certain kinds of knowledge acquisition and decision-making by nonhuman primates. We particularly argue that when individual female bonnet macaques *Macaca radiata*, a species endemic to peninsular India, acquire social knowledge of their group members and subsequently take certain decisions during triadic allogrooming interactions (Sinha 1998, 2017), it is theoretically feasible to invoke conscious awareness in these individuals. We first consider arguments made in favour of theories that conceptualise cognition without phenomenal characteristics. We then examine the main objections to such theories raised by cognitive phenomenology and finally, attempt to explain the above-mentioned decision-making processes in bonnet macaques in terms of cognitive phenomenology.

In cognitive science, a particular position argues for an understanding of cognition without the attribution of phenomenal states. In other words, a strong suggestion is made that cognition is possible even without the appearance of phenomenal states. The mind can then be considered to consist of two differentiated domains: one purely cognitive, which characteristically includes beliefs, propositional attitudes or mental states and the other, purely sensory, incorporating, within it, phenomenal awareness. Thus, even if a macaque is considered to have a cognitive capacity to hold certain beliefs, it would not necessarily mean that such a macaque is also phenomenally conscious. This view can, however, be challenged by the theory of cognitive phenomenology, which argues that phenomenal states are absolutely essential for cognition to be effective. The theoretical divide between cognitive mechanisms and phenomenal experience thus becomes obsolete during the actual workings of cognition in real life. This position also argues that any explanation of cognitive processes remains virtually incomplete if it does not consider the phenomenal aspects of conscious awareness.

Sinha (1998, 2017) notes that female bonnet macaques may be capable of successfully evaluating the social relationships among other group females and possess egotistical knowledge of their own positions, relative to those of others, in the social dominance hierarchy. These individuals, Sinha argues, may thus be able to abstract and mentally represent their own personal attributes as well as those of other members of the group. Furthermore, bonnet macaques seem capable of recognising that other individuals have beliefs that may be different from their own, potentially manipulating another individual's actions and beliefs in a variety of social situations, and selectively revealing or withholding information from others during acts of tactical deception. From these observations, Sinha concludes that such an ability to develop belief systems and form mental representations, generated by direct personal experience, is indicative of a rather early evolutionary origin for fairly sophisticated cognitive capabilities, characterised by an objectified self with limited regulatory control over more subjective levels of self-awareness, in these cercopithecine primates, pre-dating those of the great apes.

What Is crucially important to note here is that the subjective awareness invoked in these individuals is experiential in nature or, in other words, the subject bonnet macaque may be aware of its own self and may develop mental representations that allow it to successfully perform certain cognitive functions. Yet mental representations need not necessarily have a phenomenal characteristic to them if one alternatively conceptualises such representation in purely cognitive terms. A computer, to consider an analogy, may thus be able to compute large sets of data but not necessarily 'feel' a certain way while conducting these calculations. We, however, argue that it may be perfectly legitimate and feasible to include specific arguments from cognitive phenomenology in order to claim that Sinha's macaques might be phenomenally conscious when confronting critically important social decisions. In this paper, we thus propose to specifically analyse, both philosophically and logically, the arguments presented in favour of and against two opposing claims, those made by cognitive phenomenology on one hand and those of cognitive science, which invokes cognitive mechanisms alone, on the other. The claims made in our paper, especially with regard to phenomenal consciousness in nonhuman primates, we believe, have important implications for philosophical and empirical studies of nonhuman minds, cognition and consciousness, as also for the uneasy, often exploitative, relationships that we share with most nonhuman species.

Studying the structure matching thesis of time-consciousness through perceptual switching

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Abstract

Time as a property has been argued to be present both in content of experience and the mechanisms that bring about temporal experience. Theories with these foundations can explain experience of time through content. One such theory comes from coherence intervals, which states that in the absence of coherence, felt time is not registered. Thus, when perceptual mechanisms are in transient, there would be shortening of felt time. We tested this prediction asking participants to make estimates of time while viewing a Necker cube. In half the trials, we increased the propensity of the Necker cube switching to another face from the one which participants were voluntarily holding. We report shorter estimates of time for these trials where the propensity for perceptual switching is more, in line with prediction from coherence intervals. Moreover, we show that these results are more likely to occur only within a specific time scale, that is approximately within one second.

Keywords: Time consciousness, structure matching thesis, time perception, coherence intervals, perceptual switching

Introduction

One reason that makes studying time in cognitive science fascinating is that it is the only property of consciousness, which does not follow the content-vehicle distinction. Time is the only property of consciousness that is present in experience and structure of experience. This is not true for any other property, say when one experiences colour, one's experience is not coloured but only of colour. This commonality of both vehicle and content sharing temporal properties is called the "structure matching thesis". (Watzl, 2012). This thesis is not without controversy and not everyone agrees with this postulate in both cognitive neuroscience and philosophy.

In the context of conscious perception, there is a centuries old debate still persisting as to whether perception is discrete or continous. Whether we experience time from very small or duration-less frames (VanRullen and Koch, 2003) or whether our experience of time is so because consciousness itself is temporally extended (Dainton, 2000). This extension of consciousness in time is called the specious present, a block in which updated content is experienced every half second or so.

The discrete perception camp usually follows the metaphor of cinematic realism while the continous perception theorists employ extentional and retentional frameworks (for a full review see Dainton, 2010). Both of these theories put forth empirical findings, which the other finds difficult to explain. For instance, discrete perception arguably better explains illusions like phi phenomenon and apparent motion (Herzog et al, 2016).

As part of the middle ground, some have argued that conscious perception is neither discrete nor continous, but rather periodic (VanRullen, 2016). While these theories have done a significant job in explaining illusions that occur in time (phi phenomenon, wagon wheel illusion, launching effect), they have little to say about time as a dependent variable. This is mostly because discrete and periodic theories of consciousness deny the structure matching thesis and thus by default cannot explain felt time as a function of content.

One theory based on the extentional philosophical model of time consciousness that accepts the structure matching thesis and tries to explain under one framework both effects of time as dependent and independent variables is based on 'coherence intervals' (Van Leeuwen, 2007). The idea is that felt time is only registered for moments where there is coherence between brain regions. The inspiration here comes from the concept of chaotic attractors. Imagine a chaotic pendulum that dwells in two states for uneven, asymmetric amounts of time. Coherence interval would state that when the pendulum is in transition between state A to state B, since there is an absence of coherence, there will be an absence of felt time.

A psychological example of this comes from the Necker cube; a bi-stable figure with two possible states. Participants report that when the cube 'switches' from one orientation to the other, that these switches seem to occur instantaneously in time. However, neurological and psychological evidence shows that it actually takes approximately 50ms for the faces of the cube to appear switched (Poppel, 1997). This is argued to follow the prediction of coherence intervals, where when the system is switching between the two faces and is at a transient, felt time is absent.

Thus, it remains an open question whether switches in perception using bi-stable stimuli would lead to smaller estimates of judged time compared to trials where switches are absent. Moreover, what is the boundary condition in time for coherence intervals to apply? That is for what duration of time would trials with switches be reported as shorter. We hypothesized that if coherence intervals thesis holds then trials in which there is a perceptual switch should have smaller estimates of time, for duration block of one specious or two overlapping specious presents (from extensional theory of specious present), i.e., at durations of 500ms and 1000ms. To test this, we used two durations within this boundary (400 and 800 milliseconds), and two durations outside this boundary (1200 and 1600 milliseconds).

Method

Participants

A total of 23 participants completed this study. Before the main experiment, a training session was conducted in which participants were introduced to the task of following and judging time of a rod. Participants were asked give reports of time for four durations, deviance from the objective time did not matter. We checked to see if people are able to tell that the four durations are different from each other. None of the participants failed this exclusion criteria.

Apparatus

Participants sat in a dimly lit room. The stimuli were presented on a 17inch 100Hz CRT monitor and participants sat approximately 55cm away from the display. For the response participants used the number pad section of the keyboard. OpenSesame a Python based software was used for stimulus presentation.

Stimuli

In the main experiment, for the perceptual switch we used a bi-stable figure; the Necker cube. Each trial started with participants voluntarily holding one face of the cube as forward looking. On their keypress a rod passed across the screen. Left to right or top to bottom. The rod could either violate or maintain the geometry of the cube. The rod passed at four different speeds, thus taking four different durations (400,800,1200 and 1600ms).

Procedure

Participants were told to track a passing rod across the screen and report the time it took to cross the screen. They were asked to start each trial by voluntarily maintaining a particular face of the cube in their perception. As soon as they started a trial, a rod like object passed across the screen. This rod could take four different durations to do so (400, 800, 1200, and 1600ms). This rod then could violate or maintain the geometry of the face being held, passing "above" or "behind" the face being held. Both the faces of the cube were used as the initial starting point for each participant. This was done using instructions in counter-balanced blocks. At the end of each trial, participants were asked to type values in milliseconds as an estimate of the time taken by the rod to cross the screen.

We wanted to see whether geometric violations to the Necker cube face being held the participant, affected their judgement of time for the passing rod. Participants were not asked to explicitly pay attention to the switches caused by the rod. There was a total of 360 trials. In one half, the rod maintained the geometry of the face being held, and in the other half, this geometry was violated.

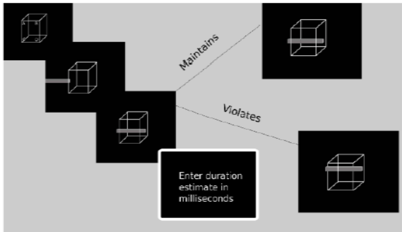

Figure 1: Breakdown of trial structure, when the face ABCD is held by the participant.

Results

A two-way repeated measures ANOVA with geometric violation and duration as the factors showed a significant interaction, $F(3,22) = 3.183$, $p = .029$, $\eta^2=.126$. Post-hoc t-tests showed significantly shorter reported estimates for duration of 400ms, $t(22)=3.263$, $p = .004$, Cohen's d = 0.680 and for duration of 800ms, $t(22) = 2.780$, $p = .011$, Cohen's d = 0.580 in trials with geometric violations. Trials where the rod took 1200ms showed significantly larger estimates of time for trials with geometric violations, $t(22) = -2.142$, $p = .044$, Cohen's $d = 0.447$. There was no significant difference in time estimates for trials at 1600ms without or without geometric violations, $t(22) = 0.752$, $p = 0.460$, Cohen's d = 0.157. Assumptions of normality were not violated (Krusal-Wallis test), p-values were corrected for multiple comparisons and sphericity violations (Greenhouse-Geisser).

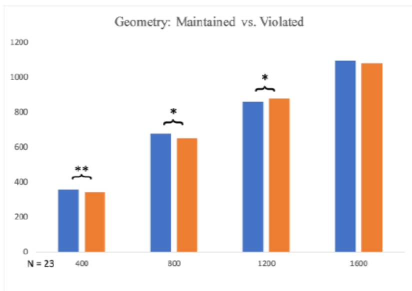

Figure 2: Bar plot of time estimates given by participants. In blue are trials where geometry was maintained and in orange are trials with geometric violations.

Discussion

Our predictions derived from the coherence intervals thesis holds, where trials with geometric violations do result in smaller estimates of duration. Moreover, our speculation of the boundaries in time where the prediction of coherence intervals will be supported are also promising. The duration of "now" or the specious present is still an ongoing empirical debate, with current consensus of it being around half a second.

In the extentional model of specious present, the experience of continuity is thought to arise from content falling within a block (thought to have a width of 300-500ms) and from the "glue" that combines two subsequent blocks (Dainton 2000, 2010). Thus, if coherence intervals are co-occurring during the phenomenal "now", then time shortening with the system being at a transient during switching should also occur within this duration.

The dilation of felt time for trials with geometric violations at 1200ms was not predicted. In previous work there is evidence of attending to unexpectedand unintended events dilating felt time (Eagleman, 2007; Makwana and Srinivasan, 2017). Since we were not asking participants to explicitly pay attention to the switch, perhaps it could be that the switch at 1200ms is more obvious and draws more attention more frequently. A follow up experiment is needed to probe this result.

Our current study is not sufficient to show that the results are due to "perceptual switching", simply because we did not ask participants whether trials with geometric violations did indeed cause a switch of the face of the cube in their experience. Here we have assumed that trials with geometric violations increase the propensity to cause a switch in participants' perception. Our personal phenomenology indicated that in many trials with geometric violations, a switch does occur. The reason for not asking this were two-fold. One was to establish a baseline effect, where minimal variables were used. The second was based on previous evidence where attention has been shown to interact with reports of perceived time. We also did not want participants explicitly attending to switches in the orientation of the cube. A follow-up experiment with reports of switching is currently underway, where trials only in which participants report a switch will be classified as such.

In this study we have shown support to theoretical prediction based on coherence intervals, where trials with greater propensity of perceptual switching are judged as having smaller durations than those without such switches in perception. We also show that this result holds true only for a certain duration in time, which is approximately one second.

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Subliminal priming of effect increases Sense of Authorship

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Abstract

Earlier research has suggested that sense of authorship (SoA) can be influenced by priming the effect of the action in both subliminal and supraliminal fashion (Custers & Wegner, 2005), providing support to the idea that the thought of effects associated with an action can enhance the SoA. The current study looks at whether priming of attributes of the outcome that are orthogonal to the intended effect of action, can influence SoA. We asked participants to believe that they have control over either color of the stimulus or its shape while priming them with the orthogonal feature. The congruency between action-outcome and prime-outcome was manipulated. Participants' subjective report of authorship indicated a greater SoA when prime matched the effect.

Keywords: Sense of Authorship; Subliminal Prime; Perceptual Control theory.

Introduction

The term agency, as used in psychology, refers to the capacity to perform an action, and/or various aspects of the event of performing that action. It refers to specific classes of actions that are in line with a person's conscious goals and intentions, and that the person themself initiates and controls. 'Sense of agency' refers to the feeling of controlling an external event through the agent's own actions (Chambon, Wenke, Fleming, Prinz, & Haggard, 2013). Control, the next important term in the present context, in some sense, talks about the quantitative awareness that the agent feels of initiating, executing, and completing the agent's own volitional actions. Together they give an implicit sense that it is I/the agent who is executing bodily movement(s) or thinking thoughts to achieve/execute the task at hand and hence a sense of authorship over action.

The experience of controlling one's own actions, and through them events in the outside world, is one of the universal features of healthy human mental life. A coherence between our actions and their outcomes whether abstract or material, is essential to our stability, functioning and well-being. Previous literature has suggested that sense of authorship (sense of being the agent of one's action) is closely linked with the control that an individual exercises/perceives in their environment. The study will look at how 'how much control we feel we have' influences sense of agency when the control in actuality is not complete.

We think we are free; we think we freely decide. It is the 'I' somewhere in the brain which is making decisions and because 'I' decide freely what I do, I can control my actions and influence the world around me. We want to look at the 'perceived control', the feeling of doing, the feeling of 'personal authorship' on an outcome. How does the brain generate our experience of being in control over our actions and their effects?

The perception of events as self-caused emerges from a comparison between anticipated and actual action-effects: if the representation of an event that follows an action is activated before the action, the event occurrence is experienced as caused by one's own action. Whereas in the case of a mismatch it will be attributed to an external cause rather than to the self (Linser & Goschke, 2007).

The influence of subliminal priming (outside of awareness) in humans is an interesting phenomenon, it can impact behavior, choices, and actions (Elgendi et al., 2018). In literature, systematic effects of subliminal action-selection primes on control judgments are studied (Wenke, Fleming, & Haggard, 2010). There are studies which use subliminal priming to directly prime an action and the sense of control over the effect is observed to increase when the action is taken concurrent to the prime. It is previously studied if subliminal cues to subsequent effects can alter the sense of control and if the conscious experience of control can modulate by unconscious anticipations of effect (Aarts, Custers, & Wegner, 2005). This conclusion was drawn using regime of a moving target and a subliminally primed stop point. It was found that not only did the participants tend to stop the moving target at the primed location (the effect of the action) but also felt more in control (enhanced experienced agency). In order to fully understand whether this increase in SoA is because of goal activation or not, we asked participants to intend either the shape or the color of the outcome, while priming the other dimension (color for shape intentions and shape for color intentions).

Based on previous findings on subliminal priming of effect, we hypothesized that the subjects would overestimate how much control they have over the effect of their action when a masked subliminal prime presented prior to action.

Methods

Participants

Sixteen volunteer participants (6 females) in the age group of 20-30 years, with normal or corrected-to-normal vision participated in the experiment.

Stimuli and Apparatus

The experiment was performed in sat in a quiet dark room in front of monitor running at a refresh rate of 75 Hz at a resolution of 1024x768 connected to a standard IBM PC. The experiment was designed in PsychoPy 3.0.7. Stimuli consisted of primes and outcomes. Primes consisted of consisted of white circle or triangle for shape-prime condition and red or green square for color-prime condition. The prime was presented for a duration 13.3ms, followed by a shape mask for shape prime condition and equiluminant metacontrast masks of the color condition color (ref. Figure 1). Outcome consisted of a triangle or a circle which could be either red or green.

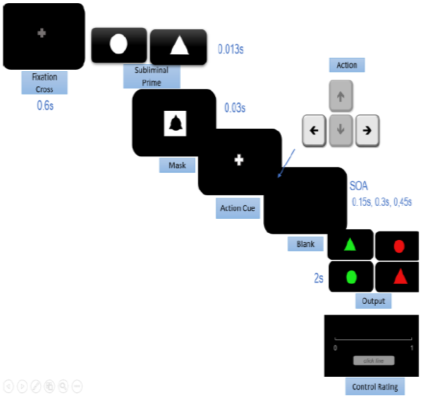
Design and Procedure

Participants were brought in the laboratory and instructed about the details of the experiment and consent forms were obtained.

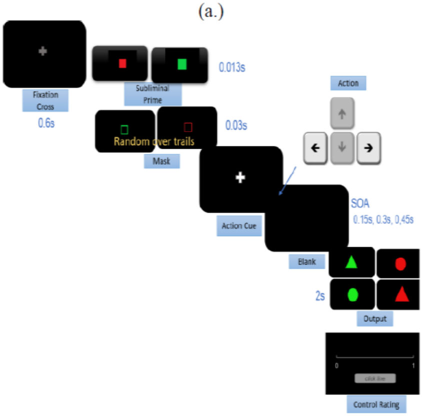
Participant was randomly assigned to either the shape-prime condition or color prime condition. In each trial participant was presented with a grey fixation cross for 0.6s, followed by the prime for 0.013s, and the corresponding mask for 0.03s after the prime. After which a bold white fixation cross was presented again to the participants as a cue for action. Participants were told that they can choose to either press left key or right key to obtain triangle or circle respectively (in color prime condition) and red or green color respectively (in shape prime condition). The outcome stimuli appeared after an SOA (Stimulus Onset Asynchrony) of 0.15s, 0.3s or 0.45s after the keypress. This was incorporated by appearance of a blank screen for that time frame.

Outcome stimuli remained on screen for 2s, after which participants were asked to rate for control in the preceding trial ('How much control did you have on the final output?') on a continuous scale from 0 to 1 with precision of 0.01, with 0 corresponding to the feeling that output has nothing to do with me (the subject) and 1 corresponding to I (the subject) control the output completely.

The congruency between prime-outcome was manipulated. The action effect was randomized such that irrespective of the action participants got each effect in 50% of the trials. For each block there were 24 condition (2Cue*2CueCong*2ActionCong*3SOA = 24). Total number of trials was kept 15*24 = 360 per participant. The order of trials was randomized.



(a.)



(b.)

Figure 1: Trail Structure for Shape Cue set-up (a.) and Colour Cue Set-up (b.)

Results

The data was recorded for 16 participants (360 trials per participant). The control rating was subjected to a 2 x2 x 2 mixed ANOVA across cue congruency (Congruent and Incongruent), action congruency (Congruent and incongruent) and cue type (Shape and Color). The main effect of Cue congruency was significant effect with F (1,14) = 5.02, p= 0.04, η_p^2= 0.26, supporting our hypothesis that subliminal activation of effect via prime would increase sense of control. Statistical ANOVA Analysis of the data collected was done. Cue Congruency and Prime type interaction was close to significant (p=0.09) as we can see in the means data that the cue effect is more prominent in shape cue than color. Action Congruency was not significant (F (1,14) = 0.02, p=

0.96, η_p^2= 0.00), which might be because in our study the outcome was independent of the action.

Test of Between-subject effects was also performed. Prime type did not come out to be significant (p=0.79 >0.05). There was a significant interaction between Cue Congruency and Action Congruency. (F (1,1) = 7.568, p= 0.02, η_p^2= 0.35). This two-way interaction is present only for Color Cue condition but not for shape cue condition (See Figure 2 and Figure 3). During debriefing, some participants reported that they were able to see the color cue. We speculate that the absence of main effect of cue congruency and presence of an interaction between action and cue congruency might be because of this methodological issue. We plan to address the concern in follow-up studies.

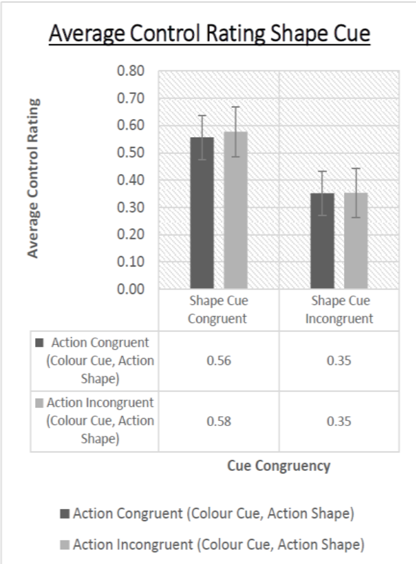


Figure 2: Mean control rating for Shape Cue, error bars represent the standard error in means.

Discussion

We found that in conditions where the condition where the relationship between action and outcome is ambiguous (outcome is independent of action) the presence of subliminal cue influences the sense of control suggesting that subliminal primes result in illusory feeling of control (Wegner & Wheatley, 1999).

This lends support to the cue integration model of agency, suggesting that to draw conclusions about agency we tend to use cues sequentially according to the amount of information they provide (Wolpe, Haggard, Siebner & Rowe, 2013). This effect of subliminal cue was seen for Shape cue but not for Color cue. One reason might be that some of the participants reported being aware of the color cue, suggesting that it might be possible that color cue was available at supraliminal level. However, previous research has suggested that both supraliminal and subliminal priming of outcome influences sense of authorship (Custers & Wegner, 2005). Further studies need to be conducted to fully dissociate effect of supraliminal and subliminal primes.

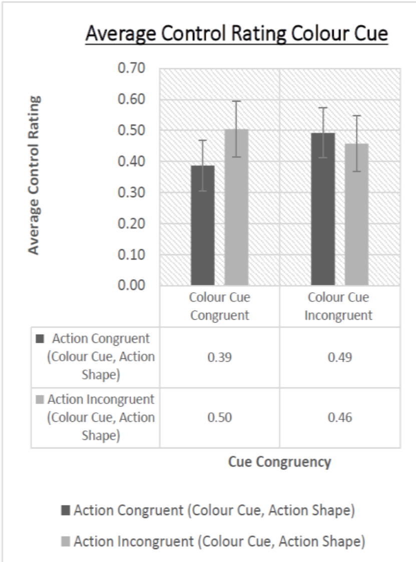


Figure 3: Mean control rating for Colour Cue, error bars represent the standard error in means

Conclusions

The present results point to the fact that feeling of being in control does not only involve inferences based on conscious expectations about the likely causes of actions (the initial association we provide) but is also modulated by unconsciously primed effects (the subliminal cues). Also, priming of outcome is sufficient to elicit a better sense of control and authorship (even when the prime is orthogonal to the goal).

We can further measure the implicit measures of control (the intentional binding) instead of explicitly measuring the feeling of control via control rating. More analysis is required in the subliminal perception of shape/ color cues and designing more appropriate masks so that the orthogonality of the two sets is indeed true, i.e. the results can be compared with each other.

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Local Coherence and Case-Marker Exchange Cause Parsing Errors in Hindi

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Abstract

Prediction in verb-final languages is considered to be very robust (Konieczny, 2000; Konieczny and Döring, 2003; Vasishth, 2003; Levy and Keller, 2013; Husain et al., 2014). In such languages (e.g., Hindi), case-markers can help in making the upcoming verbal prediction precise, leading to processing facilitation (Levy and Keller, 2013). However, recent investigations in Hindi (Apurva and Husain, 2016, 2018a,b,c,d, 2019) have found that predictions are fallible under some circumstances leading to parsing errors. For example, Apurva and Husain (2016) found that parsing errors due to incorrect predictions increases in sentences with non-canonical word order or where multiple case-markers share the same lexical form. However, the cause for such parsing errors still remains unexplored. This work fills this gap in the literature. In order to do so, we first replicated Apurva and Husain (2016) with a modified design. Results show that two major causes of parsing errors are local coherence and case-marker exchange due to similarity of case-markers. The work highlights the role of certain parsing heuristics and working memory constraints while comprehending rare structure in a head-final language like Hindi.

Keywords: Local coherence, Sentence comprehension, Prediction, Head-final languages, Cloze task, Parsing error, Encoding interference

1. Introduction

The human language comprehension system is predictive in nature. On the basis of degree of predictive capacity the sentence processing literature divides languages into two categories:

- Head initial/medial languages
- Head final languages

On average, speakers of a head-final language are exposed to more instances of verb-final structures compared to a speaker of a head-initial language. This exposure makes their parser adapt to the head-final structure (e.g., clause final verb structure) of the language. This adaptability has been argued to lead to better prediction and maintenance of the clause final verb in head-final languages. This is unlike the speakers of head medial/initial language where they get to see the verb quite early in a sentence. Therefore as far as the clause final verb prediction is concerned head-final languages are considered to be better in terms of verb prediction. This assumption is widely used in sentence processing literature to explain some well known effects such as anti-locality (Konieczny, 2000; Konieczny and Döring, 2003; Vasishth and Lewis, 2006; Levy and Keller, 2013), and lack of forgetting effect (Gibson and Thomas, 1999; Vasishth et al., 2010), etc.

However, the assumption of robust prediction in head-final languages was never validated systematically. Some recent studies (Apurva and Husain, 2016, 2018a,b,c,d, 2019) checked this assumption via several Cloze tasks in Hindi. The focus of these studies was to check the robustness of the predicted parse (grammatical vs ungrammatical) during comprehension in Hindi (a head-final language).

The results of these cloze tasks showed that predictions in Hindi were quite robust. However, they also found a large number of parsing errors due to incorrect predictions as well. In particular, Apurva and Husain (2016) showed that the overall percentage of valid parse during the cloze task was close to 50%. The remaining 50% of the parses are either incorrect ($\sim 20\%$)

or might be considered correct ($\sim 30\%$) assuming that the participants treated two consecutive nouns with the same case-markers as an instance of coordination. For example for the sequence Noun=ACCUSATIVE Noun=ACCUSATIVE ...could be treated as Noun=ACCUSATIVE *and* Noun=ACCUSATIVE .... Given the assumptions of robust parsing in head-final languages, the high percentage of incorrect parses found in Apurva and Husain (2016) is quite surprising. This is because all the incorrectly parsed instances can in principle be completed with a grammatical parse. The results revealed that the participants were mostly making grammatical predictions in case of conditions with single nouns ($\sim 95\%$) and in conditions with 2 nouns ($\sim 90\%$) conditions. Apurva and Husain (2016) found most of the incorrect parses to be concentrated in the condition with 3 nouns ($\sim 65\%$). In particular, those conditions with 3 nouns that had non-canonical positioning of case marker and the presence of similar case-marker had the highest instance of incorrect parse.
The results in Apurva and Husain (2016) can be summarized as follows:

- Prediction of clause final verbs is fallible in Hindi
- Incorrect parses are mostly found in the conditions which have identical case marker or where the case markers are arranged in a non-canonical word order

. These result raises many interesting questions such as

1. What are the causes that lead to parsing errors reported in Apurva and Husain (2016)?
2. What are the implications of invalid predictions with regards to effects such as anti-locality and forgetting?

The aim of the current study is to address the first question mentioned above. In order to do this, we first replicate Apurva and Husain (2016) with a modified design. Apurva and Husain (2016) used various combinations of 3 common nouns (e.g., ladkaa 'boy') and 4 case markers (Nominative, Ergative, Accusative, Ablative) as their experimental items. In the current study we follow their design but use proper nouns (e.g., Ravi 'Ravi') instead of common nouns. In addition, we only report those combinations that can be completed meaningfully.

This paper is organized as follows: In Section 2, we describe the design of the experiment. In Section 3, we discuss the results. Following this, in Section 4, we analyze the data in order to probe the cause of parsing errors. We conclude the paper in Section 5. We also discuss the work in progress in the final section.

1-NP	Φ: Rohit ...
	ko: Rohit-ko ...
2-NP	ne,ko: Rohit-ne, Geeta-ko ...
	ko-se: Sita-ko Hari-se ...
3-NP	ne,ko,se: Rohit-ne, Geeta-ko, Mukesh-se ...
	ne,se,ko: Sita-ne, Hari-se, Kavita-ko ...

Table 1: Sample items for the 1-NP, 2-NP and 3-NP conditions

2. Method

As stated above, we begin with replicating (Apurva and Husain, 2016) where the nature of the nouns used differs from their study – we use proper nouns instead of common nouns. In addition, the experimental items did not contain any case-marker combination that cannot be grammatically completed (e.g., a ne-ne-ne sequence).

2.1. Materials

The number of nouns in each item ranged from 1 to 3. The case- markers on the nouns were Φ (Nominative case), 'ne' (Ergative case), 'ko' (Accusative case), or 'se' (Ablative/Instrumental case). The nouns used in the items were always human proper nouns. All possible combinations of the nouns and case-markers which can be completed meaningfully were constructed. There were 4 condition with one noun (1-NP conditions). There were 15 conditions with 2 nouns (2-NP conditions), and there were 52 conditions with three nouns (3-NP conditions). In total, the experiment had 71 conditions. Table 1 shows the sample items.

12 items were prepared for all conditions. Each item and its conditions were presented to the participants. A latin-square design was used to present different items. The item id formed the basis for list (hence 12 lists) formation in the latin-square design. In addition to the experimental items there were 16 filler items.

2.2. Participants

25 native speakers of Hindi participated in the experiment. All the participants were undergraduate or graduate students from the Indian Institute of Technology, Delhi. The average age of the participants was 20.84 years. Each participant was paid INR 200 for participating in the experiment.

2.3. Procedure

We used sentence completion task using the centered self-paced reading (SPR) paradigm. Participants were given incomplete sentences and were asked to complete it meaningfully. They were asked to type the text which they deem to be meaningful and then press the 'enter' key to move on to the next trial. Each sentence appeared on the screen in the self-paced reading format. Initially, a '+' sign appeared on the center of the computer screen. When the participant pressed the space-bar key this + sign got replaced with the first word of the sentence. Successive button presses displayed the remaining words of the sentence at the center of the screen. A ... symbol prompted the participant to complete the sentence. This was done in a text box that appeared by pressing 'space-bar' after the . . . symbol. The experiment was conducted using Douglas Rohde's Linger software[1]. Items were automatically randomized by Linger.

3. Result

The key findings of Apurva and Husain (2016) were replicated in this study. The result showed that:

- The total percentage of completions with valid parses was 51%,
- The remaining 49% completions with parsing errors could be divided into two classes: 17.5% could be considered completely ungrammatical, while the rest could be considered grammatical by positing certain assumptions, e.g., by assuming that the participants treated two consecutive nouns with the same case-markers as an instance of coordination. For instance, n1-ko n2-ko was treated as n1-ko *and* n2-ko.
- Similar to Apurva and Husain (2016), most parsing errors due to invalid predictions happens in the 3-NP cases (64%) compared to 1-NP (4%) and 2-NP (8%).
- Among these 3-NP cases, the conditions with similar case markers and non-canonical case marker order have the highest number of parsing errors.

These results are completely in line with the findings of Apurva and Husain (2016). Increasing the number of NPs increases the completions that are ungrammatical, i.e., have a parsing error. Despite being a free word order language, Hindi native speakers find it difficult to complete the sentences with non-canonical word order meaningfully. These results show that the prediction of clause final verb in Hindi is fallible in certain situations. This usually happens in 3-NP conditions with non-canonical case-marker order or when two case-markers are lexically similar. In the next section we analyze the nature of these errors to investigate the probable cause probable cause of parsing errors.

4. Discussion

In this section we will only consider the 17.5% of completion data that unambiguously is a result of parsing error due to invalid prediction. Table 2 show all the conditions that we analyze. All conditions have 3 nouns; 6 have unique/non-identical case-markers and the rest have non-adjacent similar case-markers.

Analyzing the nature of completion errors in conditions shown in Table 2 shows that these errors are not random, rather they are quite systematic. In particular, we find that most of the ungrammatical completions made in non-identical 3-NP conditions as well as in non-adjacent similar case-marked conditions can be categorized broadly into two types:

- Errors due to local coherence
- Errors due to case-marker exchange

[1]version 2.94

Non-identical case markers	Non-adjacent similar case markers
ne-ko-se	ko-ne-ko
ne-se-ko	ko-se-ko
ko-ne-se	se-ko-se
ko-se-ne	se-ne-se
se-ne-ko	
se-ko-ne	

Table 2: 3-NP conditions selected for analysis.

4.1. Errors due to local coherence

A substantial number of errors were such that only the last two nouns were used to predict the verb. In this sense, the generated parse with N2-N3-Verb is locally coherent. The example below shows such an instance where the predicted verb *jane.ke.liye bola* 'go=INF tell=PERF' is not a grammatical completion considering the 3 nouns in the condition. However, this completion is grammatical if one ignores the 1^{st} noun and considers only the 2^{nd} and the 3^{rd} noun. This locally coherent string has been underlined in the example below.

*hari=se <u>gitaa=ne umesh=ko *jane.ke.liye bola*</u>
Hari=ABL Gita=ERG Umesh=ACC go=INF tell=PERF

As stated above, such completions are locally grammatical with the last two nouns forming the arguments of the predicted verb(s), but become ungrammatical for the entire sentence. In unique case-marker conditions, parsing errors due to local coherence were observed in ∼36% of the ungrammatical data. On the other hand, in the non-adjacent similar case-marker conditions, parsing errors due to local coherence were found in ∼75% of the ungrammatical data.

Following (Tabor et al., 2004), the parsing errors due to local coherence can be understood in two ways. In one scenario, the parser could attempt a locally coherent parse when it fails to find a globally valid parse. In effect, it tries to salvage some parse from the utterance to be comprehended. The other scenario assumes a 'Self-Organized' parsing where locally formed structure complete with the global structure. We hypothesize that the participants should be unaware of the parsing errors if the self-organizing account is correct. On the other hand, if the participants are trying to salvage some parse in the locally coherent errors, then they might be aware of the ungrammaticality of the completions. We intend to test these two accounts through an acceptability study in the near future. Some studies(Bhatia and Husain, 2019b,a, 2018) which has relative clause structure too have found local coherence effect in Hindi.

4.2. Errors due to case-marker exchange

In addition to the errors due to local coherence, we also find errors which can be interpreted as grammatical by exchanging one of the case-markers in the sentence. Such errors are particularly common in the non-adjacent similar case-marker conditions with 3 nouns. For example, sometimes the 'ko' case-marker is confused with 'ki'. Sometimes 'se' is confused with 'ne'. The example below shows an error where the completion become grammatical by assuming the case-marker of the 1^{st} noun to be 'ne' instead of 'se'.

*hari=se gitaa=ko umesh=se *milwaaya hai*
Hari=ACC Gita=ERG Umesh=ACC *meet=CAUS.PERF*

Parsing errors due to case-marker exchange was observed for 6% of the ungrammatical data in cases where we have unique case markers. For condition with non-adjacent similar case-marker such errors amount to 28% of the ungrammatical data.

The parsing errors due to case-marker exchange can be interpreted in two ways. Similar to the scenario discussed in previous section, such errors could be a strategy by the participants to salvage the parse given that the case-marker combinations are quite rare. Another cause for this error could be similarity-based interference (Lewis and Vasishth, 2005) during the encoding of the 3^{rd} noun. In such a case, the presence of the 1^{st} noun with very similar feature could lead to difficulty in encoding the 3^{rd} noun. This would in turn lead to difficulty in making correct predictions. Case-marker exchange might be a way to make the 3^{rd} noun more distinct compared to the 1^{st} noun.[2] We hypothesize that the participants should be unaware of the parsing errors if the similarity-based interference account is correct. On the other hand, if the participants are trying to salvage some parse, then they might be aware of the ungrammaticality of the completions. We intend to test these two accounts through an acceptability study in the near future.

5. Conclusions

Our work partially supports the claim that head-final languages are robust in predicting the clause-final verb. The results highlight certain constraints on the prediction system during comprehension of a head-final language like Hindi. The results found that parsing errors increase with (a) increase in the number of nouns, (b) presence of non-canonical order of case-markers, and (c) presence of similar case markers.

Our work also investigated the cause for the parsing errors in the sentence with the properties mentioned above. Our analysis shows that local coherence and case-marker exchange are the two causes that explain most of the parsing errors. The work highlights the role of certain parsing heuristics and working memory constraints while comprehending rare structure in a head-final language like Hindi.

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Towards measuring lexical complexity in Malayalam

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Abstract

This paper proposes a metric to quantify lexical complexity in Malayalam. The metric utilizes word frequency, orthography and morphology as the three factors affecting visual word recognition in Malayalam. Malayalam differs from other Indian languages due to its agglutinative morphology and orthography, which are incorporated into our model. The predictions made by our model are then evaluated against reaction times in a lexical decision task. We find that reaction times are predicted by frequency, morphological complexity and script complexity. We also explore the interactions between morphological complexity with frequency and script in our results.

Keywords: lexical processing, visual word recognition, lexical complexity, Dravidian languages

Introduction

The problem of word recognition is widely studied in psycholinguistics, particularly in an effort to understand the individual variables that affect the lexical processing of words. If we can quantify the influence of variables ranging from orthographic features to semantic factors on the processing of words, it would help us in understanding the critical factors underlying visual word recognition (and pattern recognition, more generally). The resulting model of word recognition can be tested easily against human judgements. Models of word recognition are especially relevant for reading studies, where they have been extensively explored (Rayner and Duffy, 1986).

In this paper, we explore the case of Malayalam and in particular examine three factors that could predict word complexity in the language: frequency, orthography and morphology. The role of variables that determine word recognition in Malayalam has not been explored, as it has been for Hindi (Husain et al., 2015; Verma et al., 2018). Quantifying these factors in a model of lexical complexity can help us in developing norms that are useful in areas such as reading studies and word generation for lexical decision tasks. Further, this would contribute towards cross-linguistic comparison of these factors from a different language family.

Lexical complexity

The task of visual word recognition involves the processing of visual information and comparing it with a particular internal representation of a word. This representation itself may be at the graphemic, phonemic, morphemic and lexical semantic level, all of which have been shown to affect word recognition (Balota et al., 2006). In the sections that follow, we describe the three factors that are included in our study.

Word Frequency

The effect of word frequency is robust and has been well studied across word recognition tasks (Balota et al., 2006). High frequency words tend to be recognized faster than low frequency words. In eye tracking studies high frequency words have lower gaze duration and fixation measures. We would expect that frequency would have a similar effect on the Malayalam data, where high frequency would contribute towards a lower lexical complexity.

Morphology

A word may be composed of a single morpheme e.g. *boy* or more than one e.g. *funnily: funny+ ly*. The role of morphology in word recognition is at a sub-lexical level. Morphology as a measure is particularly relevant for an agglutinative language such as Malayalam, which also exhibits productive word compounding e.g. Just the word മരം (tree) has a number of morphological forms such as

മരത്തിൽ(in the tree)
മരത്തിന്റെ(of the tree)
മരങ്ങൾക്കിടയിലൂടെ(through the trees)
മരക്കൊമ്പുകൾ(tree branches)

Early studies that looked at the effect of morphology on lexical access have suggested that polymorphemic words (i.e. words consisting of more than one morpheme) are decomposed into their component parts during online processing. This process would find the root first (e.g. *funny* and on finding it, proceed to search stored affix-stem combinations till *funnily* is retrieved (Taft and Forster, 1975).

Orthography

The visual processing of words involves processing at the orthographic level as well. This implies that the writing system of various languages will influence recognition. A writing system–whether alpha-syllabic, logographic or alphabetic has been shown to influence reading times (Katz and Frost, 1992). Sub-lexical properties such as letter features and their interactions with the words themselves can also influence word complexity, which needs to be accounted for in the model.

Method

In order to compute our lexical complexity metric, we included token frequency, morphology and orthography as our variables. Below, we discuss our methods for computing the values for each of these variables.

Corpus

In order to compute our metric for Malayalam, we first obtained a corpus from the Leipzig Corpora Collection containing 300,000 sentences from Malayalam Wikipedia articles and 100,000 sentences from Malayalam news crawl (Goldhahn et al., 2012). We pre-processed this corpus by removing punctuations and special characters and tokenized it using whitespace. We also normalized the text to remove inconsistencies in spelling using the Indic NLP Library[1] and this resulted in 4,711,219 tokens and 762,858 unique types.

Word Frequency metric

We used this corpus to collect counts for each word and then scaled them between 0 and 1. We then inverted this such that the most frequent tokens have a value closer to 0 and the less frequent tokens will have a value approaching 1. This score indicated the relative frequency of each word in this corpus, and the idea that highly frequent words are much easier to process than those that have lower frequency.

Morphology metric

Our morphology metric required us to obtain information about the root and the morphological affixes for a given word. Given the rich morphology and compounding processes in the language, we had to make use of a two-step process to compute our scores.

First, we used *SandhiSplitter* (Devadath et al., 2014) to split tokens that are compound words into their constituent component words. For example, consider the compound word കാരണമായിരിക്കണം (kAraNamAyirikkaNaM)

കാരണമായിരിക്കണം ⇒ കാരണം + ആയിരിക്കണം

kAraNamAyirikkaNaM ⇒ *kAraNaM* + *AyirikkaNaM*

”must be the reason” ⇒ ”reason” + ”must be”

As a second step, we passed these results through IndicStemmer[2], a rule-based stemmer for Malayalam, which further decomposed the words into stems and affixes. As an example, the word ലേഖനങ്ങളുടെ (lekhana N NaLuT.e) meaning “Of articles”. is decomposed into the stem ലേഖനം (lekhanaM) meaning article with the suffix -ങ്ങൾ (N NaL) indicating plural and -ുടെ (uT.e) indicating the Genitive case. In our metric we only considered suffixes as in Malayalam usually contains always suffixes being added to the end of the stem.

After this two-step process, we are able to obtain the stems and suffixes for a given word.

Morpheme Count By simply summing the number of stems and suffixes, we can compute the total number of morphemes contained in each word. For example, the word സമ്പത്സമൃദ്ധിയും (sampatsamRRiddhiyuM) meaning “prosperity” is a compound word split into constituent words സമ്പത്സ (sampatsa) meaning “richness” and മൃദ്ധിയും (mRRiddhiyuM) meaning “and plentiful”. മൃദ്ധിയും is further stemmed to stem word മൃദ്ധി and suffix -ും (AND). സമ്പത്സ is a root word. Thus, the number of morphemes in this case is three, counting the two stems and one suffix.

Based on this pre-processing, we then calculate the total number of morphemes for each whole word and then scale this number between 0 and 1 to give a morpheme score.

Orthography metric

Malayalam is an alphasyllabic writing system that has its source in the Vatteluttu alphabet from the 9th century. Its modern alphabets have been borrowed from the Grantha alphabet. It consists of 15 vowels and 36 consonant letters.

We devised a script score based on complexity of the script in the following three ways:-

Mismatch in spoken and visual order In the alpha-syllabic script of Malayalam, vowels may either appear as letters at the beginning of a word or as diacritics. Consonants themselves are understood to have an inherent schwa, which is not separately represented. The diacritics will appear either left or right of the consonant it modifies. If it appears to the left, there will be a discrepancy in the phonemic and the orthographic order, as the vowel will always be pronounced after the

[1] `https://anoopkunchukuttan.github.io/indic_nlp_library/`

[2] https://github.com/libindic/indicstemmer

consonant, but read before the consonant actually appear in the text. For example:

ക + െ = കെ

ka + .e = ke

Here the vowel violates the order in which it is spoken. Similarly: ക +േ = കേ (ka + ē = kē), as seen in കേൾക്കുക (kēḷkkuka) meaning hear. Such inconsistencies in spoken and visual order have been shown to incur a cost in Hindi word recogntion (which is also an alpha-syllabic script) (Vaid and Gupta, 2002).

In order to capture the lexical processing cost for such a discrepancy, we give a penalty of 1 every time it occurs in the word.

Diacritic appearing above or below In Malayalam, the diacritic may also appear above or below a consonant. In such a case, we we give a penalty of 0.5 to the word. For example the symbol ് also known as *virama* is used to replace the inherent schwa sound of consonants with ŭ. As in ക + ് = ക് (ka + virama = ku)

Ligatures and consonant clusters A penalty of one is assigned for every two letters that form a composite glyph. For example: മന്ത്രി (mantri) = മന് + ത്രി (man + tri)

With the above complexity rules in place, the total penalty cost for each whole word is calculated. Then the total penalty for each word is scaled linearly to between 0 and 1 to give us an orthographic score.

Evaluation of Complexity Metric

In order to evaluate our lexical complexity metric, we used a lexical decision task paradigm to collect reaction times for a sample of Malayalam words. We wanted to evaluate whether our lexical complexity model could predict reaction times for the given set of words.

Materials Our task consisted of a balanced set of 50 Malayalam words and 50 pseudowords. In order to select words for the task, two sets of 25 words were randomly sampled from the unique tokens obtained from Leipzig Corpus. The first set was randomly sampled from words with a frequency score between the range of 0.1 to 0.4 to obtain high frequency words as calculated by the metric.

The second set was chosen similarly but with frequency score between the range of 0.7 to 0.9 to yield low frequency words. If the sampled word turned out to be an English word written in Malayalam or happens to be a proper noun, it was replaced with another until both sets had 25 words each. The pseudowords were constructed in keeping with the phonotactics of Malayalam. Both the pseudowords and the valid words were constrained in length between 6 and 14 characters.

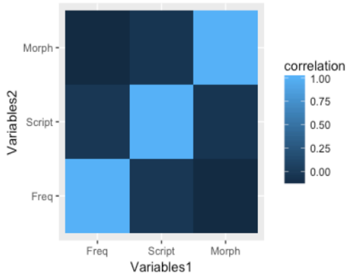

Figure 1: Heat plot showing correlation between the three variables in our test data

Participants Participants included 38 students from S.N. College, Kerala, who volunteered for the study. Participants included 20 females and 18 males between the ages of 18 and 23 (mean age of 19.7). All participants were native speakers of Malayalam and had formal education in Malayalam till grade 10 at least.

Procedure Participants were tested individually on a computer running JSPsych (De Leeuw, 2015) with the 'a' key on the left side and 'l' key on the right side standing for word and non-word respectively. The order of words and pseudowords was randomized for each participant. Participants were instructed to read the word presented and respond with the appropriate button press. Each trial consisted of a word that was presented for 2500ms. A fixation cross was placed in the center for 1600ms between each trial. The first 10 trials were practice trials from a word set different from the study. The response time for each trial was measured from the onset of the stimulus till the button press.

Results

The trials belonging to those who scored below 70% in the word-non-word accuracy were excluded, which brought the number of participants to 35.

We fit a linear model using the `lm` function in R. We use log reaction times with frequency, script and morph as the covariates. Figure 1 shows that the three variables are not highly correlated in our test set.

Table 1 shows the results of the regression analysis, where the variables Script, Morph and Frequency have a significant effect (all p-values < 0.05) on (reaction times) RTs, such that a high cost of script, morph and frequency leads to higher RTs. In addition, we also find a marginal interaction between Script and Morph (p=0.06), such that an increase in the script complexity leads to larger increases in RTs for morphologically simpler words (Cost $<$0.9) compared to morphologically complex words (Cost $>$0.9) (see Figure 2). We find also a marginal interaction between Morph and Frequency (p=0.08) such that an

	Estimate	*Std. Error*	*t-value*	*p-value*
(Intercept)	4.30	0.679	6.35	0
Script	9.157	3.76	2.43	**0.015** *
Freq	2.87	0.96	2.97	**0.003** **
Morph	1.91	0.71	2.67	**0.007** **
Script:Freq	-3.171	5.77	-0.55	0.58
Script: Morph	-7.64	4.1	-1.873	**0.06** .
Freq: Morph	-1.79	1.03	-1.743	**0.08** .
Script:Freq:Morph	0.28	6.31	0.045	0.96

Table 1: Results for all three variables and their interactions. Script and morph complexity as well as Frequency and morph complexity show a significant interaction

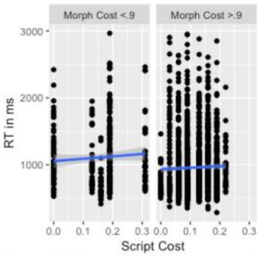

Figure 2: Interaction between morphological complexity and Script complexity

increase in the frequency cost leads to higher reaction times in morphologically complex words as compared to morphologically simpler words (see Figure 3).

Discussion

Our results replicate the robust effects of frequency on lexical processing in Malayalam. As frequency is a known predictor of reaction times, we expected to find a significant effect for frequency, but we particularly wanted to understand the effect of morphology and orthography on word recognition in Malayalam. Orthographic complexity as captured by diacritic placement and ligatures also has a significant effect on lexical processing. Similarly, we also find an effect for morphological complexity in terms of the number of morphemes in a word.

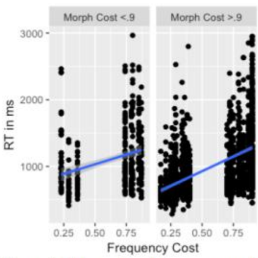

Figure 3: Interaction between morphological complexity and Frequency cost. Note that a low frequency cost corresponds to a high frequency count for a word

The interactions in our model point to an interesting relationship between high frequency words and morphological complexity. It appears that the effect of frequency cost becomes more pronounced in more complex words. In other words low frequency words lead to higher reaction times particularly when they are morphologically complex. Perhaps this is because the cost of lexical decomposition is higher in these words. On the other hand, the effect size of script is weaker and becomes visible only when the word is morphologically simple. When the word is morphologically complex, this effect is not very apparent.

This work points to many interesting future avenues for exploring lexical complexity in an agglutinative language like Malayalam. Particularly, the effect of morphological complexity on factors like frequency need to be explored more thoroughly. In the future, we plan to carry out experiments with a larger set of items for the lexical decision task, as this was a preliminary study. We also plan to experiment with other measures of morphological complexity that take into account information about the type as well as the number of morphemes.

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Semantic Lexical Decision in Hindi vs Urdu script: A matter of orthography

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Introduction

Visual word recognition needs decoding the orthographic code of the words to access their meaning. One of the most accepted reading models is non-connectionist, DRC model, which is based on the Dual Route Hypothesis of reading (Coltheart et al. 2001; Perry et al. 2007). According to this model, there are two routes to access the meaning of the printed word: a direct route which bypasses phonological recoding and the other is the indirect one, which first recodes phonological information and then accesses meaning. Which route has to be used is influenced by the depth of orthography or consistency of grapheme-phoneme mapping as proposed in Orthographic Depth Hypothesis (ODH) (Frost et al. 1987). DRC is primarily a computational realization of the dual-route theory of reading and is known to perform the 2 tasks most commonly used to study reading: lexical decision and reading aloud. In contrast to non-connectionist DRC model, connectionist Triangle model is another famous model of the reading network (Rayner and Reichle 2010; Joshi and McCardle 2018). According to this model, orthography-phonology mapping develops according to the frequency of exposure spelling-sound correspondence and pronunciation of a word is mediated by semantics

If a word is in a script which is orthographically shallow like Spanish and Italian i.e. there is consistency in grapheme-phoneme mapping, then the recognition and naming of the word is faster than when the script is with deep orthography like English, Arabic, Hebrew. There has been extensive research addressing the question of the brain's reading network and role of orthography. But most of them have attempted this with two different languages in bilingual conditions such as Arabic and Hebrew, Spanish and English, Finnish and French (Ibrahim et al. 2013; Oliver et al. 2017). Studies with vowelized Arabic as shallow orthography and non-vowelized Arabic as deep orthography (Taha and Azaizah-Seh 2017) can be misleading as well because vowelized Arabic has supplementary visual features that are unlike the majority of the text, making it unfamiliar. Given that Spanish differs from English, or Arabic differs from Hebrew not just in orthography but also in morphophonology and other linguistic properties like grammar.

Hindustani/Rekhta is a group of two twin languages: Hindi and Urdu. Considered essentially one language written in different orthographic forms (Shackle and Snell 1990; Jain and Cardona 2007), they share a large set of vocabulary and are practically similar in linguistic aspects: phonology, orthography, grammar, and lexicon. Hindi written in Devanagari script is consistent in grapheme-phoneme mapping while Urdu written in Persian script has high inconsistency in orthography-phonology coding. This combination can be a great tool to advance the understanding of the role of orthography in the reading process and impact on the development of the reading circuit of the brain.

There are very few studies which attempted to understand the mechanism of reading by the brain with Hindustani and the role of orthography with the help of Hindi-Urdu. One of them examined the DRC model with a reading-aloud task, found slow naming in Urdu than Hindi (Rao et al. 2011). In other, divided visual hemifield study role of orthography and morphology has been examined in hemispheric lateralization in reading aloud process (Rao and Vaid 2017). They have found involvement of right hemisphere for naming in Urdu but not in Hindi. One neuroimaging study reported about higher activation in language areas of the brain for Urdu than for Hindi (Kumar 2014). In this fMRI study, a perceptual level task (to identified italicized letter within words) was used and the behavioral studies by Rao et. al. employed reading aloud task. The limitation of the first approach is that it does not enforce the brain to read the word at all and in the reading aloud task, there is no enforcement on accessing the meaning of the word, so no account for semantic processing by both.

So, to study structural and functional properties of the brain's reading network with the help of the Hindustani language group, the current study tested a semantic lexical decision task to address these limitations to develop a complete framework for further neuroimaging studies. This framework would be used along with sub-lexical and perceptual-level task in neuroimaging experiments to advance the understanding of reading and the role of orthography in structural and functional properties of developing and skilled readers. We hypothesized faster recognition in Hindi than Urdu and for one-syllable words than two-syllable words.

Methods

Participants

40 healthy native Hindustani speakers divided into two groups: Group 1 Named here as Hindi-Urdu Biliterates, includes 20 Multilinguals, proficient, simultaneous early learners of Hindi and Urdu, and Group 2, Named as Hindi Mono-literates, 20 proficient literates of Hindi with no learning of Urdu reading/writing at any stage of life. All participants acquired English as L2. Language proficiency in the reading domain was measured by an indigenously developed reading test. They also filled in a language background questionnaire. The participants were matched for the age of acquisition of Urdu and Hindi, percent average daily exposure, subjective as well as objective proficiency in reading, within-and across the groups.

Stimulus and Design

Total of 245 high-frequency Hindustani words was selected based on the subjective frequencies from separate 21 raters, exempted from the main experiment. Among these 245 words, 120 were one syllable and 125 were two syllables, in each script. All the words were semantically categorized among 7 categories (Animals, Body Parts, Action, Place, Food Item, Number and Non-living objects) such that half of the words in each category were semantically related to the category and half were not. Fully balanced within-subject 2 X 2 factorial design (Script of the word: Hindi and Urdu X Syllabic length: One and Two). This resulted in 4 sets of conditions: 1. One syllable word in Urdu, 2. One syllable word in Hindi, 3. Two syllable word in Urdu and 4. Two syllable word in Hindi.

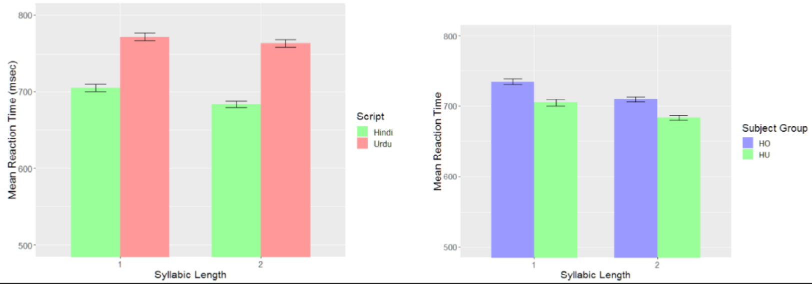
Procedure

To the Hindi-Urdu Biliterates, all four blocks to Hindi mono-literates only 2 blocks that of Hindi script were presented. The order of blocks was counterbalanced across subjects. In each set of stimuli, first, the category name was presented. Participants were asked to press a key to enter into the category. Once entered, words from that category presented sequentially for 1500ms or till the response, whichever is earlier, in the center of the screen in white on black background with an inter-trial interval of 300ms. Participants were instructed to make a lexical decision on the presented word, whether it belongs to the aforementioned category or not, with Left arrow key for 'No-Go' and Right for 'Go'. Each word was preceded by a fixation cross for 300ms. With the end of all the words of a category, other category started. Categories within each set and words within each category were randomized.

Results

All participants responded to the go and no-go trials during lexical decision task with more than 75% accuracy in each set of stimuli, indicating that they paid attention to the task. We performed two separate two-way repeated measure ANOVAs with RT as a dependent factor, one for within-subject factors (script x syllabic length) within Hindi-Urdu biliterate group and other with participants-group as between-subject Factor (Hindi-Urdu and Hindi-only) and syllabic length as within-subject factor across both groups. Outliers (RT<200ms) were eliminated before analysis. For within Hindi-Urdu group, there were main effect of Script [$F(1,18)=13.55$, $p < 0.01$], but no significant effect of Syllabic length[$F(1,18)=0.81$, $p=0.38$]. That is, RT was shorter for Hindi than Urdu, and no overall significant difference was found in RTs for one-syllable word from that of two-syllables. However, no significant interaction of Script x Syllabic length [$F(1,18)=1.53$, $p=0.23$] was found. Post hoc analysis revealed that effect arose from both scripts in both conditions of word length: Hindi one-syllable words were significantly faster recognized than Urdu one-syllable words [$p<0.05$] and similarly, faster recognition in Hindi two-syllable words than in Urdu two-syllable words [$p<0.05$]. For between groups analysis there were no main effects of within-subject variable: Syllabic length [$F(1,37)=8.54$, $p>0.05$], also for between-subject variable: Hindi-Urdu biliterates and Hindi mono-literates [$F(1,37)=0.74$, $p=0.39$]. That means RT for word recognition in Hindi by Hindi mono-literates was not significantly different from that of by Hindi-Urdu mono-literates. Also, within each group, there was no difference in RT for both one-syllable and two-syllable words. Overall, Reaction time for word recognition in Hindi was similar by both the groups and Higher RT for recognition in Urdu than in Hindi.

Fig: Mean Reaction time within Hindi-Urdu biliterates group (top) and between groups for Hindi script only (bottom). HO: Hindi only group and HU: Hindi-Urdu biliterates group



Discussion

As hypothesized based on differences of orthographies of two scripts, recognition was significantly faster for words in Hindi script than for words in Urdu script, for both two-syllable and one-syllable words. It is consistent with prior findings on non-lateralized and lateralized reading aloud tasks with these languages (Rao et al. 2011; Rao and Vaid 2017). The reaction time in recognition of one-syllable words in both the scripts was not significantly different from that of two-syllable words. This result is unexpectedly not in line with the previous study of this language-set with reading aloud task (Rao and Vaid 2017), in which reading was faster for shorter one-syllable words than for two-syllable words. One possible explanation of this could be that words of both lengths have been read as a whole as a single grain as the Grain Size theory explains (Ziegler and Goswami 2005) and the higher latency in naming two-syllable words in the previous study with reading aloud task, maybe only due to articulation of two phoneme as compared to one for one-syllable words, to produce sound. However, it could be a task-dependent difference. For lexical decision task, the direct route has to be taken which doesn't process phonology by letter assembly but decodes semantics directly from orthography. Further research is needful to be certain.

The results of within-subject word recognition by biliterates of Hindi and Urdu indicates that these two orthographies are being processed via two different ways. DRC model can be thought to explain this two-way processing but the non-lexical route, as can be thought for words in Hindi script, assumes to have no interaction with semantic information. That's why for semantics dependent word recognition as the task demanded, even in shallow Hindi script, interaction with units of semantic representation is necessary. We suggest that the triangle model will be better to explain word recognition in Hindi and Urdu, as it assumes interaction across phonology, orthography and semantic units.

Though there was a limitation to this study, one of which was that this experiment couldn't account for orthographic familiarity because of lack of standardized corpus for both languages. There is evidence of the influence of orthographic familiarity on the lexical decision (Proverbio and Adorni 2008). Further study with controlled orthographic familiarity and with a more variable length of words is needful to find the exact influence of word's length on word recognition to be certain about the grain size in both the scripts.

To conclude, this study suggests that reading in different scripts can have different mechanisms in a task-dependent manner. For different reading tasks, there may not be a universal model. It will be implicated in further investigations of functional and structural characteristics of reading circuitry of the brain relative to orthography.

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Can Reducing Encoding-Based Interference Improve Predictions During Sentence Processing?

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Abstract

Previous experiments have shown that a sentence comprising of multiple nouns with similar case-markings can lead to prediction and processing difficulty in a head-final language like Hindi (Vasishth, 2003; Apurva & Husain, 2016; Apurva & Husain, 2018a; Apurva & Husain, 2019). Lack of robust predictions during comprehension in a head-final language like Hindi could either be attributed to the rarity of encountering multiple nouns with similar case-markings, or could be due to similarity-based interference amongst the nouns with similar case-markers during the encoding stage. In order to investigate this, we increased the distinctiveness of the nouns by modifying them using adjectival phrases of differing complexity. The sentence completion paradigm was employed to see if such a manipulation lead to improved prediction during comprehension. The findings of the present study indicate that better encoding of nouns leads to improved predictions. The results demonstrate that similarity-based interference interacts with prediction processes during sentence processing.

Keywords: prediction; similarity-based interference; working-memory; head-final language; Hindi sentence comprehension

Introduction

There is a large body of experimental work that demonstrates that during sentence comprehension, we often try to predict the upcoming words even before we encounter them. Recent proposals to explain predictive processing have argued for a graded nature to prediction whereby activation of certain linguistic features of upcoming words is increased before its actual presentation (Kuperberg & Jaeger, 2016; Luke & Christianson, 2016). Prediction during sentence comprehension has been argued to be very robust especially for head-final languages like Hindi, German, Japanese, etc. (Husain et al., 2014; Levy & Keller, 2013, Vasishth et al., 2010).

However some recent investigations (Apurva and Husain, 2018a; Apurva and Husain, 2018b; Bhatia and Husain, 2019) have brought forth evidence against this assumption. This line of work has shown that prediction process in a head-final language like Hindi is fallible. In particular, Apurva and Husain (2016; 2018a; 2019) have shown that in sentences with multiple nouns with similar case-markings such as (1) there is a decrease in the number of correct predictions compared to a sentence when these case-markers are unique (2).

(1) kavita ko abhay ne kirti ko …
Kavita=ACC Abhay=ERG Kirti=ACC

(2) kavita ne abhay ko kirti se …
Kavita=ERG Abhay=ERG Kirti=ABL

Errors in predictions were observed when preverbal nominal arguments or adjuncts were added in the sentence. The analysis of the errors reflected that ungrammatical predictions were constrained. The effect of ungrammatical predictions was also reflected in the reading time during an online reading task using the self-paced reading paradigm. There could be two possible explanations for these findings. According to the expectation-based account (Levy, 2008), the parser would be unable to make the correct prediction when s/he comes across a sentence with a series of nouns such as in (1) due to their infrequency in Hindi. Alternatively, lack of robust predictions could be due to the similarity between the noun phrases that can lead to interference between them and a consequent encoding failure at the third noun, resulting in lower accuracy of the predictions.

Hofmeister and Vasishth (2014) have previously shown that making a nominal phrase more distinctive (during its encoding) reduces similarity-based interference during its retrieval. In their work, increased distinctiveness was achieved via adjectival modification of the nominal phrase which lead to facilitatory effect at the retrieval site. Here we use this finding to investigate if better encoding of a noun phrase leads to improved prediction. Similar to Hofmeister and Vasishth (2014), adjectival modification was employed to increase distinctiveness, and thereby achieving better encoding. If inaccuracy of predictions in sentences such as (1) is due to their rarity, then such modifications should not improve the predictions. On the other hand, if the ungrammatical predictions are made due to similarity-based interference while encoding the subsequent noun phrase, then a modified noun phrase would be better encoded, resulting in improved predictions. The present study, therefore, explored the role of encoding-based interference during prediction in sentence processing. To the best of our knowledge, this is the first attempt to understand the interaction of encoding interference and predictive processing.

Methodology

Participants

32 native speakers of Hindi (9 females, 23 males, mean age = 23.84 years), pursuing an undergraduate or graduate degree program from Indian Institute of Technology Delhi, participated in this experiment. All participants had normal or corrected to normal vision and were paid INR 200 for their participation in the experiment.

Items

As stated earlier, the key manipulation was to modify a nominal phrase which had an identical case-marker compared to some nouns in the same sentence. Two types of modifications were used (participle or adjectival phrases). This was crossed with word position (first or third). Thus, making this a 2x2 design.

This design was used to run 3 separate experiments. The three experiments differed in the case-marker combination; these were (a) ko ne ko, (b) se ne se, and (c) ko ne se[1]. In all the experiments, the items comprised of three noun phrases (+animate) and one of the three case-marker combinations mentioned above.

In (3) we show the sample conditions for the 'ko ne ko' experiment.

(3a) **Position3-Adjectival**

priti-ko shivam-ne Dilliwali-Uma-ko …
Preeti=ACC Shivam=ERG from delhi Uma=ACC

(3b) **Position1-Adjectival**

Dilliwali-priti-ko shivam-ne Uma-ko …
from delhi Preeti=ACC Shivam=ERG Uma=ACC

(3c) **Position3-Participle**

Priti-ko Shivam-ne
Preeti=ACC Shivam=ERG
hoki-khelne-wali-Uma-ko ...
Hockey playing Uma=ACC

(3d) **Position1-Participle**

hoki-khelne-wali-Priti-ko Shivam-ne
Hockey playing Preeti=ACC Shivam=ERG
Uma-ko ...
Uma=ACC

12 items were prepared for each experiment. The total number of items prepared for this experiment was 144 along with 96 fillers. A latin square design was adopted for presenting 60 items (36 experimental items) to the participants.

Procedure

We use the sentence completion paradigm (Taylor, 1953). Incomplete items described above were displayed on a computer screen using the centred self-paced reading paradigm by Linger software (version 2.94) developed by Doug Rohde. The participants were instructed to complete the sentences to make them meaningful. Each trial began by presenting a fixation cross (a '+' sign) at the centre of the screen, followed by the words in the sentence one by one after the participant pressed the spacebar key. An ellipsis symbol (…) was used to prompt the participant to complete the sentence by typing in a text box. After the response had been made, the participant pressed the Enter key to begin the next trial. The presentation of the items were randomised by the software used in this study.

Response Coding

The responses were assessed for grammatical accuracy (grammatical vs ungrammatical) and the verb class (e.g., [1]Intransitive, Transitive, Ditransitive, Causative) used to complete the sentence. All grammatical completions were coded as "1" and ungrammatical completions as "0".

Verb classes were coded as "T" for transitive verbs, "DT" for ditransitive verbs, "IN" for intransitive verbs, and "CAUS" for causative verbs. In completions involving a combination of these verbs and an additional noun phrase (coded as "N"), a plus sign ("+") was added between the different verb classes or the additional noun. The last verb class always referred to the matrix verb predicted by the participant for that item.

Prediction

The results from Apurva and Husain (2019) were used as the reference point for prediction accuracy. Table 1 shows the grammatical prediction percentage for the 3 case-marker combinations used in our study.

Table 1: Percentage grammatical completions in Apurva and Husain (2019)

Condition	% grammatical prediction
ko ne ko	41%
se ne se	25%
ko ne se	65%

We hypothesised that an increase in grammatical completions in comparison to the baseline values shown in Table 1 would suggest a significant positive effect of encoding on predictive processing in Hindi. An improvement in prediction will be consistent with the cue-based retrieval theory (Lewis & Vasishth, 2005).

On the other hand, the expectation-based account will predict no difference in prediction between the current manipulation and Apurva and Husain's (2019) study. In addition, it will also predict no difference between various conditions in the 'ko ne ko' and the 'se ne se' experiments.

Results

Grammaticality All statistical analyses have been done using the generalized linear mixed-effects model. Analysis for the completion data for grammatical prediction was done using generalized linear mixed-effects with logit link function. We used maximal models (Barr et al. 2013) wherever possible; random slopes and intercepts were

[1] ne: Ergative case, ko: Accusative case, se:Ablative/Instrument case

removed for model convergence (Matuschek et al., 2017). This has been done using the lme4 package (Bates et al., 2015) in R.

The percentage grammatical predictions for the 3 experiments can be seen in Table 2.

Table 2: Percentage grammatical completion in the 3 conditions. a = Position3-Adjectival, b = Position1-Adjectival, c = Position3-Participle, d=Position1-Participle.

Experiment	a	b	c	d
ko ne ko	59	53	51	43
se ne se	47	53	54	43
ko ne se	77	80	81	69

For the 'ko ne ko' experiment, results showed a significant main effect of the modification (z=-2.02) such that prediction was better when the modification was an adjectival phrase instead of a participial phrase.

For the 'se ne se' experiment, a significant interaction (z=-2.05) was found such that there was no difference between the Adjectival modification condition but a marginal difference (z=1.82) between the Participle conditions.

Finally, for the 'ko ne se' experiment, a marginal interaction (z=-1.84) was found such that there was no difference between the Adjectival modification condition but a difference (z=2.03) between the Participle conditions. In addition, in both experiments 2 and 3, nested contrast found a marginal difference between grammatical prediction between position 3 and position 1, such that prediction in position 3 was better.

Verb Class For the 'ko ne ko' experiment, most grammatical completions were a combination of transitive and ditransitive verb. Most ungrammatical completions involved only a causative matrix verb or a transitive matrix verb.

For 'se ne se' experiment, majority of the grammatical completions comprised of a combination of a transitive verb and a ditransitive verb. A causative or a transitive matrix verb was used independently in most ungrammatical completions. A more detailed analysis of the ungrammatical completions showed that 50% of the errors were due to incorrect verbs while the remaining 50% were due to incorrect parsing of the case-markers in the presented item in both these combinations.

For 'ko ne se', participants mostly used a causative matrix verb or a combination of a transitive and ditransitive verb (either without or with an additional noun) to make accurate predictions. The items were ungrammatically completed using a transitive or a causative matrix verb or a combination of a transitive and ditransitive verb, but incorrectly parsing the case-marker. Here, the ungrammatical completions due to errors in parsing the case-markers were reduced to 11% of the total inaccurate predictions.

Discussion

The results of the present study indicate three things (1) there is a positive effect of better encoding through modification on making predictions during sentence processing in a head-final languages like Hindi, (2) the complexity of modification matters, and (3) the position of the word being modified matters.

Compared to the Apurva and Husain (2019) study (see Table 1), the average grammatical prediction in all the experiment was higher. These results can be understood in the light of reduced similarity-based interference between the first and third nouns with identical features and case-markers. The results cannot be explained by the expectation-based account (Levy, 2008). However, our results provide evidence for the cue-based retrieval theory (Lewis & Vasishth, 2005), such that the improvement in predictions from encoding the nouns with a unique feature could be governed by a higher activation of encoded noun's memory chunk (Anderson, 1990).

The grammatical completions were found to be more when the descriptors were adjectives than for participles. This suggests that even though the positive effect of better encoding are observed, yet these effects could be reduced by certain structural constraints. One of the plausible reasons for this observation could be the additional cost required to build the complex structure in Participial-N1 condition. Presence of an additional verb would increase the memory load in terms of building the participial and maintaining the partially built structure. Thus, resulting in more errors in prediction as compared to an adjectival descriptor preceding the noun phrase. Another possibility could be that the initial verb in the participial phrase itself reduces the activation of the accurate predictions by interfering with the possible grammatical predictions, thereby increasing the number of errors in these sentences. Therefore, there seems to be a tradeoff between the enriching of the noun and the complexity of the modification.

Further, the results of the present study also show that the predictions were worse in the N1-ko N2-ne N3-ko and N1-se N2-ne N3-se condition than N1-ko N2-ne N3-se condition. This could be due to increased similarity-based interference in the former conditions: first and third nouns have the same semantic class as well as the same case-markers. Although the descriptor enhances the distinctiveness of one of these nouns in the sentences, yet the presence of same case-markers results in errors in predictions unlike the latter condition with three different case-markers. The analysis of verb class also supports these results. Although the verb class was accurately predicted for some sentences, the number of errors due to case-marker confusability in 'ko ne ko' and 'se ne se' experiments is significantly more (50% of the ungrammatical completions) than those in 'ko ne se' experiment (11% of the ungrammatical completions). However, these findings need to be replicated to make stronger predictions and accurate generalisations across a larger set of languages and population.

Conclusion

The current work demonstrates that in a sentence comprising of multiple similar noun phrases, improving the encoding of a noun phrase using a modification can reduce similarity-based interference and facilitate predictions during sentence processing. This effect seems to be dependent on the complexity of the modification as well as its position in the sentence. We compared the findings of the present experiment with those reported by Apurva & Husain (2019) and demonstrated improved prediction. To account for between-group variance between our study and Apurva & Husain (2019), we plan to replicate this finding with a baseline condition within the same experiment. Furthermore, the role of prediction due to better encoding needs to be investigated during online sentence processing as well. This will be taken up in the near future.

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Source level connectivity in Resting-State MEG is mediated by different frequency band with lifespan ageing

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Abstract

Anatomical and brain oscillatory activity show significant changes over the lifespan but the relation between ageing and brain oscillation in different frequency bands are not well understood (Vlahou et al., 2014). The oscillatory neural activity measured by magnetoencephalography (MEG) provides a high temporal resolution, which is characteristic for investigating both the fast and slow dynamics of brain activity (Colclough et al, 2016). In this study, we are exploring the resting state MEG data across the life span to understand the alteration with age in frequency-specific connectivity patterns. Our results demonstrate that healthy ageing is characterized by a decrease in source power spectral density (PSD) in the alpha frequency range and an increase in source PSD in beta frequency range across the lifespan. Motivated by these results we compare the whole brain MEG connectivity using envelope amplitude correlation. The results show a systematic decrease in correlation values for alpha frequency band which may be a key neural correlate of lifespan ageing.

Keywords: MEG; Source Reconstruction; Envelope correlation; resting state.

Introduction

Resting-state connectivity has been progressively concentrated to explore the impacts of ageing on the brain (Petti et al, 2016). Resting-state connectivity estimation with electrophysiology is a significant instrument for contemplating specific brain activity (Colclough et al, 2016). Neurobiological clarifications for the age-related cognitive decline have concentrated on loss of grey and white matter volume, decreased dopaminergic neurotransmission during cognitively demanding assignments, and decrease in hippocampal subregions, related to impaired memory performance. Test assessing the speed of processing, memory and executive functions have shown decline associated with alteration in the white matter along with the different age groups. Significant alterations in brain oscillatory activity are also characterized by ageing. Physiological ageing is also summed up as slowing of EEG activity, increase in beta power and decrease of amplitude in lower alpha (8–10.5 Hz) and slowing of peak alpha frequency. In certain studies, an increase in delta (1-4 Hz) and theta (4-7.5 Hz) has been reported, while different investigations have demonstrated an overall decline with age (Vlahou et al, 2014). In this investigation, we are using publicly available Cam-CAN resting-state MEG data from a large cohort, to understand neural correlates of healthy ageing and the lifespan associated dynamical changes to large-scale brain connectivity related to different frequency bands.

Methods

The resting-state MEG data and a public release is made by Cam-CAN and all the details are provided elsewhere (Taylor et al, 2017). Our group has worked with the same dataset at the sensor level, computing global coherence and metastability. The promising result at sensor level motivates us to look at the source level (Sahoo et al,2018). We have employed MNE-Python, a python-based software package that provides comprehensive analysis tools and workflows including preprocessing, source estimation, time-frequency analysis, statistical analysis, and several methods to estimate functional connectivity between distributed brain regions (Gramfort et al, 2013).

We have considered a subsample of 50 subjects in each group comprises of young (age 18-28), middle-aged (age 40-49), and old (age 78-87). We averaged the obtained sources, we use a common template, collin27 for the estimation of BEM, source space and projection of sensors on the head. Segmentation and cortical reconstruction on collin27 was performed using freesurfer (Dale, A. M., Fischl, B., & Sereno, M. I. (1999)).

sLORETA was used to reconstruct the brain activity in source space. Source PSD was estimated for all the individual subjects and was then averaged and plotted on a common template for visualization. Further, we calculate the inverse of epoched data and parcellated the sources using Desikan-Killiany(Desikan et al, 2006) atlas for computing envelope correlation on different frequency groups.

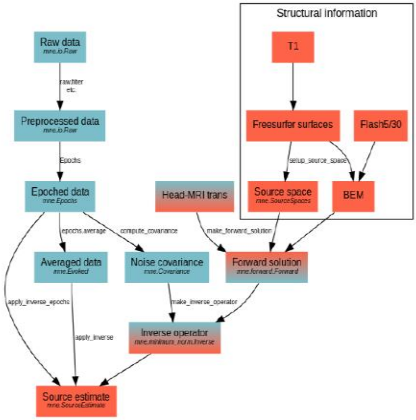

Figure 1: MNE-Python Workflow (*The typical M_EEG workflow — MNE* 0.18.2. Retrieved from https://martinos.org/mne/stable/manual/cookbook.html)

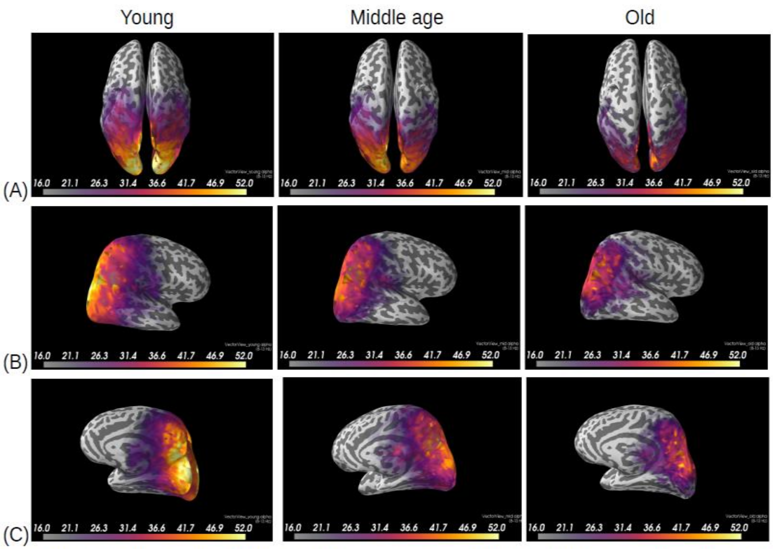

Figure 2: Visualization of source PSD for Alpha frequency in Young, Middle and Old age group (from left to right). A, B, and C represents dorsal, right lateral and left lateral view respectively.

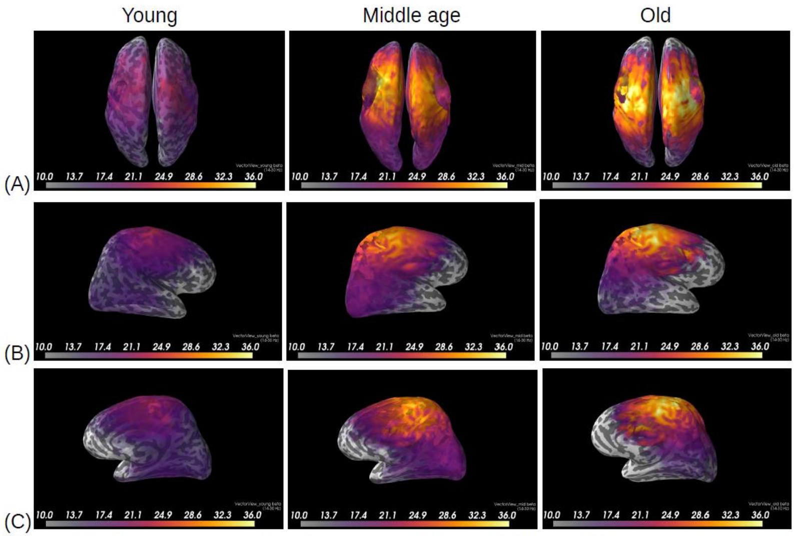

Figure 3: Visualization of source PSD for Beta frequency in Young, Middle and Old age group (from left to right). A, B, and C represents dorsal, right lateral and left lateral view respectively

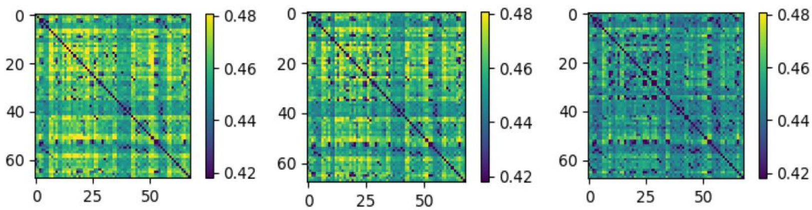

Figure 4: Envelope correlation obtained for Alpha frequency for young, middle, and old age group (from left to right)

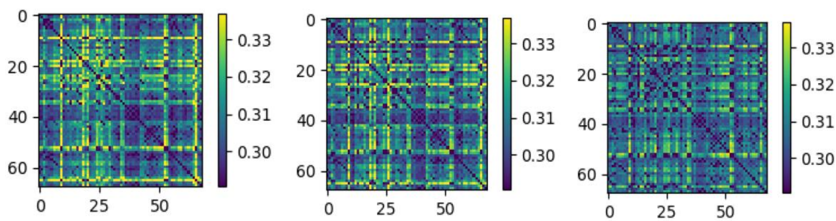

Figure 5: Envelope correlation obtained for Beta frequency for young, middle, and old age group (from left to right)

Results

PSD plots of the source space (Figure 2 and 3) shows a decrease in alpha power and an increase in beta power across the lifespan. Occipital is the primary area of the activation for the alpha frequency and parietal for the beta. From the PSD plots, the reduction in power of alpha frequency in elderly individuals is evident. To find out MEG connectivity, we computed the envelope correlation, where we found that in the case of the alpha band there is a decrease in correlation values which is evident from Figure 4, as we move across the age.

Discussion

Our frequency-specific analysis of resting-state MEG data across different age groups shows a difference in power, localization and envelope correlation. The difference we observe in power and localization might be because of the difference we have found in envelope correlation. To further consolidate the results and finding, we would further go ahead with the analysis determining the connectivity matrix, identifying the frequency-specific activated regions and statistical thresholding for significance in the results.

Acknowledgements

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The typical M_EEG workflow — MNE 0.18.2. Retrieved from https://martinos.org/mne/stable/manual/cookbook.html

Role of whole-brain structural constraints in generation of auditory steady-state responses (ASSR)

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Abstract:

Several studies have shown that structural and functional brain networks involved in auditory stimulus processing are distributed in the brain. One way to characterize the functional networks of auditory processing is to investigate the brain networks of auditory steady-state responses (ASSR). In this study, we have asked whether constraints in whole-brain structural connectivity with auditory brain regions as seed, is the cause of the asymmetry in brain functional organization. Here we obtain structural connectivity matrix from DTI data and parcellate in 68 regions according to the Desikan–Killiany brain atlas. Structural connectivity matrix was used to estimate the length of fibres between any pair of parcels. We estimated the time delays that are involved in transmitting information between any pair of nodes. The auditory parcels were triggered with 40 Hz intrinsic frequency while other parcels were set at an intrinsic frequency of 1 to 100 Hz. The computational model reveals that whole-brain 40 Hz can be obtained by locally exciting the auditory brain parcels. More notably, our results show that the oscillatory dynamics of ASSR that is empirically observed at the scalp can be attributed to structural constraints in tandem with time-delayed interactions.

Keywords: ASSR; Kuramoto model; Structural and functional connectivity

Introduction

Characterizing hemispheric dominance in the functional specialization of sensory processing is a fundamental question in cognitive neuroscience. Several studies have shown that structural and functional brain networks involved in auditory stimulus processing are asymmetrically distributed in the brain (Mišić et al. 2018; Ross, Herdman, and Pantev 2005). One way to characterize the functional networks of auditory processing is to investigate the brain networks engaged in generating steady-state auditory responses (ASSR) – a neurophysiological marker of complex auditory processing (Kuwada et al. 1986). Our earlier EEG studies with ASSR have revealed that entrainment of 40 Hz rhythms occurs in large-scale neural networks visible from scalp and source connectivity analysis. Interestingly, our results indicate there is a right hemisphere bias of leadership role in a community interaction during the binaural hearing of 40Hz rhythms. During the monaural stimulations, ipsilateral hemisphere was more dominant than contralateral in terms of information processing metrics, e.g., power spectra, global coherence, imaginary coherence, and Granger causality (Figure 1). In this study, we have asked whether constraints in whole-brain structural connectivity with auditory brain regions as seed, is the cause of the asymmetry in brain functional organization.

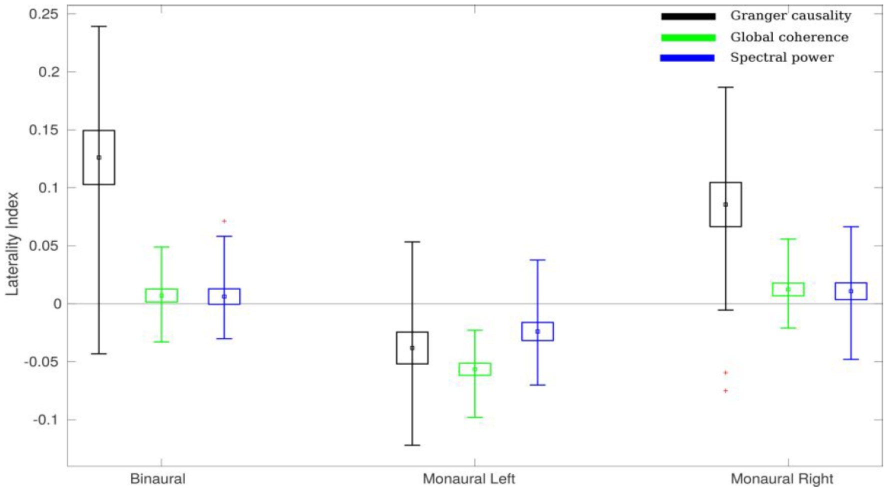

Figure 1: Group level laterality indices distribution for 40 Hz spectral power, functional network, causal network different Stimulus conditions. The central square in each box-plot represents mean of data. The lower and upper boundary of the box represents the lower and upper 95 % confidence interval, respectively. '+' symbol marks outlier (point more than 1.5 times the interquartile range above the 75th percentile or below 25th percentile). The whiskers length represent the total distribution of data excluding outliers.

Methods

Diffusion imaging data was collected in normal healthy volunteers from which the structural connectome was computed. DTI data was collected from a total of 49 participants (25 young and 24 old). Obtained structural connectivity matrix was parcellated in 68 regions according to the Desikan–Killiany brain atlas. Structural connectivity matrix was used to estimate the length of fibres between any pair of parcels. Using a value of velocity 42 m/s as communication speed, we estimated the time delays that are involved in transmitting information between any pair of nodes. These time delays were used to couple the Kuramoto oscillators (Cabral, 2011) at the 68 parcels. The auditory parcels were triggered with 40 Hz intrinsic frequency while other parcels were set at an intrinsic frequency of 1 to 100 Hz. Empirically, EEG data was collected from 20 healthy volunteers who signed informed consents, approved by the Institutional Human Ethics Committee of National Brain Research Centre, India. The participants had to stay still in a sitting position while their EEG was recorded during rest (200 s) and binaural (200 s) auditory stimulation. Pure tones at 1 kHz frequency were presented at 40 cycles a second during the periodic stimulation period to generate an auditory steady-state response.

Results

The dynamical states of the network was investigated to interpret the underlying mechanisms of hemispherical asymmetry that we observed in empirical EEG data. Secondly, the computational model reveals that whole-brain 40 Hz can be obtained by locally exciting the auditory brain parcels when the intrinsic frequency of neural oscillators reaches at least 20 Hz for the dorsal attention network and more than 30 Hz for the visual network.

Discussion

Here we show that a biologically plausible Kuramoto model of phase oscillators can be used to study the underlying dynamics of oscillatory mechanisms that lead to the generation of a steady-state response or brainwave entrainment in a large-scale brain network. More notably, our results show that the oscillatory dynamics of ASSR that is empirically observed at the scalp can be attributed to structural constraints in tandem with time-delayed interactions.

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Dynamic Repertoire of Brain During Task and Rest

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Abstract

Growing evidence has shown that brain activity at rest and task slowly wanders through a repertoire of different states, where whole-brain functional connectivity (FC) temporarily settles into distinct FC patterns. In this study, we investigate how dynamic functional connectivity patterns differ in resting-state and task, by characterizing the dominant FC patterns and capturing the evolution of these patterns across time. We analyze Cam-CAN resting-state, passive movie watching and sensory motor task fMRI data from 50 healthy adults categorized into two groups, young and old. We use a novel method which captures the dominant FC pattern in a leading eigen subspace of dynamic FC matrices. The time dependent evolution of these patterns is captured by time versus time leading subspace angle difference matrices, where each entry corresponds to the overlap between the dFC at times tx and ty. We find distinct, characteristic FC patterns in rest, movie and task paradigms, that differ significantly between young and old cohort. Frobenius distance analyses of leading subspace matrices indicate that FC patterns during rest among young and old are far apart than task conditions. These results provide new evidence in establishing the differences in brain activity across age and importance of resting state dynamics.

Keywords: dFC; Eigen subspace; Leading subspace; Resting state; Functional Connectivity; Cam-CAN

Introduction

Even at rest, when no task is performed, the brain displays the spontaneous waxing and waning of meaningful functional networks on a slow time scale (<0.1 Hz) (Beckmann, C. F., DeLuca, et al). This so-called *resting-state* activity has been proposed to reflect the spontaneous activation and deactivation of different network configurations supported by the structural *Connectome*, resulting in a constant reconfiguration of functional connectivity (FC) patterns over time (Joana Cabral et al) (Hansen et al). This cannot be captured by static FC analysis, where BOLD signal correlation is calculated for the entire recording session. By adding temporal dimension to the FC analysis switching behavior between different FC patterns can be studied. The best method to study the switching behavior is still under debate (Joana Cabral et al) but the most commonly used strategy has been to calculate successive *FC(t)* matrices using a sliding-window (Hansen et al). Recurrent FC configurations are then captured by applying unsupervised clustering to all the *FC(t)s* obtained over time (Deco et al) (Joana Cabral et al). However, the sliding-window approach has limitations associated to the window size, which affects the temporal resolution and statistical validation (Allen et al) (Hutchinson et al). Present study proposes a leading eigen subspace analysis method which focuses solely on the dominant FC pattern captured by leading eigen subspace of BOLD phase coherence signals.

Methods

Cam-CAN fMRI raw datasets of movie, rest and sensory motor task (smt) were pre-processed and time series were extracted using AAL parcellation. The fMRI scan dataset has 25 subjects in young and old cohort each with TR=2s and 261 timepoints.

Results

Algorithm: We developed a method, Leading subspace analysis, which is modelled on Leading eigen vector analysis (LEiDA) (Joana Cabral et al 2017).

dFC: We estimate time resolved dynamic functional connectivity(dFC) of the timeseries, with size NxNxT where N=116 is the number of brain regions defined by aal atlas, T = 40 total number of recording frames. First, phases of BOLD signals using Hilbert transform. Given the phases of the BOLD signal, Given the phases of the BOLD signals, the phase coherence between brain areas n and p at time t, $dFC\,(n, p, t)$, is obtained using Equation:

$$\mathbf{dFC\ (n,\ p,\ t) = cos\ (\theta\ (n,\ t) - \theta\ (p,\ t))}$$

Leading subspace difference: To compare dFC patterns over time, we propose an approach where we consider leading subspace $\sum \mathrm{Vn(t)}$

$$\mathbf{dFC(t,t') \approx \sum_{n=1}^{K} Vn(t)Un(t')}$$

of each dFC (t, t'). The leading eigen subspace captures dominant activity of dFC(t) at time t.

To study the evolution of overlap between dFC subspaces over time we compute a time versus time matrix. Representation of functional connectivity dynamics (FCD), where each entry *LSD* (t_x, ty), corresponds to the overlap between the *dFC* at times t_x and t_y. The measure of similarity between the FCD entries is the angle between the subspaces spanned by FCDs at time t_x and t_y

$$\mathbf{LSD}\ (t_x, ty) = \mathbf{angle}\ (\mathbf{V_n}\ (\mathbf{tx})\ \mathbf{and}\ \mathbf{V_n}(t_y))$$

The LSD values can vary between 0 and $\pi/2$, with 0 representing maximum overlap and $\pi/2$ representing orthogonal subspaces.

The dominant dFC patterns captured by leading subspace analysis are distinct to movie, rest and sensory motor task. The evolution of overlap of dFC patterns captured in LSD matrices indicate differences in switching behavior of dFC patterns in young and old cohort for movie, rest and sensory motor task paradigms. Frobenius distance analysis which captures the distance between dominant dFC patterns in LSD matrices between young and old cohorts, indicates that dominant dFC patterns in movie and smt are closer in young and old brain as compared to rest dFC patterns

Discussion

Our results show that the Leading Subspace Analysis is a powerful tool to characterize the dominant *dFC* patterns, as well as to capture the temporal evolution of dFC patterns. Here we find significant differences in dFC patterns in rest among young and old cohorts suggesting the dynamicity in resting state brain dynamics

Acknowledgments

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Shared and Distinct Mechanisms of Eye Movements and Attention

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Abstract

Attention is a process of selecting behaviorally relevant information from a vast pool of information in the environment. Spatial selection of information also occurs by moving the eyes to locations that are inherently salient, or are relevant to task goals. The "premotor theory of attention" hypothesizes that attention and eye movements are inextricably linked, and that they share common neural circuits. We seek to examine this theory in detail by investigating mechanisms that are common and distinct to eye movements and attention. It is increasingly clear that attention, itself, is not a unitary process, and comprises two fundamental components: sensitivity and bias. Using model-based analysis of behavior, we seek to test which of these components -- sensitivity, bias or both -- are modulated when targets of attention and eye movement preparation are either common or dissociated.

Keywords: attention; eye movement; saccade; psychophysics; sensitivity; bias; m-ADC

Introduction

At any instant, there is an overwhelming amount of information available to our senses. Not all of this sensory information can be processed at once, given the limitations of the biological system. Attention is the mechanism that enables the selection of behaviorally relevant information for enhanced processing through prioritized allocation of cognitive resources. The attention deployed towards optimally parsing information from a scene through vision, is visuospatial attention. Shifts in visuospatial attention have been proposed to be tightly linked with eye movements. This idea was formalized in the form of the "premotor theory of attention" (Rizzolatti, 1987), which hypothesized that reorienting of attention is preceded by eye movement planning, and that they share neural correlates. However, the validity of the theory and its interpretation have remained matters of contention in the field (Wollenberg, 2018).

A number of studies in both non-human (Kustov, 1996; Steinmetz, 2014) and human (Deubel, 1996; Klapetek, 2016; Rolfs, 2012) primates have investigated the premotor theory of attention. More specifically, ballistic movements of the eyes between two points in space called saccades have been extensively studied. A recent macaque study (Steinmetz, 2014) demonstrated that the modulation of neural activity in area V4 of the visual cortex by saccade preparation is qualitatively and quantitatively similar to modulation by covert attention. The monkeys selectively attended to one location where change was more likely to happen, and responded by making a saccade to a location opposite to that of change. Thus, they were able to dissociate the target of attention from that of saccade preparation, and still find comparable signatures of the two at the neuronal level. To understand better if such neuronal activity modulations through saccade preparation might translate into attentional modulation, we need to study behavior comprehensively.

It has been shown that attention is not a unitary process (Sridharan, 2014; Banerjee 2019) and can improve behavioral performance via modulation of one (or both) of two key components: perceptual sensitivity – enhanced sensory processing of attended location, and choice bias – selective gating of sensory information from attended location. We can study these components using Signal Detection Theory (SDT) where the discriminability between the signal and noise distributions is a measure of sensitivity, and criterion is a threshold value of the decision variable that determines the response of whether the signal is present or not. To measure sensitivity and bias in a detection task comprising trials with possible change at one of multiple locations, we use a multi-Alternative Detection/Change-Detection (m-ADC) model (Sridharan, 2014).

In this study, we explore the link between eye movements and visuospatial attention in finer detail by specifically examining whether sensitivity, bias or both are modulated with saccade preparation in the context of cued attention, using model-based psychophysics. We hypothesized that eye movement preparation, like attention (Banerjee 2019), would improve performance by increasing both sensitivity and bias. We expected additional saccade planning towards the attentional target to augment performance. Correspondingly, we envisaged that dissociation of saccade planning from attentional cueing will improve performance at the potential saccade target, but diminish performance at the cued location.

Methods

To understand how saccade preparation and endogenous attention interact, we had subjects perform a set of behavioral tasks with a 4-Alternative Detection/Change Detection (4-ADC) paradigm, where they responded by making a saccade either towards or away from the location of perceived change.

Participants

10 subjects (4 females, age: 20-26 years) took part in the experiment. All had normal or corrected-to-normal vision. None had a history of any neurological disorders.

Setup

The subjects performed the tasks in a dimly illuminated room, with their head stabilized with a chin and forehead rest, 60 cm from the stimulus display screen (BenQ, 144 Hz). Eye movements were tracked using SMI HiSpeed Eye Tracking System. The task was designed on Psychtoolbox and run using MATLAB 2015b. Button-press responses were recorded through an RB-840/RB-540 Cedrus response box.

Task

Participants performed cued, 4-ADC tasks. A trial (Fig. 1A) began with a central fixation cross being displayed for 1.5 s, after which 4 Gabor stimuli (full contrast, spatial frequency: 2 cpd, orientation: independently drawn from a uniform distribution) came up on the screen (5° from the fixation cross, at 4 corners of an invisible square) for 0.5 s, surrounded by placeholder squares. A central white arrowhead cue then appeared for 0.3-1.1 s (drawn from an exponential distribution), indicating the location where change was more probable (Fig. 1B). After a 0.1 s blank, the stimuli reappeared with a change in orientation (change angles: 2, 10, 15, 25, 45, 90°) of one (75% of trials) or none (25% of trials) of the 4 Gabors. The subjects indicated the location of change by making a saccade either towards the location (prosaccade) or towards the diametrically opposite location (antisaccade). To give a no-change response, they maintained fixation and pressed a button. All subjects performed both the prosaccade and the antisaccade versions of the task after adequate training (order of tasks was counterbalanced across subjects). They could respond within 0.6 s and 0.8 s of the appearance of the changed stimuli in the prosaccade task and the antisaccade task respectively. Each task consisted of 12 blocks of 48 trials.

Data analysis

For each subject, we pooled data across blocks and constructed stimulus-response contingency tables (Fig. 1D) for each change-angle tested. The rows indicate the location of changed stimuli aligned to the saccade cue (Fig. 1B): cued (location where the cue pointed), opposite (location diametrically opposite to the cued location), adjacent-ipsilateral (location in the same hemifield as the cued location), and adjacent-contralateral (location in the opposite hemifield as the cued location). The columns represent the location of change reported by the subject, similarly aligned to the cue. The fifth row and column correspond to no-change stimulus and no-change response, respectively. The values along the diagonal signify the correct responses (hits: where the subject reported the location of change accurately; correct rejections: when the subject correctly reported no change). The off-diagonal elements denote the incorrect responses

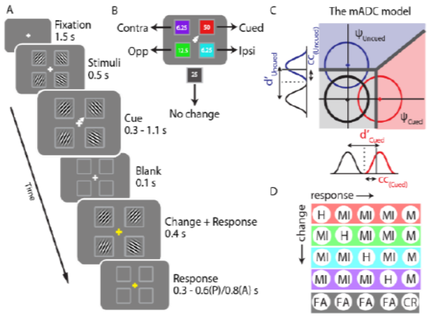

Figure 1: Task structure and model for analysis of behavior. *__A__. The 4-ADC task. After a short fixation, 4 oriented Gabors appeared, one in each quadrant. Next, a central white arrow appeared, pointing to 1 of these 4. After a brief blank, the stimuli reappeared with an orientation change in one or none of the stimuli. The subjects responded by making a saccade towards (prosaccade) or diametrically opposite to (antisaccade) the location of perceived change, or maintained fixation and pressed a button to indicate a no-change response. __B__. Proportion of trials. The numbers indicate the percentage of each type of trial: No-change (dark grey; where no change occurs at any location); Change: Cued (red; indicated by the arrow), Opposite (green; diametrically opposite to the cued location), Ipsilateral (cyan; in the same hemifield as the cued location), and Contralateral (purple; in the hemifield contralateral to the cued location). __C__. The multi-alternative detection/change detection (mADC) model. A multi-dimensional signal detection model with the decision variable modelled along orthogonal axes with Gaussian distributions for no change (black circle), change at cued location (red circle) and change at an uncued location (blue circle). The difference between the no-change and change distributions' means represent the sensitivity (d') for that location. The thick dark grey lines indicate the criteria for each location (difference between the criterion and the intersection of no-change and change distributions is the choice criterion (cc)). Marginal distributions are depicted along the axes. __D__. Change-response contingency table. Rows indicate the locations of orientation change and the columns represent the response of perceived change location. The colors indicate the locations relative to the cue (as in B.). H: hits, M: misses, FA: false alarms, CR: correct rejections, MI: misidentifications.*

(misses: when the subject reported no-change despite an occurrence of change; misidentifications: where the change was detected but incorrectly localized; false alarms: when there was no change, but the subject reported a change).

Using these contingency tables, we obtained the psychometric function (Fig. 2A) for each subject by plotting the hit rate for different locations as a function of the change angle. Along with this, we calculated the false alarm rate for each location, and an overall correct rejection rate.

We then computed the psychophysical function (Fig. 2B) for individual subjects by fitting their respective contingency tables with the m-ADC model to obtain measures of sensitivity (d') for different change angles per location, and those of criteria (c) for each location. We calculated the choice criterion (cc) for each location using the respective criterion and average sensitivity across angles. The negative of choice criterion was taken as a measure of choice bias. All multiple comparisons were corrected with Tukey-Kramer correction, unless otherwise specified.

Results

Examining the psychometric analysis (Fig. 2A) of the prosaccade task, we observe that the average hit rate was highest at the cued location (HR_{pro}: cued = 73.1±1.6, mean±SEM, p<0.001, ANOVA) and not significantly different across the opposite, ipsilateral and contralateral locations (HR_{pro}: opp = 30.8±2.1, ipsi = 26.4±4.1, contra = 32.4±2.2, p>0.05). We saw a similar pattern for false alarm rate (FA_{pro}: cued = 29.6±4.1, p<0.001; opp = 7.0± 1.1, ipsi = 6.5±1.5, contra = 4.3±0.7, p>0.05). In the antisaccade task, the hit rate was significantly higher at the cued location in comparison to the other locations (HR_{anti}: cued = 73.5±3.0, opp = 31.7±4.7, p<0.001), and that at the opposite is higher than those at the adjacent locations (HR_{anti}: opp = 31.7±4.7, p<0.001; ipsi = 15.1±3.0, contra = 14.8±2.8, p>0.05). The false alarm rate at the cued location was higher than the opposite, ipsilateral and contralateral locations, but not significantly different across these 3 locations (FA_{anti}: cued = 33.3±6.3, p<0.001; opp = 6.1±0.8, ipsi = 4.4±0.9, contra = 3.2±0.5, p>0.05).

The psychophysical analysis (Fig. 2B) also revealed differences in performance across the locations. In the prosaccade task, we observed that the sensitivity was highest at the cued location (d'_{pro}: cued = 1.6±0.1, cued vs opp: p<0.001, cued vs ipsi: p<0.001, cued vs contra: p=0.004) and not significantly different across the opposite, ipsilateral and contralateral locations (d'_{pro}: opp = 0.9±0.1, ipsi = 0.8±0.1, contra = 1.1±0.1, p>0.05). The choice criterion was lowest for the cued location (cc_{pro}: cued = -0.3±0.1, p<0.001), and comparable for the other 3 locations (cc_{pro}: opp = 0.8±0.1, ipsi = 0.9±0.1, contra = 0.9±0.1, p>0.05). In the antisaccade task, sensitivity was significantly higher at the cued location as compared to the other locations (d'_{anti}: cued = 1.3±0.1, p<0.001). Furthermore, the sensitivity was significantly higher at the opposite location compared to the adjacent locations (d'_{anti}: opp = 1.0±0.1, opp vs ipsi: p<0.001, opp vs contra: p=0.005; ipsi = 0.5±0.1, contra = 0.6±0.1, p>0.05). A similar gradation was observed in the choice criteria. The cc was lowest for the cued (cc_{anti}: cued = -0.3±0.1, p<0.001), while the cc for the opposite was significantly lower compared to those for the adjacent locations (cc_{anti}: opp = 0.8±0.1, opp vs ipsi: p=0.040, opp vs contra: p=0.017; ipsi = 1.2±0.1, contra = 1.3±0.1, p>0.05).

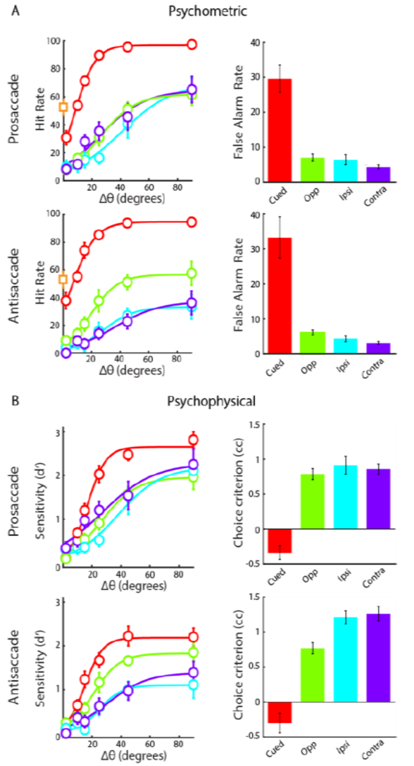

Figure 2: Behavioral performance. ***A****. Psychometric measures. (Left) The average psychometric function (n=10) exhibiting the hit rate as a function of angle of change (Δθ) for the prosaccade (top) and the antisaccade (bottom) tasks. The orange square on the ordinate represents the correct rejection rate. (Right) The average false alarm rates across the different locations.* ***B****. Psychophysical measures. (Left) The average psychophysical function showing the sensitivity (d') across the different angles of change (Δθ) for the prosaccade (top) and the antisaccade (bottom) conditions. (Right) The average choice criteria (cc) for different locations. Color conventions as in Figure 1B. Error bars: SEM (some are masked by the data points). Curve fits: sigmoidal.*

We next compared the performance at each location across the two task conditions. Notably, both the tasks had the same cueing paradigm, but differed in terms of how subjects responded through saccades, and thus where eye movement preparation was directed. The hit rate at the ipsilateral and contralateral locations was significantly lower in the antisaccade task versus the prosaccade task (HR_{pro} vs HR_{anti}: ipsi = 26.4±4.1 vs 15.1±3.0, p=0.002; contra = 32.4±2.2 vs 14.8±2.8, p=0.002, Wilcoxon signed rank test), and comparable at the cued and opposite locations (HR_{pro} vs HR_{anti}: cued = 73.1±1.6 vs 73.5±3.0, p>0.05; opp = 30.8±2.1 vs 31.7± 4.7, p>0.05). The false alarm rate was significantly lower at the ipsilateral location in the antisaccade task (FA_{pro} vs FA_{anti}: ipsi = 6.5±1.5 vs 4.4±0.9, p=0.027) and not significantly different across the two tasks for the other 3 locations (FA_{pro} vs FA_{anti}: cued = 29.6±4.1 vs 33.3±6.3, opp = 7.0±1.1 vs 6.1±0.8, contra = 4.3±0.7 vs 3.2±0.5, p>0.05).

We observed that the sensitivity (averaged across the top 3 angles) at the cued, ipsilateral and the contralateral locations was significantly lower in the antisaccade task in comparison to the prosaccade task (d'_{pro} vs d'_{anti}: cued = 2.4±0.2 vs 2.0±0.2, p=0.027; ipsi = 1.3±0.2 vs 0.9±0.2, p=0.020; contra = 1.7±0.2 vs 1.0±0.1, p=0.010). The sensitivity at the opposite location was comparable across the two tasks (d'_{pro} vs d'_{anti}: opp = 1.5±0.2 vs 1.6±0.2, p>0.05). In terms of choice criteria, we observed that for the ipsilateral and contralateral locations, there was a significant difference across the prosaccade and antisaccade tasks (cc_{pro} vs cc_{anti}: ipsi = 0.9±0.1 vs 1.2±0.1, p=0.010; contra = 0.9±0.1 vs 1.3±0.1, p=0.004). For the cued and opposite locations, we saw no significant difference across the two tasks (cc_{pro} vs cc_{anti}: cued = -0.3±0.1 vs -0.3±0.1, opp = 0.8±0.1 vs 0.8±0.1, p>0.05).

Our results show that cueing of attention increased both sensitivity and choice bias at the cued location in both the prosaccade and the antisaccade task relative to all the uncued locations. Saccade preparation increased sensitivity at the saccade target (cue-opposite) location relative to the adjacent locations. Both sensitivity and bias at the opposite location remained comparable across the two tasks. In comparison to the prosaccade task, the sensitivity at the cued location was lower in the antisaccade task, but the bias was not different. Surprisingly, the most robust effect on performance was observed at the ipsilateral and the contralateral locations, with both sensitivity and bias being lower (at both locations) in the antisaccade task as compared to the prosaccade task.

Discussion

To understand how eye movement preparation and attention interact, we had subjects perform a set of behavioral experiments that involved coupling of saccade preparation with endogenous cueing of attention. Attention and saccade planning were either coupled or decoupled by having subjects respond either to the cued location or diametrically opposite location, respectively. We employed a 4-ADC task with a prosaccade/antisaccade response. This allowed us to study the effects of saccade preparation decoupled from endogenous cueing effects towards potential saccade targets.

We had hypothesized that in the antisaccade task, there would be an increment in performance at the opposite location, accompanied by a decrement in performance at the cued location (as compared to the prosaccade task). Partly in line with our hypothesis, we saw a decrement in cued location sensitivity in the antisaccade task compared to the prosaccade task, but no increment in performance at the opposite location. The strongest effect of dissociating endogenous attention and saccade preparation is reflected in a decrease in perceptual sensitivity and choice bias at the adjacent locations, which were targets of neither attention nor saccade preparation. This can be interpreted as a reallocation of resources away from the adjacent locations and towards the cued and opposite locations, which needed to be prioritized in terms of attention and eye movement preparation respectively, in the more challenging antisaccade task.

Future work could further explore the neural and behavioral links between eye movements and attention with dual-task paradigms of saccade execution and change detection to measure spatial sensitivity and choice bias, with varied degrees of attentional cueing.

Acknowledgments

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Does cognitive load affect locomotor adaptation?

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Introduction:

Locomotor control requires very little attention in healthy individuals under usual circumstances. It has been shown previously that people can adapt to continued perturbations while walking, such as, on a split-belt treadmill (Reisman et al. 2007), or, with unilateral resistance during swing phase of gait (Savin et al. 2014). Studies in upper extremities have revealed that dual task interference during a motor adaptation task can interfere with the encoding of errors in the feedforward model, resulting in impaired learning (Taylor and Throughman, 2007). Since walking is a fairly automatic process, the effect of performing an additional task during locomotor adaptation might be different than other motor adaptation processes. Previous research in split-belt adaptation paradigm have shown that performing a secondary, unrelated task can reduce the performance during training, but lead to longer retention (Malone and Bastian, 2010), after the perturbation has been removed. A greater involvement of implicit process due to the divided attention between the two tasks has been posited as the reason for better learning. Here we tested if the same holds true in the case of adaptations to unilateral force perturbation during the swing phase of gait of healthy individuals. We hypothesized that participants who adapt to force perturbation along with a concurrent cognitive task (C.D.T group) would show longer retention of after effects as compared to the participants who did not perform the secondary cognitive task (control group).

Methods:

Seventeen healthy participants were recruited from the university population for the experiment. Participants walked on an electric treadmill operating at a speed of 3.5 km/h, which was kept constant throughout the experiment consisting of three sessions – baseline, training, and post-training, which lasted 5 minutes, 8 minutes, and 4 minutes respectively. During the training session, a rope was attached to the lower shank of the left leg, from which a load was suspended through a set of pulleys, such that the load resisted the forward movement of the leg during swing. The weight of the load was equal to 20 percent of the maximum voluntary force the participant could produce, rounded to the nearest 0.25 kg. During the training session, participants in the cognitive dual-task group (C.D.T) performed a concurrent serial seven subtraction task from a random number given by the experimenter, while the control group were given no specific instructions. Step length symmetry and swing time symmetry were calculated from gait kinematic data recorded using motion capture system.

Results:

Spatio-temporal parameters were used as performance measures for both the groups. Step symmetry values increased significantly from the baseline values during the training session for both the groups, as revealed by one-way ANOVA. The control group showed significant negative after-

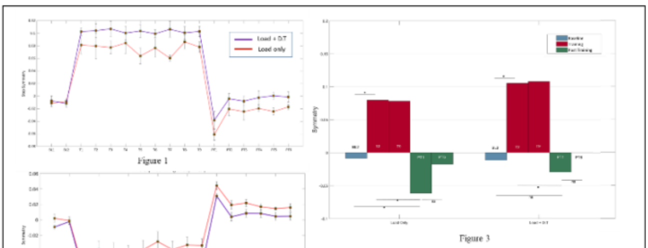

Figure 1: Variation of group mean step symmetry at 17 points throughout the experiment viz. BL1, BL2 (baseline), T1 to T9 (training), PT1 to PT6 (post-training). Figure 2: Group mean swing time symmetry at the same points. Figure 3: Comparison of step symmetry for the two groups at baseline, early and late training, and early and late post-training sessions.

effects as compared to baseline, upon removal of load, but this was not significant in the cognitive dual-task group. However, a two-way ANOVA did not show a significant difference between the groups. Swing time symmetry values also showed a significant change in the training and negative after-effects in the post-training period from baseline values, but no difference between the groups.

Conclusion:

After effects upon removal of load indicate that both the groups adapted to changes in limb dynamics using a true motor adaptation process. We had expected spatio-temporal symmetry differences between the groups, which could not be seen from the results. Previous studies have, however, reported that locomotor adaptation can benefit from a secondary cognitive task, but, unlike studies in split-belt paradigm where the participants are subjected to spatio-temporal error, here, the participants encountered a force field, which led to spatio-temporal asymmetry. This suggests that locomotor adaptation to force perturbation may be more immune to cognitive interference than other kinds of adaptations.

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Keywords: locomotor adaptation; dual task interference; neurorehabilitation.

Movement adaptation and savings upon reach target location perturbations

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Abstract

We addressed the novel question of whether, and how, movement adaptation occurs in response to changing target goals. Subjects performed point-to-point reaching movements whose goal was perturbed by "jumping" the target to a new location (45 degrees counterclockwise relative to the original location), at a fixed time after movement initiation.

We found that subjects adapted to the jump perturbation by progressively moving to the new location of the target. Straight movements to the original target on probe trials, with few stationary targets interleaved within the training block, indicated that subjects were able to "switch off" the learnt strategy when instructed. This, along with the absence of a significant after-effect on trials immediately after adaptation, suggests that learning in the task was truly explicit.

Further, we found substantial savings of the learnt strategy when subjects were re-exposed to the same perturbation after a long washout block. The results argue for the possibility of savings in motor adaptation being driven by learnt cognitive strategies. The task provides a possible window into accessing the neural correlates of the cognitive, strategy-based, facet of motor learning.

Keywords: human; reaching; double step; cognitive; adaptation; motor

Introduction

Previous research on motor adaptation have largely explored paradigms that perturb the actual or seen position of the limb. In such conventional studies, adaptation to the perturbation is characterised by an initial, rapid, decrease in sensorimotor error, followed by a gradual decrease in error as learning saturates.

These studies have found that adaptive motor behaviour culminates as a result of a combination of implicit processes, explicit strategies, and operant mechanisms. However, in typical motor adaptation tasks, movement goals remain fixed. Yet, in everyday behaviour, movement goals often change.

How the motor system adapts to changes in movement goals remains unclear. Our study addressed the previously unexplored question of whether, and how, humans show adaptation in response to changing movement goals. We hypothesised that such adaptive motor behaviour would be driven mainly by the development and expression of explicit strategies.

Methods

The task consisted of four blocks: baseline, adaptation, washout and re-adaptation.

First, we asked subjects to make 56 "baseline" point-to-point reaching movements to fixed, stationary targets with their dominant hand.

This was followed by 112 "adaptation" trials in which the target was consistently "jumped" by a fixed magnitude (45 degrees) in the same direction (counterclockwise) on each trial (TJ). Interspersed within the TJ trial block, were 3 sub-blocks of 4 trials each, in which the target was not jumped (NJ). The NJ trials served as probes to determine how learning progressed over the training block.

We instructed subjects to reach to the new location of the target on the TJ trials and the location of the original target on the NJ trials. Subjects were provided these instructions every time the jump conditions changed from NJ to TJ and vice versa.

Following the adaptation block, subjects performed 112 "washout" (NJ) trials and then a second "re-adaptation" block identical to the first..

Results

We found that subjects easily adapted to the jump perturbation. Hand direction data reflected that they progressively directed their movements straight to the new target on the TJ trials in the adaptation block.

Interestingly, subjects also rapidly "de-adapted" on the NJ trials, i.e. they moved their hand directly to the original target location. This movement pattern held even on the last sub-block of NJ trials.

This indicated that subjects had evolved a strategy to account for the target jump, which they switched off when instructed to do so. Significantly longer reaction times on TJ trials, as compared to NJ trials, and the complete absence of an after-effect during washout also supported the idea that adaptation was truly explicit.

During re-adaptation, subjects showed faster learning than naïve and rapid "de-adaptation" again, indicating substantial savings of the strategy that they learnt during adaptation.

Discussion

We explored, using a "target jump" perturbation learning task, changes is motor behaviour that occur when target locations are perturbed. We showed that adaptation occurs in the context of changing movement goals, specifically, by reach directions closing in on the new location of the target as time progressed in the adaptation block. Learning to adapt in this context also seemed to be primarily explicit, with evidence of the lack of an implicit component reflected on "no-jump" trials interspersed within the adaptation block. The findings are consistent with the view that savings emerges from the use of movement strategies developed during adaptation. Furthermore, our task and approach provide a foundation to probe the neural correlates of strategy-use in motor adaptation in the future.

Acknowledgments

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Will your L2 proficiency influence my language choice?

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University of Hyderabad

Aim

Bilinguals are often situated in a socio-interactional context and they very effortlessly plan their language that is appropriate in such contexts. Using a visual world paradigm, we investigated if bilinguals' language selection and production occur as a function of their awareness of their interlocutors' L2 language proficiency.

Method and prediction

Thirty-six high L2 proficient and 24 low L2 proficient Telugu-English (unbalanced) bilinguals were familiarized to audio-visual stimuli that consisted of animated human-like cartoons (interlocutors) that spoke in English (L2) and Telugu (L1). After the exposure, participants briefly interacted with these interlocutors and were asked to identify which interlocutor was either high or low proficient in L2. Participants also reported that they would choose L2 if they were to interact with the interlocutor that was perceived as high L2 proficient and would choose L1 for low L2 proficient interlocutor. During the familiarisation phase, images of neutral interlocutors were also familiarised. Participants were not aware of the language proficiencies of L1 or L2 of the neutral interlocutor. In the main experiment, the trial began with a fixation screen for 1000ms, followed by visual world screen that consisted of images of one high L2 proficient, one low L2 proficient and two neutral interlocutors (distractors) that were presented on the four corners of the screen. At the center of the screen, the object naming stimuli was presented. There was no SOA between the presentation interlocutors and object naming stimulus. The duration of visual world screen was 3000 ms. The participants were instructed to name the object presented at the centre of the screen in the language that comes to their mind. We predicted that the bilinguals would take an account of their interlocutors' L2 language proficiency and would look at the interlocutor that would facilitate their language plan. Example, if the participant plans to name the object in L2 they would look at the high L2 proficient interlocutor, as it would boost/facilitated L2 lexical access. This would be reflected through higher number of fixations to a particular interlocutor before naming.

Results and conclusion

Repeated measures were performed on the percentage of the choices and naming latencies with the proportion of fixations from the onset of the visual world stimuli till the onset of the participants' voice response. The results indicate that, the high L2 proficient participants choose L2 more often ($p < 0.0001$) and were faster while naming than L1 ($p = 0.004$). However, they made higher fixations towards high L2 proficient interlocutor irrespective of their language choice (L1 or L2) ($p = 0.76$). Whereas, low L2 proficient participants choose L1 higher number of times ($p = 0.02$) and their naming latencies were faster while naming in L1 ($p = 0.008$). They made higher number of fixations to low L2 proficient interlocutor while they named in L1 and also looked at high L2 proficient interlocutor when they named in L2 ($p = 0.03$). These results suggest that the high and low L2 proficient bilinguals perceive interlocutors L2 language proficiency and their adaptation occurs as a function of their own language proficiency.

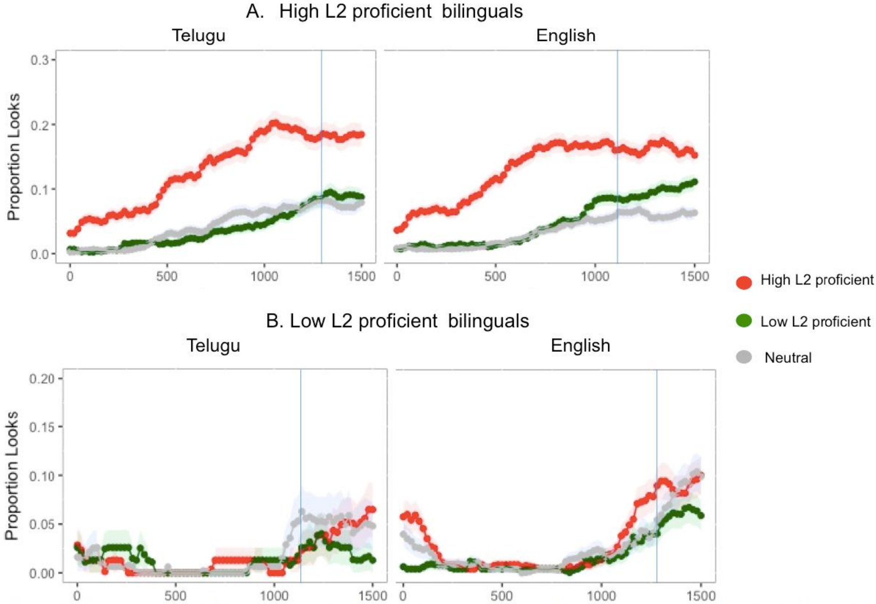

Figure 1: Time course plots indicating interaction between language choice and interlocutor type. The blue line indicates the average naming latencies for L1 and L2.

Probability cueing does not modulate masked cueing of attention

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Abstract

Recent studies have found that unconscious cueing of actions is not a completely automatic process. The amount of attention allocated to the unconscious or masked cue is said to control the degree to which it can influence actions. But studies have examined only the role of explicit attentional allocation on masked cueing effects. The present study investigates whether implicit attention can also control masking cueing effects. We used probability cueing which is a form of implicit attention. In the reported experiment, frequentist and Bayesian analyses indicate that implicit attention does not control the effect of masked cueing.

Keywords: attention; implicit attention; probability cueing; masked cueing; unconscious orienting; eye movements

Introduction

Masked stimuli can influence responses even though participants fail to report their presence. It has also been suggested that masked stimuli can affect more complex actions such as orienting of attention. For instance, Palmer and Mattler (2013) asked participants to attend to the location indicated by a supraliminal central cue. The central cue predicted the upcoming targets' location with 100% accuracy. Unbeknownst to the participants, a masked central cue preceded the central cue. They found that the match between the cues influenced how quickly the participants oriented their attention.

However, recent theories suggest that such influence of masked cues is limited. They argue that attention must be allocated to the masked cue for it have an effect (Kiefer 2012). Supporting this, Reuss et al., 2011 found that masked central cues are used influenced orienting of attention only when participants were explicitly aware that the central cues predicted the location of the upcoming target i.e., when participants allocated attention to the cue. In light of these findings, one may ask whether it is necessary for attentional allocation to be explicit for it to influence masked cueing. To address this, the current study investigated whether the implicit attentional allocation can also influence masked cueing.

Probability cueing is one form of implicit allocation of attention. If in a task, the target object is presented in one region with higher probability than other regions, then participants are found to be faster on the high-probability region than other regions due to an attentional bias towards the high-probability region (Geng and Behrmann, 2005; Druker and Andersen, 2010). It is considered implicit because participants often fail to report probability cueing even though the modulation in their performance reflects it (Jiang et al., 2018).

In the current study, we investigated implicit probability cueing can modulate the degree to which masked cues can affect orienting of attention. If masked cueing is independent of implicit or explicit nature of the attention, then we expected to find interaction between probability cueing and masked cueing. We employed a modified version of the spatial cueing task used by Mulckhuyse et al., 2007. The participants were asked to make an eye-movement towards the target. But without informing the participants, an uninformative peripheral cue is presented under masked conditions before the target is presented. If the location of the cue and target match, the participants are known to be faster (valid cue trials) and slower in case of a mismatch (invalid cue trials). We examined if this masked cueing effect is modulated by probability cueing.

Methods

Participants

Eighteen students from the University of Hyderabad (all male, mean age: 23.8 years, SD = 1.83) participated in the experiment.

Stimuli and Procedure

Training phase. There were 384 trials. In each trial, a black filled-disc was presented among eight black hollow circles (henceforth "placeholders"), which were arranged along an imaginary circle around a fixation sign (see Figure 1A). Unbeknownst to the participants, the target disc was presented in the placeholders on one side of the fixation twice as often (256 trials on "biased" hemifield) than the other side (128 trials on "unbiased" hemifield). The participants were not informed of the probability manipulation.

Testing phase. In this phase, a black hollow circle (henceforth "cue") that resembled the placeholder was presented for 33ms. Following this, the target and the eight placeholders was presented suddenly, similar to that of the training phase (see Figure 1B). The sudden onset of placeholders is said to mask the cue by inducing an illusion that all placeholders appeared at the same time. The target and cue locations matched ("valid cue" trials) only on 50% of the trials making the cue uninformative. The participants were not informed of the presence of the masked cue. The target was presented on the biased hemifield on 240 trials and on the unbiased hemifield on 120 trials. To ensure that the masked cue was uninformative, there 120 filler trials were added. In filler trials. the masked cue was followed by the placeholder screen but the target was absent. There were 480 trials in total and were inter-mixed randomly.

Recognition test. Following the testing phase, participants answered 6 questions on whether they noticed any unusual probability patterns. This test was used to identify if probability cueing was implicit.

Cue visibility test. The stimuli from the testing phase was used. But in this phase, the participants were informed of the presence of the masked cue and were asked to report its location with a mouse click (see Figure 1C). Out of the total 128 trials, the target was presented in biased hemifield in 48 trials and in unbiased hemifield in 24 trials. 24 filler trials were added. Beyond this, there were 32 catch trials with both cue and target appearing in both hemifields with equal frequency. On catch trials, the cue was presented for 100ms followed by the target.

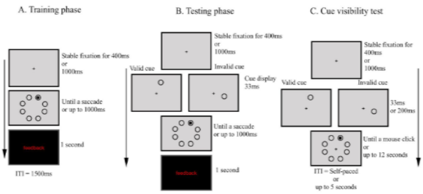

Figure 1: Illustration of the sequence of screens in the three phases.

Results

Three participants' data was discarded since more than 50% of their data was lost during data cleaning procedures.

Training phase

One-way repeated measures ANOVA revealed that saccadic reaction times were significantly faster when target appeared on the biased hemifield than on unbiased hemifield, $F(1, 14) = 8.32$, $p = .012$, $\eta_G^2 = .008$ (see Figure 2A).

Testing phase

Two-way repeated measures ANOVA revealed significant difference in saccadic reaction times when target appeared on the biased hemifield versus on unbiased hemifield, $F(1, 14) = 10.15$, $p = .007$, $\eta_G^2 = .013$ (see Figure 2B). We found that saccadic reaction times were significantly faster following a valid cue than invalid cue, $F(1, 14) = 232.95$, $p < .001$, $\eta_G^2 = 0.252$ (see Figure 2C). The interaction between trial type and validity was not significant, $F(1, 14) = 0.12$, $p = .735$, $\eta_G^2 = 0.00$.

Bayesian analysis. A Bayesian two-way repeated-measures ANOVA indicated the model including the main effects of trial type and validity yielded the highest Bayes Factor, $BF_{10} = 1.181e + 17$. On the other hand, the model with both main effects and their interaction had a lower Bayes Factor, $BF_{10} = 4.073e + 16$. When the models were compared, the main-effects-only model was preferred with a Bayes Factor of 2.83 over the main effects plus interaction model.

Recognition test

Five participants correctly reported the high-probability hemifield. Out of them, one participant identified only two out of four high-probability locations as high-probability locations. The remaining four participants reported just one location to be high-probability. Overall, the participants did not seem to be subjectively aware of the probability cueing.

Cue visibility test

A t-test indicated that the d-prime (1.11) of the 33ms masked cue was significantly higher than chance-level, $t(71) = 26.39$, $p < .001$. A Pearson correlation was performed between d' (d-prime) and mean validity effect for each participant. We did not observe a significant correlation, $r = .45$, $p = .069$ (Figure 2D).

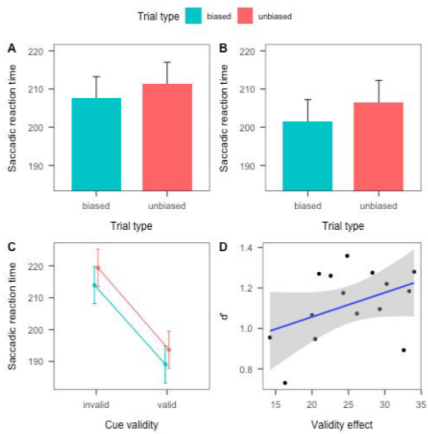

Figure 2: Results from experiment 1. The error bars indicate the standard error. A. Significant effect of probability cueing in training phase. B. Significant effect of probability cueing in testing phase. C. Significant effect of masked cueing in testing phase, but no significant

A Velocity Driven Hierarchical Anti Hebbian Oscillatory Network Model for Object Vector Cells and Other Spatial Cells

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Keywords: Object Vector Cells; Lateral Anti-Hebbian Network; Object Vector Score; Symmetrical Firing; Path Integration.

Introduction

Place Cells (O'Keefe and Dostrovsky, 1971) and Grid Cells (Hafting et al., 2005) found in Hippocampal Formation including CA1, CA3 and Entorhinal Cortex (EC) are known to encode the location of the organism as well as the geometry of complex environments (Krupic et al., 2015).

OVC (Høydal et al., 2019) are one such specialized cells found in the Medial Entorhinal Cortex (MEC) that are characterized by the presence of a salient object in a given environment. These cells fire distinctively when they are at a particular distance and direction from the location of restrained space or an object, and maintain that relationship when the object is displaced over a limited range.

In this study, we used the a Velocity Driven Oscillatory Network (VDON) (Soman, Muralidharan, and Chakravarthy, 2018) to model the characteristic firing of an OVC. Along with an OVC, this model also shows a peculiar behavior of symmetric firing in circular environments with diametrically opposite objects which are rotated symmetrically with respect to the environment. The model of OVCs also show asymmetric firing fields in the case of asymmetric orientation of objects.

Methods

The VDON model (Fig. 1) consists of 4 Layers. Head Direction (HD), Path Integration (PI), Lateral Anti-Hebbian Network (LAHN) 1 and LAHN 2 layers respectively. A virtual agent forages in a circular environment of 2 unit radius with a circular objects of varying size and the representations of neurons in LAHN 2 are observed

Head Direction Layer

The HD Layer containing 100 neurons takes the Heading Direction of the animal foraging randomly through the environment as input and each neuron in this layer codes for a particular direction.

$$\theta_{HD} = \psi^T W \quad (1)$$

ψ is the two-dimensional input given to a self-organizing map (SOM) such that ψ = [cos(θ) sin(θ)] where θ is the actual direction of navigation, W is the afferent weight matrix of the SOM, where the weight vectors are normalized. This directional data is fed forward to PI Layer.

Path Integration Layer

This layer has one-to-one connection with the HD layer. Therefore, the speed of the animal at any given location is integrated with the directional information from the HD Layer at that location with the help of PI Layer. The base frequency modulation of the oscillatory neurons in PI layer is done by

$$PI_i = sin\{\int 2\pi \ (f_0 + \beta s HD_i).dt\} \quad (2)$$

where β is a modulation factor and s is the velocity of the organism. The PI layer is thresholded by some threshold value ϵ_{PI} and the difference is passed through Heaviside function (H).

$$PI_i^{Thr} = H(PI_i - \epsilon_{PI}).PI_i \quad (3)$$

This information is passed on to LAHN 1 Layer.

LAHN Layers

The model consists of two LAHN layers which use unsupervised learning for optimal feature extraction. Simulations show that the first LAHN layer predominantly captures grid cells and second LAHN layer captures place cell and other specialized cells like OVC. The output of LAHN is computed as follows

$$\Gamma_i(t) = \sum_{j=1}^{n} w_{ij}\,\Gamma_j(t-1) + \sum_{k=1}^{n} q_{ik}\,I_k(t) \quad (4)$$

$$\Delta w_{ij} = -\eta_L \Gamma_i(t)\Gamma_j(t-1) \quad (5)$$

$$\Delta q_{ik} = -\eta_F (I_k \Gamma_j - q_{ik}\Gamma_i^2(t-1)) \quad (6)$$

Here Γ_i is the response of the ith neuron in the LAHN layer. q_{ik} is a Hebbian connection from $k_{th}\ I$ to the i_{th} neuron in LAHN whereas $w_{ij}$is the lateral anti-Hebbian connection from $j_{th}$to i_{th} LAHN neuron. m is the number of LAHN neurons and n is the dimension of the input layer. η_L and $\eta_F$are rates of learning.

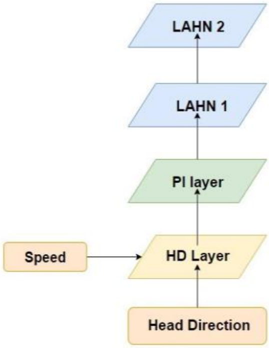

Fig 1: Architecture of velocity driven oscillatory network model.

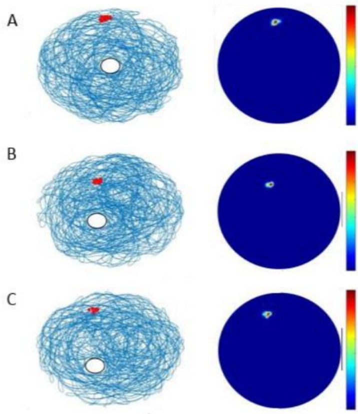

Fig 2: Left plots show firing fields over a randomly generated trajectory. Right plots show spatial firing rate maps over a thresholded value. Results from the same neuron tested over different object placings. A shows reference object vector firing field with respect to the object. B and C show displaced firing field when the object is displaced.

Results

OVCs that are observed in LAHN2 are verifiable with empirical results. The vector relationship maintains itself as the firing field shifts along with the object (Fig 2). The same is noted for the firing field of varying size of the object (Fig 3).

In order to evaluate the accuracy of an OVC, an Object Vector Score (OVS) is calculated (Eqn 1) for which a metric is formulated. This metric depends on the square of the deviation of the observed displacement of the firing field from its expected displacement and is defined as:

$$OVS = e^{\frac{-d^2}{r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

where 'd' is the error in the displacement of actual mean firing field from expected mean firing field and 'r' is the radius of the circular environment.

In fig 2, A shows the reference activity of a neuron. B and C show the activity of the same neuron when the object is shifted in the environment. For B and C, the observed OVS are 0.9776 and 0.9438 respectively.

In fig 3, A shows the reference activity of an object in the environment. B and C show the maintained neural activity of an OVC even for the variable size of the object in the environment. The OVS of B and C are observed as 0.9715 and 0.9988 respectively.

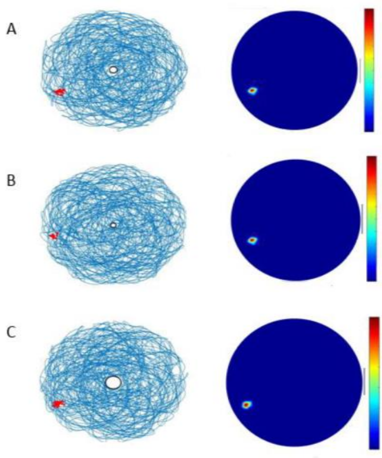

Fig 3: *A shows reference object vector firing field with a given object size. B and C show a decrease and increase in the size of objects and their corresponding firing field.*

Another observation was made with multiple objects in the environment. Symmetrical firing is observed when the two objects are placed diametrically opposite to each other. The neurons maintain the symmetric firing fields when the objects placed diametrically opposite are rotated by equal angles. Whereas, the symmetric firing fields are lost when the objects are moved asymmetrically (fig 4).

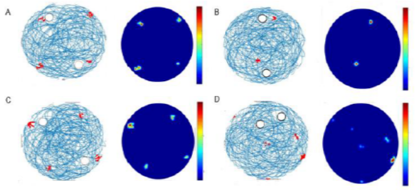

Fig 4: A, B and C show symmetric firing when objects are rotated diametrically opposite to each other. D shows asymmetric firing when orientation of objects is asymmetric.

Discussions

A VDON model is being proposed which verifies the experimental results of Object Vector Cells (Høydal et al., 2019). The neurons in the LAHN2 layer of the model were able to maintain the firing field with respect to the object as the object is shifted in the arena. The firing field also maintained itself for the objects of varying sizes. The experiments and simulations are performed on simpler environments, therefore there is a lot of scope for modeling OVCs in more complex environments.

A new metric is proposed to measure the object vector property for neuron called Object Vector Score (OVS). OVS gives the deviation in the firing field of a neuron with respect to the environment when shifted. For 17 neurons in the model, OVS ranged from 0.1548 for worst cell and 0.9512 for the best performing cell, where good performing cells were later labeled as an OVC. Hence, OVS serves as a good measure for separating OVCs from other cells.

Besides modeling experimental results, the proposed model also codes for a symmetric relationship of the object with the circular environment. Symmetric firing fields are observed when two objects are placed diametrically opposite to each other. The symmetric relationship of firing field is maintained when the objects are rotated maintaining the symmetric relationship among them whereas, if the symmetric relationship of the object is disturbed, the firing field observed are also asymmetric.

Through all the experiments, we also postulate that although visual input might confer stability to OVC firing, the emergence of these cells do not explicitly depend on a visual input and that there is sufficient information in the trajectory dynamics encoded by the path integration to account for this class of spatial cells.

Acknowledgments

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A Computational Pharmacological Model of Levodopa Medication of PD Patients

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Keywords: Levodopa; Dopamine terminal; Parkinson's disease; Pharmacological model;

Introduction

Parkinson's disease (PD), a progressive movement disorder that affects muscle control and balance, is caused by a gradual deterioration of dopaminergic cell within an important midbrain nucleus called the Substantia Nigra pars compacta (SNc) (Surmeier, Guzman, Sanchez-Padilla, & Goldberg, 2010). Neurons in this region produce a neuromodulator called dopamine, a molecule with diverse signaling functions.

Dopamine deficiency caused by loss of SNc cells manifest key PD symptoms, including tremor, bradykinesia, and rigidity.

First discovered in the 1960s, Levodopa (L-dopa), a precursor to dopamine, is still one of the primary drugs used to treat Parkinsonian symptoms at all stages of the disease. Levodopa works as a dopamine substitute, compensating for dopamine deficiency in PD (Salat & Tolosa, 2013).

When a tablet of levodopa is swallowed, it is absorbed in the small intestine and makes its way into the blood stream, which carries the drug all around the body. Outside the brain, our bodies contain proteins that break down levodopa. This means much of the drug (around 60–80%) is deactivated before it even reaches the brain. In this paper, we construct an integrated computational model of dopamine synthesis, storage, release, reuptake and metabolism in the dopaminergic neuron terminal and how an external dose of L-dopa is processed.

Methods

The computational model developed in this paper combines previous computational models of the dopaminergic terminal (Reed, Nijhout, & Best, 2012) and L-dopa medication (Baston, Contin, Calandra Buonaura, Cortelli, & Ursino, 2016). The overall model consists of a two-compartment: L-dopa pharmacokinetics and a dopamine terminal (Figure 1).

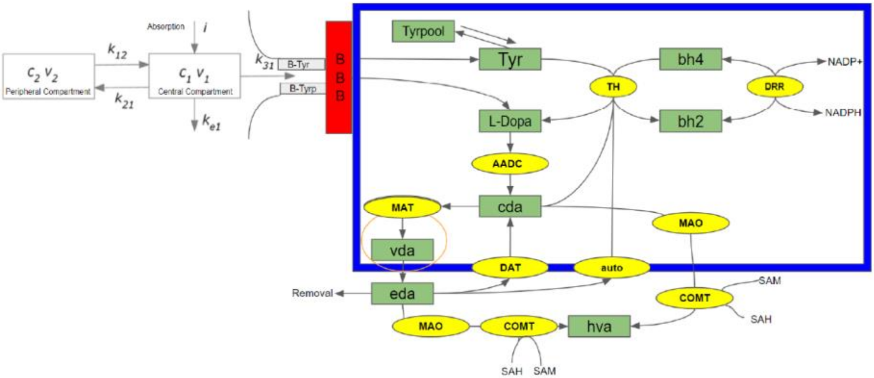

Figure 1: Schematic diagram of the model. The pharmacokinetic model is represented in **white rectangular** boxes. **Blue boundary** indicates the dopamine terminal. **Green rectangular** boxes indicate substrates and yellow ellipses contain the acronyms of enzymes or transporters. **B-tyr**: Blood Tyrosine; **B-Tyrp:** Blood tryptophan; **cda:** Cytosolic dopamine; **vda:** Vesicular dopamine; **eda:** Extracellular dopamine; **hva**: Homovanillic acid; **bh2:** Dihydrobiopterin; **bh4:** Tetrahydrobiopterin; **TH:** Tyrosine hydroxylase; **AADC:** aromatic amino acid decarboxylase; **MAT:** vesicular monoamine transporter; **DAT:** DA reuptake transporter; **auto:** DA autoreceptors; **MAO:** monoamine oxidase; **COMT:** catacholamine methyltransferase, **Removal** means uptake by capillaries or glial cells or diffusion out of the system.

Modeling the Levodopa Pharmacokinetics

The model was subdivided into two compartments. The first compartment represents a central (plasma) compartment, where Levodopa was administered (at a rate of 'i'), and plasma concentration was measured. The second compartment represents a peripheral compartment, where the interaction between plasma and other body fluids occurs. The pharmacokinetic model shown in Figure 1, is defined by the following equations,

$$V_1 \frac{dc_1}{dt} = -(k_{21} + k_{31} + k_{e1})c_1 + k_{12}c_2 + i$$

$$V_2 \frac{dc_2}{dt} = k_{21}c_1 - k_{12}c_2$$

The parameter values are from (Baston et al., 2016).

Modeling the Dopamine Terminal

The dopaminergic terminal model includes transport of tyrosine across the Blood-Brain Barrier (BBB) and into the terminal followed by synthesis of L-dopa by tyrosine hydroxylase (TH) and synthesis of cytosolic dopamine (DA) by Amino Acid Decarboxylase (AADC). Cytosolic DA is then packaged into vesicles by Vesicular Monoamine Transporter (VMAT) followed by the release of vesicular DA into the extracellular space depending on firing rate.

Additionally, this model also assesses the reuptake of extracellular DA into the cytosol by the dopamine transporters (DATs) and the effects of extracellular DA on DA synthesis via the autoreceptors. Furthermore, DA in both the extracellular space and the cytosol was catabolized by monoamine oxidase (MAO).

The serum levodopa, tyrosine, and tryptophan are transported across the BBB (red rectangular box in Figure 1) and into the terminal by competing through the L-transporter (Riederer, 1980). It was represented using the Michaelis–Menten equation (Chou, 1976) as follows,

$$V = \frac{V_{max}\,[S_1]}{K_{S1}\left(1 + \frac{[S_2]}{K_{S2}} + \frac{[S_3]}{K_{S3}} + [S_1]\right)}$$

As an enhancement of the model from (Reed et al., 2012), the proposed model also considers the conversion of levodopa to dopamine outside of terminals by AADC present in the extracellular fluid (Gandhi & Saadabadi, 2018). This is represented using the Michaelis–Menten (Chou, 1976) equation as follows-

$$V = \frac{V_{max}[S]}{K_m + [S]}$$

Integrated Network Model

To establish a relation between terminal loss and extracellular dopamine, a network of terminals was simulated. The output of each terminal in the network was dependent on the collective dopamine output of all the terminals in the network. Here, we have assumed that a single blood vessel innervates network of terminals (Figure 2). The total drug released into the network was divided equally to each terminal in such a way that each terminal gets an equal amount of drug (Figure 2).

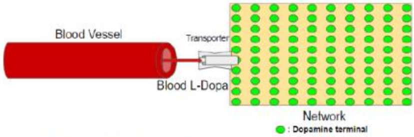

Figure 2: A network of DA terminals innervated by a single blood vessel.

Results

The Effect of Levodopa Medication

On administration of L-dopa (100 mg), there was a rapid increase in the serum L-dopa levels with the maximum value reaching ~130 μM similar to (Reed et al., 2012) (Figure 3).

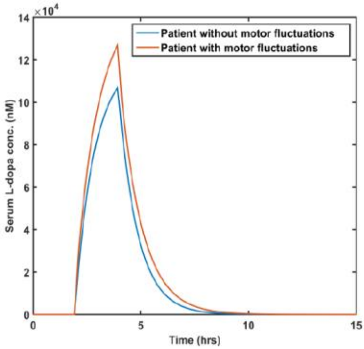

Figure 3: Effect of Levodopa medication on serum L-dopa concentration for different categories of patients. (Drug was administered at the second hour for 2 hours to match (Reed et al., 2012))

Furthermore, the extracellular dopamine levels also show a sudden increase. The effect is observed for around 10-12 hours until the concentrations drop back to normal values (Figure 4).

The Effect of Terminal Loss

With the loss of terminals in the dopamine network, the maximum value of dopamine released extracellularly during L-dopa dosage undergoes a slight increment with the increase in number of terminals lost (Figure 5).

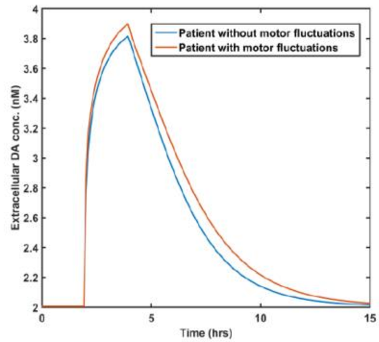

Figure 4: Effect of Levodopa medication on extracellular dopamine concentration for different categories of patients.

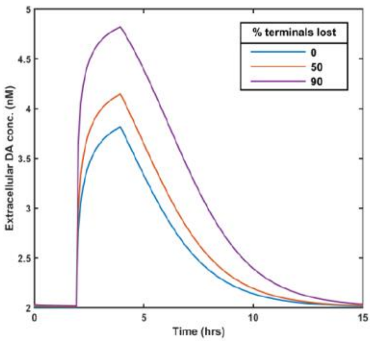

Figure 5: Effect of terminal loss on the extracellular dopamine concentration in the integrated network model.

Discussion

In recent years many computational models have been developed that represent the various processes underlying the dynamics of dopamine release in the brain (Reed et al., 2012; Tello-Bravo, 2012).

The model developed in (Baston et al., 2016) assists in analyzing the effect of external levodopa and helps in moving beyond the dependency on clinical results. With the integrated network model, the effect of terminal loss and levodopa medication can be studied simultaneously, as shown in Figure 5.

With the loss of terminals in the network, as evident from Figure 2, each terminal will get an increased amount of drug since the total drug is being equally distributed among the remaining terminals. This leads to an increase in the maximum value of extracellular DA during L-dopa medication (Figure 5). Hence, this model helps us to analyze how dopamine release is affected by the loss of terminals. In order to understand L-dopa induced dyskinesia, the present model can be extended by introducing serotonin terminals also (Reed et al., 2012). Using a systems-level computational model, it was recently shown that dopamine deficiency causes pathological oscillations in the subthalamic nucleus, which is a hallmark of PD (Muddapu, Mandali, Chakravarthy, & Ramaswamy, 2019). The proposed model can be integrated with a complete basal ganglia model that can capture the effect of dopamine dysfunctions and L-dopa medication on the basal ganglia output, which helps in characterizing impaired movements such as bradykinesia or tremor (dopamine dysfunctions) and dyskinesias (side-effects of L-dopa medication).

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Role of astrocytes in metabolic support of neurons

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Keywords: Astrocytes; Dopaminergic neuron; Metabolic deficiency; Parkinson's disease; Lactate shuttle; Excitotoxicity

Introduction

Parkinson's disease is attributed by a significant loss in dopaminergic cells in the Substantia Nigra pars compacta (SNc) region of the basal ganglia. Due to their peculiar morphology and high metabolic demands, neurons of the SNc are highly susceptible to energy deficiency leading to cell loss. Astrocytes provide a compensatory metabolic mechanism to the SNc neurons during energy-deficient conditions as they are ideally positioned to sense neuronal activity and respond with adequate metabolic supply if required (Bélanger, Allaman, & Magistretti, 2011).

The brain has an unusually high energy requirement, where neurons consume a majority of energy in the maintenance of ion gradients through pumps, recycling of neurotransmitters, and other essential activities. Since neurons have a high rate of oxidative phosphorylation and do not store glycogen, the energy substrates required to sustain this high rate of oxidative phosphorylation is supplied externally in the form of lactate. Flux through glycolysis in neurons is low (Itoh et al., 2003) to allow shunting off of metabolites to the pentose phosphate pathway, which is essential for the maintenance of antioxidant potential. On the other hand, astrocytes have a very high glycolytic rate and prefer the production of lactate over the entry of pyruvate into the tricarboxylic acid cycle (Itoh et al., 2003).

We have built a comprehensive computational model of the SNc neuron integrated with its metabolic connections to the astrocyte in order to find out the role of astrocytes in neuronal support in normal energy conditions as well as in deficient energy conditions.

Methods

We have used Michaelis-Menten enzyme kinetics for metabolic equations, Euler's method for solving first-order differential equations numerically, and MATLAB programming.

We have created an integrated model by adapting the four-compartment model from (Cloutier, Bolger, Lowry, & Wellstead, 2009) and the comprehensive model of SNc from(Muddapu & Chakravarthy, n.d.). Our model contains four compartments, namely blood capillary, extracellular, SNc neuron, and astrocyte with connections between compartments, as shown in Figure 1. In the proposed model, dopamine uptake into astrocyte was incorporated. The following equation was added to show the dynamics of glial dopamine:

$$\frac{dDA_a}{dt} = V_{da}^{ea} - V_{da_{met}}^{a}$$

The entry of extracellular dopamine into the astrocyte was defined as,

$$V_{da}^{ea} = Vmax_{DAT}^{a} * DA_e/(DA_e + Km_{DAT}^{a})$$

The flux of breakdown of dopamine in the astrocyte was defined as,

$$V_{da_{met}}^{a} = k_{COMT} * DA_a$$

where, $Vmax_{DAT}^{a}$ is the maximum velocity of the dopamine transporter, $Km_{DAT}^{a}$is the concentration of DA at the half-maximal velocity of $Vmax_{DAT}^{a}$, k_{COMT} is the rate constant for enzyme catechol-O-methyltransferase, DA_a and DA_e are dopamine concentrations in the astrocyte and extracellular compartments, respectively.

The equation for glial sodium dynamics was also modified to take into account the sodium ions' co-transport with dopamine as follows,

$$\frac{dNa_a}{dt} = V_{leak_{Na}}^{a} + 2 * V_{da}^{ea} - \; 3 * V_{pump}^{a}$$

where, $V_{leak_{Na}}^{a}$is the flux of sodium ion leak channels, V_{pump}^{a} is the flux of the glial sodium pump and Na_a is the glial Na concentration.
To simulate the changes in blood flow in the capillaries, the parameter Cerebral Blood Flow (CBF) was modulated.

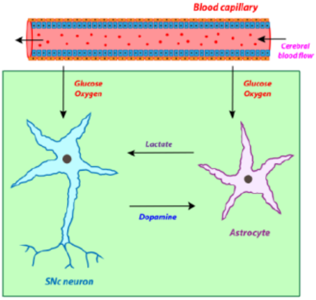

Figure 1: Model architecture of the proposed model and interactions between the four compartments.

Results

Changes in energy substrates in neuron and astrocyte with changes in cerebral blood flow

The capillary glucose level varies proportionally with CBF (Figure 2, green bar). However, this trend was not observed in other compartments, where an increase in CBF results in an increase in glucose level in the neuron, astrocytes and extracellular compartments whereas a decrease in CBF results in a decrease in glucose level initially and then a subsequent increase in glucose level for CBF values below $8x10^{-6}$ ms^{-1} (Figure 2). This might be due to the oxygen level falling below a critical threshold, where oxidative phosphorylation gets hindered (Figure 4).

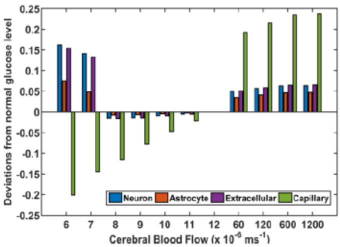

Figure 2: Deviations from glucose values at normal CBF ($12x10^{-6}$ ms^{-1}) in all four compartments with change in CBF.

Similarly, the capillary lactate levels vary proportionally with CBF (Figure 3, green bar). However, this trend was not observed in other compartments, where an increase in CBF result in a decrease in lactate levels in the neuron, astrocytes and extracellular compartments whereas a decrease in CBF result in an initial increase and then sudden drop for CBF values below $8x10^{-6}$ ms^{-1} (Figure 3). The initial increase in lactate levels might be due to falling levels of oxygen which result in reduced oxidative phosphorylation but for CBF values below $8x10^{-6}$ ms^{-1} glucose levels also fall below a critical threshold (Figure 2, 4) and lactate was utilized for energy production.

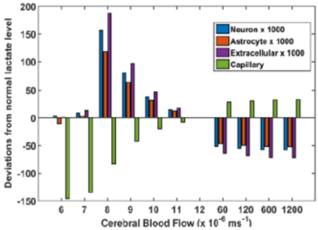

Figure 3: Deviations from lactate values at normal CBF ($12x10^{-6}$ ms^{-1}) in all four compartments with change in CBF.

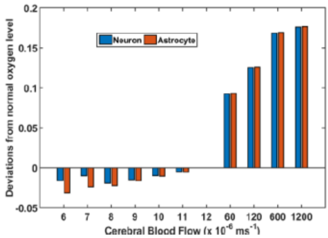

Figure 4: Deviations from oxygen values at normal CBF ($12x10^{-6}$ ms^{-1}) in neuron and astrocyte with change in CBF.

Changes in these energy substrate levels are supposed to in turn affect the ATP levels in neurons and astrocytes. The ATP levels increase with an increase in CBF and decrease with a decrease in CBF in the neuron compartment (Figure 5, blue bar). For CBF values below $8x10^{-6}$ ms^{-1}, the ATP levels fall drastically due to decreased levels of glucose and oxygen. However, this trend was not observed in astrocytes, as ATP levels increase with an increase in CBF and fall after a slight increase as CBF decreases (Figure 5, orange bar) corresponding to a sharp decrease in astrocytic lactate.

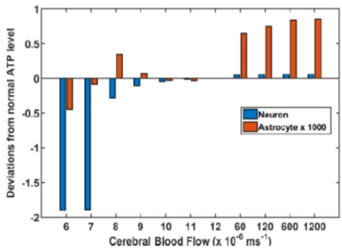

Figure 5: Deviations from ATP values in neuron and astrocyte at normal CBF ($12x10^{-6}$ ms^{-1}) with change in CBF.

Changes in calcium and dopamine levels in the neuron with changes in ATP levels

To see the effect of change in ATP levels on calcium and dopamine, their concentrations in various compartments were observed. The cytoplasmic calcium levels increase when ATP levels due to reduced CBF fall below a critical threshold (Figure 6, blue bar) that might be due to limited availability of ATP to efflux calcium ions from the neuron. The endoplasmic reticulum (ER) calcium levels decrease when ATP levels due to reduced CBF fall below a critical threshold (Figure 6, orange bar) that might be due to limited availability of ATP for sequestering calcium ions into ER from the cytoplasm. Due to higher cytoplasmic calcium levels, mitochondrial calcium levels decreased (Figure 6, purple bar).

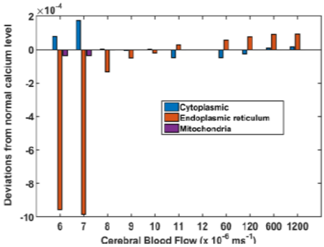

Figure 6: Deviations from calcium levels in the neuronal cytoplasmic, endoplasmic reticulum, and mitochondrial compartments at normal CBF ($12\text{x}10^{-6}$ ms^{-1}) with change in CBF.

The cytoplasmic dopamine levels increased when ATP levels fell below a critical threshold due to reduced CBF (Figure 7, blue bar). This increase might be due to the limited availability of ATP to pack dopamine into vesicles from cytoplasm that was reflected with the decrease in vesicular dopamine levels (Figure 7, purple bar). The dopamine levels in the extracellular and astrocyte compartments were nearly unchanged with changes in CBF that might be due to perturbation of smaller magnitude (higher vesicular dopamine buffering capacity).

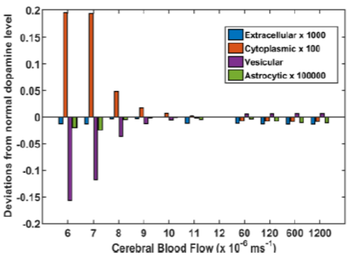

Figure 7: Deviations from dopamine levels in the neuron (cytoplasmic and vesicular compartments), extracellular compartment, and astrocyte at normal CBF ($12\text{x}10^{-6}$ ms^{-1}) with change in CBF.

Energetic support from astrocyte in the form of lactate

To study the magnitude of metabolic support being extended towards the neuron by the astrocyte, the fluxes of lactate entering the neuronal energy production pathways were limited to different degrees via two channels.

The flux of lactate traveling from extracellular space to the neuron compartment via the lactate shuttle, V_{LAC}^{en}, and the flux of lactate moving towards pyruvate conversion in the neurons via lactate dehydrogenase enzyme (LDH), V_{ldh}^{n}, were increasingly inhibited upto a factor of 0.1 times the normal values. It was observed that average neuronal ATP concentration decreases with increased inhibition on V_{lac}^{en} and V_{ldh}^{n} fluxes and falls drastically beyond the inhibition factor value of 0.3 (Figure 8).

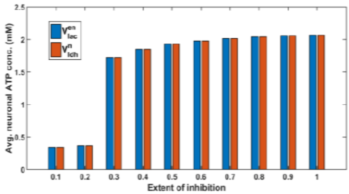

Figure 8: Average neuronal ATP concentration with the extent of inhibition.

Synergetic effect of over-excitation and energy deficit on the neuronal ATP levels

To explore the idea of weak excitotoxicity (Albin & Greenamyre, 1992), the SNc neuron was stimulated to observe the recovery of neuronal ATP levels after two seconds of chemical and electrical excitations along with change in CBF. During the stimulation, basal ATP level dips, and two seconds after the stimulation, the basal ATP levels decreases (increases) with a decrease (increase) in CBF (Figure 9).

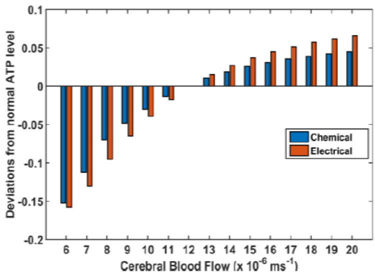

Figure 9: Deviations from the amount of neuronal ATP recovered at normal CBF ($12\text{x}10^{-6}$ ms^{-1}) after two seconds of chemical and electrical stimulations with change in CBF.

Discussion

The proposed model consists of SNc neuron, astrocyte, blood capillary, and extracellular compartments that showed the effect of the fluxes of different energy substrates on neuronal ATP levels. An increase in glucose and lactate levels in the capillary, as well as neuronal and astrocytic oxygen levels, were observed with an increase in CBF. The increased glucose on increasing CBF in all three compartments can be explained similarly. However, high glucose levels upon decreasing the CBF beyond a threshold may be due to the low utilization of glucose for energy production.

Under high oxygen conditions, cells use glucose directly for energy production rather than going towards lactate formation. This explains the low levels of lactate in the remaining three compartments as the CBF rate increases. The relatively low lactate values at very low CBF can be explained by the high rate of lactate utilization for energy metabolism to sustain the cell in heavily anaerobic conditions. The increase in lactate concentration observed for intermediate CBF values is because of the increased lactate synthesis as oxygen levels gradually begin to decrease.

The concentration of ATP in cells is directly related to the concentrations of oxygen, lactate, and glucose available. Neuronal ATP concentration continues to diminish with a reduction in CBF. The ATP levels in astrocytes show an increase with increasing CBF and fall after a slight increase at decreasing CBF. The sudden fall of ATP levels corresponds to a sharp decrease in astrocytic lactate due to increased flux through the lactate shuttle pathway.

Calcium ions are essential for the excitability of the neuron and other important functions such as dopamine release. Sequestration of calcium into the endoplasmic reticulum requires the breakdown of ATP. Thus, a decrease in neuronal ATP concentration would result in a decrease in calcium present in the endoplasmic reticulum along with an increase in cytoplasmic calcium ion concentration, as observed from our simulations. The ATP levels control the number of vesicles readily available for extracellular release. With a decrease in ATP levels at low CBF, the vesicular dopamine level in the neurons was observed to be decreasing, whereas the cytoplasmic level of dopamine was observed to be increasing.

On decreasing the lactate fluxes, V_{LAC}^{en} and V_{ldh}^{n}, the amount of lactate available for energy generation processes in the neurons reduces, resulting in a decrease in neuronal ATP concentration at low CBF values. This observation verifies the idea of astrocytic metabolic support to the neurons via lactate (Pellerin et al., 1998).

Electrical and chemical stimulations along with increasing and decreasing values of CBF show that the neuronal ATP concentration takes longer to return to its normal level after excitation when present along with an energy deficit condition such as a low CBF. Over-excitation precipitates the effects of energy deficiency or vice versa, with no significant effect being observed when only one of them is present. This is in accordance with the model of (Muddapu, Mandali, Chakravarthy, & Ramaswamy, 2019) which hypothesizes that energy deficit along with over-excitation of neurons can consequently lead to excitotoxic loss of SNc cells in Parkinson's disease.

The proposed model has only unidirectional interactions between a neuron (and astrocyte) and blood capillary. In the future, we would like to incorporate bidirectional interactions between neurons, astrocytes, and blood vessels.

Acknowledgments

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Variation of metastability with age at fast and slow timescales

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Abstract

In this paper, we report the use of the Kuramoto model with time delay to generate neural oscillations and study the synchronization and metastability dynamics of the brain. The dynamics are simulated at two different timescales- the fast neuronal level oscillations, and the relatively slower BOLD oscillations. We compare the metastability properties across two different age groups for resting state networks. An increase in the metastability with age is observed in the simulated results, which matches with empirical observations of the same. The increase is substantially higher in the Salience Network as compared to other resting state networks. One possible reason behind this difference may lie in fact that due to the degeneration of the neural fibers with age, a compensatory mechanism for arresting cognitive decline leads to reorganization of different modules of the brain, which is seen as an increase in the metastability.

Keywords: Metastability; Synchronization; Resting State network; Kuramoto model; Healthy Aging

Introduction

Synchronization and Metastability of the brain Even the simplest functions of the brain depends on information sharing and processing between multiple functionally specialized areas, which occurs in a highly coordinated fashion. A common paradigm for the working of the brain is the integration-segregation hypothesis, by which the various different brain regions act sometimes in coordination (integration) and at other times in isolation (segregation), in order to effectively share common information and process specialized information dynamically. This integration-segregation dynamics in the brain network can be characterized through the measure of synchronization and metastability respectively [1]. Synchronization is the tendency of two or more nodes of the network oscillations to occur, as the name says, in sync with each other. This is the 'integration' paradigm in this hypothesis, by which information is mutually shared and integrated across different brain areas. On the other hand, metastability measures the tendency of the network to remain in-between synchronized regimes. When the network is maximally de-synchronized, the metastability is highest, and the different brain areas are maximally decoupled from each other, performing their individual specialized activity. This reflects the 'segregation' paradigm of the integration-segregation hypothesis. Together, synchronization and metastability form a measure of coordinated brain dynamics for the entire brain network.

The Kuramoto model in the context of neuroscience is a well-known model for generative neural activity [2,3]. We use a generalized Kuramoto model with time delay [4] for the generation of cortical activity, following the procedure described previously in [5] among others [6,7]. The modelling pipeline is given in described in the 'methods' section.

In this study we use the Kuramoto model to generate cortical oscillations in a model of the brain and study the dynamics of the synchronization and metastability with respect to the model parameters. The dynamics are recorded at two different timescales- the fast neuronal level oscillations, and the relatively slower BOLD oscillations. We compare the metastability dynamics across two different age groups for the resting state networks at both timescales. Variations in the observed empirical metastability are corroborated with the simulation results.

Methods

The Kuramoto model The neural model used in this paper to generate cortical activity is based on the Kuramoto model adapted for N number of nodes connected to each other by weighted, undirected connections [5]. The matrix used to represent this anisometric connectivity between the nodes is call the SC matrix, C_{ij}, in which the connection weights (or strengths) are normalized to 1. The distances between any given pair of nodes is represented by the distance matrix L. The Kuramoto model (with time delay) is given below.

$$\frac{d\theta_i}{dt} = \omega_i + k\sum_{j=1}^{N} C_{ij}\, sin\left[\theta_j\left(t-\tau_{ij}\right)-\theta_i(t)\right]$$

where $i, j = 1,2,\dots,N$

And where: N is the total no. of nodes, θ_i is the phase of the node i, ω is the intrinsic frequency of oscillation of the node i, k is the global coupling coefficient, and τ_{ij} is the time delay between the pair of nodes i and j defined as the ratio of the fiber distance and mean conduction speed L_{ij}/v where v is the mean conduction speed of the neural fibers. We can also define a mean delay as $\langle\tau\rangle=\langle L\rangle/v$ where $\langle L\rangle$ is the mean fiber length across the brain. We do not consider the effect of noise in this study.

For the sake of simplification the nodes in the model behave like homogenous neural masses within which all neurons oscillate together. The intrinsic frequency of oscillation of such neural assemblies has been previously shown to lie in the gamma band [5], and thus in our model we fix the value of $\omega=2\pi*60$ Hz. The nodes are free to oscillate, with the phase of the oscillation, θ, defining the state of the node. This network is thus a phase oscillator.

The free parameters in this model are k and $\langle\tau\rangle$, for which we perform parameter space sweeps in order to characterize the network dynamics for the entire set of relevant parameter ranges, and the plots so computed are called the parameter maps.

Empirical Structural Connectivity The Structural Connectivity was obtained from 25 young and 24 old subjects through T1-weighted MRI scans. The cortical regions were parcellated into 68 regions of interest (ROIs) following the Desikan-Killiany brain atlas [8]. White matter tractography was used to obtain the white matter fiber connections, lengths and density or connection strength. From this data we could construct the 68x68 SC matrix. The strength of the connections was normalized to values between 0 and 1, while the fiber length was represented in millimeters. The 68 ROIs or nodes had no self-connection loops meaning that the diagonal values of the SC matrix are all zero.

Empirical Functional Connectivity The same subjects were subjected to an fMRI scan during which their eyes-closed, resting-state BOLD activity was recorded for a duration 22 minutes (TR=2 sec). The BOLD activity was then down sampled to fit the 68 ROIs defined in this parcellation scheme.

Results

Young versus Elderly brains

The simulated functional connectivity (FC) is obtained from the Kuramoto model and the results compared with the empirically observed FC from fMRI data (Fig.1) Measures of similarity are obtained by taking the Pearson correlation and Euclidian distance and plotted across the parameter space (k, τ). While the young group shows regions of high correlation, with values as high as 0.6, the correlation in the old group, is relatively lower along with the island of high correlation being substantially reduced. The FC Euclidian distances, on the other hand, for the two groups have a larger common area of agreement. However, the region of high correlation is confined to a much smaller area in the case of the older population group. This reduction in the older population may be viewed as a case of the brain becoming more idiosyncratic with age, something which has been reported in literature [9].

Thus, the region of high FC correlation suggests that the Kuramoto model can be a good source of generating realistic neural activity. At the same time, the reduction in correlation values for the old group, indicates that as the brain ages, the effectiveness of the predictive tools used in brain modelling tends to reduce.

The parameter maps of synchronization, for both age groups and for both the fast neuronal and slow BOLD timescales, show narrow bands where complex dynamics exists. These bands, denoted in yellow, are regions where the network is neither in a locked state (red regions) nor in an uncoupled state (blue regions). The yellow regions of partial synchronization is where the network displays non trivial dynamics, as it lies balanced in the transitory space in between no-coupling and complete locking. The profiles (or shapes) of these yellow bands of rich, non-trivial synchronization dynamics are different for the two timescales. This indicates some major underlying differences in the activity at the fast and slow timescale.

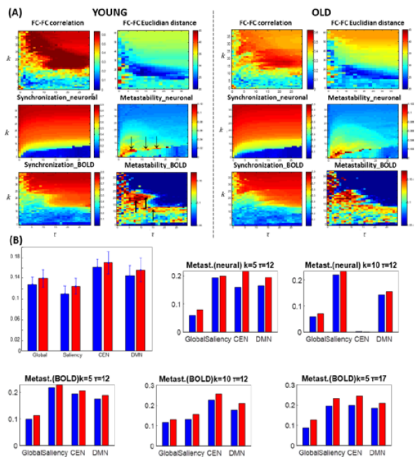

Figure 1: (A) Plotting and comparing metastability and synchronization maps in the parameter space, for young and old groups at fast and slow timescales. (B) Metastability values at different points in the parameter space in comparison with the empirically obtained fMRI results.

The parameter maps of metastability complements the results of the synchronization maps, where regions of high metastability lie in the same parameter regions where partially synchronization occurs (yellow bands). If

metastability, as it is often described, is the measure of the preparedness of the brain to switch between tasks [1], the above results imply that this preparedness is highest when the brain is partially synchronized or in an optimal balance of coupled and decoupled state. In other words, metastability is, in this respect, a measure of the balance between the integration and segregation functionalities of the brain [10,11], and thus the level of the metastability can be a marker for the optimum performance of the brain.
In the lower panel of Fig. 1, the simulated metastability for different representative points of the parameter map are plotted side by side. The results from the empirical fMRI data reveals that the metastability tends to increase with age. This is true for the whole brain resting state network as well as from three different sub-networks, namely the Saliency network (SN), Default mode network (DMN) and the Central executive network (CEN). These results are described in the next section.

Resting-State Functional Networks The results here shows a comparative study of the variation of metastability across the two age groups, for three different functional networks- SN, CEN and DMN. These three networks comprise the most important part of the resting state brain activity in humans being involved in a variety of higher cognitive functions. The Salience network has an important role to play in healthy aging [12] and it is in this network that the most evident and major difference is seen across the two age groups. While the metastability of the CEN and DMN do not show major variations with the age, we find that the metastability of the SN increases substantially with age. This is shown in Fig. 2. Moreover the increased metastability, visualized in the parameter space, occurs in the region where the parameters are relevant to realistic values and within which the model has high prediction accuracy.

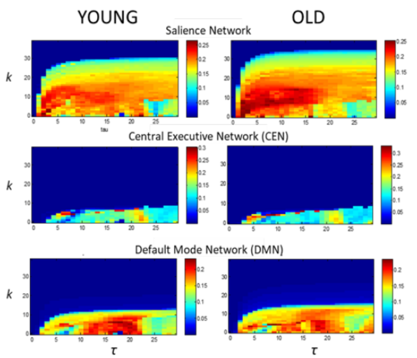

Figure 2: The profiles of metastability in the parameter space for different resting state networks. It is seen that the metastability across the age groups significantly increases in the case of the Salience network while not so much for the other networks.

Discussion

We have seen that the FC results from the simulation matches well with the fMRI obtained FC. Thus the Kuramoto model with time delay has been shown to be an effective generator of cortical oscillations, simulating brain activity at both the fast and slow oscillation timescales.

The metastability and synchronization dynamics at the fast and slow timescales are compared across the young and old age groups, revealing subtle differences in the metastability across them. The increased metastability with age in the simulated results match with the empirical observation of the same. The increase is substantially higher in the SN as compared to other networks. One possible reason behind this difference may lie in fact that due to the degeneration of the neural fibers with age, a compensatory mechanism for arresting cognitive decline leads to reorganization of different modules of the brain, which is seen as an increase in the metastability. However, the nature of the decay and its relation with the metastability and synchronization dynamics etc. of the brain are, as of yet, still open questions and topics for future research.

Acknowledgments

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EEG Characterization of Healthy Aging and its Effect on Working Memory

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Abstract

Healthy aging is characterized by myriad cognitive changes accompanied by structural changes in multiple brain regions. The cognitive domain most vulnerable in aging is memory. Studies have indicated that even if performance of healthy aging population on cognitive tasks is similar to young subjects, they employ different strategies. The ability to retain information for short periods in working memory (WM) involve numerous cortical regions which are thought to atrophy on aging. Online EEG rhythms with varying cognitive load, can uncover interesting findings. Additionally, resting state EEG may regulate attention and arousal, which prepare brain networks for WM functions. The n-back paradigm is a WM paradigm which can uncover insightful findings which can be probed on examining neural oscillations. This comparative study between old and young individuals attempts to understand effects of aging on WM probing task related and resting alpha, beta and gamma rhythms with behavioural accuracy and reaction time (RT) data. It was observed that older individuals activate less attentional resources, there is over recruitment of neuronal networks to compensate for neurons which are thought to undergo aging related atrophy and clustering over whole brain electrodes throws light that older individuals can encode less items in their WM.

Keywords: Working memory; aging; n-back task; resting EEG rhythms; task EEG rhythms.

Introduction

Memory decline is typically the first symptom observed in patients with Alzheimer's disease (AD). According to a survey conducted in 2010, more than 35 million people worldwide have been diagnosed with AD making it the most common form of dementia. (Querfurth and Laferla, 2010). The study of the healthy brain aging, especially age-related changes in memory is essential to understand the deficits associated with AD. WM involves the ability to maintain and manipulate information over short periods of time. It can be subdivided into two parts: the initial encoding of information and maintenance and retrieval of WM items (Roux and Uhlaas, 2014). Much larger age-differences are seen for WM tasks than for short-term memory tasks that require only storage and maintenance of information (Bopp and Verhaeghen, 2009).

One of the most popular experimental paradigms for WM studies has been the n-back task. Participants are asked to monitor the identity or location of a series of verbal or nonverbal stimuli and to indicate whether the currently presented stimulus is the same as the one presented previously (Owen et al., 2005). In a 1-back task, the participant decides if the current letter is the same as the letter previously shown, whereas in a 2-back task, the participant decides if the current letter is the same as the item that was shown two items before, and so on as n increases. As n increases beyond 1, participants must not only store the items presented, but also their sequence to provide the correct answer. Much effort has been made to elucidate the aggregated alterations of behaviour during n-back tasks and to uncover their underlying mechanisms using functional magnetic resonance (fMRI) and electroencephalography (EEG). EEG is a sensitive approach for rapid cognitive processes such as those involved in WM, in which changes occur on a time scale of several 100 m/s. Analysis of EEG results allows researchers to obtain information on brain functioning during different behavioural and cognitive states.

There is considerable evidence that gamma-band activity is associated with processes involved in memory and increased gamma activity while performing a memory task. This increase in gamma activity is said to have arisen due to an increase in theta activity. This phenomenon is known as theta gamma coupling (TGC) which is thought to code for the ordering of items of information during working memory time intervals, i.e., the manipulation component of working memory (Lisman and Jensen, 2013; Rajji et al., 2017). Gamma oscillations represent the individual items of information, while theta oscillations represent the time interval during which the items are held in memory (Lisman and Jensen, 2013). However, the functional role of distinct EEG oscillations, typically involving theta, alpha, gamma and beta activity and their relationship is not completely clear. A comprehensive understanding of the behaviour of these rhythms under ideal conditions is thought to aid in the investigation of rhythm related markers to identify cognitive deficits thought to be associated with AD in its prodromal phase.

The observation that there are relatively consistent distributed patterns of activity during rest has led to the suggestion that it might be possible to characterize network dynamics without needing an explicit task to drive brain activity. This possibility has been explored in studies of resting-state networks. In the recent past, it has been well established that resting-state activity plays an important role in cortical function and cannot be ignored in understanding brain-behaviour relationships (Raichle & Snyder, 2007; Arieli, Sterkin, Grinvald, & Aertsen, 1996). Resting state activity is said to interact with external input to impact stimulus induced changes in the brain, which could be used to predict subsequent neural activity and mental states. In this regard, resting-state EEG could be a reliable indicator of functional reorganization of brain networks, supporting a wide range of perceptual and goal-directed tasks. Converging evidence regarding the functional relevance of spontaneous brain activity has revealed prominent differences not only in patients with brain disorders but also in healthy aging. While many studies have investigated resting state EEG connectivity in aging related diseases, relatively few have characterized the connectivity changes that occur with healthy aging. Beta rhythms are thought to underlie the process of attention during a working memory task, gamma rhythms are thought to correspond to the number of items held in working memory and alpha rhythms are thought to be an indicator of cognitive load which is thought to be correlated with task difficulty. If the working memory task employs appropriate neural circuitry in an individual then the power observed in pre task rhythms is expected to be greater than the power observed in post task rhythms. Comparative studies between young and older adults can throw light upon the difference in the power spectrum at different frequencies for various rhythms. Coupled with behavioural data, accuracy and reaction time for performance during the n-back task, meaningful interpretations can be made by epoching task related EEG data at desired time windows and also checking the differences in power for pre and post task resting EEG rhythms. These measures together can serve to provide a clear understanding by correlating rhythms to distinct cognitive processes involved in WM which can constitute attention, processing speed, encoding, maintenance, manipulation, strategizing and retrieval. The study aimed to examine the behavioural differences in RT's and accuracy in old and young participants as a function of load along with patterns of differences in resting and task related alpha, beta and gamma EEG oscillations. It was predicted that older subjects would show poor performance in the n-back task and exhibit less power in pre and post resting rhythms as compared to old subjects. Both groups were expected to exhibit greater power in pre resting rhythms as compared to post resting rhythms.

Methods

The study included 15 healthy young adults (YA; 18-25 years mean age 21) and 15 healthy older adults (OA; 55-80 years; mean age 66). All the participants had formal school education for 12 years. Demographic details including socioeconomic strata and occupation related information was collected. Personal proforma was prepared to collect information about the medical history. Participants with a history of any neurological, neurosurgical, psychiatric disorder were not included in the study. Participants were screened on the basis of Mini- Mental State Examination (MMSE). Individuals whose MMSE score was more than 26 were included in the study. Visual acuity test was also administered. Individuals with normal or corrected vision (6/6) were taken for the study. These measures ensured that the experimental results were not confabulated due to differences in education level, due to medical conditions and current medication or due to differences in sensory abilities. Written informed consent was taken from the participants and ethical approval for the study was obtained from the Ethics Committee of the University of Allahabad.

The n-back task of working memory was employed. In the n-back task, a series of stimuli were presented and participants were required to decide if the current stimulus is the same as the item presented n positions back. The stimuli employed for the study were the same as those employed for the perceptual matching task which were circular Gabor patches of 8 different orientations which were 0 degrees, 22.5 degrees, 67.5 degrees, 90 degrees, 112.5 degrees, 157.5 degrees, 292.5 degrees and 337.5 degrees respectively and were of the same size and colour with a 100% contrast on a grey background. The experiment was designed using E-Prime version 2.0 and was conducted in a dark room on a dell monitor of 19 inches at a distance of 50 cm. There were two conditions, one of low load, which was the 1-back task and the other of high load which was the 2-back task. In the 1-back task, the participant decides if the orientation of the current gabor patch is the same as the orientation of the just previous gabor patch whereas, in a 2-back task, the participant decides if the orientation of the current gabor patch is the same as the orientation of the gabor patch that was shown two patches before.

Each block consisted of 80 trials and each stimulus was presented for 500ms and 1.5 seconds being allowed for response before the next trial. Each block of trials lasted roughly four minutes. There was a short training session prior to the experiment. Participants were instructed to respond as quickly as possible and to press ' z ' if the present gabor patch matched the previous gabor patch in the low load condition or was the same as the two patches presented before in the high load condition. They were instructed to press '/' if the present gabor patch did not match the previous gabor patch in the low load condition or was not the same as the two patches presented before in the high load condition. Participants performed two blocks of each of a single condition serially with a rest period between blocks if they desired. In both conditions, low load and high load, 50% of the trials were match trials and 50% were non-match trials, which were presented in a random order. Before data collection, the study protocol was explained to each participant so that they were aware a working memory task would follow the resting state conditions, but they were not explicitly instructed to prepare for the task. To assess resting-state activity, participants were first asked to sit quietly with their eyes closed for five minutes. While performing the n-back task, the participants were subject to online EEG recording. Again, after completion of the task, to assess resting state activity, participants were asked to rest quietly with their eyes closed for five minutes.

EEG rhythms were recorded using a 128-channel electrode-EGI-Geodesics NetStation system (Electrical Geodesics Inc., HydroCel GSN 128 1.0) at a sampling rate of 250 Hz. The sensor net as per the head size of each participant was positioned according to the 10-20 International system of placement of electrodes. The impedance of all electrodes was less than 5 kΩ. The electrodes were referenced to Cz. During the recording, participants were instructed to close their eyes, keep their chin on the chin rest and sit calmly. Performance for the task was evaluated using the d prime (d') measure, which is the difference between the z-scores of the true positive rate and false positive rate. d' = z (hit rate) – z (false alarm rate), c criterion scores and ANOVA for accuracy and reaction times.

Results

Accuracy and reaction times were recorded for the working memory task and the two groups of participants were compared on both the measures of performance. The d prime scores were computed to account for the commission errors (false alarms) in order to measure accuracy on the working memory task. A two-way ANOVA was performed between age (young and older adults) and working memory load (high load: n 2 back task and low load: n1 back task). Performance in the high load condition at ($p > .05$) was significantly less accurate (F=9.240, p=0.004) than the low load condition for both age groups. Young individuals performed significantly better (F=17.499, p=0.0001) at ($p > .01$) on the task as compared to older adults. (Fig. 1)

To examine the age-related effects on response criterion, a two-way ANOVA was performed between age and load with the response criterion scores. At ($p > .05$), statistical significance (F=9.941, p=0.003) was observed for the age-related effects on response criterion. No significant effects of load were observed for load related effects on response criterion. A two-way ANOVA between age and load with mean reaction times across low load and high load conditions was also performed. The age-related slowing in reaction time was evident in the high load condition of the task and at ($p > .01$) statistical significance (F=38.729, p=2.29) was obtained on comparing reaction time between groups, young and old on both, high and low load conditions of the task. Significant effects for reaction time were obtained for age related slowing and not for the load condition.

Resting EEG analysis was performed using EEG Lab toolbox, version 14.1.2 (Delorme, A., & Makeig, S, 2004). Results showed trends of differences between pre and post resting beta rhythms for young and older adults as well as between group comparisons although did not reach statistical significance ($p > .01$). Young individuals have greater beta power in pre task resting rhythms as compared to post task resting rhythms. The beta power was comparable between pre task and post task resting rhythms for older adults. A clear difference in pre task resting rhythms between old and young individuals in anterior frontal electrodes was observed.

Resting alpha rhythms were assessed at frequencies between 8-12 Hz. In young individuals, alpha power reduces in post resting rhythms as compared to pre resting rhythms in the frontal and occipital regions. In older individuals the power observed in pre task resting rhythms is much lesser as compared to the pre task resting rhythms observed in younger adults and alpha power in older adults was observed only in occipital regions. There is greater power observed in posterior sites in older individuals as compared to young individuals in both, the pre task resting condition and the post task resting condition.

Resting gamma rhythms were assessed at frequencies between 30-60 Hz. Clustering at this frequency yielded statistical significance ($p > .01$) on comparing pre resting rhythms for young adults which exhibited higher power as compared to pre resting rhythms for older adults. (Fig.2) There was no significant difference in gamma activity between pre and post task resting data in case of older adults. There is greater power observed in posterior sites in older individuals as compared to young individuals in the pre task and post task resting phase.

Discussion

It was observed that the d prime values were significantly less for older adults than for young adults and for both groups, the d prime values were less for the high load condition as against the low load condition. Irrespective of load, the d prime values were significantly less for older adults compared to young adults. However, working memory load did not show a significant interaction with age group. This finding can be attributed to the fact that the task was difficult for both groups. The task is a spatial judgement task whereby individuals have to hold the orientation of items in working memory which might have added to the task difficulty. In addition, older adults showed fewer number of false alarms as compared to young adults. On analyzing their C scores to understand their response criterion, a significant between group effect was found irrespective of the load. Older individuals seem to be more conservative while making their response. This could be attributed to the fact that the processing speed in older adults is slow which is supported by finding a significant group effect for RT's between young and old individuals. Slower RT's in older individuals lends support to the fact that the analysis of the stimulus itself maybe slow and thus the older individuals cannot effectively distinguish between signal and noise. In order to improve their performance, the older individuals might have a conservative response bias since they take probably take longer to evaluate the stimulus to improve their performance. Thus, due to these factors, it can be inferred that the process of encoding of items in working memory does not take place appropriately in older adults. The gamma rhythm (30-60 Hz) is thought to underlie the process of encoding by being responsible for the number of items which are encoded in working memory. Lesser overall gamma power in older individuals even in resting rhythms before the task could potentially be an effect of poorer sensory gating of items in working memory

The beta frequency is said to be inversely correlated to attentional resources, i.e., the more attentional networks which are active, the lesser the activity will be in this frequency band. High beta power across all electrodes in the pre task resting data in young adults suggests the involvement of Default Mode Network at rest. Lesser activity in post resting rhythms as compared to pre resting rhythms indicates that attentional mechanisms were involved while the task was being performed. This finding was observed in the whole brain analysis and more so, in anterior frontal sites including the prefrontal sites. In elderly adults on the other hand, the difference between beta power in pre and post res ting rhythms was not observed. The older adults showed less beta activity even in the pre resting data. This observation suggests that attentional resources may be poorly employed or exhausted during task performance resulting in a lower discriminability index (due to the task difficulty in a spatial working memory task). Post task resting data was expected to show reduced beta as observed in case of young adults in whole brain analysis as well as at the anterior frontal sites due to the greater engagement of attentional control processes in the working memory task, which may sustain in the post task resting data. Absence of difference in beta activity between pre task resting and post task resting data in anterior frontal sites in older adults suggests less engagement of attentional resources during the task.

Resting Alpha rhythms were assessed at frequencies between 8-13 Hz. The magnitude of alpha activity during cognitive tasks has been hypothesized to be inversely proportional to the number of cortical neurons recruited into a transient functional network for task performance. In young individuals, alpha activity is high in pre resting rhythms in the frontal and occipital regions recorded prior to the task. After completion of the task, power in alpha in post resting rhythms reduces indicating task related activity. In older individuals, even in the rhythms recorded prior to the task, very low power of alpha was observed in the occipital electrode sites which indicates that certain networks could be faulty to begin with. There is a switch in the trend observed between young and old subjects in terms of alpha rhythms. Older adults tend to exhibit more power in post resting alpha rhythms than pre resting alpha rhythms which could indicate that these networks are activated to support task demands but oversaturate and fail to do so. It is observed that the peak power for alpha in pre resting rhythms is much lower in older adults than young adults which could indicate that resources are scarce to begin with. It is also observed that posterior regions in the old exhibited greater power both, in pre task resting and post task resting rhythms as compared to young individuals. High power in the posterior electrodes observed in old individuals in the post task resting condition could indicate that since the frontal regions in the aging brain are thought to atrophy, there is over recruitment of posterior circuits in an attempt to facilitate the task.

Resting gamma rhythms were analyzed between 30-60 Hz. Gamma rhythms are thought to be responsible for the number for of items to be encoded in working memory. In young individuals, high power in pre resting rhythms as compared to post resting gamma rhythms indicates that it is likely to support encoding of items in working memory during the task. However, there was no difference in gamma activity between pre and post task resting data in case of older adults indicating saturation of resources to hold items in working memory. In addition, clustering analysis showed that the respective peak power for the pre task resting gamma rhythms for young individuals was more than that of older adults. This is known as the gamma gating hypothesis which is to say that the encoding store is gated and it is not capable of holding greater items in working memory. This is consistent with the overall slower reaction times during the working memory task suggesting slow processing speed in older adults compared to young adults.
On comparing plots across all electrodes for the entire frequency spectrum 2-60 Hz, it was evident that in both, pre and post resting rhythms, the peak powers are higher for young individuals as compared to older individuals. The most prominent changes in activity are observed in the alpha (4-13 Hz) and gamma (30-60 Hz) frequencies. The robust difference in the alpha and gamma power between young and old individuals confirms the hypothesis that attentional resources are scarce and encoding is faulty in older individuals since the gamma band is thought to underlie the number of items which can be held in working memory. Since encoding is faulty to begin with, working memory is thus bound to be affected. Results obtained for the resting rhythms need to be confirmed after obtaining results for EEG rhythms recorded while the n-back task is being performed.

Figures

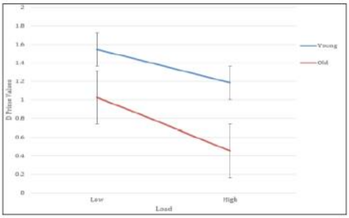

Figure 1. Effect of load on individuals belonging to both groups, young and old as against d prime scores

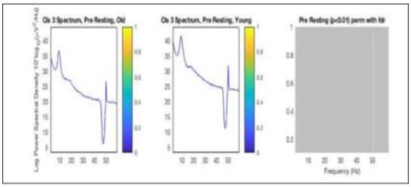

Figure 2. Clustering analysis over the entire brain for a range of frequencies between 2 Hz and 60 Hz for a comparison between pre task resting rhythms between young and old individuals

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Understanding Consumer Preferences for Movie Trailers from EEG using Machine Learning

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Abstract

Neuromarketing aims to understand consumer behavior using neuroscience. Brain imaging tools such as EEG have been used to better understand consumer behavior that goes beyond self-report measures which can be a more accurate measure to understand how and why consumers prefer choosing one product over another. Previous studies have shown that consumer preferences can be effectively predicted by understanding changes in evoked responses as captured by EEG. However, understanding ordered preference of choices was not studied earlier. In this study, we try to decipher the evoked responses using EEG while participants were presented with naturalistic stimuli i.e. movie trailers. Using Machine Learning techniques to mine the patterns in EEG signals, we predicted the movie rating with more than above-chance, 72% accuracy. Our research shows that neural correlates can be an effective predictor of consumer choices and can significantly enhance our understanding of consumer behavior.

Keywords— Neuromarketing, EEG, Machine Learning, Discrete Wavelet Decomposition

1 Introduction

Consumer neuroscience systematically aims to understand consumer behavior and underlying preferences through the lens of psychology, neuroscience, marketing and economics (Ariely & Berns, 2010). Currently, consumer research relies on the stimulus-reponse model to capture the underlying brain processes. The development of human neuroscience tools to understand the latent mechanisms gave rise to progress of using neuroscience to effectively understand what the consumer prefers going beyond the traditional subjective scores (Hsu & Yoon, 2015; Silberstein & Nield, 2008). Understanding what contributes to the observed behavior by complex, naturalistic stimuli has immense importance in marketing research (Hubert & Kenning, 2008; Dmochowski et al., 2014; Plassmann, Ambler, Braeutigam, & Kenning, 2007). Preferences of consumers have been widely studied using other modes than self-reported measures. The idea of 'preference' has been historically approached differently in psychology, economics, marketing and neuroscience. One neuroscience study has shown that behavior preferences can be attributed to brain activity in the ventromedial prefronal (vmPFC) cortex and ventral striatum (McClure et al., 2004).

Electroencephalography (EEG) is being recently used as a tool to understand the neural correlates of consumer behavior due to its advantage of providing temporal resolution of stimulus-response . Previous research suggests using EEG to understand the patterns of brain activity of participants watching advertisements to understand their buying preferences (Wang & Minor, 2008). The main motivation behind this current study is to understand consumer neuroeconomics from a machine learning perspective, primarily to understand movie preferences, which is a line of research that has not received much attention. For instance, the US movie box office revenue is above $10 Billion per year. However, investing in such projects is risky. It has been found that only 36% of movies achieve a break-even over the production cost, in terms of profits. Movie producers spend huge amounts on movie trailers and use different marketing techniques to gauge consumer reactions, and eventually, box-office earnings. Boksem et al (2015) used EEG for predicting brain responses to movie trailers based on individual consumer preferences, where brainwave signals in the beta frequency oscillation range were found to be a good predictor for like/dislike of a movie trailer (Boksem & Smidts, 2015). In another work, EEG was used to study consumer behavior where it was found that future choices in terms of which product a consumer will prefer buying, was predicted using EEG (Kang, Kim, Jang, Cho, & Kim, 2015).

In this study, we study consumer behavior in terms of movie trailer preferences using both neural and behavioral measures, with the main aim to use pattern recognition techniques to understand evoked responses in EEG. The present study tries to systematically investigate whether neural correlates can be a valuable predictor of individual choice preferences.

2 Method

2.1 Experiment Design

The dataset was collected using a 128 channel Net Station Electroencephalography (EEG) device from 18 healthy individuals (13 were men, and 5 were women) at Indian Institute of Technology, Gandhinagar. The mean age of participants was 22.4 years within the range of 18-26 years. No participant reported any history of neurological or psychiatric disorder. Fifteen participants were right-handed, and three were left-handed. Data acquisition was done using EGI Netstation 5.2. The experiment consisted of 12 trial blocks. In the experiment, every subject was asked to watch 12 trailers of upcoming movies, and after each trailer, there were four questions to be answered on a likert scale of 1-5:

1) Rating
2) Familiarity
3) Purchase Intent
4) Willingness to Spend

Lastly, participants were asked to report an ordered preference to arrange the movies in descending order, the movie trailers they liked the most to least preferred.

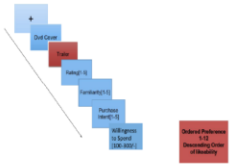

Figure 1: Experiment Design

2.2 Data Pre-processing

This step consisted of removal of data points in the dataset that were erroneous. Those samples where the electrodes were not in proper location, or not in contact with the scalp, were excluded from the dataset before further processing. EEG signal is susceptible to noise or artefacts and has to be corrected as part of the signal pre-processing step as mentioned in the below. All the pre-processing was performed using EEGLab Package in MATLAB (Delorme & Makeig, 2004). Further, bad channels were rejected using Artifact Subspace Reconstruction using Makato's Pre-processing pipeline (Makoto, 2008). Re-referencing was performed across all channels. The following artefacts were identified and removed:

2.2.1 Physiological Artefacts

Electrooculogram (EOG): This is the electrical noise generated by eye blink and cornea movement that is captured in the EEG signal and has to be removed. It can be estimated as the change of potential in electrodes near the eyes at Fp1-Fp2 (Fronto Parietal). Fluttering of the eyelids appears as a 3Hz –10Hz signal, and hence was removed using Band Pass filters.
Electromyogram (EMG): This is the electrical "noise" generated by muscle activity. Facial Muscle movement; swallowing, grimacing, chewing can be captured in EEG and has to be removed. This noise commonly appears in the frontal and temporal electrodes.

2.2.2 External Artefacts

Physical movement: This can lead to lose contact of electrode due to abrupt physical movement of subjects and is captured as a high amplitude, low frequency noise.
Electrode Contact: Poor electrode contact gives rise to low frequency artifacts and all such trials were removed which had lost any electrode contacts.

2.3 Feature Extraction

In order to extract features from EEG signals, a well-established method is to decompose the mother wavelet into sub-frequency bands. There are primarily 5 types of frequency bands:

Table 1: EEG Wavelet Decomposition

Frequency Band	Frequency Range (Hz)
Delta	0 - 3.5
Theta	4 - 7
Alpha	8 - 13
Beta	14 - 30
Gamma	30 - 60

A general method for decomposition is to use Fast Fourier Transform. But since EEG electrode signal is non-stationary, FFT might not be the best alternative (Gross, 2014; Azim, Amin, Haque, Ambia, & Shoeb, 2010; Hamad, Houssein, Hassanien, & Fahmy, 2016). Instead, we used Discrete Wavelet Transform (DWT) Method (db-8 wavelet) using Matlab Wavelet Toolbox to extract two features, Power and Entropy for all 5 frequency sub-bands in range of 0-60 Hz, across all 128 channels.

2.4 Feature Elimination

Since the feature set had a large number of features consisting of 5 DWT features for both Power and Entropy, two feature elimination techniques were used:

1) Recusrive Feature Elimination: This algorithm ranks the features by associating the weights with features and prune the features as per the weights. It forms the smaller set after each iteration and terminate until the given (k) number of features is achieved.
2) Sequential Backward Selection: A greedy search technique to reduce dimensions of the feature vector from a d space to lower dimensional k space.

Scikit-learn provides implementation of these two algorithms and were used in our analysis (Pedregosa et al., 2011). These two methods were used to select features which were further trained with the set of classifiers.

2.5 Machine Learning Classifiers

Choosing the correct set of Machine Learning models is a crucial step for classification. 9 Machine Learning classifiers were used to predict the labelled class using the extracted feature set, which includes: k Nearest Neighbors, Random Forest, Quadratic Discriminant Analysis, Decision Tree, Multilayer Perceptron, Gaussian Naive Bayes, Gaussian Process Classifier, Ridge Classifier, Support Vector Classifier. Every classifier was trained with a Cross-Validation set and test for performance using the test set. The hyper-parameters of the classifiers were tuned iteratively.

3 Results

The total sample size of 216 data points was divided into train set with 151 and test set with 65 samples. All the 4 bands were found to have discriminating information for the classifier. Machine learning classifiers were then used to train and were tested accordingly, with the top 5 classifiers using 10 Fold Cross-Validation with their results as follows:

Table 2: Classification Performance

Classifier	Feature Elimination	Test Accuracy
kNN	RFE	0.7237
Random Forest	SBS	0.7069
Random Forest	SBS	0.7069
kNN	SBS	0.6923
Multilayer Perceptron (HL(5,2), ReLU)	SBS	0.6769

4 Discussion

The use of EEG in Neuromarketing to understand consumer behavior is an important area of research given its wide implications. Machine learning techniques have aided immensely in this regard, to decode the information in EEG signals. In this study, we attempted to find whether consumer preferences can be predicted using EEG signals and achieved high accuracy to predict ratings. The main aim to predict ordered preference of movie trailer still needs to be studied, which is the primary goal of this study.

However, using EEG for consumer research has its own challenges. EEG signals have a low Signal-to-Noise ratio and hence, it becomes a challenge to accurately process the signal. Sensitivity to various artefacts also poses problems in the data cleaning process. Better signal processing techniques could further improve the Signal-to-Noise ratio and could improve classification performance which needs to be explored. However, the most significant challenge faced was the small-n-large-p problem i.e. large number of features as compared to number of samples. One limitation of our work is that we had averaged the feature values across channels, which may have led to loss of information. One way to resolve this would be to use dimensionality reduction techniques. We made a preliminary attempt to use PCA but did not get any significant improvements. Using non-linear dimensionality reduction techniques such as t-SNE and UMAP which are considered to be the state-of-the-art techniques need to be further explored. Deep Learning techniques have been found to be quite powerful when learning internal representations of features, which could be significant as a dimensionality reduction step, which can be further explored.

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Novel metrics to quantify the efficacy of inhibitory control

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Abstract

Inhibition of response in preparation is critical for adaptive goal-directed behaviour. Inhibition of response is often investigated by stop-signal task (SST) which requires participants to generate a primary response in majority of trials, and inhibit the response in the rest when a stop-signal appears. Race model elegantly describes the performance in SST as an independent race between GO and STOP process to reach a threshold. It provides means to estimate the latency of the unobservable stop process (stop-signal response time-SSRT). However, the assumption of independence between GO and STOP is violated invalidating the SSRT. Cancellable rise-to-threshold model that does not assume a STOP competing with GO is an alternative to race model. Previously we extended this model to show that the inhibition of response is attained by spontaneous deceleration of the go activity triggered by the stop-signal. We established that the non-cancelled saccade latency is an exponential function of the delay between onset of non-cancelled saccade and the stop-signal, which is referred to as parallel processing time (PPT). In this study, we propose an efficient alternative method, not vulnerable to assumptions of race model, to quantify stopping efficacy derived from the best exponential fit of non-cancelled RT plotted against PPT.

Keywords: response inhibition; stop-signal task; eye-movement; model

Introduction

Cancellation of a motor response is often studied by using stop-signal task in laboratory (Lappin & Eriksen, 1966; Logan & Cowan, 1984). In this task, in major proportion of trials, called *'no-stop trials'*; a go-signal appears instructing to make a primary response within a stipulated time period. In the remaining trials, called '*stop trials*'; a stop signal appears after a variable delay from the onset of go-signal, which is referred to as '*stop-signal delay*' (SSD), instructing participants to withhold the impending primary response. No-stop and stop trials are randomly interleaved. Stopping performance is quantified by plotting inhibition function i.e., the proportion of non-cancelled trials (stop trials where participants executed the primary response) as a function of SSD. Independent race model (Logan & Cowan, 1984) describes the stopping performance as an outcome of race between GO process trigger by the go-signal and STOP process triggered by the stop-signal rising independently towards a fixed threshold. If the GO process reaches the threshold before the STOP, the primary response is emitted (non-cancelled trials) and if the STOP process reaches to threshold first, the primary response is inhibited (cancelled trials). The assumptions for race model incorporate two categories of independence between the GO and STOP process - context independence and stochastic independence. Context independence (also called signal independence) assumes that the go process is not affected by the presence of the stop signal (or stop process) i.e. the finishing time distribution of go process (no stop RT distribution) is the same even in the stop trials. Stochastic independence assumes that for a particular trial, the latency of the go process is independent from the latency of the stop process.

Race model provides methods to estimate the latency of the unobservable internal STOP process to reach the threshold, called stop-signal response time (SSRT). SSRT is used as a metric to measure the efficacy of inhibitory process in different tasks, conditions, populations and clinical disorders. SSRT is used as a crucial proxy for inhibitory process across disciplines. However, a valid estimation of

SSRT is possible only if the independence assumption of race model holds (Band, Van Der Molen, & Logan, 2003; Hanes & Carpenter, 1999). The violation of independence assumption is pervasive across SSDs, participants, tasks, and population (Bissett, Poldrack, & Logan, 2019; Özyurt, Colonius, & Arndt, 2003). Bissett and colleagues (2019) found that the violation is severe at the short SSDs (< 200 ms). Moreover, they found that if the short SSDs data is removed for the estimation of SSRT, the fundamental findings change. Additionally, the physiological evidence for the existence of racing STOP process is debated (Hanes, Patterson, & Schall, 1998; Hasegawa, Peterson, & Goldberg, 2004). A recent study (Jana, Hannah, Muralidharan, & Aron, 2019) found that the inhibition of an action is achieved almost ~ 60 ms before the SSRT that questions the studies where a turnaround in neural activity just before the SSRT (5-10 ms) was considered as a proxy for inhibitory process (Boucher, Palmeri, Logan, & Schall, 2007). Therefore, the use of SSRT as a metric of inhibitory ability might not be appropriate and an alternative means to quantify inhibitory efficacy that does not depend on the assumptions of race model is warranted.

Cancellable rise to threshold (CRTT) (Salinas & Stanford, 2013) provides an alternative explanation for the stopping process. CRTT model advocates that ongoing motor activity is decelerated after the stop signal is detected. If the magnitude of deceleration is large and stop signal is detected fast, the rise of motor activity ceases and diminishes down before reaching the threshold, resulting in cancelled trials. We extended the CRTT model and showed that the magnitude of deceleration is proportionate to detectability of the stop-signal and non-cancelled RT increases exponentially as a function of parallel processing time, which is the delay between the onset of primary response and stop signal (Indrajeet & Ray, 2019). In this study, we propose novel methods to estimate the stopping efficacy based on extended CCRT model. The metrics are estimated from the best exponential fit of noncancelled RT plotted against PPT. First metric is the intercept on the ordinate and second is the magnitude of deceleration triggered by stop signal, referred to saccade procrastination time (SPT) and stop triggered deceleration (STD) respectively. Together these metrics explain more variance in stopping performance than SSRT. These metrics provide an alternative explanation for stopping performance and a feasible neural mechanism of inhibitory control.

Methods

Twenty healthy human participants (mean age ± *SD*: 23.15 ± 6.11 years) voluntarily performed a standard saccade countermanding task. TEMPO-VideoSYNC software created and displayed stimuli on a LCD monitor (size: 19 inch, resolution: 640 × 480, refresh rate: 60 Hz), stored eye positions, set and/or stored other task related parameters in real time. Eye positions were sampled and recorded by a video-based desktop-mounted infrared eye tracker at 240 Hz (ETL-200; ISCAN). Data processing and statistical analysis were performed by using either Matlab or SigmaStat software.

Each trial began with a fixation spot (~ 0.25° × 0.25°) in white colour at the centre of the monitor. After a continuous gaze-fixation within a virtual window (± 4°) for ~ 500ms by the participant, the fixation spot disappeared and a white square (~ 2.5° × 2.5°) appeared in periphery at one of the 8 possible locations and remained until trial ended. In 60 % of total 600 trials labelled as 'no-stop trials', disappearance of the fixation stop (go signal) indicate participants to generate a saccade to the square in the periphery. In the remaining 40 % trials, the fixation spot reappeared (stop-signal) after a variable delay from go-signal called stop –signal delay (SSD) instructing participant to hold her/his gaze at the fixation spot. SSD values were randomly selected from a set of six values i.e. 50, 100, 150, 200, 250, 300 ms. The background of the display was black throughout a trial. An auditory tone was played to indicate the correct performance by the participant.

Results

We grouped positive PPT (delay between onset of saccade and stop signal: PPT = non-cancelled RT-SSD) of each individual's data into consecutive bins of size 50 ms from 0 to 350 ms. We calculated the mean PPT and non-cancelled RT in each bins for each participants. Subsequently we fitted each participant's data with an exponential function we derived earlier of the form $RT = a \times e^{b(PPT)} + c$, where a, b, c were fitting coefficients (Indrajeet and Ray, 2019). The reciprocal of SEM of non-cancelled RT in each bin was used as weight for fitting. The mean (± SEM) goodness of fit (R^2) was 0.83 (± 0.04). *Figure 1 A* shows the average (± SEM) of best fits across participants. It reflects an exponential increase in non-cancelled RT with the increase in PPT. We calculated two measures from the best fit of each participant's data: (1) saccade procrastination time and (2) Stop triggered deceleration. Saccade

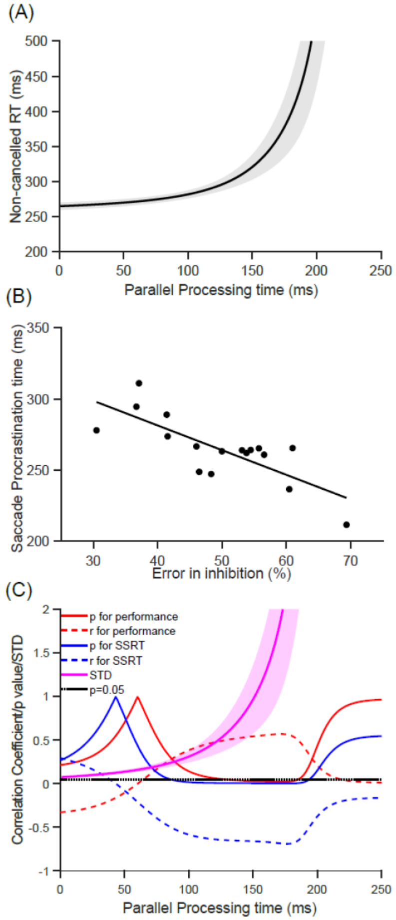

Figure 1: *Best exponential fit, relationship between SPT and stopping performance, and relationship of STD with stopping performance and SSRT.* **(A)** Average of best exponential fit across participants shows an exponential increase in noncancelled RT as PPT increases (average: magenta line, SEM: patch). **(B)** Correlation between SPT and overall percentage error in stopping. The more a participant procrastinated, the better success in stopping. **(C)** Relationship among STD, stopping performance and SSRT. Stop triggered deceleration (STD) increased exponentially as a function of PPT (mean-magenta line, SEM-patch). Initially, STD was not significantly correlated with stopping performance or SSRT. But correlation between STD and SSRT and STD and correct stop performance significantly correlated after ~**86** ms and ~**128** ms respectively and the correlations remains significant for **few** period of PPT. Interestingly, both the correlations have similar dynamics. The red and blue dashed lines indicate correlation between STD and correct stop performance and between STD and SSRT respectively. The red and blue solid lines indicate p value of correlation between STD and correct stop performance and between STD and SSRT respectively. The horizontal dotted line indicates the p value of 0.05.

procrastination time (SPT) is the average maximum time a participant procrastinates or holds saccade in stop trials. This equals to the intercept of the best fit on the ordinate. In other words, SPT is an estimated non-cancelled RT when onset of saccade and the stop-signal coincide (i.e., SPT= a + c, at PPT = 0). non-cancelled RT when onset of saccade and the stop-signal coincide (i.e., SPT= a + c, at PPT = 0). Stop triggered deceleration (STD) is the instantaneous slope of the fit calculated at each millisecond between 0 and 250 ms of PPT (STD = a × b × $e^{b(PPT)}$).

We found (1) significant negative correlation between SPT and the percentage of error in saccade inhibition [r *(15)* = - 0.78, p = 0.0002, R^2 = 0.608] (*Figure 1 B*), (2) significant positive correlation between STD (at PPT = 175 ms) and percentage of cancelled trials across participants [r (14) = 0.568, p = 0.022, R^2 = 0.323], and (3) negative significant correlation between STD and SSRT (median method) [*r (14) = -0.688, p = 0.003, R^2 = 0.473*], across participants.

To explore the temporal dynamics of association of STD with SSRT and stopping performance, we plotted the correlation coefficients and p values for their relationships (*Figure 1 C*). The correlation between STD and SSRT becomes significant at ~86 ms and remains significant up to ~193 ms (duration= 107 ms ; mean r= -0.633, min r= -0.69, max r = -0.5 , all ps < 0.05, mean p =0.011, min p = 0.003, max p = 0.048). The correlation between rate of deceleration and correct stop performance becomes significant at ~128 ms and remains significant up to ~185 ms (duration= 57 ms ; mean r = 0.542, min r = 0.499, max r = 0.569 , all p's < 0.05, mean p = 0.031, min p = 0.021, max p = 0.049).

We built regression models with different predictors to investigate whether and how much variance of stopping performance can be explained. The model with SPT, STD and no-stop accuracy as predictors could explain 85.6 % of the variance and the model was significant predictor of correct stopping performance [F (3, 12) = 23.827, $p < 0.001$]. Significant contribution in the model was by all three independent variables i.e., SPT (β = 0.344, $p <$ 0.001), STD (β = 1.045, p = 0.003), and no stop accuracy (β = -0.264, p = 0.026). The final estimate was: Correct stop performance = -26.103+ (0.344× SPT) + (1.045× STD) - (0.264 × no stop accuracy). But the model with SSRT and no-stop accuracy as predictors could explain only 47 % of variance of stopping performance. In sum, our metrics explained 38.6 % more variance in stopping performance than SSRT.

Discussion

The pervasive and severe violation of independence assumption of the race model invalidates the estimation of SSRT and its use as proxy of stopping efficacy (Bissett et al., 2019). If SSRT is estimated by removing the data for short SSDs (<200ms) where violation is severe, the fundamental findings does not hold. However, the quantification of stopping efficacy is crucial to study the inhibition of actions in different tasks, condition, healthy and clinical population. We propose alternative metrics to quantify the stopping efficacy i.e. the procrastination of saccade (primary response) and the magnitude of stop triggered deceleration, both derived from a single best exponential fit of noncancelled RT plotted against PPT. The new metrics are valid in data irrespective of whether independence is violated or not and explained more variance in stopping performance than SSRT. Theoretically, the cancellation of an action might be implemented by deceleration of motor planning, not necessarily by an independent race between a preparatory (GO) and an inhibitory (STOP) process.

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Value-of-Information based Arbitration between Model-based and Model-free Control

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There have been numerous attempts in explaining the general learning behaviours using model-based and model-free methods. While the model-based control is flexible yet computationally expensive in planning, the model-free control is quick but inflexible. The model-based control is therefore immune from reward devaluation and contingency degradation. Multiple arbitration schemes have been suggested to achieve the data efficiency and computational efficiency of model-based and model-free control respectively. In this context, we propose a quantitative 'value of information' based arbitration between both the controllers in order to establish a general computational framework for skill learning. The interacting model-based and model-free reinforcement learning processes are arbitrated using an uncertainty-based value of information. We further show that our algorithm performs better than Q-learning as well as Q-learning with experience replay.

1. INTRODUCTION

Skill learning or skill acquisition is learning of a sequence of actions. A skill is learnt or improved when executed multiple number of times. An example of this could be playing a sport like long jump or bicycling. Since this could be seen as learning from a chain of events, it could be understood as a Markov Decision Process (MDP). It is formally defined as a 5-tuple $[S, A, P_a, R_a, \gamma]$ where S is the finite set of possible states of the environment, A is the finite set of actions available, $P_a(s, s')$ is the probability that action a in state s at time t will lead to state s' at time $t+1$, $R_a(s, s')$ is the immediate reward received after transitioning from state s to state s', due to action a and $\gamma \in [0, 1]$ is a discount factor which is used to make an infinite sum finite. In this context, the skill learning problem as a MDP can be solved using reinforcement learning (RL). Thus skill learning can be understood as a reinforcement learning problem where an agent needs to be trained to take a sequence of optimal decisions.

In reinforcement learning, agents are trained by either model-based or model-free methods or a combination of both [1][2]. Similarly, there have been many studies showing the role of two distinct learning processes in sensorimotor skill acquisition [3][4]. In this paper we implement an algorithm that arbitrates between both model-based and model-free methods. The advantage of a model-based method is that it builds or assumes a model of environment dynamics (formally speaking, the agent has an estimate of P_a). Iterative methods like policy iteration or value iteration are used to solve MDPs in a model-based manner. The value-iteration exhaustively iterates through all the state and action spaces using a dynamic programming Bellman update equation to converge at an optimal value [5]. However, we may not know the environment dynamics in every situation and also it is computationally not feasible to iterate through all state-action when number of states increases dramatically (think Atari games). Hence, we use model-free methods where we sample trajectories and update the state-action values in every iteration using a temporal-difference learning equation [6]. Even though model-free methods are computationally inexpensive, they take a lot of time to converge i.e. it requires a substantial number of steps to explore and solve the environment.

Previously there have been many attempts at arbitrating between the two processes in decision making, however, none of them categorically evaluated the role of dual processors in skill learning. For example, [7] represented the 'hybrid' learner's action value with weighted sum of action values of SARSA and FORWARD learner. [8] proposed an arbitration scheme that selects the dominant processor such that it outputs the optimal action with least uncertainty. The approach in [9] presents a 'plan-until-habit' strategy in order to balance the exploitation and exploration. In [10], a value of information based arbitration is proposed in order to flexibly combine use of model-free(Q-learning) and model-based(sequential Monte-Carlo) methods for solving double T-maze environment.

2. METHOD

The basic idea behind our model is that we do a cost-benefit analysis of evaluating each action at a particular state to determine if model-based or model-free controller should be used for planning. Our interaction with the environment is set up in two stages: 'plan' and 'act'. The 'plan' stage is executed only when the agent is uncertain of it's actions given a state. The 'act' stage is a typical off-policy learning technique such as Q-Learning.The model-based method is implemented as a forward search technique using depth-limited search. When the depth is zero it acts like a normal off-policy algorithm and when depth is infinity it acts like a sampled value-iteration algorithm.

Value of Information (VoI) as an cost-benefit measure for planning

In this paper we propose using VoI as a cost-benefit analysis parameter that helps the agent decide whether to execute model-based or model-free method at a given state. Since it is computationally expensive, we would like the agent to execute model-based method only when it is uncertain about taking a particular action. The model-free search is preferred when the agent is certain about the outcome of the particular action in the given state. Such cost-benefit-analysis is done and then the decision is made for every action at a given state. The arbitration is such that if VoI is above a threshold, it performs model-based search because the benefits outweigh the costs involved in executing it. A model-free planning is executed if VoI is below the threshold. The VoI is a directly proportional to variance of a state value given a state. The VoI is given by:

$$VoI(s,a) = C_{(s,a)} / (\sigma(s) + \epsilon)$$

where $C_{(s,a)}$ is the uncertainty which is defined as the variance over the values of Q-values. The variance of the history of Q-values for a particular (s,a) pair gives an estimate of uncertainty because if the trajectory involving that particular state-action pair is explored and estimated with a substantial confidence bound, the uncertainty (or variance) of the history of Q-values will be lesser than what would be the case otherwise if the exploration is not substantial and the estimation is uncertain. The quantity $\sigma(s)$ denotes the variance of the tuple $Q - values[s]$ for a particular state s. The value $(\sigma(s) + \epsilon)$ enables a systematic evaluation of a particular action a in a given state s if there is no clear and distinct candidate action in the tuple $Q - values[s]$, that can be chosen in order to maximize the agent's episodic reward.

In our planning stage we use value-iteration update but only considering those states within depth of two, which acts like a sampled value iteration every time planning is done.

Off-Policy learning for Acting

We have used Q-learning as our model free control algorithm:

$$Q(s,a) = Q(s,a) + \alpha * (r_{s,a} + max_a Q(s',a') - Q(s,a))$$

where $Q(s,a)$ is the state-action value of the current state and the action taken and $Q(s',a')$ is the optimal next state-action value under the current policy.

In a nutshell, before an action is chosen (either by exploration or exploitation using a softmax function) we decide whether to update a state-action value by planning ahead. We hypothesize that model-based method is executed more often during initial episodes and decreases almost constantly with model free method being on the rise as number of episodes increases as shown in Fig. 1. This means that the environment is very uncertain initially and gets more familiar with more training.

Environment

For simulation purposes, we are using Taxi-v2 environment available in OpenAI gym [11]. It is a discrete, deterministic and fully observable environment with 500 states and 6 actions for each state. The episodic goal is to pick-up and drop-off the passenger to the right location while navigating the grid-world. Each time step results in -1 reward, each invalid pick-up or drop-off results in -10 reward and each successful episode gives +20 reward.

Algorithm 1. VoI-based arbitration algorithm

```
Initialize Internal Model
for Iteration i do
    Reset the environment
    s = new state
    j = 0
    while Till reward reached do
        for a in actions do
            VoI(s,a) = C_(s,a) / (σ(s) + ε)
            if VoI(s,a) ≥ VoI_threshold then
                Do model-based evaluation
                Simulate policy execution using depth-limited search
                Use 'simulated reward evidence' to update transition probabilities and Q-table
            else
                Do model-free evaluation
                Retrieve the corresponding (cached) Q-value
            end
        end
        Choose an action using softmax function on Q(s)
        Perform action
        Learn value of actions and states
        Update Q-table
    end
end
```

3. RESULTS

Arbitration between MB and MF controllers

In the beginning, during the first training episode, almost equal number of model-based and model-free evaluations take place. Since the agent is just starting to learn the new environment without no previous experience, it realizes that model-based depth-limited-search will help in exploring the environment efficiently. The agent opts for the expensive but flexible model-based evaluations because not much is known about the environment dynamics. So initially, the VoI associated at each state-action pair will be high, thereby favouring model-based evaluations. We can see in Fig. 1 that in the initial phase of the training, model-based evaluations dominate in comparison to a very few model-free evaluations.

With further training, the agent has enough experience to learn the environment dynamics (the model of transition probabilities). The VoI now starts to decrease owing to the model-based exploration that the agent has already done in the initial phase. The algorithm now favours model-free exploration because it is fast, computationally inexpensive and also there is sufficient knowledge of the environment now. The model-based evaluations continuously decreases whereas the model-free evaluations increases with the training episodes. During the late phase of training, the environment is completely explored and known so doing expensive depth-limited-search would not be worth value agent achieves. Thus, model-based evaluations decrease to zero and remain so thereafter. The later phase of

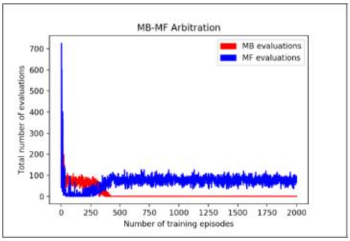

Fig. 1. MB-MF arbitration during the training

the training is dominated by model-free controller because it is relatively inexpensive in spite of the inflexible planning.

Performance Comparison

Each experimentation consisted of averaging the total rewards obtained over 100 iterations of the complete episode of the Taxi environment. We ran 100 such experiments and averaged the rewards in order to measure the agent performance. The corresponding standard deviation was measured and plotted. We further do a side-by-side analysis of Q-learning agent as well as Q-learning with experience replay agent.

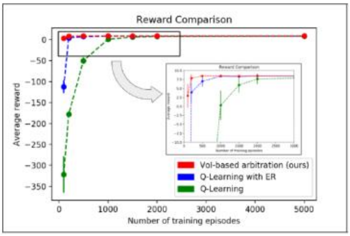

Fig. 2. Average reward received during training

As evident from Fig. 2 (see Appendix for in-image), our VoI-based arbitration algorithm was the fastest to converge and solve the environment. While the naive Q-learning agent performed poorly over 500 training episodes with an average reward of -50.31±8.71, our algorithm received an average reward of 8.49±0.25. This is a significant difference in terms of learning and performance. Even though the Q-learning with ER agent outperformed the naive Q-learning agent with an average reward of 7.00±1.48 over 500 training episodes, it was not able to match the performance of VoI-based arbitration algorithm. Even from a convergence perspective, our algorithm required less than 500 training episodes whereas Q-learning with experience replay requires almost 1000 episodes to learn the environment. The Q-learning algorithm is the slowest to converge requiring almost 2500 episodes to converge.

4. DISCUSSION

In the typical discrete skill learning task, the stimuli-response(S-R) outputs are slow at first due to the cognitive phase of execution where the cognitive processor is dominant. The average response time in the initial training phase is reasonably high. This is mostly attributed to the model-based depth-limited search. The results shown are for max depth set to 2. Increasing the depth will make the agent learn the environment dynamics quickly but it incurs more computational cost. From a cognitive perspective, we can consider this limited-depth search as the limitation of our cognitive resources (more specifically working memory). The model-based steps routinely take more time because they are data-efficient especially when there is not much information available about the environment at the start of the experiment. However, a purely model-based learning will follow the minimal number of steps to reach the goal state provided the optimal actions it takes by calculating the state prediction error. The model-free is quick and inexpensive search and is more suited to the later phase of the training when there is enough experience of the environment. However, in the later phase of the training, the execution speed gradually increases to attain a maximum after substantial practice. This is because the actions are now executing in motor mode which is autonomously controlled by the motor processor. We see a minimal cognitive processor activity in this phase as the motor processor executes a sequential learning task in an open-looped control. The motor processing takes a significantly lesser execution time at each step because it uses experience directly in form of reward prediction error. This is indicative of the fact that the model-free process has taken over from the earlier model-based reinforcement learning process. Therefore, the model-based reinforcement learning can be taken to obtain a typical representation of the early phase practice in sequential skill learning task such as Discrete Sequence Production.

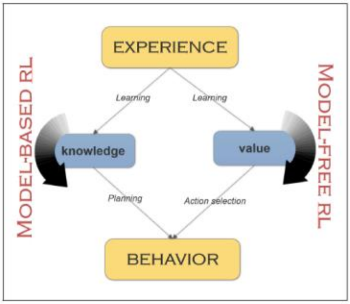

Fig. 3. Model-free and model-based Reinforcement Learning. Ref. Toussiant (2010)

The VoI estimate improves as the learning progresses. Learning the 'world-model' implies learning the transition probabilities table (in terms of MDP formulation). In the initial phase of the training when the model-based learning dominates, our framework is also capable of learning the transition probabilities. However, in case of OpenAI-Taxi environment, since the world-model is deterministic, it really doesn't matter if we are learning transitions as well. Thus, our framework is able to learn transitions alongside Q-values in order to provide a reliable estimate of good-ness of taking a particular action in a given state.

The model-based reinforcement is flexible and immune to any changes in the environment (say, reward devaluation or contingency degradation). It will accordingly try to adapt the action strategies. If we change the reward that the agent is getting on taking a particular action in some state, the q-values will reflect the change and thereby the value of VoI will adjust accordingly to favour model-based learning in order to update the model of the environment.

Our model agrees with the typical behavioural phenomenon in Fitts' three phases of learning [12]. The initial phase is cognitive phase which is dominated by model-based learning processes. The planning during this phase is data-efficient and adaptive with a substantial computing cost. The intermediate associative phase is where we see a change of dominant processor - from model-based to model-free planner. The later motor phase is dominated by model-free processor. The planning during this phase is inexpensive but not flexible. As seen from Fig. 1, the model-based processor is dominant for almost 200-300 training episodes, after which the control is slowly arbitrated to the model-free planner. After about 400 episodes, model-based evaluations reach zero and all the behaviour is guided by model-free processor. The model-based evaluations reaching zero indicate the transition of arbitration mechanism from goal-oriented to habitual. It implies that the agent has already learned the environment and the reward pay-offs for taking a particular action in a given state and therefore, it would be an optimal strategy (in terms of speed-accuracy trade-off) to employ computationally inexpensive model-free reinforcement. Behaviourally, it is analogous to the last phase of the proposed Fitts' theory of skill learning.

Comparing our framework with the others from the literature, we can argue that VoI-based arbitration is a more biologically-plausible framework of dual-processor model. Also, it is capable of validating many testable prediction from previous studies. For example, the Daw task proposed in [7] hypothesized and argued for the existence of two learning strategies involved in guiding our learning behaviour. However, it is not clear what kind of learning strategies are employed during various stages of learning. Our hybrid model is able to predict that the early phase of training is dominated by goal-oriented model-based processes whereas the later phase is dominated by habitual model-free processes.

5. CONCLUSION

In conclusion, our algorithm tries to balance the search efficiency of model-based planning and computational efficiency of model-free planning. The scope of future work can include proofs of convergence in order to establish that the arbitration happens properly. This arbitration is controlled by VoI measure that dynamically changes depending upon the variance of Q-value history and the Q-value difference among different actions available in a particular state. Such a scheme provides a systematic combining model-based and model-free mechanisms in one algorithmic model. Moreover, the results show that the performance of the agent agrees with the typical behavioural phenomenon of skill learning as shown in the literature.

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APPENDIX

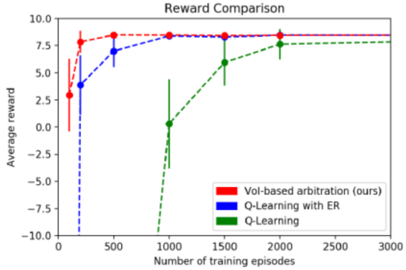

Fig. 4. Average reward received during training

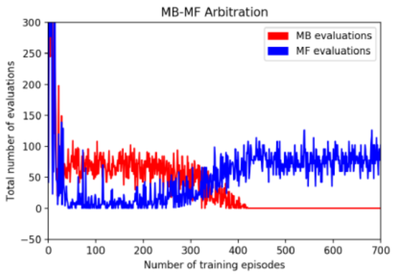

Fig. 5. MB-MF Arbitration

Table 1. List of Parameters

Hyper-parameter	Notation	Value
Learning rate	α	0.8
Discount rate	γ	0.9
Max. depth	d	2
Inverse temperature	ρ	0.9
VoI threshold	$VoI_{threshold}$	0.1
VoI threshold multiplier	VoI_{mult}	1.005
Epsilon	ϵ	0.000001

Task Difficulty Modulates Control Over Suppression of Irrelevant Salient Distractors

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Abstract

Observing the visual world involves scanning through visuospatial maps of objects. Advance processing of these objects demands attention. However, a limited attention resource makes the selection of goal-relevant stimuli a necessary strategy for advanced processing. Selective attention is influenced by purely goal-directed as well as stimulus-driven processes. Newer studies on selection propose a more dynamic selection mechanism affected by statistical regularities, habituation, rewards as well as selection history. Interestingly, all the above-mentioned factors enhance target selection in visual search tasks. Recent studies have also found evidence for a cursory suppressive mechanism aiding in the selection process. While most studies propose that such suppressive mechanism are a result of implicit processes, to what extent cognitive control influences suppression of distractors has not been extensively tested. In experiment 1a, we manipulated attentional control setting in a visual search task such that the need to exert suppression varies across blocks of trials. Participants were instructed to find a circle or a diamond target among heterogeneous distractor shapes and report the orientation of a dot on the target shape. On some of the trials, one of the distractors was a colour singleton. Trials with the singleton distractor and without the singleton distractors were randomly presented in three blocks containing 20 per cent, 50 per cent and 80 per cent singleton distractor present trials respectively. The order of presentation of the blocks was randomized. Results showed that manual reaction times on singleton present trials were significantly faster than on singleton absent trials. Such reaction time benefit is evidence of reactive suppression of the salient distractor. Similarly, proportion of first saccades to the singleton distractor were significantly less than those to other distractors, suggesting and oculomotor deprioritization of salient distractor location. Overall gaze duration showed a similar trend. Surprisingly, blocks of salient distractor present trials did not influence RTs as well as saccades. We hypothesized that control influences suppression salient distractor only in the situation of need, hence an easy task did not require modulation of control settings. To test this hypothesis we performed experiment 1b. It was similar to experiment 1a except that the all distractors resembled target closely such that search was difficult. We expected task difficulty to enhance blockwise differences in suppression. Interestingly, blockwise differences in suppression remained insignificant in spite of enhanced task difficulty. However, overall suppression in RTs and eye movements was enhanced in experiment 1b compared to experiment 1a. We proposed that implicitly learned information like frequency of a certain distractor does not get influenced by top-down control but explicitly enhanced task difficulty does.

Keywords: visual selection; distractor suppression; cognitive control; task difficulty

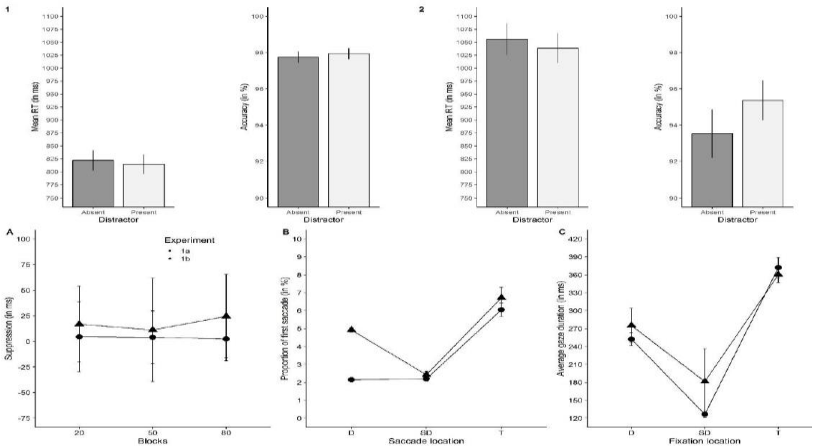

Figure 1: (Top row) Mean of manual reaction time and Mean accuracy on singleton distractor present and absent trials in Experiment 1a and 1b. (Bottom row, A) Difference in manual RTs on salient distractor present and absent trials in experiment 1a and 1b. B)Proportion of first saccade to the target, salient distractor and average non-salient distractor in experiment 1a and 1b. C) Average gaze duration on target, salient distractor and average non-salient distractor in experiment 1a and 1b.

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Building a low-cost eye tracker which can be used for teaching and conducting experiments

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Abstract

Eye movements form an important part of the mechanism for visual perception. The idea of tracking the movement of the eye is not new, as it provides us with important information regarding the gaze patterns along with insights into visual attention among other things. In this article, we provide a detailed method to build a low-cost eye tracker, which uses simple and computationally less costly algorithms implemented in an open source framework, coupled with comparatively cheap hardware to track the eye and estimate the gaze points. We have used a webcam which can detect the infrared light that is used to illuminate the eye, and used the property of the pupil as the darkest point on the eye to detect its position at each frame. The gaze points are then estimated from the pupil coordinates using a linear interpolation technique. Further, codeblocks for PsychoPy are written to combine eye tracker with PsychoPy so that it can estimate the gaze points during the course of an experiment.

Keywords: eye-tracker; video based eye tracking; infrared illumination; PsychoPy; GUVCview; calibration

Introduction

The eye tracker is a device which is most commonly used to measure the movement of the eye, ranging from where we look, for how long to the reaction of the pupil to certain stimuli. The eye tracker works on the principle stated by Donder's law (Tweed and Villis, 1990) which states that the eye assumes the same unique orientation corresponding to a gaze point. This unique orientation for each gaze point is independent of the previous orientation of the eye.

The most commonly used method of eye tracking in recent times is video based eye tracking. In this method, the position of the pupil is determined from the image of either one or both eyes recorded by a camera and subsequently the gaze point is estimated as the viewer looks at some object of interest. Modern video based eye trackers mostly use infrared/ near-infrared light as a source of illumination for the eye, as it enhances the chance of detecting the location of the pupil accurately. The eye trackers comes in many variants, from being head mount, which allows for free movement of the head while tracking the eye, to table-mount or tower-mount eye trackers wherein a chin-rest keeps the head stable so that there is no noise induced by head movement during tracking the eye.

The academic researchers form the oldest group which has been using the eye tracker extensively. Apart from this, the eye tracker also finds its use in media and advertising, human factors research and clinical usage. The eye tracker is used to answer a diverse set of questions in various disciplines such as Cognitive Science, Psychology, Psycholinguistics, User Experience, Human-Computer interface and Marketing. Hence, there comes a need for students to get a hands-on training with this device due to the advent of many academic courses which focuses on the aforementioned disciplines, along with the availability of the product for research. However, the eye trackers that are available commercially are often quite costly, and therefore restricts its widespread availability for teaching and research purposes. Moreover often the eye-tracker is mystified and portrayed as complicated, expensive device, not accessible to everyone.

Many researchers have built their own eye tracking systems (Hansen et al, 2004; Hennessey et al., 2006) which are low cost and provides accuracies in tracking at par with the systems available commercially. However, it is not enough that the eye tracker is limited only to the tracking algorithm. Rather, it should be able to track the eye as and when required and also use the metrics of the tracked eye to perform some other functions. There are very few open systems which specify how to build an eye tracker by modifying any camera and then use it in conjunction with a freely available stimulus presentation software.

This motivated us to build a low cost eye tracker with a high speed webcam, which uses simple algorithms and then combining it with PsychoPy (an open source stimulus presentation software based on python) so that the eye tracker can successfully track the movement of the eye during the course of an experiment. Hence, building such an eye tracker will help researchers and students by providing them with exposure to learn the process of eye tracking hands-on and later use it for their research.

Materials and Methods

The Hardware

Infrared light source: An infrared light source with 16 near-infrared LEDs readily available in the market (arranged in a 4x4 matrix on a general purpose printed circuit board which draws power from the computer through a USB cable) was used for the purpose of illuminating the eye.

Camera: To capture the image of the eye we have used a PS eye (trademarked PLAYSTATION eye) camera which is similar to a webcam. It has the capacity to capture standard video at a resolution of 640x480 pixels at a frame rate of 60 fps and 320x240 at a frame rate of 120fps. This camera comes with an infrared filter which blocks IR light from entering it, therefore we had removed the IR filter and attach a lens arrangement in front of the camera such that a clear image of the eye is captured from a distance. Though we used this particular camera, any webcam that will cater to your experiments sampling requirement will do. A simple Keplerian telescope was built using off the shelf lenses and attached to the camera so that the camera can be placed at a distance from the eye without obstructing the view for the subject.

The chin-rest: The chin-rest is used to keep the head still while tracking the eye, so that there is no additional noise induced by the head movements. It consists of two vertical rods attached to the table for support along with two horizontal planks - one for resting the chin and the other for resting the forehead. This structure when kept at a distance from the screen reduced head movement considerably as well as maintains a constant distance of the eyes from the screen.

A schematic of the complete setup is shown in Figure 1.

The Software

Acquiring the image of the eye: To obtain the image of the eye and track the pupil position, we modified the code of the open source webcam software for linux, called GUVCview (the modified version henceforth called E-GUVCview). The application for the software is written in C programming language and the source code is available for download freely in SourceForge (https://sourceforge.net/projects/guvcview/files/).

Detecting the center of the pupil: After the image of the eye is acquired, it is required to detect the location of the center of the pupil at each frame of the video. The property of the pupil that it is the darkest part of the eye under IR-illumination, is used to detect the center of the pupil. However, before detecting the pupil, it is required to detect those frames which has eye blink and discard them. The absence of glint or corneal reflection when the eye is closed is used as a property to detect blink. After this, the center of the pupil is detected by taking 1D filter of 20 pixels (since the number of pixels which the pupil covers in the camera is approximately 20x20) in the horizontal direction and then repeating the filtering in the vertical direction over the horizontally filtered image. This smoothened image will give us the means of 20X20 pixels taken horizontally and vertically at each point. The pupil being the darkest point on the eye will have the lowest pixel values at those points. Therefore, the position of the minimum value of the smoothened image will give us the position of the center of the pupil. When this is done for each frame in the video containing the eye, we get the online tracking of the center of the pupil. We then store the positions of the coordinates of the center of the pupil in a file online i.e., simultaneously while the video is being captured without having to record the video. The file consists of the date and timestamp of each of frames along with x and y coordinates of the center of the pupil.

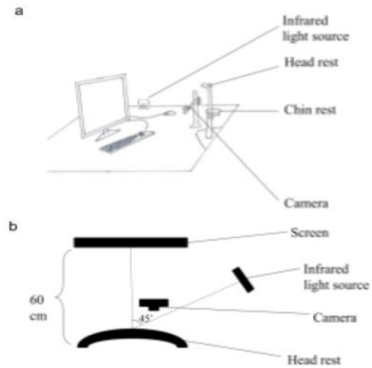

Figure 1: Schematic showing the complete setup. (a). Detailed setup of the hardware. (b). Schematic showing details of the position of each component of the eye tracker.

Calibration: After successfully tracking the pupil of the eye, the next step is to estimate or map the gaze points on the screen based on the position of the pupil. This is done through the process of calibration. The calibration process starts with presenting a set of predefined points on the screen simultaneously and the participants are asked to look at them. The corresponding pupil position is recorded in the camera coordinates. After obtaining these points a gaze estimation algorithm is employed, in our case it is a simple linear interpolation algorithm to estimate the gaze, given any point on the pupil coordinate. The linear interpolation is done separately on x and y axis. Equation 1 shows the form of the linear interpolation used (Ramanauskas, 2006).

$$\widehat{S_x} = S_{x1} + \frac{x-x_1}{x_2-x_1}(S_{x2} - S_{x1}) \text{ --------------- Eq.1a.}$$

$$\widehat{S_y} = S_{y1} + \frac{y-y_1}{y_2-y_1}(S_{y2} - S_{y1}) \text{ --------------- Eq.1b.}$$

Where, (S_{x1}, S_{y1}) and (S_{x2}, S_{y2}) are the screen coordinate of point 1 and point 2 respectively, for each pair, whereas, (x1, y1) and (x2, y2) are the corresponding pupil coordinates of point 1 and point 2. The coordinates of the pupil for which the gaze points are required to be estimated is given as (x,y). The coordinates of the estimated gaze point on the screen is denoted by $(\hat{S_x}, \hat{S_y})$.

Using the eye tracker with PsychoPy: We present the dots for calibration in a randomized manner in PsychoPy, while storing the timestamp of the beginning and end of each of the dots saved in a file. This is done alongside E-GUVCview which is recording the eye positions of each frame along with the timestamps in a file. We now compare the timestamps of the files generated from E-GUVCview and PsychoPy so as to track the position of the eye at each dot during the process of calibration. We then have the coordinates of the pupil center for each of the points presented in PsychoPy. We then carry out the gaze estimation using these coordinates in PsychoPy itself. Next, we validate our estimation by presenting another set of dots and estimating the gaze on the screen. After which we calculate the accuracy of the system.

Results

We calculate the average accuracy with which the eye tracker performs and then look at some tracked images.

Accuracy

We calculate the accuracy of the eye tracker separately in the x and y- coordinate since the x and y coordinate use 2 different coordinate system as the height of the screen is not equal to the width of the screen. The average accuracy (3 trials) of the eye tracker is: x-axis = 1.046277° and y-axis = 2.4156°. The value of accuracy differs from calibration to calibration and the range of accuracy provided by other systems is 0.3 to 2°. The accuracy in the x-axis is always below 2°, however, the accuracy in the y-axis is slightly higher since our chin-rest is not very rigid and it contributes to a considerable amount of head swing in the forward and backward direction that translated into the greater error in the y-axis. Many systems use corneal reflection to correct for smaller head movements, however, in our case it added to the noise of tracking. One possible reason for this could be that the camera is placed at 10 cm distance, which is considerably near to the eye. In a future version we will try nonlinear mapping to see if the glint can give head movement correction.

Precision

Precision measures the ability of the eye tracker to reliably reproduce a measurement at each fixation point. We measure the precision using the Root Mean Square (RMS) of successive samples for a particular fixation. The average precision (20 fixation points) for the x-axis is 0.049° and that of the y-axis is 0.17°. We see here that the precision for the y-axis is higher. This is due to the unstable chin-rest which contributes to the greater error in y-axis.

Temporal Resolution

The temporal resolution of the eye tracker essentially depends on the frame-rate of the camera being used, which is 60 fps for all our present calculations. Although in the current setup, a single system is used for stimulus presentation and processing of eye image, it has been found that there is no significant drop in the frame rates of the camera during image acquisition at 60Hz. However, it would be beneficial to use two separate system for stimulus presentation and for eye image processing, in case the camera used provides a higher frame-rate, to avoid any slowdown of the system.

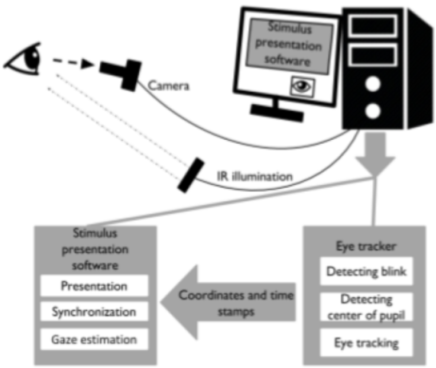

Figure 2: Overview of the eye tracking system

Conducting experiments using eye-tracker

We performed proxy experiments by presenting a set of stimuli using PsychoPy and detecting the gaze using the eye tracker. The first stimulus was a comic which has both text and pictures in it. Figure 3 (a) depicts the gaze coordinates as estimated by the eye tracker. We can notice a shift in the detected gaze from the actual gaze. This is due to the non-rigid chin-rest that we are using. And in such a scenario, our eye tracker is in the middle of completely head restrictive and completely head free state. In some of the head free eye trackers, there is use of shift compensation methods to eliminate the noise induced by the head movement (Sanches et al., 2016). Figure 3 (b) shows the heat map of the gaze coordinate after it is manually shift compensated.

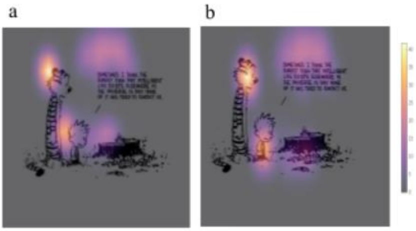

Figure 3: Heat map showing density of gaze points as estimated by the eye tracker (a). The shift in gaze detection due to the presence of head movement is quite prominent in this picture. (b). Heat map showing density of gaze points after shift compensation.

The next stimulus that was presented was that of a paragraph. This stimulus provides us with insights as to how well the eye tracker performs in reading studies. Figure 4 shows the shift compensated heat maps of the gaze points while reading the paragraph.

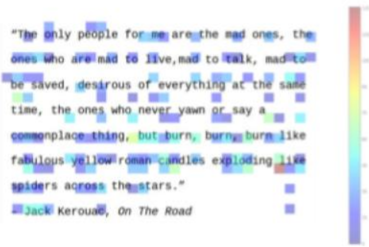

Figure 4: Heat map showing density of gaze points as estimated by the eye tracker while reading a paragraph

Discussion

In this article we have provided a detailed description of how to build a low-cost eye tracker, which uses simple and computationally less costly algorithms along with the use of comparatively cheap hardware in order to track the pupil and estimate the gaze points. However, like most systems this eye tracker is also not devoid of limitations and there is scope for improvement in a number of aspects. For instance, the blink detection algorithm though is simple and computationally less costly, will not be able to detect reliably the blink for people with glasses. Another limitation is the chin-rest in our current system is not very rigid and hence accounts for noise in eye tracking due to head movement especially in the y-axis. Hence, we require a more rigid chin-rest so as to reduce the noise in eye tracking. We can also modify the eye tracker so that it can track the area of the pupil, which might provide us with important metrics for cognitive load. Another modification we can make is to increase the magnification of the optical system by fitting a better lens system so that the pupil occupies more number of pixels in the camera (20x20 pixels at present), which would contribute to higher resolution in gaze tracking, as it would facilitate the detection of smaller eye movements. However it has to be emphasized that it is clear from our data that this eye-tracker is sufficient for experiments requiring ROI accuracy that is a few partitions of the visual field.

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Simple and complex cells of the visual system of an insect

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Abstract

Optic lobe of insect is thought to include processing analogous to the retina, LGN and the Visual cortex (V1) in its various layers, lamina, medulla and the lobula. The anatomy and the cell types are well understood in certain insect systems like *Drosophila* and *Calliphora.* Also some types of neurons are well characterized in these systems.

We use in vivo electrophysiology and immunohistochemistry to functionally characterize neurons from the optic lobe of grasshopper *Hierogliphus banian.* We record from the neurons in the optic lobe while presenting a variety of stimuli including, grating, looming and white noise stimuli and inject dyes in the cells we record from to characterize their morphology. We use clustering of the responses and couple this with the confocal imaging to test if the cells are identifiable from a response vectors alone. Linear nonlinear models are fitted using the response to white noise to identify receptive field properties of the different spectral components. This model is used to predict the responses to the other set of stimuli and thus test if these can be characterized as simple or complex cells.

Keywords: Optic lobe, *Hieroglyphusbanian*, Lobula complex, Linear-nonlinear model, Insect vision

Introduction

Vision plays an important role in insect behaviours, such as flight, prey detection and collision avoidance. Optic lobe of the insects have modules and layers that may correspond to the retina, LGN and the visual cortex of vertebrates (Millard SS, Pecot MY.2018, Sanes, Joshua R. et al.2010). Large interneurons that respond to visual features relevant to these behaviours have been found in the lobula complex (LOX) of the optic lobe of the insect brain. In *Schistocercaamericana* and in *Schistocercagregaria* it was shown that LGMD/DCMD neuronal path way is responsible for collision avoidance and escape behaviours. Lobula plate tangential cells (LPTCs) in flies responded to wide field optic flow generated by self-motion and they are likely involved with visual course control during flight. Another class of lobula neurons respond to small target movement detectors (STMDs) which respond to small moving targets. Even though many neurons in the layers of the optic lobe and their properties have been characterized, the circuit details and the response properties are not clear enough to be predictable from morphology or vice-versa. Our aim is to characterize the neuronal circuit in the medulla and lobula in aspects a) If the cell types are predictable from response to a panel of stimuli b) If the cells can be classified as simple or complex, in the sense of (Carandini M. 2006).. For studying the response properties and morphology. We will record the responses to a panel of visual stimuli from a large number of neurons, image their morphology. To test ff the cell types are predictable from response to a panel of stimuli we will use a classifier on the response pattern to the panel of stimuli. To test of the cell can be a simple cell we will build linear non-linear model for these neurons based on response to white noise stimuli and test response of the model to the stimulus set. If the LN model cannot predict the response it is classified as a complex cell.

Materials and methods

Display

Custom was built using Arduino and 8x8 LED matrix and programmed to apply the visual stimulus set. Angle subtended at the eye for a pixel was 0.0714°It had a refresh rate of 596Hz as measured using a high-speed camera at 4000Hz. The display illuminates in the bandwidth 540-610nm. In all the recordings the matrix was oriented and placed at the same distance relative to the eye. A photodiode was used to obtain the illumination from the display and recorded along with the signals from the brain to keep track of the stimulus times. The display system was triggered from the pclamp at particular times in the recordings so that stimulus triggered data processing can be carried out.

Electrophysiology

Lab grown adult male & female *Hieroglyphus banian*were used. The animal was immobilised and a wax cup built around the head to hold the saline. The cuticle and underlying fat bodies and air sacs were removed to expose the brain. The brain was held up by a small wire platform for stability and the sheath removed using protease. Saline was perfused continuously while recording. The glass electrodes were pulled to have an impedance of ~100M impedance and used to record from neurons using Axoclamp 900A amplifier. The signals were digitized using digidata 1440 and experiment was controlled using pClamp and analysed using custom codes in Matlab.

Imaging

Capillaries were backfilled with Alexa 633 salt or Neurobiotin. If recording was successful the dyes were injected into the neurons using current pulses of 4nA or greater at 2Hz for 10mns. After the experiment the brain was extracted and fixed in 4% PFA overnight. They were then washed in PBS incubated in avidin conjugated with alexa dyes for five days in the cases were neurobiotin was injected. Then they were washed in PBS, dehydrated using ethanol series, mounted in methyl salicylate and imaged in Zeiss LSM 710 confocal microscope at appropriate wavelengths.

Analysis

The data was processed to extract the spike timings and the stimulus timings. Peristimulus histogram (PSTH) (10msec bins) for each stimulus type was obtained by averaging the PSTH across trials of the identical stimuli. PSTH vectors for each stimulus type was concatenated to obtain the characteristic response vector (CRV) of the particular neuron. The set of CRVs of the different neurons were then clustered using k-means clustering, (6 clusters) to obtain the neurons types based on the responses. These neurons are then compared for their morphological similarities to test if the neurons in the optic lobe can be identified using the CRVs.

For white noise analysis and prediction the spike timings obtained during the white noise stimulus was used to calculate the spike triggered average (STA) of the stimulus for a lag of 300msec. For the stimulus, a video stream corresponding to the white noise to be displayed was generated in Matlab. The STA is a 300msec video showing white sequence. For linear prediction this STA was used as impulse response function and white noise as input. The non-liearity was estimated by plotting the actual firing rate from the PSTH for the white noise against the linearly predicted firing rate. Then the STA and the nonlinearity were used in the linear-nonlinear model framework to predict the PSTH for the other stimuli.

Results

Cells can be clustered based on their response to the stimulus set

We have successfully recorded from >300 neurons and out of it 9 cells were filled with either neurobiotin or 633 hydrazide salt. Out of which we have got five medullary inter neurons, two of them are bilateral neurons and four LOX inter neurons.

Here I'm presenting 17 cells data for which we have presented loom in of dark, loom out of dark, drifting pattern from left to right & right to left, flash off, quadrates, white noise, and flash on stimuli respectively for a minimum of 5 trials. Clustering them using Euclidian distance as a measure showed that in this set there are mainly two clusters i.e. showing similar kind of response (Figure 1c). The morphologies of the cell types are also different as can be seen.

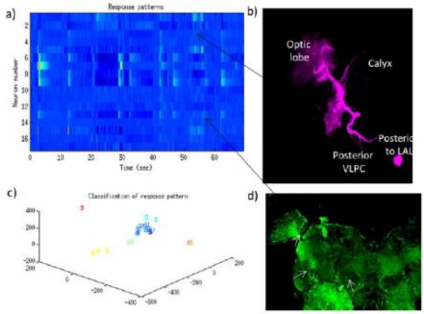

Figure 1: a) Response patterns of 17 cells for 7 stimuli (loom in of dark, loom out of dark, drifting pattern from left to right & right to left, flash off, quadrates, white noise, and flash on). Each row represents the concatenated responses for each stimuli b&d) Morphology of the two neurons whose response vectors are indicated in (a). c) Clustering of the response vector of 17 cells in a using Euclidian distance as a measurement. Cells cluster together indicating similar response vectors for the panel of stimuli. Yellow colour (6,8,9) are clustered together i.e., their response patterns are very similar, which indicates either they are same or same type of cells.

Linear nonlinear model can fit the white noise responses

Spike triggered average was used to estimate the linear component video of the linear-nonlinear system. We can see in Figure 2 an example of the STA for a neuron. Notice that this neuron responds maximally when the stimulus increases in brightness gradually and then become dark abruptly. There is a lag of ~40msec to the response. The cell is wide field because the STA in most of the pixel locations are similar. Using this linear nonlinear model predicts the responses to white noise well. This may look trivial but it is not guaranteed that STA would yield a linear nonlinear model that fits the data. However the same model failed to predict the responses to a looming stimulus. This would indicate that this is not a simple cell.

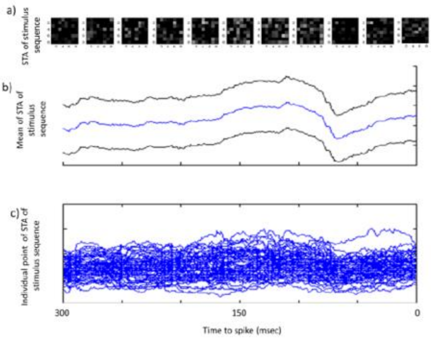

Figure 2: Spike triggered averaging of the white noise stimulus. a) Sample frames (8x8) from the STA video. Rows and columns ranging from 1 to 8 in each frame.

b) Mean and standard deviation pixel values of the white noise. c) Values of the individual pixels over time for the STA.

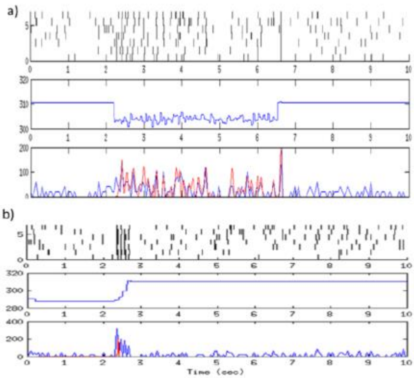

Figure 3: Prediction using the STA works well for the white noise but not for the looming stimulus. a) Rasters, photodiode reading and the PSTH (blue) for this neuron for white noise stimulus. In red is the prediction from the linear nonlinear model. b) Rasters, photodiode reading and the PSTH (blue) for this neuron for looming in stimulus. In red is the prediction from the linear nonlinear model showing that it fails to predict the responses.

Conclusion

We show evidence to support that notion that response pattern to a set of visual stimuli may be used to cluster and identify neuron types. White noise analysis may be used to identify simple and complex cell types in the insect visual system.

Acknowledgement

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Traditional Artificial Category Learning: Improved Learning of Partially Diagnostic Features Lead to Less Preference for Unidimensional Rule

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Abstract

In traditional artificial category learning (TACL), participants first learn to correctly categorize the training stimuli. All stimuli are presented one by one. After successful learning of the training stimuli, participants categorize the transfer stimuli. Studies have shown that participants prefer a perfectly diagnostic unidimensional rule for category generalization. Also, the perfectly diagnostic feature is learned better compared to the partially diagnostic features. It is not known whether poor learning of the partially diagnostic features influences the preference for unidimensional rule in TACL. In this study, we make participants memorize the partially diagnostic features through repeated testing. Different number of features are memorized in different experimental conditions. The results show that when participants learn the partially diagnostic features with greater accuracy, there is a corresponding decrease in unidimensional rule-based generalization. Our results show that in TACL only the perfectly diagnostic feature is learned with a high accuracy, and not the partially diagnostic features. This could be the reason for the preference of unidimensional rule-based categorization in TACL. Our results suggest that the nature of the experimental procedure must also be taken into account while predicting human categorization behaviour in artificial category learning.

Keywords: category learning, classification, rule-based categorization, learning partially diagnostic features

Introduction

Category learning is a field of research where we study the representations humans use for learning categories. Most studies support the theory that a concept is represented using the overall similarities (family resemblances) shared by the category members (Rosch & Mervis, 1975; Minda & Smith, 2001; Xu & Tenenbaum, 2007). But, studies done using artificial categories often report a preference for a unidimensional rule-based categorization (Ashby et al., 2002; Minda & Miles, 2009; Conaway & Kurtz, 2014; Rabi et al., 2015). The experimental procedure used in these studies have been called the traditional artificial category learning paradigm (TACL) (Kurtz, 2015).

In TACL, there is a training phase where participants categorize training stimuli into, usually, two categories. Stimuli are presented one by one, and participants are given feedback as to whether their categorization response is correct. When participants achieve high accuracy with the training stimuli, they can proceed to the transfer phase. In the transfer phase, participants are presented stimuli that they have not seen before. These transfer stimuli are presented one by one and participants must categorize the stimuli into one of the two categories. Sometimes at the end of TACL there is a surprise all features test phase (Rabi et al., 2015), where participants have to identify the category in which each feature occurs more commonly. Figure 1 shows the flowchart for the experimental procedure in TACL.

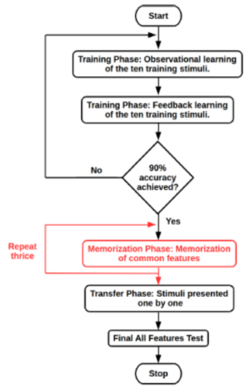

Figure 1: The flowchart shows the difference between TACL and the experimental conditions in Experiment 1. The boxes shown in black constitute the TACL. The experimental conditions in Experiment 1 have an additional Memorization phase (shown in red).

Almost all studies that follow the TACL paradigm report a preference for unidimensional rule-based categorization strategy (Minda & Miles, 2009; Conaway & Kurtz, 2014; Rabi et al., 2015). Also, the studies following the TACL paradigm report that the perfectly diagnostic (defining) feature is learned better compared to the partially diagnostic features (Rabi et al., 2015; Levering & Kurtz, 2015). It is not known whether the preference for unidimensional rule affects the learning of the partially diagnostic features in TACL, and vice versa. Rabi et al. (2015) report that there were four participants who preferred a similarity-based categorization strategy, and these four participants also performed the best when tested on their knowledge of the partially diagnostic features (Rabi et al., 2015, p. 164).

In TACL, the category level information must be recalled from memory. Studies in learning science show that repeated retrieval from memory (testing) leads to better long term retention, but not repeated encoding (studying) of information (Karpicke & Roediger, 2008). In the current study, we evaluated changes in category level knowledge of partially diagnostic features through repeated testing of information.

In this study, we have experimental conditions in which we repeatedly test features that occur more commonly in the two categories. In each condition, a different number of features are repeatedly tested. Each experimental condition is just like TACL, except for the addition of the memorization phase. We expect repeated testing to lead to better learning of the partially diagnostic features. If poor learning of the partially diagnostic features causes a preference for a unidimensional rule, then as learning is improved there should be a corresponding decrease in rule-based categorization across the experimental conditions. An experiment was performed to understand whether preference for rule-based categorization is influenced by the poor learning of partially diagnostic features in TACL.

Karpicke & Roediger (2008) show that it is repeated testing that leads to better retention, and not repeated encoding. So, we modified the experimental procedure in TACL by including a memorization phase as shown in Figure 1. In the memorization phase, participants are repeatedly tested about their knowledge about the features that occur more commonly in categories A and B. This experiment has five conditions: M0, M1, M3, M4 and M5. These conditions differ in the number of features that participants are made to learn through repeated testing.

In M0 condition, participants memorize task irrelevant features. In M1 condition, participants memorize only the perfectly diagnostic (defining) feature, and so on. In M5 condition, participants memorize all five features, that occur commonly in each of the two categories.

In conditions M0 and M1, we did not expect participants to learn the common partially diagnostic features for each category. The results for conditions M0 and M1 should not be different from the results in Rabi et al. (2015). In condition M5, we expected participants to learn the common partially diagnostic features for the two categories. If the preference for rule-based categorization is due to poor learning of the partially diagnostic features, then we should expect a significant decrease in rule-based categorization for condition M5 compared to condition M0.

Method

Subjects

Fifty volunteers (25 females, mean age = 20.2 years) participated in this experiment. The experiment used a between-subject design, where participants were randomly assigned to one of the five conditions — M0, M1, M3, M4 and M5. The five conditions had ten participants each. The effect size was expected to be (Cohen's) d=1.4 based on our previous study. We performed power analysis (Bausell & Li, 2002), which indicated that 9.1 subjects per experimental condition would yield an 80% chance (power=0.80) of detecting an effect size of d=1.4 between condition M0 and condition M5 using an independent samples t-test (two-tailed alpha=.05).

Materials

We used fish-like stimuli as shown in Figure 2. The stimuli have five feature dimensions —the body pattern, shape of the lower-fin, shape of the tail, shape of the upper-fin and shape of the mouth. Each feature along the five stimuli dimensions either occurs more frequently in category A or in category B. For example, the small tail occurs more frequently in category A compared to category B. One stimulus dimension (upper fin) was perfectly diagnostic of category membership and the remaining four dimensions were partially diagnostic.

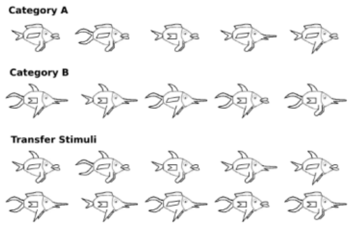

Figure 2: Sample categories used in the experiment. One feature was perfectly diagnostic of category membership, and the remaining four features were partially diagnostic.

The first two rows of Figure 2 show the training stimuli. In Figure 2, a flat upper-fin is the perfectly diagnostic feature that occurs in every member of category A. This feature can be used to correctly categorize all the training stimuli; hence, can be called the defining feature.

The transfer stimuli were created from the training stimuli by flipping the defining feature. For example, the transfer stimuli in the third row of Figure 2 differs from the training stimuli in the first row (category A) only along the defining dimension (shape of upper-fin). Thus, each transfer stimulus has the defining feature of one category, but is more similar to the members of the opposite category. How participants categorize the transfer stimuli would help us determine the categorization strategy that is preferred. If participants use a perfectly diagnostic unidimensional rule, then transfer stimuli in row four should belong to category A. If participants use a similarity-based strategy, then transfer stimuli in row four should belong to category B.

Procedure

Participants were tested in a silent room on a laptop with a 15 inch screen. All the instructions were presented on the screen. The instructions were the same across the five conditions.

In the training phase (see Figure 1), participants were required to learn how to correctly categorize the training stimuli. In the observation learning sub-phase, participants were shown stimuli one by one with its correct label. Participants had to press the same key as the category label (i.e. A or B) to proceed to the next screen. In the feedback learning sub-phase participants were again shown stimuli one by one, but without any label. Participants were asked to categorize the stimuli into categories A or B. Feedback was given as to whether their categorization response was correct. Each stimulus was shown until participants pressed a response key.

After the training phase participants could proceed to the memorization phase. To proceed to the memorization phase, participants had to achieve an accuracy of 90% on the training stimuli. A partially diagnostic unidimensional rule can achieve only 80% accuracy. In order to achieve 90% accuracy participants had to either use the perfectly diagnostic unidimensional rule, or a similarity-based strategy that is based on multiple (at least three) partially diagnostic features.

In the memorization phase, participants were asked to memorize the features presented on the screen. In the transfer phase, participants were asked to categorize the transfer stimuli without providing them any feedback. Stimuli were presented one by one. Each stimulus was presented until participants pressed a response key. In the all features test phase, participants were asked to identify the category in which a given feature occurs more frequently.

Condition M5. In the memorization phase of condition M5, participants were shown all the five common features of each category. Then participants were asked to recall the common features of category A. If participants could not recall the features, then they could go to the previous screen and study the common features again. After this, participants were tested about their knowledge of the common features of category A. Participants were shown all the features, and they were asked to select the common features of category A. No feedback was given.

The process was repeated for category B. Each memorization phase block consisted of learning the common features of both categories A and B. The memorization phase block was repeated three times. After the memorization phase participants proceeded to the transfer phase. After the transfer phase there was a final all features test phase. Participants were not told about the final all features test phase before the start of the experiment.

Condition M4. Condition M4 was just like condition M5, except that participants learned about only four common features in each category. These included the defining feature and three partially diagnostic features.

Condition M3. In condition M3, participants learned about only three common features of each category. These again included the defining feature and two partially diagnostic features.

Condition M1. In condition M1, participants learned only the defining feature of each category.

Condition M0. In condition M0, participants were made to memorize features that were not task relevant. These features looked like parts of robot like stimuli. This condition was included to control for the effect of adding the additional memorization phase to the TACL procedure. Since the memorization phase of M0 is task irrelevant, the results for condition M0 should be same as those observed for other TACL studies.

As mentioned earlier, the different memorization conditions differed only in the number of features that participants had to memorize. No feedback was given to the participants during the memorization phase.

Results and Discussion

The results in this section help us identify whether better learning of partially diagnostic features lead to less preference for unidimensional rules. The accuracy for the defining feature in the final all features test was more than 92% for all the five conditions. The result of one-way between-subjects ANOVA shows that there was no significant effect of memorization on the accuracy of the defining feature for the five experimental conditions, $F(4,45) = 1.40, p = 0.25, \eta^2 = 0.11$.

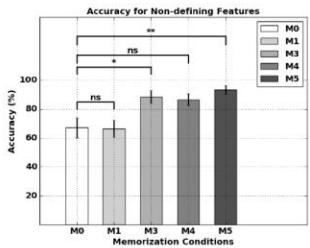

Figure 3: Accuracies for the partially diagnostic features in the final all features test. The significance levels were computed using Tukey HSD test and independent-samples t-test.

We expected participants to learn the partially diagnostic features better when their knowledge is repeatedly tested. Figure 3 shows the accuracy for the partially diagnostic features in the final all features test. The result of one-way between-subjects ANOVA shows that there was a significant effect of memorization on the accuracy of the partially diagnostic features across the five experimental conditions, $F(4,45) = 6.26, p = .001, \eta^2 = .36$.

Post hoc comparisons using the Tukey HSD test (at $p <$ .05) indicates that the accuracy for the partially diagnostic features for condition M0 was significantly different from condition M3 and condition M5. Independent-samples t-test shows a significant difference in the partially diagnostic feature accuracy for condition M0 ($M = 67.19\%, SD = 20.69$) and condition M5 ($M = 93.44\%, SD = 9.0$); $t(18) = 3.49, p = .002, d = 1.56$. Overall, the results show that the category level knowledge about the partially diagnostic features improved when more features were learned through repeated testing.

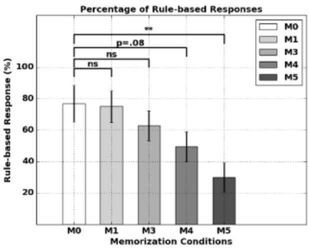

Figure 4: Percentage of rule-based categorization in the transfer phase. The significance levels were computed using Tukey HSD test and independent-samples t-test.

As mentioned earlier, transfer stimuli were created by flipping the defining feature for each training stimulus (see Materials section). So each transfer stimulus was more similar to members of one category, but had the defining feature of the opposite category. Hence, categorization response for each transfer stimulus will tell us whether participants were using a unidimensional rule-based categorization. Figure 4 shows the percentage of rule-based categorization in the transfer phase of the Experiment 1 conditions. The result of one-way between-subjects ANOVA shows that there was a significant effect of memorization on the percentage of rule-based categorization of the transfer stimuli across the five experimental conditions, $F(4,45) = 3.76, p = .01, \eta^2 = 0.25$.

Post hoc comparisons using the Tukey HSD test (at $p < .05$) indicates that the percentage of rule-based categorization in the transfer phase (Figure 4) for condition M5 differed significantly from condition M0. Independent-samples t-test shows a significant difference in the percentage of rule-based responses for condition M0 ($M = 76.75\%, SD = 34.44$) and condition M5 ($M = 30.0\%, SD = 28.02$); $t(18) = 3.16, p = .005, d = 1.41$. The above results show that the preference for unidimensional rule-based categorization decreased as more partially diagnostic features were learned with high accuracy.

As participants acquired a better category level knowledge about the partially diagnostic features, the percentage of rule-based categorization dropped significantly. This indicates that the preference for rule-based categorization in TACL is due to poor learning of the partially diagnostic features.

Conclusion

In traditional artificial category learning (TACL), perfectly diagnostic feature is learned significantly better compared to partially diagnostic features. Also, participants prefer a perfectly diagnostic unidimensional rule. The relation (if any) between the preference for unidimensional rule and poor learning of partially diagnostic features was not known. Our results show that when partially diagnostic features are learned better (through repeated testing), there is a corresponding decrease in the preference for unidimensional rule-based categorization. Our results show that the nature of the experimental procedure determines which category-level information is learned with a high level of confidence. This in turn determines whether participants opt for a rule-based or a similarity-based categorization strategy. Our results imply that the nature of the experimental procedure must also be taken into account while predicting human artificial category learning behaviour.

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Section III
Poster Presentations

Pupillary constriction indexes latency of impending saccade

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Preparation of saccadic eye movement and cognitive loads, for example, effortful decision-making, influence pupillary constriction and dilation mediated by change in luminosity. However, so far no study has reported any relationship between pupil size and saccadic reaction time. We recruited healthy young participants to perform an alternative-forced-choice oculomotor task. Our study shows that the saccade-latency has robust relationship with the (1) onset of pre-saccadic pupillary constriction, (2) rate of constriction, and (3) average non-oscillatory component of constriction. These findings strongly suggest that the oculomotor network has more direct influence on pupillary light reflex than it was previously thought.

Encoding Temporal Relations using Complex-Valued Synapses

Srinivasa Chakravarthy, Bhadra S Kumar, Sundari Elango and Nagavarshini Mayakkannan
IIT Madras

In this work, we show that by representing the neural activity and synaptic activity in the complex domain, it is possible to encode temporal relations among the neural oscillations. The complex representation is also able to bring out learning property like Spike-Timing Dependent Plasticity (STDP) observed in a network of neurons.

Cognitive control as a target of treatment in common mental disorders

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Common mental disorders (CMDs) are associated with neurocognitive and functional impairments which may persist despite symptom remission. There is a critical need for interventions to enhance neurocognition and everyday functioning in psychiatric disorders in order to reduce associated disability. Cognitive control may underlie neurocognitive and functional impairments across CMDs, and may be particularly amenable to achieving transfer of training effects to untrained domains. A case illustration is presented of a 12-week cognitive training program focussed on cognitive control in an individual with obsessive-compulsive disorder. Improvements were observed on neurocognitive, clinical and functional measures, suggesting that cognitive control may represent a suitable choice for intervention to enhance overall functioning.

Role of Posterior Parietal Cortex in motor adaptation to a gradually imposed perturbation

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Motor adaptation may be defined as the adjustment of motor output in response to externally imposed perturbations. Previous studies have demonstrated that the cerebellum and the posterior parietal cortex (PPC) are essential for motor adaptation, but this has been established only in cases where the perturbation is introduced abruptly. It remains unclear whether these areas are also critical for adaptation to perturbations that are introduced gradually. In this study, we examined the role of the PPC in adaptation and generalization to a gradually imposed perturbation using visuomotor rotation adaptation(VM) paradigm. Based on our past work, we hypothesized that HD-tDCS over left but not right PPC would produce adaptation and generalization deficits to a gradually imposed VM perturbation. Young, healthy, right-handed participants performed reaching movements to a gradually induced VM perturbation while receiving either sham or real stimulation to PPC. Our results indicated that all participants adapted to the perturbation, and there were no significant deficits in adaptation or generalization because of the PPC disruption over the left or the right hemisphere. This lack of disruption in adaptation and generalization with PPC stimulation suggests that the neural substrates that mediate adaptation to the gradual perturbation lie outside the PPC.

Emotion Facilitates Appearance and Perceptual Contrast

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Previous literature reveals the modulatory role of emotion on cognitive processes like attention, memory and decision making. Further, early cognitive processes like orientation discrimination and luminance sensitivity are shown to be influenced by cognitive functions like attention. The present study aimed to delineate a combinatory question; whether emotion would influence early visual and perceptual processes, namely contrast sensitivity. We adopted a modified paradigm in order to observe the effects of affective manipulation on contrast judgements. We integrated a behavioural approach with an eye tracking methodology for a holistic analysis of the modulatory role of emotion on early visual processes. Behavioural results revealed that emotional faces do effectively alter perceived contrast appearance as compared to neutral faces. Secondly, we investigated the role of emotional valence at three levels (happy, angry, neutral) on contrast perception and found significant effects of valence. Thus, the present study demonstrates that emotion affects early visual processes in a manner comparable to cognitive functions like attention. It also provides direct evidence for the influence of emotional stimuli on contrast judgements in an analogous manner to that of attentional Gabor stimuli. Future investigation includes discerning underlying neural mechanisms, neurophysiological scrutiny alongwith a more integrative behavioural approach.

Does Congruent/Incongruent Task-Irrelevant Magnitude Information Affect Temporal Processing in Sub- and Supra-Second Duration?

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A Theory of Magnitude (ATOM) suggests that space, time and quantities are processed in the brain through a common magnitude system. One of the ATOM's predictions is that these magnitudes are converted into a common currency and then processed in the brain/mind and hence interferes with each other. Previous studies have substantiated ATOM's predictions while presenting information of two magnitudes (number and time) together and asking participants to judge/reproduce the duration information. Researchers observed that large magnitudes lasted longer compared to small magnitude information. However, so for no effort has been made to establish whether magnitude information is really converted into a common currency and then processed. Therefore, we designed an experiment to investigate whether magnitudes of various dimensions are processed through a common magnitude system. We used a temporal comparison paradigm to present the task-irrelevant cross-domain (number and size) magnitude information in congruent and incongruent fashion for sub- and supra-second durations. Participants were asked to judge the duration of congruent and incongruent magnitudes. We observed overestimation for long-congruent magnitude compared the small-congruent magnitude. However, this effect disappears when the two magnitude dimensions were incongruent. Further, our experimental data support ATOM's predictions for sub-second but not for supra-second durations.

Age related changes in alpha spectrum: A computational study

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It is a well-established fact that the brain undergoes structural decline with age. These structural changes are accompanied with changes in patterns of brain oscillations. For example, a number of studies in the past have reported a slowing of alpha rhythms with normal ageing. At the same time, recent neuroanatomical studies have indicated an age-related decline in thalamocortical connectivity. These two empirical findings, taken together with the long held view that the thalamocortical circuitry is the primary generator of alpha rhythmicity in the brain, led us to postulate that the age associated changes in alpha dynamics arise as a result of changes in the axonal pathways that connect the cortex and thalamus. Using a well-studied model of thalamocortical circuitry, we demonstrate that impaired thalamocortical axonal transmissions can indeed account for age-related changes in ongoing alpha dynamics. Our study provides a parsimonious explanation for a well-known observation in the field of ageing neuroscience and in doing so, provides insights into pathological processes that share similarities with normal ageing such as Mild Cognitive Impairment(MCI) and Alzheimer's disease.

Resting state gamma oscillations across levels of trait anxiety

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The current study examined resting EEG oscillations in high and low trait anxious participants in the age range of 20-30 years screened on State Trait Anxiety Inventory (N= 34; 14 low trait anxious and 20 high trait anxious), recruited from University of Allahabad. Resting EEG data was recorded using a high density 128 channel EEG system. EEG data was analyzed using EEGLAB toolbox to examine the power spectrum. Increase in gamma power (lower and upper gamma) was observed in parietal and parieto-occipital sites in high trait anxious individuals. High gamma power has been associated with higher order cognition, negative emotionality and disorders like depression and post-traumatic stress disorder for which anxiety is the underlying symptom. Trait anxiety appears to influence brain states resulting in gamma oscillations as a function of high trait anxiety. These findings have implications for studies on pre and post task resting EEG comparisons in trait anxious participants on attention, working memory and cognitive control tasks.

Referential Context Effects on Hindi/Urdu Learners of Arabic are not Stronger than Syntactic Cues during Online Comprehension: Evidence for Deep Parsing

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L2 processing models have been extensively examined. Some argue for Shallow Parsing Hypothesis (SSH) among learners (L2ers). Others claim that both natives (L1ers) and L2ers utilize the same parser, but working memory limitations or memory cue-retrieval skills could explain inconsistencies in L2 parsing that persist even among advanced L2ers. However, most studies focus on European languages and very few address the influence of contextual cues on processing. We tested model predictions on Arabic (VSO) and Hindi (SOV) investigating online processing of syntactic and pragmatic cues among L1ers and L2ers using contrastive (un)ambiguous relative clause attachment in offline questionnaires and online self-paced reading (SPR) experiments. Results have shown that both populations parse similarly offline. Interestingly, SSH online parsing predictions were only partially met: High default attachment driving the significant effect showed L2ers parsing like L1ers. We argue that despite initial sensitivity to context, L2ers do employ deep parsing.

Sensory Attenuation of Predicted Sensation is Modulated by Spatial Attention

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Sensory attenuation is the observed reduction in sensitivity to predicted sensory effects. According to the Free Energy formulation of perception and action, the reduced sensitivity is a result of withdrawing attentional resources away from the predicted sensory effects. The current study tests if the nature of attention allocation influences the sensory attenuation of the sensory effects of self-generated action. Participants performed a detection task in which they report the presence or absence of a pre-defined signal. The signal prediction and attention were manipulated independently and orthogonally. In experiment 1, the signal identity was mapped to a motor prediction, and in Experiment 2 the signal identity was mapped to non-motor prediction. The results suggest that sensory attenuation of predicted action-effects is present when the attention is directed away from the action-effect. However, sensory attenuation was observed in the attended location for non-motor predictions.

Wandering Mind, Brewing Ideas

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It isn't unfathomable to think of situations when we strive to come up with a novel thought and fail but it could occur randomly while we involve ourselves in some other activity. We try to investigate how such experiences of de-focused attention and mind wandering occur during multiple creativity tasks. The primary tasks addressed in this study are divergent (Alternate Uses Task) and convergent (compound Remote Associations Task) creativity tasks. These tasks have been modified on their difficulty levels to observe if one tends to mind wander more in an easy condition versus a difficult condition. Mind wandering tendencies are measured through probes, presented intermittently throughout the tasks. We hypothesized that divergent task would entail more mind wandering considering it necessitates exploration of ideas, compared to convergent task which requires a funnel like approach towards a solution. 30 student volunteers participated in the study. The results indicate significantly higher levels of mind wandering in divergent tasks over convergent tasks. Task difficulty does not show significant variation in mind wandering tendencies in both the creativity tasks. These results imply some aspect of shared mechanism between the aforementioned phenomena that might throw light on a holistic understanding of birthing a creative idea.

Understanding saccadic time-distortion: Relationship between intentional binding and chronostasis

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Our experience of reality is constructed by the visual system by stitching together events across saccades. During this process visual system does not have access to events at the time of saccade. This loss is compensated by guessing the missing information resulting in distortion of reality across space and time. Chronostasis represents one such distortion, where there is a dilation of time for events occurring towards the end of the saccade. The current study investigates the relationship between chronostasis and a more general motor action related distortion of time, intentional binding. We looked at how the nature of action being performed (keypress vs saccadic movement) and the intentionality of the action, influence perception of time. Results indicate that although, both type of action being performed and the intentionality of action influence subjective perception of time. This influence is occurring at different stages. We conclude that saccadic eye-movement is influenced by subcortical mechanisms resulting in

chronostasis and higher-level mechanism underlying intentional binding in an independent manner.

Effects of contextual violations in static and dynamic spatial configurations as contexts

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Statistical learning of spatial configurations in visual search provides implicit attentional guidance outside top-down goals and this facilitatory phenomenon is referred to as contextual cueing. Contextual cueing has been studied by maintaining tight coupling between the identities and locations of the items of the to-be-learnt configurations (referred to as ‘static’ contexts). In this study, we provide evidence for contextual cueing effect even when the item locations of the configurations are made identity-independent (referred to as ‘dynamic’ contexts). By introducing occasional violations in the context by relocating one of the items to a new location, the cost that emerged in target search was compared between static and dynamic contexts. It was observed that the static contexts are prone to relocation of targets whereas the dynamic contexts are prone to relocation of distractors. Moreover, the target relocation cost decreased with the progress of the experiment in static contexts whereas the distractor relocation cost increased with the progress of the experiment. The results indicate that the prioritization of item locations that existed for the target location in static contexts can be extended to the rest of the item locations and still observe contextual facilitation in a dynamic context setting.

Modelling postural sway in terms of planar Center of Pressure (COP) variations of healthy adults in sagittal and coronal planes

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A complex control strategy is required to maintain upright posture of human while standing quietly on two legs. Muscles all over the body are activated to bring stability in the upright posture. One of the easiest though an effective way to measure and characterize the postural stability is to measure and characterize the planar centre of pressure (COP) variation w.r.t. time. Most of the previous modelling studies on the same line have focused on modelling postural sway in terms of COP variation while standing quietly on both legs with eyes open either in sagittal plane or in coronal plane separately, adapting mechanical models of human with various complexities whereas the controller has been modelled either as PID controller or using reinforcement learning (RL) paradigm. To get a better insight into the governing controller which represents the neuronal circuits located in the central nervous system, we have been able model features of planar COP variation, universally observed in healthy young adults by adapting spherical inverted pendulum as the simplified mechanical model of human and the controller is modelled as an adaptable MLP trained as an actor-network using advanced actor-critic RL algorithm.

Is Event Encoding a Sufficient Explanation for Event Boundary Advantage?

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We perceive our environment by breaking it down in segments known as events. This segmentation influences the way we process information including better retention of information at event boundaries as compared to information that is contained within the boundaries of an event. Previously this effect has been attributed to changes in attention during perception of events. The current study investigated greater attention allocation at event boundaries as a sufficient explanation for event boundary advantage. We asked participants to watch a video of some daily task being performed, while simultaneously performing a Go/No-Go version of a dot-probe task. We varied the attentional load (low, high) and temporal position of dot-probe (boundary, non-boundary). Results indicate an interaction between load and boundary for memory recall. Recall accuracy showed a preserved boundary advantage at low levels of concurrent processing load but absence of the effect at high levels of load. The results provide further evidence for the role of attention in processing event boundaries but are also indicative of only a contributive role of attention to event boundary enhancement effect in memory.

Temporal Structure in Reaction Time Data is sensitive to exercised control

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Control systems helps in explaining the complex patterns of behavior. Hierarchical control theories of perception and action conceptualize action as a control of input, occurring simultaneously at multiple levels. These levels differ in terms of spatio-temporal proximity of the perception controlled. In this study we propose that these multi-level systems show the presence of long-range temporal correlations (LRTC) which can be used to measure coupling between different control levels in the complex system. Participants performed the task of controlling stimulus at two different temporal levels (1000ms and 2000ms) in which the level of control and noise are manipulated. We found difference in pattern of LRTC for different level of control in the no noise condition.

Engagement of Motor imagery correlates to the frontal- parietal- basal ganglia regions: Assessment based on EEG engagement index informed fMRI approach

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This study aims to understand the engagement of motor imagery and motor tasks through the multi frequency EEG engagement index and evaluates its neural correlates using EEG-informed fMRI in simultaneously acquired EEG-fMRI information. Ten healthy right handed volunteers (7 males and 3 females; Mean age: 21.3 years) participated in a simultaneous EEG - fMRI investigation using 3T MRI Siemens and 32 Channel MR Compatible Brain Product system. The volunteers performed both motor imagery and motor action cued tasks in a random order for an experiment duration of 21 minutes. The results of the study suggest that the EEG based engagement index reveals strong differential engagement of motor imagery as compared to the motor task. The observations of our experiment support the hypothesis that engagement of imagery is primarily controlled by differential involvements of frontal, parietal and basal ganglia regions.

Prediction Errors Mediate Episodic Sequence Learning

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Sequence learning is a cornerstone for acquiring skills or knowledge. Non-declarative sequence learning like reinforcement learning, conditioning etc. is underpinned by the formation of prediction errors. However, the same cannot be said about in declarative domain encompassing episodic memory. Despite it being affected by reward prediction errors, effects of contextual prediction errors have not been demonstrated so far and more so in acquiring sequences. Using naturalistic movie stimulus and a 3-day paradigm, we show for the first time how contextual prediction errors can drive declarative episodic sequence learning by updating older sequences for newer ones with higher accuracy, faster reaction times, imbued with more confidence and how this can be enmeshed into a predictive coding framework.

Expectation and Locality Effects in the Prediction of Speech Disfluencies in English

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This study examines the role of two influential theories of language processing, viz., Surprisal Theory and Dependency Locality Theory (DLT), in predicting disfluencies in speech production. To this end we incorporate features based on lexical surprisal, syntactic surprisal, word duration and DLT integration and storage costs into mixed linear effects models aimed to predict disfluencies in the Switchboard corpus of English conversational speech. We find that disfluencies occur in the face of upcoming difficulties and speakers tend to handle this by lowering cognitive load before disfluencies occur. Further, we see that reparandums behave almost similarly to disfluent fillers with differences possibly arising due to lessening of the cognitive load also happening in the word choice of the reparandum, i.e., in the disfluency itself. We see that lexical surprisal and DLT costs do give some promising results in explaining language production. Further, we also find that as a means to lessen cognitive load for upcoming difficulties speakers take more time on words preceding disfluencies, making duration a key element in understanding disfluencies.

Newly learned social associations disrupt target search

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Visual attention literature shows attentional benefit for perceptually salient stimulus (color, motion, orientation, etc.). Recently, Humphreys and Sui (2015) proposed that Self mimics perceptual saliency effect. They argue that similar to perceptually salient stimulus, associating Self to a stimulus enhances its perceptual saliency. Using a perceptual learning task, they showed attentional benefit for newly learned Self associated stimulus and referred this effect as Self-referential processing (SRP). However, the nature of attentional control involved in SRP is not yet investigated. In the current study, we combined a perceptual matching task with visual search task to study the nature of attentional control involved in SRP. To do that in two experiments, participants first learned to associate Self and friend with two geometric shapes and then they performed a visual search task. We hypothesized that if Self mimics perceptual saliency effect then Self associated stimulus will capture attention despite being irrelevant to the task and will disrupt the target search. We found slower search in the presence of both self and friend associated stimulus. Study suggest that Self-bias effect is fragile and is dependent on task setting. Results are discussed in terms of learning.

The Effect of Hand Proximity on Attentional Repulsion Effect

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Attentional Repulsion Effect (ARE) refers to the perceived displacement of a stimulus away from the location of focused attention. The present study investigated a two-fold purpose- First, replication of the previously established results of the ARE. Second, to understand the effect of hand-proximity on the magnitude of the ARE. Previous studies have shown that the presence of hand can affect spatial attention. Considering the spatial nature of the effect under study, an attempt was made to understand how the presence of hand can affect the magnitude of ARE. In Experiment 1, participants were presented a pair of peripheral cues in the diagonal quadrants followed by Vernier stimuli. They were asked to report the position of top Vernier line. In Experiment 2, they were asked to place their hand on the display (hand condition) or on the lap (no hand condition). An ARE was observed in Experiment 1 and in Experiment 2, the current trend of results shows a stronger ARE in the presence of hand.

Selection in visual working memory due to exogenous visuospatial attention

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Working memory (WM) is our ability to hold and manipulate task relevant information for a short period of time. Since our working memory capacity is limited, attention plays an important role in allowing only behaviorally relevant information to enter into this limited capacity system. The effects of attentional selection of the contents of visual WM are well known. However, the effects of exogenous visuospatial attention, modulated by an

uninformative retro cue on visual WM is not yet known. Here we examined the effects of uninformative, exogenous retro cues presented during the delay period of the WM task on selection in visual WM. We found that exogenous retro cues enhanced the precision of the memorized item, when the cue was aligned with the item's spatial location. Furthermore, we found that the subjects' responses were systematically biased towards the retro cued item in trials in which the uncued item was probed. Overall, our results indicate that exogenous retro cues can produce improvements in behavioral accuracy by inducing a selection bias in favor of memorized items that overlap spatially with the cue's sensory representation. The results motivate the search for neural mechanisms underlying this interaction between exogenous cueing and working memory.

Affordance based Human Problem Solving: A Step Towards Ecological Theory of Problem Solving

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We propose our affordance-based analysis of human problem solving as a small but vital step towards developing a full-fledged ecological theory of problem solving. In the first section, we have briefly discussed the information-processing theory of problem solving as the received view in the cognitive study of problem solving. We have also included the primary objections to the received view. In the second section, we have presented a survey of different conceptions of affordances, and argued for an emergent, dynamic, relational, consideration of affordance, for dealing with interactive nature of human problem solving. Starting from Gibson's original intentions to the latest developments in the area, we have tried to maintain a chronological order of the crucial conceptual developments of affordance. In section three, using the notions of affordances, constraints, and attunement as elements for the affordance-based framework, we have collected pieces to build an alternative framework of problem solving. Applying the affordance-based framework, we have evaluated relevant examples available in empirical studies. In the concluding section, we have discussed the feasibility and approach to develop a full-fledged ecological theory of problem solving, and outlined the potential objections it might face.

Concentrative Meditation increases Temporal Resolution for Local Processing

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Previous studies have shown that meditation influences time perception. Given that meditative techniques involve training attentional processes like attentional scope differently, we decided to study the effect of long-term Concentrative Meditation (Sahaj Samadhi) practice and spatial scope of attention (focused and distributed) on time perception. We predicted that time perception for narrow scope or local processing would be different with meditators compared to non-meditators. Participants from both groups performed a prospective duration judgment task (durations ranging from 210 ms to 1310 ms) with hierarchical letter stimuli (global and local processing). Participants were asked to estimate the duration and report whether the presented stimuli were global or local.

We fitted a linear regression line to duration judgments for global and local processing for both groups. We found a significantly higher slope (increased pacemaker speed) for SS-meditators compared to non-meditators only for the local (focused attention) condition indicating that concentrative meditative training possibly results in increased pacemaker speed when attention is focused.

Can Learning a Movement Element Help Learn a Complex Movement Trajectory?

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A movement element or a motor primitive is the representational unit of a complex movement which stores the specific movement characteristics and is thus thought to be capable of generating the full complex movement trajectory (Gizster, 2015). We tested this by making subjects learn one element of a complex trajectory and further test their performance on the full complex trajectory. The element is defined as the part of the trajectory that is governed by major velocity change in one direction. We also had another group that learns the full trajectory (Full_T) which, as expected, performed significantly better than their baseline. However, the experimental group was also significantly better at generating faster and accurate complex trajectories as compared to their baseline performance despite learning only an element. We thus support the hypothesis that the complex movement could be generated by combining the movement elements by a feebly understood process. It is also known that the motor primitives remain unaffected after stroke (Krebs, 1999); thus a neurorehabilitation paradigm consisting of learning the movement elements would help patients regain the lost skills or movement patterns faster as the patients may find it motivating to learn short movement trajectories than a complex movement task.

Anticipation during sentence comprehension in second language (L2): an eye tracking study with Hindi-English bilinguals

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Anticipation is an essential ability for the human cognitive system to survive in its surrounding environment. Anticipation in language is the ability to help the language processor to prepare for future sentence processing (good preparation for the future should free up cognitive capacity for subsequent events the system encounters). The present study aimed to examine the effect of language proficiency on anticipation during sentence processing in second language using visual world paradigm. The participants were divided in to two groups: high proficient and low proficient Hindi-English bilinguals. The study used a visual world paradigm, in which participants listened simple sentences containing a target word (e.g., “cake”) while at the same time looking at visual display of four objects (a target and three distractor). There were two types of sentences, one type of sentences contained verb whose selectional restrictions dictated that only a single object in the visual scene could be referred to post-verbally, and the second type of sentences contained verb which permitted all the four objects to be referred post-verbally. The eye-movement results suggested that information at the verb can be used to predict the post-verbal noun but no significant difference was found between two groups of subjects.

Generalization of Self-Reference Effect: Group Reference Effect on the basis of Visual Features

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Self-relevant association has been previously observed to affect performance in basic identification tasks. Following association of social labels with 3 simple geometric shapes corresponding to self, friend, stranger, across trials in baseline matching task, there was replication and confirmation of the benefits of self-referential effect for our participants. With that, we also do a similar association identification task across families of the initial shapes and see if the effect of self-relevance is generalized across the entire family of similar shapes with reliable measures of benefit across shape and label matching categories. We see from our second experiment that a shape and its associated social label matching may enable it to be generalizable to a family of shapes having just a single visual feature in common, meaning that benefits of Self Reference Effect may also be generalized to group level prioritization, or Group Reference Effect.

High-definition tDCS reveals a causal association between posterior parietal cortex and the slow, implicit process of visuomotor learning

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The phenomenon of motor adaptation is imperative in everyday life to minimize errors when we encounter perturbation in the form of changing the body or environmental condition. Motor adaptation is conventionally linked to the cerebellum. We here demonstrate a causal link between posterior parietal cortex and adaptation to broaden this cerebellum centric view. In this study 60 right-handed, healthy participants adapted to a 30-degree visuomotor rotation with their contralateral arm while receiving cathodal hd-tdcs stimulation over the left or right posterior parietal regions respectively. We found a deficit in adaptation with left but not right parietal inhibition. We used a computational framework which essentially uses multiple error-sensitive processes to model the adaptation, and it was found that only the slow, implicit process of adaptation was disrupted by left parietal stimulation. These outcomes suggest a clear, causal involvement of parietal cortex in adaptation and also link it to a specific learning mechanism.

Lateralization in perception of emotions: comparison of different models

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Emotion perception of faces is currently a debatable topic. EEG and lesion data support the idea of lateralized processing of emotional experience (Abbott et al., 2012; Jansari et al. 2000; Adolphs & Tranel, 2001), but it is not known that such asymmetries are also found during emotional processing. Three main hypotheses have however been put forth: the right hemispheric hypothesis (RHH) that right hemisphere is relatively better for processing of all facial emotions, the valence-specific hypothesis (VSH) that right hemisphere tends to process negative emotions while left hemisphere advantage is seen during processing of positive emotions and the approach-withdrawal (AWM) model, which is just the other version of VSH, that approach motivated behavior have advantage in processing by left hemisphere and otherwise (Borod, 1992). To explore this issue, we asked 19 normal subjects to discriminate between emotional and neutral faces in visual half field (VHF) paradigm. The aim of the study was to compare different models of lateralization. Results revealed LVF/right hemisphere advantage for perception of emotions in faces in both dependent variables (hit rates and mean RT). Only happy and disgust faces revealed an RVF/left hemisphere advantage in both DVs.

Effect of emotion in response inhibition: Role of working memory

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Emotional stimulus capture attention (Fox et al., 2001), attentional capture varies across different type of emotions (Schimmack, 2005; Fox, 2002; Fox et al., 2005). Emotional information affects ongoing cognitive processes, such as negative emotional stimuli impaired executive control process (Gray 2001, 2004; Gray et al., 2002; Williams et al., 1996). Cognitive control requires inhibiting ongoing process in terms of hand movement or eye movement that has been explained using go-nogo/stop signal task. Go-Nogo task involves a go trial type which requires a response but in nogo trial type requires withhold of response, as oppose to go-nogo task in stop signal task there is one type of trials which requires a response but an infrequent stop cue to stop the ongoing action. Cognitive control is required to process ongoing information in terms of detection of stimuli and execution of response. Emotion stimuli have ability to capture attention that has been explained in two ways one is attentional approach and freezing account (see Houwer & Tibboel, 2007). Emotional stimulus requires cognitive/ attentional resources to process and requirement of resources varies as different emotional context vary (Fox et al., 2001; Sutton and Altarriba, 2011; Laura, 2017).

The Dilemma of Neural Computation: Prospects from Network Neuroscience

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For a system to be considered as performing some computation, it is necessary that its operations be describable in sufficiently abstract terms. This constraint arises from the assumption that computation is, in some fundamental sense, medium independent. However, the mechanistic approach that departs from classical cognitivism emphasizes the causal mechanisms that underlie cognition. In this paradigm, to explain a cognitive phenomenon is to reveal the causal functional components that realize the phenomenon. The paper is divided into two parts. The first part deals with flushing out the central tension in the dilemma of neural computation by engaging with arguments of mechanistic philosophers who advance a theory of physical computation. My aim here is not to get into the debate between mechanists and non-mechanists about the functional autonomy of cognitive science from brain processes studied by neuroscience. I take up three questions that lay the conceptual groundwork for clarifying the importance of the dilemma posed. The first is the nature of brain information. How should we understand the notions 'information' and 'computation' when we talk about the neurons or neural populations performing information processing? Secondly, is computational explanation causal or non-causal? And thirdly, is neural computation compatible with multiple realization?

Where is the 'Duality' in Dual Process Theorizing?

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That our mental lives exhibit dichotomy is a widely held notion in the sciences of the mind. This dichotomy is central to the Dual Process Theorizing (DPT). According to the DPT, at times our behaviors and corresponding mental arithmetic appear to be Type 1 and at the other times they appear Type 2. While Type 1 mental processes are unconscious, uncontrollable, efficient, and unintentional, the Type 2 processes are characterized by consciousness, control, inefficiency, and intentionality. Critics raise questions on this rigid categorization of mental processes based on co-occurrence of features. While we concur with the critics, we raise deeper concerns on the DPT. We argue that the DPT is based on a misplaced notion of how the human mental capacity works. Drawing from recent understanding in neuroscience, we present an alternative model of how the human mental capacity works to give rise to behavior. We term this the general model of human mental capacity. Based on the general model, we suggest that the duality of mental life is more a consequence of the type of motives that underlie mental functioning than individual mental processes and their associated features. To conclude, we suggest few implications to the theory.

Studying Trust and Risk in Economic Games

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Mutual trust is an essential and existential process to help humans engage in financial and social transactions. Customarily, decision-making in economic transactions are significantly influenced by existing trust between parties or trust enforced by a third party. A very complex construct, recent research has attempted to explore ways to measure trust using surveys and brain-level neural activity changes using techniques like EEG/fMRI and physiological measurements - skin conductance. The study presented in this report aims to find possible psychophysiological correlates of trust. The Centipede and Trust game was applied to examine whether trust (in the opponent) and risk propensity of player modulates Skin Conductance Response. Results reveal that lower trust in the opponent increases the skin conductance values of players. Additionally, opponents' reciprocal action (enforcing the placed trust or breaking it), also modulate skin conductance response of player. Findings of our study highlight the application of psychophysiological correlates as a measure of trust in game play.

Upright bigram processing predicts reading fluency

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Learning to read is an important developmental milestone, but reading skills vary widely across individuals. While phonological awareness is a major predictor of reading fluency, the contribution of visual processing to individual differences in fluency is poorly understood. A role is suggested for example in studies that manipulate visual elements in reading tasks but underpinning perceptual-cognitive processes are unclear. Here, we sought to characterize how phonological and visual processing factors can influence reading fluency. We selected a group of 68 children aged 8-11 years. Each participant performed several tasks to probe reading fluency: passage reading, word reading and rapid automatic naming (RAN). In a separate session, they performed several visual search tasks: visual search involving single letters as well as upright and inverted bigrams. Our main findings are: (1) Reading fluency was significantly correlated with RAN scores across children consistent with previous reports; (2) Reading fluency was predicted exclusively by upright but not inverted bigram processing. These two factors (RAN and upright bigram processing) explained most of the variance in reading scores, compared to single letter processing and other global task measures. Thus, a highly specific component of visual processing, namely upright bigram processing, predicts reading fluency in children.

Reduced variance in theta and alpha during rajyoga practice in long term meditators

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The psychosomatic effects of meditation have been critically explored in the past decades. Neurophysiological mechanisms behind meditation were empirically postulated using the different frequency bands of electroencephalography (EEG) data. EEG was recorded from rajyoga meditators practiced by Prajapita Brahmakumaris Spiritual University. Wavelet decomposition was used to extract frequency bands of interest. Theta (4-8 Hz), alpha (8 to 12 Hz) and betal (12 to 16 Hz) bands are considered for the analysis. A novel approach of using the variance of power is proposed to study the meditation and non-meditation states. Decreased variance is observed during the state of meditation. Correlation between the states is higher across the meditation states than the non-meditation states.

Role of load and emotion in conscious perception

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Past research has established an attentional bias to emotional stimuli whether as target or as distracters. However, as distracters that is to be ignored, when manipulation the availability of left over resources, recent studies have indicated not only that the anger superiority effect disappears but instead there is a bias to happy or positive stimuli. This indication probes further investigation on the interaction between attentional availability and positive and negative valence of emotional distracters. In addition, as studies have not understood the impact of the aforementioned variables directly on conscious perception, we introduced a task irrelevant neutral stimulus to study this effect. In this study we varied attentional resource availability by manipulating perceptual load in a well-established letter search task and introduced angry, neutral and happy faces as task irrelevant emotional distracters. The direct measure of conscious awareness was the presence or absence of the neutral stimulus in the periphery, expressed as detection sensitivity (DPrime or d'). The results of 53 participants (10 females) showed a drop in d' in high load- angry distracter condition in relation to happy conditions. This indicates that the anger superiority effect has an impact on high load driven conscious perception.

Learned-productiveness produces hemispheric asymmetries in visual processing

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Stimuli that reliably herald the availability of rewards or punishers can acquire value associations, potentially imbuing them with emotional significance and attentional prioritization. Previous work has shown that an emotional stimulus (prime) presented just prior to an attention-demanding task disrupts performance in a lateralized manner that is independent of the prime's emotional valence. Here, we asked whether neutral stimuli with acquired value associations would similarly disrupt attention. In three experiments, adult participants first learned to associate specific face or chair stimuli with a high or low probability of either winning or losing points. These conditioned stimuli then served as primes in a speeded letter-search task. Primes with high versus low outcome probability, regardless of valence, slowed search for targets appearing in the left but not the right visual hemifield, mirroring previous results using emotional primes, and suggesting that motivational mechanisms that compete for control with non-emotional cognitive processes are right-lateralized in the human brain.

Effect of Context Relevant Initial Information on Gain-Loss Asymmetry

Shruti Goyal and Krishna P Miyapuram
IIT Gandhinagar

Aim of the study was to investigate the effect of context relevant initial information on loss aversion using bisection method. We manipulated initial information at three levels: small, control and large and found that value of loss aversion parameter was influenced by the initial information. We observed gain-loss symmetry for small and equal initial information condition and loss aversion for large initial information condition. These results support value construction account of loss aversion and provide evidence in favour of context dependent nature of loss aversion.

Limits on Predictability of Risky Choice Behavior

Anjali S and Nisheeth Srivastava
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Attempts to incrementally improve models of risky choice behavior has led researchers to aim towards maximizing the correlation between the predictions and empirically observed response choices. We challenge using such criteria by documenting a high degree of variability in the similar correlation values obtained using the human model. We define human model where humans serve as a model for their own choice behavior. Estimation set based on certainty equivalence protocol from Technion competition was taken as the problem space for this study. Human participants are presented with the same set of problems twice at a gap of at least one week to control for memory effects. The second elicitation of response choices can be used as a prediction to the observed response choice in the first presentation. We found only moderate correlations between observed and predicted response choices, much lesser for sampling duration for this human model. Thus, we empirically quantify and showcase fundamental limits on cognitive realistic models of risky choice behavior. Interestingly, the baseline model in Technion competition reproduced this human variability. Further improvements to such models which produce excessively high correlations and low errors may indicate subtle over-fitting to the validation set in light of our findings.

Investigating Academic Performance and Financial Risk-Taking

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We studied financial risk-intelligence and decision-making behaviour in a salary/career choice simulator designed to test one's ability to weigh risks effectively. The risk/decision behavior was correlated to academic performance (as indicated by Grade Point Average (GPA)). The role of employer brand-allegiance was analyzed as a secondary objective. Fifty selected undergraduate engineering sophomores, twenty-five with a GPA less than eight, and twenty-five having greater than eight-point GPA were recruited to play an interactive game-like web-app, designed and developed as a part of the experimental setup. A significant and positive correlation was found between financial risk-intelligence and GPA. The findings indicate a possibility that students who excel in academics also possess higher financial risk-intelligence or the ability to better estimate probabilities. Though further experimentation is required, we presume the role of working memory as a common construct for academic performance and financial risk processing.

RNNs as Cognitive Models for Learning Syntax-Sensitive Dependencies

Rishubh Singh and Sumeet Agarwal
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The goal of our research is to create cognitive and biologically plausible recurrent neural networks for learning syntax-sensitive dependencies. Long short term memory models (LSTMs) are able to capture long-range statistical regularities, but it is questionable how plausible they are as models of brain architecture. We begin addressing this problem by

using biologically plausible neural networks like the Excitatory-Inhibitory Recurrent Neural Network (EIRNN) (Song, Yang & Wang, 2016) to model number agreement learning tasks and comparing it to LSTMs. We probe the competence of multiple recurrent neural network architectures over a variety of closely related tasks, which show that vanilla RNNs are worse at remembering/finding the locus of grammatical errors than capturing long range dependencies when compared to LSTMs. We further find relations between performance on similar tasks that indicate expectation vs. locality effects of providing more information. We also study ablation effects on LSTMs which show that the input and forget gates are the most important for LSTMs to learn grammaticality. Finally, we propose a new model termed 'Decay RNN' that may be more biologically plausible and captures grammaticality as well as LSTMs without using gates.

Reinforcement Learning unable to recombine external and internal navigation structures

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Humans build novel tools, external knowledge structures (markers, maps etc.), and internal structures (analogies, mental models etc.) to facilitate cognition. Humans also recombine these building strategies to suit any task. Other organisms generate such structures as well, but they use them to optimize single tasks. This suggests that the human species' cognitive advantage stems from the capability to recombine built structures, and the resulting extended mind. Chandrasekharan & Stewart (2007) hypothesized that this capacity could emerge from reinforcement learning. Shinde, et.al, 2019 tested this proposal, by studying three foraging models, which examined whether novel recombinations of building (external and internal navigation structures) emerged in reactive agents, from just reinforcement learning. Results showed that recombination does not emerge with just reinforcement. In this paper, we test the hypothesis that complex reinforcement learning algorithms could lead to the recombination. The results show that even then the recombination did not emerge.

The role of spatial attentional control settings on unconscious cuing of attention

Seema Prasad and Ramesh Mishra
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Is it possible to ignore irrelevant objects in our environment, even when we are not consciously aware of them? In two experiments, we examined whether spatial attentional control settings (ACS) generated by task-goals could modulate unconscious attention. In Experiment 1, a blue circle directed the participants to freely make a saccade to one of the two target-circles in the upper visual field. A green circle was associated with the two target circles in the lower visual field. Before the response, an unconscious cue was displayed for 16 ms followed by a display with variable SOA (33, 50, 100 ms). The unconscious cues could be presented in either the relevant visual field or in the irrelevant visual field. On one-third of the trials, no cue was presented which served as the baseline. Experiment 2 involved the same design and procedure except the blue and

green circles referred to left and right regions, respectively. The results showed that spatial ACS failed to prevent attention capture by spatially irrelevant unconscious cues. These findings have important implications for understanding the nature of unconscious processing as well as its relationship with attentional selection.

Effect of Context on Implicit and Explicit Sense of Agency

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Any action and followed external environmental change give rise to the feeling of being the agent of the outcome. Such modification to the conscious mental state is known as the ‘Sense of Agency’ (SoA). This experience of being the agent of our actions doesn't necessary reflect actual control over our actions, SoA can be modulated by internal cues, like prior thoughts, context estimation, and external or situational cues, e.g., by subliminal and supraliminal priming. In the current study we look at how movement of non-target stimuli, influences sense of agency for control over a target stimulus. We asked participants to perform a key-press after which a central stimuli started moving in direction either congruent or incongruent to the key-press. In some of the trials this movement was accompanied by flanker stimuli that moved either in congruent or in incongruent direction to the central target. At the end of each trial we measure implicit (experiment 1) and explicit sense of agency (experiment 2). Results indicate that context affects implicit and explicit sense of agency in a differential fashion.

The Role of Partial and Complete Feedback in Reward Based Decision Making

Prashanti Ganesh, Narmadha Nagaraj and Krishna Miyapuram
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Outcome monitoring is crucial to reward based decision making as the consequences of decisions are highly impactful and aid in modifying expectations and subsequent predictions. Comparison of chosen outcome with foregone alternatives usually plays a role in influencing choice behaviour. Theoretically, however, regret could be induced irrespective of the nature of alternative choices. In this study, the responses of 17 participants in a two choice mixed gambles was used to check if they predicted choice behaviour. Along with expected value of gambles, the extent of resolution of uncertainty of a gamble could predict whether an alternative is chosen indicating that regret plays a role irrespective of feedback of the unchosen gamble. This allows us to make a distinction between anticipated regret and their respective influence on value-based decision making.

Mind and Body in Balance: Assessing Yoga to Demystify its Effects on Cognitive Performance

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Though yoga is considered a mind-body practice, the motor component of yoga posture is widely ignored. There is no measure to assess the motor performance in yoga, and as a result, the effect of yoga on cognitive performance are unclear. We used Kinect Microsoft for assessing motor demands in yoga postures, and explored its link with cognitive performance using executive function tasks. We found that motor demands in yoga postures (posture duration) affected immediate working memory performance, and posture instability was marginally linked with time spent in problem solving task. As expected, the result demonstrated a link between motor demands in yoga posture and cognitive task performance.

High frequency to low frequency band power ratio in Rajayoga meditators: an indicator for meditation experience

Kanishka Sharma, Pradeep Kumar Govindaiah and A.G. Ramakrishnan
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Meditation or contemplative practices in some form are popular throughout the world and part of almost every religion. However, the east has been considered as the origin of these practices. Three decades of empirical research have found low-frequency bands i.e. alpha and theta after processing the EEG signals. However, some research showed high bands visible during meditation. In the current research, we have explored the ratio of EEG band power between high frequency (24-42 Hz) and low frequency (4-14 Hz) components. The experimental subjects are long term meditators with practice experience of at least ten years. After processing the 64-channel EEG data, the ratio is found to be increased during meditation compared to their baseline in a few subjects. Also, the ratio continues to increase over time during the meditation practice. The findings of the study suggest the activation of neural generators of gamma during meditation and rest in long term meditators.

Unconscious cueing of free and instructed saccades

Sneha Kedia, Seema Prasad and Ramesh Mishra
University of Hyderabad

Unconscious cues can bias visuo-spatial attention in saccade generation tasks that involve mechanisms ranging from bottom-up (automatic), automatized (selection history) to top-down (goal driven, voluntary). Compared to task instructions, the superior form of voluntary control is self-generation of goals or free choice, typically defined as freedom from external influences. We use the spatial orienting paradigm to investigate the facilitative and inhibitory influence of an abrupt onset unconscious cue on choice frequency and latency of the first free saccade. Motor priming studies showed that an unconscious prime does not affect responses in pure blocks due to weak stimulus-response mapping. This study used similar blocking to compare free saccades on pure block and mixed block. Participants were asked to make a saccade to a single target (instructed saccades) or to one of the four target circles (free-saccades) following the presentation of an unconscious cue. We found that the cued location was selected above chance-level on free-saccade trials for short SOA condition, and below chance-level for long SOA condition. Further data collection is in progress. Preliminary analysis reveals that unconscious cues are capable of influencing eye movements even when they are voluntarily generated.

An EEG based framework for measuring advertisement effectiveness

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Application of neuroscientific methods to understand the biological underpinnings of economic behavior has gained massive research attention in the recent years. By understanding the neural dimensions of decision making, marketers and firms can design products that better suit the preferences of their consumers. 9 healthy male students from the institute were shown 18 selected advertisements, and their responses recorded through electroencephalogram (EEG) – the central premise being that cognitive effects of advertisements have a major role to play in our perception of brands and cognitive ease factors in developing brand loyalties. The aim of this study is to identify and characterize neuronal activation in reaction to television advertisements. This will be further used to create a EEG based effectiveness testing framework for advertisements.

No evidence for rational adaptation of encoding variability in absolute identification

Prabhath Nampally and Nisheeth Srivastava
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How is abstract information about magnitudes stored and processed in the mind? The absolute identification experimental paradigm offers a very rich test-bed for testing various hypotheses about the nature of such mental representations. It has been contended that complex variations of the familiar bow-tie effect in absolute identification could potentially be explained via rational adaptation of encoding variability of an internal magnitude scale. We test the premise of rational adaptation of encoding variability in absolute identification using a novel variant that rewards participants extra for identifying some arbitrary stimulus correctly. Our empirical results show that extra reward does shift humans' accuracy for the rewarded stimuli, but not its intrinsic discriminability. This finding supports viewing theoretical claims of possible rational adaptation of encoding variability for magnitude judgments with caution.

Relative deprivation increases prosocial giving towards Immoral causes for material benefit

Abhishek Sahai and Jaison Manjaly
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It has become commonplace to be asked to make a donation to some organization (morally good or morally bad). Importantly, such pro-social requests are made to people regardless of their economic status. Pro-social choices create moral conflict pitting material gains for personal benefit against moral values. How are such choices affected by relative economic deprivation? Under high economic inequality we had three experimentally induced relative deprivation groups; best-off, middle, and worst-off. We found that worst-off group gave more to morally bad organization as compared to best-off group. However, it was the middle group that donated most to morally bad cause for

material benefit. Our findings have important implications for understanding charitable activities of not just rich and poor, but also middle income groups in high economic inequality.

Mental health professionals: Wired same or different

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The mental health professionals deal with emotions of self and others on a day today basis. Perspective taking and emotional contagion, elements of empathy is both innate and acquired. This study could into shed light into networks which possibly could help in inferring in the process. The aim was to study the brain resting state of mental health professionals. A total of 45 healthy subjects from Mental Health Professionals (MHP) and other Professionals (OP) group were recruited in single assessment design study. They were screened on mini-international neuropsychiatric interview (MINI), standard progressive matrices (SPM). Both the groups were at above average level of intellectual capacity. The resting state analysis indicate that there was significant connectivity of amygdala with right frontoparietal network in OP ($p=0.047$) and almost significant connectivity of temporal gyrus with bilateral frontal network ($p=0.094$) in MHP. There are both common and unique connections in both group.

Multiscale shape integration explains global and local processing

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A classical finding in visual search is that we see forest before the trees: when viewing circles made of diamonds, humans can detect circles faster than diamond and this phenomenon is known as global advantage. People are faster to report circle when global and local shapes are same which is called as incongruence effect. Understanding these phenomena has been difficult because they require a shape detection task, where a categorical judgement is made on an unknown feature representation. Here we set out to elucidate these phenomena. First, we show that these phenomena are also present in a same-different task. Second, we propose a linear model that explains all the variance in the behavioural responses with two factors: the dissimilarity between the two images, and the net distinctiveness of the two images. Third, we show that these phenomena are also present during visual search, suggesting that they are properties of the underlying representation. Fourth, we show that behavioural responses from visual search can be explained by a linear model based on dissimilarity. Taken together, our results show that global and local processing of hierarchical stimuli are driven by a systematic underlying feature representation in which shapes at multiple scales combine linearly.

Human Color Categorization and Naming in Normal, Deficient and Mixed Populations Using Agent Based Modelling

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Categorization is a fundamental function of the cognitive system. Perceptual information is compressed and classified into discrete categories, in order to make sense of the world. A major consideration regarding categorization in humans is that we are profoundly social and cultural creatures with a high level of cooperation and communication. Hence categories in humans are not only internally consistent but consistently named across a linguistic community. Communicative success is the ground where culture exerts its pressure. Color naming is a categorization process in which a continuous stimulus domain is split into discrete categories achieving tremendous utility. The World Color Survey, showed that even though individual and cultural variation exists there are some universal tendencies over large populations in color naming. Agent based computational models have been shown to have reached enough maturity to contribute to this debate. Here in this work, one such model has been explored and extended to show that it may even provide insights into biological deficiencies like color blindness.

Walk the talk: does formal education change people’s gaits in discernible ways?

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Embodied cognition theories argue that the brain evolved for movement, and cognition emerged to support movement. Supporting this view, studies show that improved motor control (such as writing with both hands) improves cognitive control (such as response inhibition). Here we explore the reverse link, i.e. whether improved cognitive control leads to a difference in motor control. We operationalized this question using different levels of education (cognitive control) and gait differences (motor control). Gait patterns of two groups of people with different levels of formal education (less than 5 years, more than 15 years) were captured using point-light walkers. We then examined whether educated observers could recognize the walker with the higher level of education, when two point-light-walkers were presented side-by-side, one from each group. If differences exist between the gait patterns of the two groups, owing to the principle of movement resonance, it would be picked up implicitly by educated people, allowing them to identify the point-light walker of the educated group more significantly. Results showed that the overall accuracy was not significant (~57%). However, the data revealed some interesting trends, which suggest more focused ways to examine the relation between cognitive control and motor control.

Modelling Neurons as Kuramoto Oscillators

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The Kuramoto model is employed to model the synchronization between regularly spiking neurons appropriately. Neurons are treated as coupled phase oscillators present

in a small-world network. The firing rates of neurons are estimated from the Poisson process generated spike trains having a specific baseline firing frequency. Increasing the baseline firing rate desynchronizes the system. The perpetually positive coupling strength matrix is modified to include a fraction of negative coupling strength. The mixed coupling strength or the 80:20 coupling strength takes more time to produce synchronization. Increasing the coupling strength increases the synchrony and reduces the desynchronizing tendency of higher baseline firing rates.

Can Working Memory be affected by academic stress and what could be a good intervention?

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Academic curriculum is a mentally demanding endeavour, given the age and academic lifestyle; students find it difficult to cope with the pressure and this leads to adverse effects on the mind and body, thus assessment of a student’s cognitive health is vital and working memory plays a pivotal role. Using electroencephalographic in tandem with working memory task which provides an insight into the cognitive aptitude along with brain activity following which comparison of three different population groups within an institution was carried out; volunteers were either yoga practitioners, physically active and recreationally active students. The experiment focuses on two key aspects of the brain, the regions involved with vision and memory. The behaviour of the brain, when exposed to visual Sternberg item recognition task and the possible effects of the exercise regime might have on these evaluations. On analysis of event related spectra, in terms of frequency, spectral power; the alpha, beta and gamma band activity, we find that participants who practiced yoga had 2% higher beta and 12% gamma activity and participants who took part in sports generally showed high beta activity when compared to recreationally active further response time was compared between groups.

Metacognition and Decision Making: A Study of Maximizers and Rationalizers

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Rationalizers and maximizers have a common characteristic of exploring all the alternatives before making a decision. Although both the decision styles follow the principle of maximizing utility, they were found to be unrelated to each other. The present study explored how metacognition, the ability to monitor and regulate our cognition, helps in explaining the rational and the maximizing decision style. Data was collected from 249 managers belonging to marketing, sales, finance or human resource departments of various private organizations of Kolkata. Correlational analysis, as well as regression analysis, established the role of metacognition in explaining both the decision making styles. Metacognition positively predicted rational decision style but was found to be a negative predictor of maximizing decision style. Metacognition, emerging as a significant indicator, differently predicting the two decision styles have important implication for future research and practice.

Exploring Global and Local Properties in Category Learning

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The ability to categorize stimuli into distinct and related groups allows humans to make sense of the world and to interact with it in meaningful ways which further helps to ensure their survival. Successful categorization implies well learned categories. However, category learning, a higher level cognitive process, may be expected to be preceded by relatively perceptual processing stages involving the visual organization of individual categorical elements into their component parts and features. In the present study we examine the learning difficulty of categories defined by dimensions that are distinctly global or local using the well-known 32[4] family of category structures consisting of 4-elements each, defined by 3 binary dimensions. Early findings indicate support for Navon's (1977) Global Precedence Hypothesis such that categories defined by global features appear easier to learn. The Generalized Invariance Structure Theory Model (GISTM, Vigo, 2013) has been found to provide a good fit for the observed data.

Cognitive Reserve: Current concepts and need for new approaches

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Cognitive reserve (CR) enables a person to efficiently perform a task and accordingly adapt to the varying task demands despite neuropathology. The currently used measures of CR majorly include education, IQ, occupational complexity, leisure and physical activities and bilingualism. The cognitive mechanisms that underlie these proxy measures, which enables an individual to build better resilience to cognitive decline is largely ignored. This paper attempts to understand the cognitive mechanisms associated with some of the proxy measures of CR and proposes plausible cognitive and affective measures that would help to understand and better characterize the notion of cognitive reserve. We propose that empirical studies are needed to establish the validity of using these measures and related them to already proposed proxy measures of cognitive reserve.

Effect of Feature-based Attention on sensory attenuation

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Feature-based attention and its effects on sensory attenuation is less explored in contemporary research. Most studies focus on the influence of spatial attention on sensory attenuation. We explore this question using a discrimination task, associating cue feature (colour) with action. In the first experiment, the expected colour of the cue (congruency) is kept constant while manipulating the feature cue validity. It assesses whether the observed effects are solely due to congruency manipulation or due to the combined effect of validity and congruency manipulation. In the second experiment, both

congruency and validity are manipulated. The main effect of validity is observed in both our experiments. However, the significant validity effect for response criterion makes the claim about the effects being attributable to change in sensitivity debatable. Nevertheless, it could be argued that the expectations play a significant role in decision criteria, and does not have a direct modulating effect over sensory processing efficiency. Regardless, the barely significant effect of action in the second experiment demands more elaborate studies for more conclusive inferences.

Does Cooperation help: A Study Based on Agent Based Modelling

Neelabja Roy and Harish Karnick
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Cooperation is widespread in biology and animal and human societies. Cooperation always involves paying a cost and as such is in seeming contradiction with natural selection. Cooperation has been studied in varied settings and many possible theories have been proposed for why it exists at all. We study cooperation in an extremely simple setting using an agent based model. The world contains energy sources and agents use these sources to replenish their own energy to survive. An agent can cooperate with another agent by informing it about the details of energy sources that it knows. Levels of cooperation can be modelled by communicating more or less detail. Simulations show that higher levels of cooperation help. Communities that cooperate have higher average lifetimes and are able to survive in harsher conditions.

Intentional Referential Communication amongst Conspecific Individuals in a Wild Nonhuman Primate

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Referential communication, the act of referring to external entities in various communication modalities, has been considered fundamental to the unique symbolic nature of human language. It directs the attention of the receiver to the sender's object of interest and the meaning of the referent is deciphered through an understanding of the communicative intent of the signaler, suggesting an underlying cognitive capacity of mental attribution. In this paper, we report potentially referential gesturing, used intentionally as well, by wild individuals in four troops of a monkey species, the bonnet macaque Macaca radiata, in the Bandipur National Park of southern India. Our study individuals used four distinct referential actions during allogrooming, possibly to indicate a particular body part that they intended to be groomed. These acts were successful in drawing the recipients' attention to the indicated part, which they began to groom subsequently. This study thus enriches our understanding of non-ape primate gestural communication but more significantly, adds to the growing evidence for early human language-like capacities in certain nonhuman species that are evolutionarily closely related to humans.

Evidence for Gender Bias in Color Perception: Men recognize colors faster

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The paper proposes a divided visual field experiment for studying possible gender bias in chromatic sensitivity, a novel experimental methodology is presented using virtual reality headset for delivering visual stimuli. The use of virtual reality headset enables us to present distinct visual stimuli to the two visual hemispheres, also giving freedom on the choice of stimuli presentation time and reducing the chances of error. Two separate android applications have been developed for the experiment. The first android application is used for presenting the same or different visual stimuli to the two eyes of the subject. The second android application is used for recording the responses. Each test subject goes through sixty trials in the experiment, where each trial consists of displaying the target color for a brief period of time followed by a black screen and then distinct colors are displayed separately to each visual field for a very brief period of time. The experiment has been conducted on 16 individuals (8 males and 8 females). A significant result is observed that males have a faster reaction time than females. ANOVA analysis on the data revealed a p-value of 0.0376, thus indicating statistical significance.

Time course of Sensory attenuation

Vinaya E H, Nithin George and Meera Sunny
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Past studies have attempted to understand the effects observed when a stimulus is perceived as an action-outcome. Two main effects have been identified — sensory attenuation and intentional binding. Through the following experiments, I intend to determine whether action execution is necessary for this effect to manifest. Additionally, I propose to identify whether this effect follows a time course in the visual domain.

How people make mitigation and adaptation decisions against climate change with descriptive or experiential climate information?

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IIT Gandhinagar and IIT Mandi

Climate change poses a big threat to our society and our decisions play a critical role in our fight against climate change. Little is known on how people make mitigation and adaptation decisions against climate change from descriptive and experiential information. The primary goal of this research was to study people’s decisions against climate change through a Collective-Risk-Social-Dilemma (CRSD) simulation, where people need to collectively decide their investments in mitigation and adaptation against climate change against descriptive or experiential information. In CRSD, one human player and five non-human agents had to reach a specific climate target collectively in a group across 10-rounds by contributing to a climate protection fund (mitigation) and personal insurance (adaptation). If groups failed to reach the collective climate target, then they would face monetary damage due to the occurrence of climate disasters with varying probability over rounds. The climate disaster probability was influenced by players' mitigation actions, and players' adaptation actions influenced the monetary damages due to climate change. Results revealed that the proportion of investments against climate change were higher in the mitigation-cum-adaptation condition compared to the mitigation condition. Also, participants reached the desired target early in the mitigation-cum-adaptation condition compared to the mitigation condition.

Word2Brain2Image: Visual Reconstruction from Spoken Word Representations

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Recent work in cognitive neuroscience has aimed to better understand how the brain responds to external stimuli. Extensive study is being done to gauge the involvement of various regions of the brain in the processing of external stimuli. A study by Ostarek et al. has produced experimental evidence of the involvement of low-level visual representations in spoken word processing, using Continuous Flash Suppression (CFS). For example, hearing the word 'car' induces a visual representation of a car in extrastriate areas of the visual cortex that seems to have a spatial resolution of some kind. Though the structure of these areas of the brain has been extensively studied, research hasn't really delved into the functional aspects. In this work, we aim to take this a step further by experimenting with generative models such as Variational Autoencoders (VAEs) (Kingma et al 2013) and Generative Adversarial Networks (GANs) (Goodfellow et al., 2014) to generate images purely from the EEG signals induced by listening to spoken words of objects.