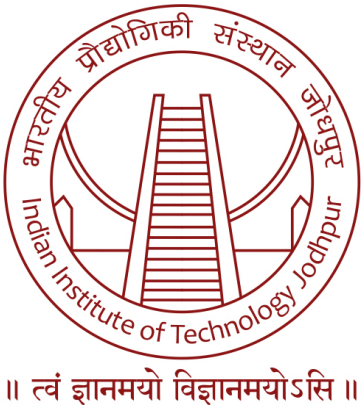
Computational Model of Time Perception

A Project Report Submitted by

Yash Kumar Singhal

in partial fulfillment of the requirements for the award of the degree of

M.Tech.



Indian Institute of Technology Jodhpur

Computer Science and Engineering

May, 2022

Declaration

I state the work which is presented here in this project report titled Computational Model of Time Perception is submitted to Indian Institute of Technology Jodhpur as a partial fulfilment towards the requirement for the award of the professional degree M.Tech., This report thus serves as an authentic work of the research work which is done under the supervision of Dr Romi Banerjee. I also declare that in no circumstance the contents of this work is submitted by me or any entity to any Institution, domestic or abroad towards the requirement for award of any other degree

Yash Kumar Singhal

Signature

Yash Kumar Singhal

M20CS065

Certificate

This certificate is to attest that the Project Report titled Computational Model of Time Perception, submitted by Yash Kumar Singhal(M20CS065) to the Indian Institute of Technology Jodhpur for the award of the degree of M.Tech., is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, whether in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Signature

Dr Romi Banerjee

Acknowledgements

The work done towards the project titled Computational Model of Time Perception wouldn't have been possible had it not been for the great deal of support from my guide Dr Romi Banerjee. The topic was quite challenging and advisor helped me enough to traverse this research area as smooth as possible. Furthermore I really am indebted to my friends for all the help in arranging the logistics for the project as without them the project wouldn't have been easy to implement

Furthermore I want to thank all of the participants who agreed to be part of the experimentation's. The experimentation was long, which took about 11 minute for one participant and involved form filling as well as watching the video and hence I am really indebted for all the trouble participants went through for the purpose of my project,

Additionally I would also like to thank the faculty members of CSE department at Indian Institute of technology Johdpur, without the guidance of whom the project might not have been completed as they were instrumental in not only telling the possible areas I can improve my project upon but also helping me to arrange the logistics needed for the project

Lastly and not the least I would also like to thank the evaluation panel for their constructive feedback on the project, they helped me in iterating over the project as they succinctly told the shortcomings and possible areas I can improve my project upon ...

Abstract

The report contains the contents of the work done towards the project computational model of time perception. The project has two motivations. One of the motivation includes eliminating the discrepancy between the incorrect classification of the embodiment and disembodied emergent models by providing the evidences which support their amalgamation in various fields of study which include neuroscience and psychology. Additionally we would also be also stressing on the recent computational papers which support that the claim that the embodiment and disembodiment emergent models are not mutually exclusive

Second Part of the project involves incorporation of embodiment in the time perception model by encoding the anxiety level through GSR sensors. The attempt is thus to identify the strength of the parameter lets say alpha to denote the strength of the anxiety towards the distortion in time perception. For this objective a peer study was conducted, the results of the study was then noted and then subsequently analyzed for the findings

Contents

List of Figures

List of Tables

Computational Model of Time Perception

1 Introduction and background

There is growing interest in recent time regarding the time perception, broadly it refers to the subjective time that any entity or human being experiences. It differs significantly from the actual physical time , with the notion that human being either underestimates or overestimates the flow of time. With the advent of the increase interest in usage of the social robots many researchers have increasingly are looking into the ways of incorporation of the algorithm governing the time perception in robots with the general conseous that incorporating the algorithm would prove to be a breakthrough towards realization of general artificial intelligence. This mathematical modelling of algorithm would prove to be significant because it would allow the robots to be more sympathetic towards the needs of an individual.

The subjective time the human being often feels is something as a result of the evolution over the larger period of time, for example there are cases where an individual require their immediate focus over a long period of time , then subjective time they feel is a lot shorter than physical time. To the contrary there also has been cases where in the event of the anxiety subjective time was felt a lot longer than normal. Furthermore there also have been evidences that the feeling of time perception depends on a lot on genetic and physical parameters, hence accurately modelling the time perception remains a challenging task. To the relief however there have been some recent attempts by the researchers to look into the problem of incorporating the time perception into individual autonomous system as there has been an increased focus in recent times to simulate artificial general intelligence and thus to model the time perception remains a core problem towards realization of the artificial general intelligence

The Time Perception is not only important to stimulate the artificial general intelligence, it is also subsequently important within the context of many diverse and interdisciplinary fields like the psychology and cognitive sciences. There have been several studies where through discussion on how people perceive time has been instrumental in finding deeper findings how human mind works in general. While evidently there indeed has been lot of studies, there are relatively very few studies describing the relationship how people ability to perceive time changes in the face of anxiety. Our project seeks to find the relationship by allowing the people to watch the video while measuring their anxiety through the help of GSR Sensors. By allowing the people to watch the video we are allowing the users to leverage their embodiment to interact with the surroundings and hence measuring anxiety in this circumstances

2 Literature survey

There are two types of models however that are studied in literature [1], one is the cognitive model that usually focuses on the information processing and symbol manipulation to explain cognition, while the emergent models tends to focus on the abilities that emerges from the relationship that is developed through the autonomous system and its environment. Emergent models are further categorized into the embodied emergent models and disembodied emergent models , the distinction which is we are particularly targeting in the paper

The Pacemaker accumulator model arguably the most popular framework [2] [3] still remain the most popular for the researchers to explain the observations of the experiments involving the time perception. According to this model, we all have something a pacemaker which generates rhythmic pulses which is fed into the accumulator. The path between the path and accumulator is controlled by a switch which purposely can get affected by the internal processor or external stimuli. The rhythmic pulses from the accumulator is then fed into the memory area containing two units one is being the reference memory and the other is being a working memory. The working memory keeps a track of pulses per unit time while the reference memory is a accumulation of all the pulses accumulated so far. The working memory is thus compared with the reference memory and based on the comparison the brain gets an intuition of subjective time, however the model remains controversial and isn't able to explain many of the results There has been some effort to polish some of the shortcoming of the pacemaker accumulator clock for example, researcher [4] suggested an improvement in which she argued regarding the intensity and nature of the stimuli and as different properties of the stimuli creates different neural activation' and hence the various process that realize the experience of stimuli realize the functions of the peacekeeper. Nevertheless its still clear that peacekeeper accumulator model is plagued with inefficiency where the model seems to exhibit both disembodied and the embodied properties even though it might not assume a relationship between sensory information and time processing in theoretical framework [5]

A recent paper however in 2021 [6] researchers tried to include both the embodiment and disembodiment structure to put forward the hypothesis of the time processing models in humans. They did so by including the neural timing component by imagining two separate timing sources, first is internal neural mechanism and secondly an external stimuli . For the first they tried to replicate the dopaminergic behaviour using the means of temporal difference learning algorithm, for the later they stimulated the passage of time from the environmental data by using the results obtained from Gaussian process. Hence the model is biologically inspired reinforcement framework that tries to replicates the neuronal mechanism of time (which is believed to be responsible for time perception) and tried to combine them with the time estimates obtained from the environment. Thus the model exquisitely combines the embodiment and disembodiment nature that we usually associate with the mechanism underlining time perception and thus could serve as the good model for the future research going forward

3 Problem definition and Objective

To iterate the computational model on time perception focuses on using the computer programs in order to study and stimulate the phenomenon of the time perceptions using an algorithm/mathematical model which can then be used in the diverse range of fields spanning from Artificial Intelligence to Cognitive Sciences

Hence our main objectives for the project are as follows

- Explore the Literature involving experimental papers on time perception involving Human subject research and the recent papers on Computational model on time perception to identify the gaps/inconsistency that which we can dissect and explore
- Having Identified the gap that is how anxiety affects the time perception in embodiment engagement with surroundings, to conduct a peer review experimentation and to allow the embodiment engagement by making the participants watching the video while measuring their anxiety through the GSR Sensors. Additionally participants will be asked to fill the form which is basically a likert scale for measuring their attentiveness and their comfort level which might give us additional insights
- Through experimentation, analyzing the data obtained through peer study in order to obtain the parametric value which would tell us how much the anxiety effects the time perceived while a human being is in engagement with the surroundings. To describe this parametric value we would be taking help of the explainable AI more specifically SHAP which was proposed in neurips in a landmark paper
- To come up with the parametric values regarding anxiety etc so as to mathematically model the equations which would help us deciphering how much the person would perceive the time without experimentation

4 Methodology

This Given section would be divided into individual subparts as the the M.tech project consists of two main objectives that we intend to address

4.1 Embodied and Disembodied characteristics of time processing

One of the primary objective of our M.tech project is to provide evidence against the argument that embodiment and disembodiment characteristic's of time processing should not be treated as mutually exclusive. To support this argument we take evidence from the recent papers within the realm of the neuroscience, cognitive science and psychology. The abstract of this resultant academic paper is as follows

"The paper attempts to provide the arguments in favour of the embodiment and disembodiment characteristic's of time processing and hence to provide evidence that these individual characteristics should not be treated as separate when hypothesising computational models based on time perception. To support that we would aim to provide evidence of the recent literature which showed either embodiment or disembodiment or even an amalgamation of two. The paper also aims to talk about the changes in approach of the computational models of time perception over time, while also commenting on the recent papers which showed promise of incorporating both embodiment and disembodiment characteristics. The paper would thus conclude by providing the mapping between the study on time perception and the hypothesised computational model"

4.2 Effect of Anxiety on Time Perception in embodied interaction with surroundings

To measure or quantify the effect of anxiety on Time perception we stimulated an environment in which the participants were asked to watch two specific video. A reading from GSR Sensor is taken before the video is played and after the video is played, furthermore a form based on likert scale is made to fill before the experimentation. The in depth detail regarding the procedure and the instrumentation are described as followers

4.2.1 Instrumentation

The Instrumentation of the project consists of GSR Sensor, a LCD Screen as well as the Arduino embedded into the cardboard box as depicted in the figure 4.1 . The Whole Apparatus gets its power by connecting it to the computer. The GSR Sensor consists of two cables padded with smooth microfiber cloth at the end. An individual would insert two fingers inside these microfiber cloth during the experimentation. One needs to make sure the sensor is touching the soft part of the finger which is not the same side where there is the nail. The LCD Screen will then give you the GSR Value reading which you can monitor all during the experimentation, furthermore the GSR Values would be also uploaded to the computer through Arduino interface

Figure 4.1: Instrument

4.2.2 Experimentation

The Experimentation starts by asking the participants to sit in a comfortable position at upright facing the computer

1. Asking the Participants to fill the form. The form would contain details which might indicate their attentiveness level, confidence as well as any prior discomfort regarding the background of the videos. This would provide us additional insight in the analysis and to discern whether there are any additional details which might result in the change of the time perception

2. Participant are made to wear the GSR Sensor in a comfortable position. The reading before the video is made to watch is noted as a data point. Furthermore participant are asked to wear the headphone for the proper simulation. The Videos are of GO-Pro video type which provides the effective simulation as described in the paper [5]

3. Participant are also given a Tap counter application, in which they were asked to tap onto the mobile as soon as they perceive one second has passed while watching the video. The no of Taps accumulated at the end would amount to the total time perceived by the Participant

4. After a video is completed, the GSR Value is noted and a break of 1-2 minutes is given for the GSR Value to get stabilized to baseline level

5. After cool-down period, a second video is made to watch which is of different nature than the first. In the same way like the previous after the Video is completed the GSR Value is immediately noted down

6. The two videos here are of different types and the juxtaposition of these two videos is important for our experimentation and what we are trying to find. The first video is of 110 seconds and of the crowded khan market while the second video is of the same 110 second and is of the Shimla which is eye pleasing

Figure 4.2: Experimentation

4.2.3 After Experimentation

After the Experimentation a participant is made to fill another form which asks what video they felt to be a longer video and how attentive were they are during the whole procedure. As said these metadata would provide to be essential details for our experimentation

4.2.4 Analysis

After the data is collected, the data is transformed and analyzed for further modelling. The one important transformation is the calculation of the difference between the baseline GSR value and GSR value after the video is watched. This is important as this transformation is not only directed related to what we are trying to find (ie the effect of anxiety on time perception), but also standard GSR Value is a lot unstable and differs by the individual as they measure the resistance of the body and is affected by moisture present in the body

4.2.5 Data Collection or features

There are various information that we collected from the people during the experimentation. These information in totality constitutes what we call a feature set. In total we collected data from 34-35 Participants. The description of data we collected are as follows

- **GSR Sensor Baseline** - This refers to the Baseline GSR Value before the experimentation. While GSR Measures the resistance of the body, it more or less also reflects the anxiety as GSR Value is directly proportional to Anxiety as noted in [7].
- **GSR Sensor Nature** - This refers to the GSR Value observed soon after the completion of nature video during the experimentation
- **GSR Sensor Crowded Market** - This refers to the GSR Value observed soon after the completion of crowded video during the experimentation
- **Difference** - This refers to the difference between the baseline GSR Values and soon after the video is watched. This is important as the baseline GSR Value is sensitive to the skin moisture. Usually a person with not too high or low moisture would have a GSR Value which ranges around 100 in a happy mood
- **Multitasking** - A likert scale parameter in which a participant have to rate themselves in the scale of 1 to 5 describing how good are they with multitasking
- **Concentration** - A likert scale parameter in which a participant have to rate themselves in the scale of 1 to 5 describing how tough they feel to concentrate to a video over a long period of time
- **Energetic** - A likert scale parameter in which a participant have to rate themselves in the scale if 1 to 5 describing how energetic they are feeling before the experiment
- **Nature U C** - A likert scale parameter in which a participant would rate themselves 1 to 5 describing how uncomfortable they feel in nature environment
- **Crowded U C** - A likert scale parameter in which a participant would rate themselves 1 to 5 describing how uncomfortable they feel in crowded marketplace
- **Attentiveness** - A likert scale parameter in which a participant would rate themselves 1 to 3 describing how attentive they were throughout the experimentation. This is done post experimentation
- **Extra** - A disembodied Value parameter taken from the here [5]
- **Nature Taps** - The No of Taps noted after the experimentation denotes the time that is perceived by an individual during experimentation on nature video.The actual length of Nature video is 110 seconds
- **Crowded Taps** - The no of taps noted after the experimentation denotes the time that is perceived by an individual during experimentation on a crowded video. The actual length of crowded market video is 110 seconds

5 Theoretical/Numerical/Experimental findings

Similarly to above the given section would be divided into individual sections as the the M.tech project consists of two main objectives that we intend to address

5.1 Embodied and Disembodied characteristics of time processing

Post our survey we were able to found out the discrepancy of the classification between the embodied emergent models as well as disembodied emergent model and hence we described this discrepancy through an academic paper explaining our findings. More specifically we found out that

- That there is evidence that segregation between the embodiment and disembodiment may be ambiguous as the time perception may be a factor of both experience formation as well as the the processing in specialized areas of the brain (aka there may exist a specific functions in the brain for the cognition of time)
- Furthermore the embodiment emergent models similarly to the disembodiment emergent models may consist of the processing which are neuro computational in nature

Some of the brief summary of our findings below which shows a strong favour for both embodiment and disembodiment nature of time processing

- Isolation of the Many Brain Regions each of which is responsible for specialized timing functionality
- Literature related to how variability in brain structure and mental disorders leads to the difference between the perception of Time , as well as how the effect of Alcohol and LSD tends to affect the perception of time
- Numerous Literature which argues what you smell, what you taste, the physical activity and even where you currently are affects the perception of time (strong favour of embodiment)

5.2 Effect of Anxiety on Time Perception in embodied interaction with surroundings

The Main experimental work consists of finding the parameter which tells us how much the anxiety affects the time perception while in embodied interaction with the surroundings. During the experimentation we also tried to analyze the affect of other parameters on the time perception more concretely like attentiveness, concentration etc

For the Purpose of modelling we trained a neural network which consists of the 5 hidden layers ,the no of nodes in each layer are 1,8,16,24,16 respectively. The RELU activation layer is taken in all the layers except the last. The purpose of 1 node in the first hidden layers is for the purpose for the mathematical formulation. Furthermore the Given architecture is chosen after taking the result of the lowest error on cross validation.

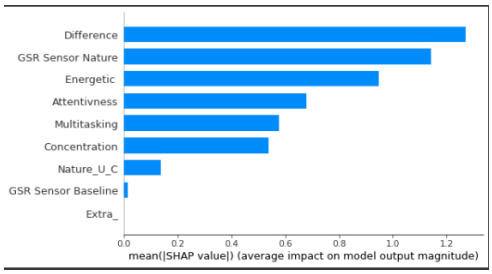


Figure 5.1: Average Impact on model output perfomance

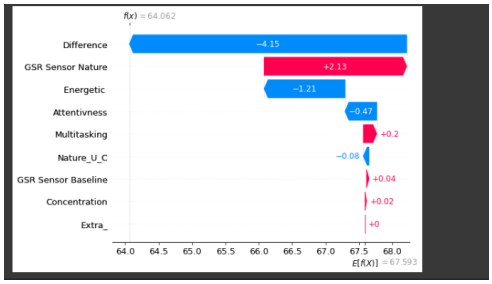


Figure 5.2: Effect of parameters on individual data point

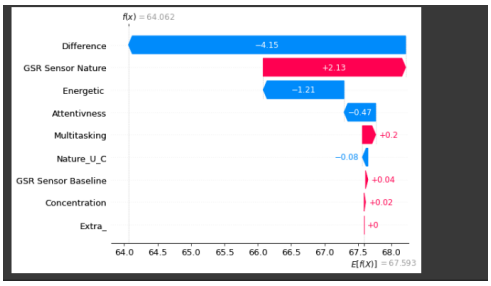


Figure 5.3: Effect of parameters on individual data point

Since the Given network is non-linear we took the help of SHAP [8] - one of the major papers on the explainable AI. The SHAP Value results obtained after training the network with the given set of features are given above as Fig 5.1 and Fig 5.2

According to the figure 5.1 we observe of all the given set of feature, the parametric difference (which calculates the difference between the baseline GSR value and the one one obtained after the video) seems to have the most effect on the final output where final output refers to the no of taps or time which is perceived during experimentation. The parameter difference seems to have the highest average impact on model output difference with the value being 1.3. After the feature difference, the GSR Value obtained after the experimentation effects the most in the model output value with the values being closer to 1.1 or 1.2. Taking in combination it makes sense these two features would have the largest effect in model output performance. One interesting thing to note that baseline GSR Value seems to have not much of an effect in model output (here output refers to the time perceived). This makes sense by noting the phenomenon the baseline GSR Values for most of the individuals are highly varied as value are quite sensitive to the moisture of the body. Furthermore it's also to be noted that the value in fig 5.1 only shows the extant to which the model output gets affected by the features, it does not tell whether it affects positively or negatively

The Figure 5.2 shows a snapshot of how the set of features combines to produce a row's output, as you can see how the difference plays a large negative role towards degradation of perception of time which makes sense in retrospect. The larger the difference more relaxed is the person and subsequently the lesser is the time perceived. This findings seems consistent with the literature findings [9]

The Fig 5.4 shows the architecture which we used for modelling and analyzing the experimental data. Kindly notice that the first layer have a 1 hidden layer, which makes it easier and appropriate to suggest

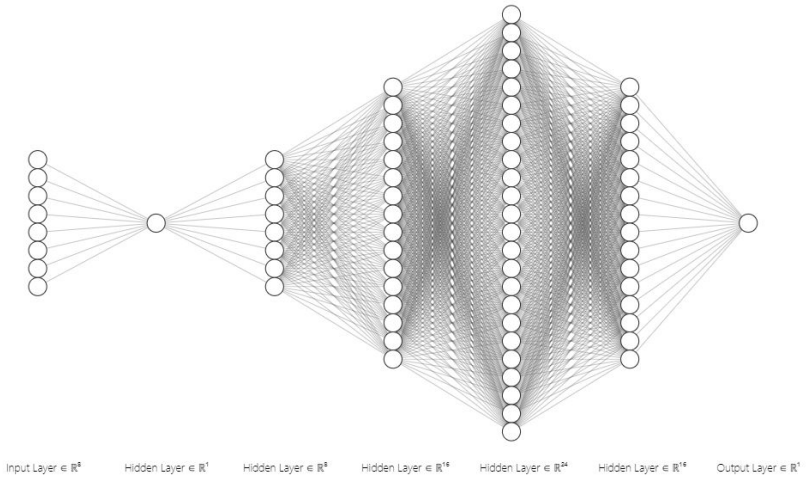


Figure 5.4: Architecture

the mathematical linear equation which would be provided as an input to the mapping function

Parameters	Coefficients
GSR Sensor Baseline	0.009
GSR Sensor Nature	0.739
Difference	-0.848
Multitasking	0.460
Concentration	0.341
Energetic	-0.527
Nature U C	0.112
Attentiveness	0.588
Disembodiment	0.291

Table 5.1: Table to test captions and labels.

The Table 5.1 Shows the coefficient each of the feature is contributing towards the final output. The coefficients are taken from the weight which connects the input layer to first hidden layer. According to coefficients the parameter difference has the highest absolute coefficient and is instrumental in providing the most impact on model output (The time perceived by an individual)

Hence Taking into the account the coefficient Tables, mathematically we can propose the following mathematical equation

$$Y = f(0.009\times X1+0.739\times X2-0.848\times X3+0.460\times X4+0.341\times X5-0.527\times X6+112\times X7+0.588\times X8+0.291\times X9) \tag{1}$$

Here $f(X)$ is the function the neural network learn for modelling the time perception. The function therefore could very well be nonlinear an hence there is a limit to the exact function we can propose, however through this arrangement we could very well propose the mathematical coefficients that we provide as an input to the function

However it is to be noted the values in Table 5.1 are of the pilot study and are not true experimental because the parameters we are testing for have cross interaction term and not mutually exclusive terms

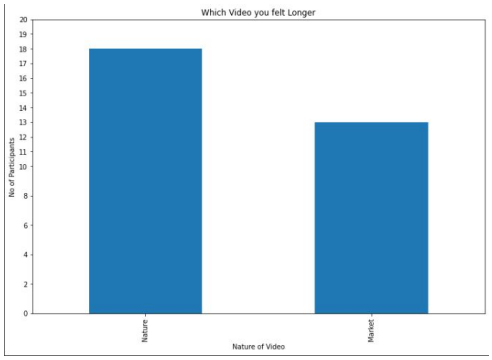


Figure 5.5: Which video You felt Longer

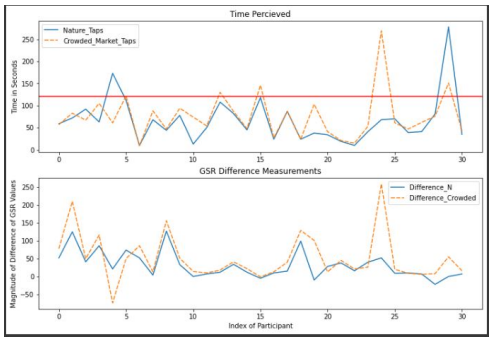


Figure 5.6: GSR Difference and Time Perceived

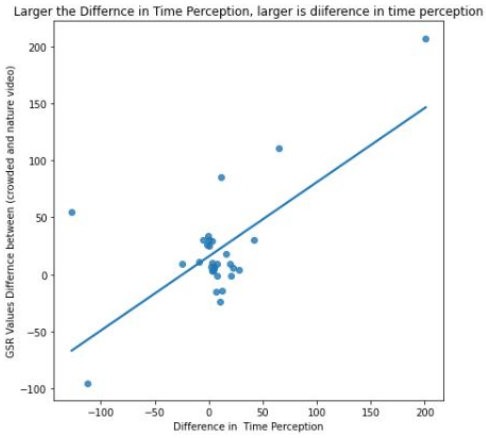


Figure 5.7: GSR Magnitude Difference and Time Perception Relationship

. Hence the Equation (1) should be taken with a grain of salt and while they provide us with baseline model , but should not be taken as true representative

The Fig 5.5 and Fig 5.6 provides additional insight into how the time are perceived by the individuals in the crowd setting as well as the nature setting. It is evident from the graph when people watched a crowded video they perceive time to be go by generally faster than when people watched a nature video. This is supported by the lower plot in Figure 5.6 as we had a significantly much more difference(GSR Values before the experiment and moving average after the experiment) in crowded market video than the nature video which suggest the people were much more relaxed in the crowded market video. This is an interesting observation however it could be explained with the phenomenon of mind wavering as its a possibility in crowded market video people get distracted by the liveliness of the place and thus felt less stressful

The Fig 5.7 provides a compelling argument that more the difference between the GSR Values, better is the time percieved by an individual as we can see a linear relationship between them too. Hence to rephrase the more the individual is relaxed, more likely he is able to judge time normally. This may be attributed to the phenomenon of mind wavering as we described above

6 Summary and Future plan of work

The project thus attempted to provide how thin line of distinction between embodiment and disembodiment is not quite present by providing the evidences from the literature arguing in favour of both disembodiment and embodiment characteristic involved in time perception. The project thus provides an attempt to motivate the research towards the computational model that invites the characteristics of both embodiment and disembodiment as discussed

Our M.tech project also successfully initiated a pilot study in which we measured how the humans perceive the time in embodied interaction . This is done using an experimental controlled setting in which people were also asked of their concentration and attentiveness which are the embodied parameter while also measuring anxiety during the experimentation and thus analyzing the effect of these in the time perception.

However as mentioned the embodied parameters are not exactly mutually exclusive and hence have several cross interaction terms, thus the future plan of the work is to experiment on a larger crowd in more experimental study. The future scope would study more deeply the individual parameters for instance the pupil dilation, measuring the values by more sophisticated instruments like EEG. The effort would also be done to isolate the parameters as much as possible for instance specifically testing for attentiveness like asking the participants did they observe the bird in the video during the experiment and exploring its effect for time perception.

Thus this particular research work is very useful for wide variety of the cases as we are tackling the time perception with respect to the embodiment perspective

References

[1] H. Basgol, I. Ayhan, and E. Ugur, "Time perception: A review on psychological, computational and robotic models," *IEEE Transactions on Cognitive and Developmental Systems*, 2021.

[2] C. Addyman, R. M. French, and E. Thomas, "Computational models of interval timing," *Current Opinion in Behavioral Sciences*, vol. 8, pp. 140–146, 2016.

[3] P. Simen, F. Rivest, E. A. Ludvig, F. Balci, and P. Killeen, "Timescale invariance in the pacemaker-accumulator family of timing models," *Timing & Time Perception*, vol. 1, no. 2, pp. 159–188, 2013.

[4] V. Arstila, "Experience and the pacemaker-accumulator model," *Journal of Consciousness Studies*, vol. 24, no. 3-4, pp. 14–36, 2017.

[5] W. Roseboom, Z. Fountas, K. Nikiforou, D. Bhowmik, M. Shanahan, and A. K. Seth, "Activity in perceptual classification networks as a basis for human subjective time perception," *Nature communications*, vol. 10, no. 1, pp. 1–9, 2019.

[6] I. Lourenço, R. Mattila, R. Ventura, and B. Wahlberg, "A biologically-inspired computational model of time perception," *IEEE Transactions on Cognitive and Developmental Systems*, 2021.

[7] H. Kurniawan, A. V. Maslov, and M. Pechenizkiy, "Stress detection from speech and galvanic skin response signals," in *Proceedings of the 26th IEEE International Symposium on Computer-Based Medical Systems*. IEEE, 2013, pp. 209–214.

[8] S. M. Lundberg and S.-I. Lee, "A unified approach to interpreting model predictions," in *Advances in Neural Information Processing Systems 30*, I. Guyon, U. V. Luxburg, S. Bengio, H. Wallach, R. Fergus, S. Vishwanathan, and R. Garnett, Eds. Curran Associates, Inc., 2017, pp. 4765–4774. [Online]. Available: http://papers.nips.cc/paper/7062-a-unified-approach-to-interpreting-model-predictions.pdf

[9] A. D. Whyman and R. H. Moos, "Time perception and anxiety," *Perceptual and motor skills*, vol. 24, no. 2, pp. 567–570, 1967.