**Introduction**

* Hypothesis:

**Methods**

* **Design:** independent and dependent variables.
* **Planned sample**
  + **Nonparametric estimation of power**
  + **Parametric power estimation**
  + **Exclusion criteria**
* **Procedure**
  + **Apparatus**
  + **Materials and stimuli**
  + **Procedure**

**Analysis plan**

* Confirmatory analysis

**Bibliography**

## Introduction

A citation with 🡪 after-words means that the articles that come after the arrow are from the paper that appears before the arrow.

### Background

#### What is unconscious processing

**General idea of paragraph:** What is UC processing?

**TODO:**

* Find articles about what is UC processing
* Write:
  + What is it? (from references)
    - Inattention:
      * Hyman Jr, I. E., Boss, S. M., Wise, B. M., McKenzie, K. E., & Caggiano, J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Applied Cognitive Psychology*, *24*(5), 597-607.
    - Weak stimuli:
      * Holland, R. W., Hendriks, M., & Aarts, H. (2005). Smells like clean spirit: Nonconscious effects of scent on cognition and behavior. *Psychological science*, *16*(9), 689-693.
    - Suppression from awareness:
      * Breitmeyer, B. G. (2015). Psychophysical “blinding” methods reveal a functional hierarchy of unconscious visual processing. *Consciousness and Cognition*, *35*, 234-250.
      * Kim, C. Y., & Blake, R. (2005). Psychophysical magic: rendering the visible ‘invisible’. *Trends in cognitive sciences*, *9*(8), 381-388.
    - Bargh, J. A., & Morsella, E. (2008). The unconscious mind. *Perspectives on psychological science*, *3*(1), 73-79.
    - Berger, J., & Mylopoulos, M. (2019). On scepticism about unconscious perception. *Journal of Consciousness Studies*, *26*(11-12), 8-32.
    - Eriksen, C. W. (1956). Subception: Fact or artifact?
    - Koch, C. (2011). Probing the Unconscious Mind
    - Kouider, S., & Dehaene, S. (2007, MAY 29). Levels of processing during non-conscious perception: a critical review of visual masking
  + Provide exp that show examples for it.
  + Mention it is "hotly debated"

**2:**

Our brain is a computational machine. It receives input via our senses (e.g., a sight of a ball flying your direction) and uses it to perform various computations, a.k.a. processing (e.g., what is the trajectory of the ball? Will it hit us?)

(Cite

Poirier 2005 - Specific activation of the V5 brain area by auditory motion processing an fMRI study.

Kanwisher 1997 - The fusiform face area a module in human extrastriate cortex specialized for face perception

Willander 2006 - Smell your way back to childhood Autobiographical odor memory

Kappers 2013 - Haptic perception).

The results of this processing could lead to a change in behavior (e.g., making us duck)

(Cite Aivar, M. P., Brenner, E., & Smeets, J. B. (2008). Avoiding moving obstacles. Experimental Brain Research, 190(3), 251-264.

von Hofsten, C., & Lindhagen, K. (1979). Observations on the development of reaching for moving objects. *Journal of experimental child psychology*, *28*(1), 158-173.

) and internal state (e.g., cause fear)

(cite Sawchuk 2002 - Emotional responding to fearful and disgusting stimuli in specific phobics

Schienle, A., Schäfer, A., Stark, R., Walter, B., & Vaitl, D. (2005). Gender differences in the processing of disgust-and fear-inducing pictures: an fMRI study. *Neuroreport*, *16*(3), 277-280.

Siedlecka 2019 - Experimental methods for inducing basic emotions A qualitative review

).

Some of the computations will also give rise to consciousness

(Cite Dehaene 2001 - Towards a cognitive neuroscience of consciousness, basic evidence and a workspace framework,

Dehaene 2011 - Experimental and theoretical approaches to conscious processing,

Mashour 2020 - Conscious processing and the global neuronal workspace hypothesis

Lamme 2000 - The distinct modes of vision offered by feedforward and recurrent processing

Tononi 2008 - Consciousness as integrated information a provisional manifesto

Tononi 2016 - Integrated information theory from consciousness to its physical substrate

Brown 2019 - Understanding the higher-order approach to consciousness

), meaning we will be aware of their results (e.g., perceive the flying ball). Others will not produce awareness (e.g., miss a voice shouting "Duck!" when extremely occupied by a very engaging game on your smartphone)

(Cite Jensen 2011 - Change blindness and inattentional blindness

Shapiro 1997 - The attentional blink

Kanwisher 1987 - Repetition blindness: Type recognition without token individuation

) and thus be called unconscious (UC) processing

(Cite Levels of processing during non-conscious perception: a critical review of visual masking

Bargh 2008 - The unconscious mind

Kihlstrom 1987 - The cognitive unconscious

). Although we aren't aware of their results they can still affect our behavior / internal state

(Cite Holland, R. W., Hendriks, M., & Aarts, H. (2005). Smells like clean spirit: Nonconscious effects of scent on cognition and behavior. *Psychological science*, *16*(9), 689-693.

Yes It Can: On the Functional Abilities of the Human Unconscious

).

Studying UC processing in the lab requires rendering a stimuli UC which can be done in three ways:

diverting attention away from the stimulus

(Cite Hyman Jr, I. E., Boss, S. M., Wise, B. M., McKenzie, K. E., & Caggiano, J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Applied Cognitive Psychology*, *24*(5), 597-607

Mack, A., & Rock, I. (1998). Inattentional blindness: Perception without attention. *Visual attention*, *8*, 55-76.

Fougnie, D., & Marois, R. (2007). Executive working memory load induces inattentional blindness. *Psychonomic bulletin & review*, *14*(1), 142-147.

),

presenting the stimulus very weakly

(Cite ~~Holland, R. W., Hendriks, M., & Aarts, H. (2005). Smells like clean spirit: Nonconscious effects of scent on cognition and behavior.~~*~~Psychological science~~*~~,~~*~~16~~*~~(9), 689-693.~~

Daltrozzo 2011 - Subliminal semantic priming in speech

Li 2007 - Subliminal smells can guide social preferences

),

or suppressing the stimulus ~~by surrounding it with more salient stimuli~~

(Cite

Review of many methods - Breitmeyer, B. G. (2015). Psychophysical “blinding” methods reveal a functional hierarchy of unconscious visual processing;

Review of many methods - Kim, C. Y., & Blake, R. (2005). Psychophysical magic: rendering the visible ‘invisible’. *Trends in cognitive sciences*, *9*(8), 381-388

Inter-ocular-occlusion- Moutoussis 2002 - The relationship between cortical activation and perception investigated with invisible stimuli.

CFS - Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature neuroscience*, *8*(8), 1096-1101.

CFS - Almeida, J., Pajtas, P. E., Mahon, B. Z., Nakayama, K., & Caramazza, A. (2013). Affect of the unconscious: Visually suppressed angry faces modulate our decisions. *Cognitive, Affective, & Behavioral Neuroscience*, *13*(1), 94-101.

Masking - Dehaene 1998 Imaging unconscious semantic priming

).

All three methods reduce brain's response to the stimuli

(Cite

Neural correlates of subliminal and supraliminal letter processing—An event-related fMRI study

)

thus making it less likely to evoke awareness. ~~Albeit the signal has to be strong enough to generate a change in behavior or state.~~

This weak signal usually translates to small behavioral changes, which are hardly detectable in behavioral experiments (@@ read and check if it says UC effects are usually small Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*(5282), 1699-1702.@@).

The difficulty in finding significant results is partially why contradicting findings are common in the field of UC processing, which makes it hotly debated.

**1:**

~~Conscious processing occurs when a stimuli is captured and processed by our brain, we become aware of it and it affects our behavior / attitudes / goals / judgments / reasoning / emotions…(@@ Find papers that show this @@).~~

~~Unconscious processing is occurs when a stimuli is captured and processed by our barin, but since that stimuli is degraded or outside the scope of our attention we do not become aware of it. Still it affects our behavior / attitudes / goals / judgments / reasoning / emotions…(@@ Find papers that show this @@).~~

~~In order to research UC processing we need to render stimulus UC in the lab. There are three methods for doing so: diverting attention away from the stimulus, presenting the stimulus very weakly, or suppressing the stimulus by surrounding it with more salient stimuli.~~

~~Either one is meant to reduce the size of the signal the stimuli generates just enough as to it not being perceived consciously but still be strong enough to affect other processes in the brain.~~

~~Since the signal in the brain is small usually the behavioraly measurable signal is also reduced, which makes it harder to locate in lab experiments (@@ read and check if it says UC effects are usually small Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation.~~*~~Science~~*~~,~~*~~273~~*~~(5282), 1699-1702.@@. This is partially why contradicting findings are common in the field of UC processing.~~

#### Contradicting findings

**General idea of paragraph:** Describe cases that found and others that didn't.

Do not describe methodological criticism, just the findings.

* **UC effect found**
  + Look in Ran Hassin Yes it can
  + Liad's grant:
    - Response priming:
      * Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Sciences*, *100*(10), 6275-6280.
      * Schmidt, F., Haberkamp, A., & Schmidt, T. (2011). Dos and don’ts in response priming research. *Advances in Cognitive Psychology*, *7*, 120.
      * Furstenberg, A., Breska, A., Sompolinsky, H., & Deouell, L. Y. (2015). Evidence of change of intention in picking situations. *Journal of Cognitive Neuroscience*, *27*(11), 2133-2146.
    - Emotion:
      * Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and behavioral evidence for affective priming from unconsciously perceived emotional facial expressions and the influence of trait anxiety. *Journal of Cognitive Neuroscience*, *20*(1), 95-107.
      * Pessoa, L. (2005). To what extent are emotional visual stimuli processed without attention and awareness?. *Current opinion in neurobiology*, *15*(2), 188-196.
      * Olsson, A., & Phelps, E. A. (2004). Learned fear of “unseen” faces after Pavlovian, observational, and instructed fear. *Psychological science*, *15*(12), 822-828.
      * Faivre, N., Berthet, V., & Kouider, S. (2012). Nonconscious influences from emotional faces: a comparison of visual crowding, masking, and continuous flash suppression. *Frontiers in psychology*, *3*, 129.
      * Sweeny, T. D., Grabowecky, M., Suzuki, S., & Paller, K. A. (2009). Long-lasting effects of subliminal affective priming from facial expressions. *Consciousness and cognition*, *18*(4), 929-938.
    - Semantic:
      * Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., ... & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, *395*(6702), 597-600.
      * Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision and visual masking
      * Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B., & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature neuroscience*, *4*(7), 752-758.
      * Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General*, *127*(3), 286.
      * Stenberg, G., Lindgren, M., Johansson, M., Olsson, A., & Rosén, I. (2000). Semantic processing without conscious identification: Evidence from event-related potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(4), 973.
    - Contextual:
      * Biderman, D., Shir, Y., & Mudrik, L. (2020). B or 13? Unconscious top-down contextual effects at the categorical but not the lexical level. *Psychological science*, *31*(6), 663-677.
      * Van Opstal, F., Calderon, C. B., Gevers, W., & Verguts, T. (2011). Setting the stage subliminally: unconscious context effects. *Consciousness and cognition*, *20*(4), 1860-1864.
    - Integration:
      * Mudrik, L., Faivre, N., & Koch, C. (2014). Information integration without awareness. *Trends in cognitive sciences*, *18*(9), 488-496.
      * Mudrik, L., Breska, A., Lamy, D., & Deouell, L. Y. (2011). Integration without awareness: Expanding the limits of unconscious processing. *Psychological science*, *22*(6), 764-770.
      * Faivre, N., Dubois, J., Schwartz, N., & Mudrik, L. (2019). Imaging object-scene relations processing in visible and invisible natural scenes. *Scientific Reports*, *9*(1), 1-13.
    - Cognitive control / decision making:
      * van Gaal, S., De Lange, F. P., & Cohen, M. X. (2012). The role of consciousness in cognitive control and decision making. *Frontiers in human neuroscience*, *6*, 121.
    - Arithmetic:
      * Sklar, A. Y., Levy, N., Goldstein, A., Mandel, R., Maril, A., & Hassin, R. R. (2012). Reading and doing arithmetic nonconsciously. *Proceedings of the National Academy of Sciences*, *109*(48), 19614-19619.
    - Face perception:
      * Barbot, A., & Kouider, S. (2012). Longer is not better: nonconscious overstimulation reverses priming influences under interocular suppression. *Attention, Perception, & Psychophysics*, *74*(1), 174-184.
      * Kouider, S., Eger, E., Dolan, R., & Henson, R. N. (2009). Activity in face-responsive brain regions is modulated by invisible, attended faces: evidence from masked priming. *Cerebral Cortex*, *19*(1), 13-23.
    - Loftus, E. F., & Klinger, M. R. (1992). Is the unconscious smart or dumb?. *American Psychologist*, *47*(6), 761.
    - Van Gaal, S., & Lamme, V. A. (2012). Unconscious high-level information processing: implication for neurobiological theories of consciousness. *The neuroscientist*, *18*(3), 287-301.
    - Hesselmann, G., & Malach, R. (2011). The link between fMRI-BOLD activation and perceptual awareness is “stream-invariant” in the human visual system. *Cerebral Cortex*, *21*(12), 2829-2837.
* **Effect not found**
  + Look in reply to Ran Hassin (Hesselmann 2015)
  + Failed replications:
    - Levels of processing during non-conscious perception: a critical review of visual masking
    - Integration:
      * Biderman, N., & Mudrik, L. (2018). Evidence for implicit—but not unconscious—processing of object-scene relations. *Psychological science*, *29*(2), 266-277.
      * Moors, P., Boelens, D., Van Overwalle, J., & Wagemans, J. (2016). Scene integration without awareness: No conclusive evidence for processing scene congruency during continuous flash suppression. *Psychological science*, *27*(7), 945-956.
    - Arithmetic:
      * Moors, P., & Hesselmann, G. (2018). A critical reexamination of doing arithmetic nonconsciously. *Psychonomic Bulletin & Review*, *25*(1), 472-481.
    - Semantic:
      * Rabagliati, H., Robertson, A., & Carmel, D. (2018). The importance of awareness for understanding language. *Journal of Experimental Psychology: General*, *147*(2), 190.
  + Liad's grant:
    - Gayet, S., Van der Stigchel, S., & Paffen, C. L. (2014). Breaking continuous flash suppression: Competing for consciousness on the pre-semantic battlefield. *Frontiers in psychology*, *5*, 460.
    - Moors, P., Hesselmann, G., Wagemans, J., & van Ee, R. (2017). Continuous flash suppression: Stimulus fractionation rather than integration. *Trends in Cognitive Sciences*, *21*(10), 719-721.
  + Other papers that failed to find UC effect.

**UC Effect found**

One theory claims any fundamental function performed by conscious (C) processing can also be done unconsciously (Hassin 2013). A line of empirical evidence supports it by showing a variety of functions being performed unconsciously: cognitive control, goal management, information broadcasting, reasoning, memory, implicit learning, emotional cues extraction and comparison of self with others. @@ Consider replacing this by simply describing each finding @@

**UC Effect not found**

#### Explaining The discrepancy between findings

**General idea of paragraph:** Assuming a phenomenon either exists or it doesn't,

Gettingcontradicting results indicate something is done wrong.

The mistake might lay in the usage of measurements.

Either positive results are false since UC processing is overestimated

(when awareness is underestimated),

Or null results are false since UC processing is underestimated.

Do these contradicting findings represent a genuine heterogeneity in unconscious processing, or could they stem from methodological limitations of some of these studies?

Maybe you these paper would be of interest:

For:

* Dubois, J., and Faivre, N. (2014). Invisible, but how? The depth of unconscious processing as inferred from different suppression techniques @@@ Do you wish to read this? @@@
* Extra:
* Bargh, J. A., and Morsella, E. (2008). The unconscious mind
* Bargh, J. A., Schwader, K. L., Hailey, S. E., Dyer, R. L., and Boothby, E. J. (2012). Automaticity in social-cognitive processes
* Van den Bussche, E., Van den Noortgate, W., and Reynvoet, B. (2009). Mechanisms of masked priming: a meta-analysis.
* Dehaene, S. (2014). Consciousness and the Brain: Deciphering How the Brain Codes Our Thoughts

Against:

* A critical reexamination of doing arithmetic nonconsciously

These aren't reviews, but might be interesting:

* Doyen, S., Klein, O., Pichon, C.-L., and Cleeremans, A. (2012). Behavioral priming: it’s all in the mind, but whose mind?
* Stein, T., Kaiser, D., and Hesselmann, G. (2016). Can working memory be non-conscious?
* Street, C. N. H., and Vadillo, M. A. (2016). Can the unconscious boost lie-detection Accuracy?

##### positive findings – Over estimation of UC processing = Underestimation of awareness

**General idea of paragraph:** Describe ideas that show how awareness can be underestimated which leads to UC

overestimation.

For each idea show exps that showed this happens.

**TODO:**

* Liad's grant –
  + Find papers that show the under estimation of awareness

(over estimation of UC effect)

Include the empirical evidence.

Add these to the paragraph "Even when these…".

* + Find papers with failed replications? – they show the UC effect was indeed overestimated.

One source of methodological difference relate to the way consciousness is being measured.

Some claim UC processing is extremely limited and instead attribute the existing UC effects to the failure of discovering the residual awareness of the stimuli.

This type of underestimation occurs when the awareness measure fails to be reliable (influenced by the factors that affect performance), relevant (measures aspects of awareness relevant to the performance task), immediate (follows immediately after the performance task, hence preventing forgetting and interference) or sensitive (able to discover residual awareness if it exists) (@@ Cite Newell 2014 @@). @@ Split this sentence, it's too long @@

Even when these four criterions are met, awareness can still be underestimated if the participant sets a high criterion for reporting a seen stimuli (@@ From Newell 2014, and find empirical evidence there @@) or if the awareness assessment task is too difficult (@@ From Newell 2014, and find empirical evidence there @@); A difficult task could diminish the motivation for exhaustive introspection and hinder the accurate report of awareness.

Another factor that can inflate the UC effect is "bad" experimental design; Failing to include a proper baseline condition could lead researchers to conclude a positive UC effect when in fact the result stems from a negative C effect (@@ Cite Newell 2014 @@). For example, when C memories and judgments are distorted by "over thinking" a solution (@@ Find empirical evidence in Newell 2014 @@).

A False UC effect might also be deducted when behavioral results can be explained by direct associations between stimuli and response, thus making the mediating unconscious stage between them redundant (@@ From Newell 2014, and find empirical evidence there @@).

Finally, a major cause for inflation is pitfalls in the analysis, such as failing to account for regression to the mean. When taken into consideration regression to the mean can show that previously found UC effects are a result of noise in the awareness measurement (@@ Cite Shanks 2014 @@), (but see @@ Cite Sklar 2021 @@).

##### Explaining null findings – Insensitive measures cause unconscious processing under estimation

**General idea of paragraph:** Show UC can be underestimated when UC measures aren't sensitive enough.

Use your chapter about keyboard RT vs motion tracking.

First describe why RT is bad and give experimental evidence.

Then describe why Motion tracking is better.

Another option, conversely, is that the null findings reflect insensitive measures that have a hard time discovering the already small effect (@@ read this: Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*(5282), 1699-1702.@@).

#### Prev papers with motion tracking

Put the chapter you wrote. Before writing this, ask Liad if it is needed, and if this is the appropriate location.

#### Prev papers with motion tracking and keyboard

Put the chapter you wrote. Before writing this, ask Liad if it is needed, and if this is the appropriate location.

#### Xiao + reaching vs mouse

Put the chapter you wrote. Before writing this, ask Liad if it is needed, and if this is the appropriate location.

#### Current Research

**General idea of paragraph:** Will deal with the the false null findings, trying to improve the sensitivity of measures.

RT vs. motion tracking.

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#### Motion VS Keyboard

The difficulty could be due to the measure being used.

Trajectory tracking has become a popular tool for revealing the development of cognitive effects and may be the answer for that. Some studies have utilized the rich nature of the data it produces to probe different cognitive processes.

One aspect of richness could be the temporal domain. Regular measures usually produce a discrete value for each trial, while the cognitive process they measure might be continuous. For example (Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors) used trajectory analysis to show that a distractor word that shares phonetic properties with the target word's beginning delay the point when the answer is selected, concluding that spoken words are processed incrementally, creating multiple possible representations in every step along the way.

Another example could be inspecting the development of evolving semantic processes. (Farmer et al., 2007a,b).

Motion tracking can even be used to reveal private / hidden attitudes. For example (The action dynamics of overcoming the truth.) showed a difference in trajectory between truthfull answers and lies. Another example is revealing stereotypical thinking with motion tracking (Motions of the hand expose the partial and parallel activation of stereotypes).

A slightly different directin is using trajectory to perform online confidence monitoring (Dotan 2018 - Online confidencemonitoring during decision making). Motion tracking enabled to inspect the unfolding of the decision but also the fluctuations (instead of a single discrete value @put more emphasis on this in the sentence@) in the confidence as the decision is being made. Another advantage is the fact that this measure of confidence is implicit.

Another aspect of richness is expressed in that vast number of parameters that can be extracted from it:

Movement time, onset time, velocity, acceleration, position in time, deviation from optimal path, number of changes in direction, timing of changes in direction, area difference from optimal path

@@@@@ From response on email to Nadav's question @@@@@

Me:

* Decision making processes are continuous: they develop and change over time until you reach your final decision. Keyboard responses can only capture the final decision and the time it took to reach it. In contrast, motion tracking can capture fluctuations in our final decision as it formulates (since changes of mind are reflected by our reaching movements). These fluctuations might be exactly what we are looking for when researching unconscious effects on behavior.
* While keyboard response only provides you with RT and accuracy, motion tracking also produces: velocity, acceleration, position across time, deviations from optimal path, reach area and much more. Some effects might not be reflected in RT but appear in other parameters of the response
* Changes of mind are represented in movement:
  + *Changes of Mind after Movement Onset Depend on the State of the Motor System –* Read only abstract. Changes of mind occur naturally and happen most often when both targets have equal reward. But they can also be artificially induced by perturbating the motor system (applying force to sub’s hand).
  + *Rapid Online Changes of Mind during Value-based Action Decisions –* Read only abstract. subjects reaches a target which has highest value, values are changed as they move, and they adjust accordingly. Thus, a COM is represented in their movement.
  + *The real-time link between person perception and action: brain potential evidence for dynamic continuity* – Read only abstract. The Process that categorizes stimuli immediately shares its output with the motor cortex. Motor cortex starts preparing for response while categorization knowledge evolves in parallel. This means initial movement is guided by partial information only.

**Amir:**

Hey, Mudrik lab ghost from the past here,

I think that's a great answer, and perhaps one addition that can be made is that RT is typically a backward-looking (retrospective) measure, while motion tracking is online.

It depends on what you're studying, but typically we're interested in the process happening before a subject makes a response (e.g. anticipation, preparation, decision making..). With RT we interpret what happened before the response using how quickly that process ended. So it's an indirect measure. Motion tracking, on the other hand, captures the data *while the process is happening,* so in that respect is more directly measuring the phenomenon in question (and with more sensitivity as you put very nicely).

I used that argument when using eye tracking instead of RT to gauge anticipation, but the same goes for motion tracking. See Dale, Duran & Morehead 2012 for that argument exactly.

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

@@

Articles showing trajectory analysis has a rich nature:

* It enables to investigate the temporal dynamics of cognitive processes
* Regular measures are discrete while cognitive processes are continues.

Maybe in the introductions of these papers there would an explanation for why trajectory analysis is good, and a citation of papers showing that:

Dotan 2019 - Track it to crack it Dissecting processing stages with finger tracking

Dotan 2013 - How do we convert a number into a finger trajectory

Dotan 2016 - On the origins of logarithmic number to position mapping

Papers showing the usefulness of trajectory analysis:

Dotan 2018 - Online confidence monitoring during decision making

Gallivan & Chapman 2014 - Three-dimensional reach trajectories as a probe of real-time decision-making between

Freeman et al. - 2011 - Hand in Motion Reveals Mind in Motion (good information in my abbreviation).

@@

When considering keyboard response, it can be understood that it represents only the final decision after the subjects have already made up their mind.

In contrast, when using motion tracking subjects can start moving before making their final choice and correct their trajectory on the fly. The changes in trajectory will reveal the cognitive conflicts on the way to formulating the final response (Freeman et al. - 2011 - Hand in Motion Reveals Mind in Motion).

If so, trajectory tracking might be a preferable venue for researchers studying unconscious processing.

Motion tracking also allows subjects to change their mind and still fall within the timing constraints of the task. @@ maybe you should just say that motion tracking can capture changes of mind while keyboard response can't @@

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#### Prev papers with motion tracking

Indeed, some articles have utilized trajectory tracking to investigate unconscious processing.

In an interesting paper (Exp 1 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming.) who ever wrote it used motion tracking to reveal unconscious semantic processing of images (see also: Temporal dynamics of masked congruence priming: evidence from reaching trajectories, **Exp1** in: Engaging the motor system with masked orthographic primes: A kinematic analysis, **Exp2** in: Engaging the motor system with masked orthographic primes: A kinematic analysis). The writers presented participants pictures of animals / persons and ask them to categorize the images accordingly by reaching the appropriate category. Each image was preceded by an unconscious prime image of an animal / person, which when incongruent to the target caused deviations from the optimal path to the target.

Others have demonstrated conceptual priming by asking participants to reach the appropriate category (digits / letters) of the target stimuli which was preceded by an unconscious prime. Incongruent primes caused greater deviation in the trajectory to the target (Exp 2 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming.).

Response priming has been replicated with motion tracking in an exp by (Subliminal semantic priming in near absence of attention: A cursor motion study, The role of attention in subliminal semantic processing: A mouse tracking study) where subjects had to judge a target digit as smaller / larger than 5 by pressing the correct side of the screen. When the target was preceded by an incongruent prime digit, the trajectory length was bigger. A common measure, used also in that paper is Area Under the Curve (AUC) which measures the area between the optimal path and the actual path, where areas central to the optimal path indicates a conflict between the possible decisions and is considered positive, while areas lateral to the optimal path are considered negative. A larger AUC indicates a greater effect of the prime on the trajectory.

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#### Prev papers with motion tracking and keyboard

Some have even included both keyboard and trajectory analysis measures in their research.

(On-line control of pointing is modified by unseen visual shapes) used keyboard response to show that unconscious primes influence the onset time of motor responses, and then used motion tracking to expand the finding and show that unconscious prime also influenced the ongoing execution of the motor response. This indicated that the movement trajectories were processed in a feed forward manner, initially influenced by an unconscious prime and then by the target when it became available.

(Exp 4 in: Grasping with the eyes: The role of elongation in visual recognition of manipulable objects) has shown an unconscious semantic priming effect once using a keyboard and again using motion tracking. Congruent prime pictures of animals / tools facilitated the RT in the keyboard experiment, in the motion tracking experiment incongruent primes caused a larger AUC than congruent ones. That being said, this experiment used a small set size of stimulus and as mentioned by the authors the effect found could be explained by the shape of the items instead of their semantic category.

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#### Xiao + reaching vs mouse

However, to date, in the context of unconscious effects, only one study made a direct comparison between this measure and a classic dichotomous keyboard response measure.

(Assessing Masked Semantic Priming: Cursor Trajectory versus Response Time Measures) has shown that unconscious images of positive / negative items facilitate same / different response accordingly when judging the similarity between two digits. Critically, this effect was marginally significant when recorded with a keyboard, in contrast to a strong effect when using the AUC parameter in a mouse tracking version of the experiment.

However, this study did not use a subjective measure of awareness in every trial, but rather an objective measure in a separate session from the test session. This means the prime visibility in a single trial level cannot be assessed. In addition, the number of awareness trials (96) didn't reach the minimal required threshold (200) for discovering conscious processing of supposedly unconscious stimuli (as shown in recent work in our lab). Finally, the measure used by the authors to evaluate awareness of the prime was checking for a correlation between d' and the size of the priming effect. This measure has been shown to inflate unconscious effects (Correlation analysis to investigate unconscious mental processes: A critical appraisal and mini-tutorial). They didn't statistically evaluate the absolute value of d'. When examining the single subject's d' it seems it is larger than zero for a large number of subjects, meaning they were actually aware of the prime.

The conclusion in the paper about semantic priming might also be put into question considering the unintuitive semantic connection claimed to exist between positive / negative stimuli and same / diff responses.

One more aspect to be taken into consideration is the comparison between natural movements of reaching and limited movements while using mouse tracking to probe cognitive processes. Responding with a mouse requires subjects to remap the representation of the stimuli in the real world into the 2D screen representations, this transformation could affect the trajectory and timing (@@ read this @@ Moher and Song 2019🡪 Palluel-Germain, Boy, Orliaguet, & Coello, 2004 @@) and place constraints on the subjects movement (@@ Make sure it appears in these papers @@ Moher and Song 2019🡪 Desmurget, Jordan, Prablanc, & Jeannerod, 1997; Desmurget, Prablanc, Jordan, & Jeannerod, 1997; Palluel-Germain, Boy, Oliaguet, & Coello, 2004) and inhibit process which might be of interest to us from being expressed in the motion.

Indeed, when comparing it to reaching for an answer in the real world, reaching has been shown to have faster movement times, larger movement curvatures (Moher and Song 2019🡪 Desmurget, Jordan, Prablanc, & Jeannerod, 1997; Desmurget, Prablanc, Jordan, & Jeannerod, 1997; Palluel-Germain, Boy, Oliaguet, & Coello, 2004 @@ Read abstract and discussion to check if relevant in the next paper: "larger curvature represents uncertainty about predicted target position" Reaching for known unknowns: Rapid reach decisions accurately reflect the future state of dynamic probabilistic information@@), faster velocities and most importantly to respond faster to changes of mind, which makes it optimal for detecting fast and short lasting processes such as unconscious priming effects. Even more importantly, it has been shown that changes of mind are less likely to occur when a motor demand of a task is higher (@@ Read this @@ Moher and Song 2019🡪 Burk, Ingram, Franklin, Shadlen, &Wolpert, 2014; Moher&Song, 2014), this means incongruent effects might occur less frequently.

-----------------------------------------------------------------------------------------------------------

#### Current research

In the current research we will compare two measures of unconscious processing: response time given via a keyboard and reaching area derived from 3D motion tracking of reaching movements. Subjects will perform a semantic classification task (does the target describe an "natural" / "artificial" item) in which the target word will be preceded by an unconscious prime that can be congruent / incongruent to the target's category. Next, the subject will be asked to recognize the prime in a two forced choices task, and finally they will rate the prime's visibility in a PAS scale (from 1 for "Didn't see anything" to 4 for "Saw the prime clearly"). In an unreported pilot study we found out subjects have a hard time providing correct answers in the short time constraints of the task, thus the experiment will be comprised of two sessions in two consecutive days. The first day includes only a training session without primes and its purpose is to allow subjects to hasten their responses in the reaching task while keeping their accuracy high. The second day includes a short training and a test session.

Since our expected effect size isn't large and our variability is (according to our pilots, so I need to check this is the case in our pilots) we will be using a withing subject design, so that the unconscious effect won't be shadowed by individual differences.

To avoid practice effect, the order of sessions will be counterbalanced between subjects.

You need to mention this is a replication of Deheane's study.

-----------------------------------------------------------------------------------------------------------

We used the previous studies results and compared their keyboard response time measure and their trajectories measures.

Almeida et al. – 2014:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure** | **Parameter** | **Contrast type** | **Mean difference**  **Congruent – incongruent**  **Mean (SEM)** | **t-value** | **Cohen's dz** |
| Keyboard | RT (ms) |  | 9 (3) | 2.86 | 0.53 |
| Reach | AUC (mm2) |  | 2.3 (1.4) | 2.334 | 0.38 |
| Keyboard | RT (ms) |  | 16 (6) | 2.55 | 0.47 |
| Reach | AUC (mm2) |  | 3 (1.3) | 2.252 | 0.37 |
| Keyboard | RT (ms) |  | 13 (6) | 2.06 | 0.38 |
| Reach | AUC (mm2) |  | 2.4 (1.2) | 2.4 | 0.39 |

* t=tool, a=animal, .=oblong, \_=elongated
* Cohen's dz calculated using t-value.
* Keyboard RT – N=29
  + Con-incon 1: mean diff (SEM of diff), 9ms (3), t = 2.86,

Cohen's dz = 0.53

* + Con-incon 2: 13ms (6), t = 2.06,

Cohen's dz = 0.38

* + Con-incon 3: 16ms (6), t = 2.55,

Cohen's dz = 0.47

* AUC – N=37
  + Incon-con 1: 2.3mm2 (1.4), t = 2.334,

Cohen's dz = 0.38

* + Incon-con 3: 2.4 mm2 (1.2), t = 2.4,

Cohen's dz = 0.39

* + Incon-con 2: 3mm2 (1.3), t = 2.252,

Cohen's dz = 0.37

Cressman et al. – 2007:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure** | **Parameter** | **Congruent Mean (SE)** | **Incongruent**  **Mean (SE)** | **Cohen's dav** | **Hedge's gav** |
| Keyboard | RT (ms) | 333.2 (9.5) | 389.9 (7.1) | 2.16 | 2.06 |
| Motion tracking | MT (ms) | 515 (12.1) | 571.7 (10.9) | 1.53 | 1.47 |
| Motion tracking | Correcting movement onset (ms) | 277.3 (4.4) | 333 (4.6) | 3.91 | 3.74 |
| Motion tracking | Correcting movement length (mm) | 70 (SD=15.3) | 79.2 (SD=14.9) | 0.6 | 0.58 |
| Motion tracking | Correcting movement velocity (mm/s) | 475.7 (SD=38.9) | 533.3 (SD = 64.8) | 1.11 | 1.06 |

* Keyboard RT – Cohen's dav = 2.16, Hedge's gav = 2.06
  + Congruent: mean (SE), 333.2ms (9.5)
  + Incongruent: 389.9ms (7.1)
* Reach MT – Cohen's dav = 1.53, Hedge's gav = 1.47
  + Congruent: 515ms (12.1)
  + Incongruent: 571.7ms (10.9)
* Correcting mvmnt onset – Cohen's dav = 3.91, Hedge's gav = 3.74
  + Congruent: 277.3ms (4.4)
  + Incongruent: 333ms (4.6)
* Correcting mvmnt length – Cohen's dav = 0.6 , Hedge's gav = 0.58
  + Congruent: 70mm (SD=15.3)
  + Incongruent: 79.2mm (SD=14.9)
* Correcting mvmnt velocity – Cohen's dav = 1.11, Hedge's gav = 1.06
  + Congruent: 475.7 mm/s (SD = 38.9)
  + Incongruent: 533.3 mm/s (SD = 64.8)

~~Indeed it shows that trajectory measures bring about a greater effect size.~~

~~This supports our hypothesis.~~

@@ When writing your thesis @@ @@ Explain about our pilot studies, how did we start, what did we change in each one and why, how does it help us produce greater effects @@

### Hypothesis

In-line with previous comparisons between motion tracking and keyboard responses, we expect motion tracking to detect a greater incongruency effect (when comparing the effect size of both measures).

## Methods

### Design

IV:

1. Congruency: A within subject variable of two levels:
   1. Congruent: prime and target are the same word.
   2. Incongruent: Prime and target are from a different semantic category and do not share letters in common locations.
2. Item type: A within subject variable of two levels:
   1. Natural: target and / or prime represent a natural item (e.g. "Plant", "Cloud").
   2. Artificial: target and / or prime represent an artificial product (e.g. "Radio", "Phone").
3. Response measure: A between subject variable of two levels:
   1. Motion tracking: Subjects choose the correct answer on by reaching and touching it on the screen.
   2. Key press response: Subjects choose the answer on the left / right half of the screen by pressing "F" / "J" accordingly.

DP:

1. Area under the curve (AUC): Area between the actual trajectory and the optimal path (a straight line connecting the start and end points). Area central to the optimal path is considered positive, while area lateral to it is considered negative. The area is evaluated for each trial separately.
2. Reach area: Area between the average path to a left target and an average path to a right target in a single condition (congruent / incongruent). Path is averaged across trials in a single condition.
3. Response time: The time it takes a subject to classify the target as natural / artificial, measured from target display until keyboard response.
4. MAD @@@@@@@@@@@@describe it@@@@@@@@@@@@@@@@@@@
5. X-position @@@@@@@@@@ describe it @@@@@@@@@@@@@@

### Planned sample

All subjects will be right-handed, native Hebrew speakers who aren't color blind have normal or corrected-to-normal vision using contact lenses (the reflection on glasses could create problems with the motion tracking system). Only subjects declaring that they have no neurological, attentional, or mental disorders, and not taking psychiatric medicines, will be included.

Data will be collected at Prof. Liad Mudrik's lab of high cognition in Tel-Aviv University, from students or other young adults at the ages of 18-35, in two session on two consecutive days, the first lasting 30 minutes and the second lasting 90 minutes.

Subjects will be reimbursed with course credit or cash payment.

### Sample size estimation

#### Non-parametric sample size estimation

In the correspondence with Craig "Missing frames in trajectory" he mentions about 1/4 of the subjects are disqualified:

"".

[Power analysis guide with G\*Power](https://osf.io/zqphw/)

[Power analysis guide on lab handbook](https://osf.io/zqphw/)

[Online calculator for power analysis in LMM](https://jakewestfall.shinyapps.io/crossedpower/)

[Using simulations to conduct power analysis in LMM](https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.12504)

[Tutorial on power analysis in LMM](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6646942/)

[Sample size estimation tool for between group design](https://journals.sagepub.com/doi/10.1177/25152459211054059)

* What effect size parameter fits a mixed model?
  + Power analysis and effect size in mixed effect models: a tutorial
  + Statistical Power and Optimal Design in Experiments in Which Samples of Participants Respond to Samples of Stimuli
  + <https://www.ssc.wisc.edu/sscc/pubs/MM/MM_TestEffects.html>
  + A practical guide to calculating Cohen’s f2, a measure of local effect size
* Do you need multiple datapoints in order to use subject as a random factor?
  + <https://stats.stackexchange.com/questions/65371/mixed-model-with-1-observation-per-level>
  + <https://stats.stackexchange.com/questions/242821/how-will-random-effects-with-only-1-observation-affect-a-generalized-linear-mixe>

This is a description of non-parametric power analysis:

To estimate the required sample size for receiving a power of 0.8 we used resampling of the data.

We sampled with replacement *n* subjects out of the *N* = 20 available subjects from the pilot study, and calculated the effect size and *p-value* on that sample. This was done 104 times for each sample size from 1 to 20, and the percent of significant *p-values* was computed for each sample size. This estimate was used as power.

#### Parametric power estimation

### Exclusion criteria

@@ Add exclusion criteria after adding the keyboard experiment @@

The following trials will be excluded:

1. Trials in which there was a technical malfunction with the setup or recording:
   1. Over 100ms of missing samples in the trajectory.
   2. Less than 100ms of existing samples in the trajectory.
   3. Stimuli presentation time deviated from desired duration by more than 2ms.
   4. No response was given /recorded via the keyboard.
2. Trials in which the subject provided a problematic response:
   1. Short reach distance: the reach on the *Z* axis is shorter than the distance between the starting point and the screen minus the finger size.
   2. Missed both targets: touch point is outside a 12cm radius circle surrounding each target laying flat on the screen.
   3. When reaching, moved too early (less than 100ms after target display, implying a planned response), too late (more than 320ms after target was displayed) or too slow (time to reach the screen from movement onset was longer than 420ms).
   4. Keyboard press was too early (less than 200ms after target), or too late (more than 4000ms after target).
   5. Wrong answer in classifying the target. Cognitive processes on correct and incorrect answers may be different. @@ Find a citation for this or ask Craig @@

The following subjects will be excluded:

~~During data collection:~~

1. ~~Who failed to respond within the time constraints on at least 30% of the trails on the training day. This implies the subject won't be able to handle the required response times on the test day, and thus he will be disqualified. @@ Add this criterion to the analysis (Put a threshold of 30% in code) (Insert the checkDay1 to the tests or something to make sure you run it after every subjects) @@~~

After data collection:

1. Who has less than 30 valid (that weren't excluded) trials in each level of the congruency IV.
2. Who failed to classify the target correctly on at least 70% of the trials (verified using a binomial test).
3. Who's answer at recognizing the prime are found to be better than chance level in a binomial test.

### Procedure

#### Apparatus

The stimulus is displayed on a VPIXX monitor (VIEWPixx /3D Lite LCD display and data acquisition system, version 3.7.6287) using Matlab 2018b @@ Cite @@ and Psychtoolbox @@ version?@@ @@ Cite @@. The monitor is used with full brightness at a resolution of 1920 x 1080 and refresh rate of 100Hz with VPIXX's "Scanning backlight" feature turned on which synchronizes the stimuli display to the screen's refresh rate. A Perspex cover is placed over the screen to protect it when participants are reaching for it. The cover was spray painted with a light layer of transparent matte lacquer to avoid reflections. The subjects sit approximately 60 cm from the screen and place their finger on a marked starting point which is located on the table 35cm away from the screen, in line with its center. The stimuli is displayed 24cm above the table and the calssification answers will be displayed 10 cm to the left and to the right of it. Subjects wear a Velcro ring on their index finger to which a reflective marker is attached. A system of 6 OptiTrack Flex 13 cameras @@ cite @@ tracks the marker's location using Motive 2.2.0 software @@ cite @@ at a sampling rate of 120Hz. The coordinates are broadcasted online to a NatNet client @@ cite @@ on the experimental computer and recorded with Matlab.

#### Materials and stimuli

**Stimuli Selection**

Sixty 4-letter Hebrew words will be used as targets on the training day of the experiment, and one hundred 5-letter words will be used as primes and targets on the test day. All words will be imageable nouns with a frequency of at least 10 per million (Cite: <http://word-freq.mscc.huji.ac.il/>). Half will describe artificial products (e.g. radio, train) and half natural items (e.g. fruit). Target words will be written in typescript while prime words will be written in handwriting font. Masks will be composed of a semi-random combination of squares and diamonds whose line thickness is equal to the word's font size and will cover the central area of the screen where words can appear (approximately ).

Hebrew letters in typescript and handwriting:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| א | ב | ג | ד | ה | ו | ז | ח | ט | י | כ | ך | ל | מ | ם | נ | ן | ס | ע | פ | ף | צ | ץ | ק | ר | ש | ת |
| א | ב | ג | ד | ה | ו | ז | ח | ט | י | כ | ך | ל | מ | ם | נ | ן | ס | ע | פ | ף | צ | ץ | ק | ר | ש | ת |

**Trial Lists Generation**

The order of the stimuli will be taken from a list of 10 stimuli sequences called "Trial sequences". One sequence will be randomly sampled (without replacement) for every participant. Once all sequences were selected (after 10 subjects), the list will be refilled with the original sequences.

The order of the words will be random with the following constraints:

Each word will be used as a target in the same frequency in the congruent and incongruent conditions.

All words will be used as targets the same number of times.

In the congruent condition an identical prime will assigned to the target word.

In the incongruent condition a prime from the alternative category (artificial/natural) which doesn't share letters in common locations with the target will be selected.

For example, "phone" would be preceded by "PHONE" in the congruent condition, but by "GRASS" in the incongruent condition.

Each prime will be paired with a random distractor to be used in the prime recognition task. The distractor will be from the same category but will share no letters in common locations with the prime.

**Target Calssification**

Subjects will classify the target word as describing a natural / artificial item by selecting the side of the screen with the appropriate category. "Motion" group will use reaching to do so while "Keyboard" group will use "F"/"J" keys.

**Prime Recognition**

An objective measure of prime awareness. Subjects will have to identify the prime in 2 forced choice task between the prime word and a distractor word. "Motion" subjects will respond by reaching the chosen answer, while "Keyboard" subjects will press "F"/"J" to choose the word on the left/right side of the screen.

**Perceptual Awareness Scale**

A Subjective measure of prime awareness. Subjects will use the keyboard numbers 1-4 to rate how well did they see the prime from 1 ("didn't see anything") to 4 ("Saw the prime clearly").

#### Procedure

The experiment will be held in two sessions in two consecutive days, the first day is a training day and the second is the test day, their duration is approximately 30min and 90 minutes accordingly.

Subjects will be randomly assigned to a "Motion" / "Keyboard" group, each will use a different measure to respond on the tasks. "Keyboard" group will place their index fingers on "F" and "J" keys and use them to select an answer on the left/right half of the screen accordingly. "Motion" group will wear a reflective marker on their right index finger and use it to reach the screen and touch the answer they choose. After each response they will return their finger to the starting point, thereupon the next task will begin.

**Training day**

The first day consists of target classification trials, each trial will begin with a fixation cross (1000ms) followed by a sequence of three masks (270ms, 30ms, 30ms) and finally a target (500ms). Then, subjects will determine as fast as they can if the target describes an artificial or natural item. The subjects will perform 240 such trials, divided to 6 blocks of 40 trials each, and will be given a break between each block.

**Test day**

The second day will contain 2 practice blocks and 12 test blocks. Both practice blocks will contain the same 5-letter words but in a different order.

The second day will start with a response speed training block (40 trials) in which each trial will consist of a fixation cross (1000 ms), 1st mask (270 ms), 2nd mask (30 ms), 3rd mask (30 ms) and a target (500 ms). Once the target is displayed the subject is required to classify it as natural / artificial within the time constraints. "Motion" group is bound to onset time and movement time constraints. Onset time count starts from the target's onset until the subject's finger is 1 cm from the starting point (Euclidean distance), it has to be longer than 100 ms to prevent predictive movements but shorter than 320 ms. Movement time starts once the finger leaves the starting point and ends when the subject is 1.5 cm (on the Z axis) from the screen, it has to be shorter than 420 ms. "Keyboard" group has to reply within a time window of 250-4000ms from target display.

Next subject will take a second training block (40 trials), in which a prime word will be induced for 30 ms between the 2nd and the 3rd masks. In this block after Classifying the targets, the subjects will be asked to recognize the prime. The prime and the distractor will be assigned randomly to each side of the screen. "Motion" group will respond by reaching the correct answer while "Keyboard" group will select it with "F" / "J" keys. A 7 seconds response window was selected to reduce the amount of recorded trajectory data. Then the subjects will rate the prime visibility using a PAS scale and the response keys 1-4.

Subsequently, subjects will perform 12 test blocks (40 trials each), which will be identical to the second training block except for the stimuli to be used, which will follow the selected "trial sequence".

Finally, the subjects will debriefed about the experiment and perform a 5-minutes personality questionnaire designated for a future experiment in the lab.

In the classification task, a notification will be given if subjects provided a wrong answer, started moving too early (Onset time < 100ms) or too late (Onset time > 320 ms), or moved too slowly (movement time > 420 ms). "Keyboard" Subjects will be prompted if they responded too late (>740ms) @@ What is the correct timing limitation @@

## Analysis plan

### Trajectory preprocessing

@@@@ describe the entire process @@@@

### Dependent variables extraction

@@@@Describe how do you calculate and produce each dependent variable. @@@@

### Confirmatory analysis

[How to use](https://www.researchgate.net/publication/256097211_Linear_models_and_linear_mixed_effects_models_in_R_with_linguistic_applications) LMM (assumptions are found in the end).

IV:

1. Congruency: A within subject variable of two levels:
   1. Congruent: prime and target are the same word.
   2. Incongruent: Prime and target are from a different semantic category and do not share letters in common locations.
2. Item type: A within subject variable of two levels:
   1. Natural: target and / or prime represent a natural item (e.g. "Plant", "Cloud").
   2. Artificial: target and / or prime represent an artificial product (e.g. "Radio", "Phone").
3. Response measure: A between subject variable of two levels:
   1. Motion tracking: Subjects choose the correct answer on by reaching and touching it on the screen.
   2. Key press response: Subjects choose the answer on the left / right half of the screen by pressing "F" / "J" accordingly.

The significance of the fixed effect of congruency and response measure on each of the dependent variables will be tested.

Random:

1. Subject – subject will be used as a random effect.

DP:

1. Area under the curve (AUC): Area between the actual trajectory and the optimal path (a straight line connecting the start and end points). Area central to the optimal path is considered positive, while area lateral to it is considered negative. The area is evaluated for each trial separately.
2. Reach area: Area between the average path to a left target and an average path to a right target in a single condition (congruent / incongruent). Path is averaged across trials in a single condition.
3. Response time: The time it takes a subject to classify the target as natural / artificial, measured from target display until keyboard response.
4. MAD @@@@@@@@@@@@describe it@@@@@@@@@@@@@@@@@@@
5. X-position @@@@@@@@@@ describe it @@@@@@@@@@@@@@

@@@@ Mention the fact that you are not planning on testing the recognition results for "congruent" trials @@@@

@@@@ Describe the entire analysis plan, what comparisons you make. Basically just describe your code. @@@@

## @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

## @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

## Trajectory Preprocessing

All preprocessing was done according to Gallivan, J. P., & Chapman, C. S. (2014). Three-dimensional reach trajectories

### Fill Missing Data

Applies only to trajectories that have more than 1 sample.

Replaces NaNs with interpolated values.

Uses inpaint\_nans to do so.

**Inpaint\_nans**:

Written by John D'Errico.

Citation:

John D'Errico (2022). inpaint\_nans (https://www.mathworks.com/matlabcentral/fileexchange/4551-inpaint\_nans), MATLAB Central File Exchange. Retrieved February 15, 2022.

Is a advanced method for interpolating trajectory data while keeping the dynamic information of the reach.

Was used by Gallivan, J. P., & Chapman, C. S. (2014). Three-dimensional reach trajectories

### Filter Trajectory

Applies only to trajectories that have more than 1 sample.

Apply low pass butter worth filter of 2nd order with cutoff at 8Hz on each axis separately to clean any noise in the recording.

Since the noise is canceled, we can later overfit the data without concern for capturing noise with our fit (Using Functional Data Analysis\_v1\_april2011).

### Set Origin

Set the first sample in each trial as the axes origin by reducing it from each sample.

Set the time of the first sample in each trial as t=0 by reducing it from each sample.

### Trim Onset Offset

Applies only to trajectories that have more than 1 sample.

Compute velocity and apply low pass butter worth filter of 2nd order to it with a 10Hz cutoff.

**GetOnset:**

Trim trajectory to the first sample in which the 3 consecutive samples had a velocity greater than 2mm/s and a total acceleration greater than 2mm/s^2.

**GetOffset:**

Trim trajectory ending as the point closest to the screen.

### Normalize

We wish to compare the X coordinates between trials. To do so the Z index must be equal between trials.

We achieve that by fitting a function to the data and extracting 200 points that are equally spaced along the Z trajectory.

Applies only to trajectories that have more than 2 samples.

toNormalize = I think this is the marker you wish to normalize (it is an input to the normalization function).

**B-spline –** is a function composed of sections (splines), each section is a separate polynomial function.

Degree – the highest order of the polynomials.

Knot – the point where two splines connect.

Knots = coefficients + degree.

B – basis functions. A list of functions that are used to create each of the spline functions.

Cubic spline – spline function where all the polynomials are of the 3rd degree.

C – Continuity, a property of a spline indicating how smooth it is.

**Roughness penalty –** A parameterthat is added to the spline function and determines how

much emphasis to put on smoothness (as opposed to overfitting the data).

This type of spline is called a "Smoothing spline".

Error function (which we try to minimize when fitting the spline):

Text, whiteboard

Description automatically generated

– penalty factor, determines how much weight will be given to smoothness as opposed to

overfitting the data.

~~Chart, diagram

Description automatically generated~~

More information about roughness penalty might be in these links:

[Mathlab's cubic spline function](https://www.mathworks.com/help/curvefit/csaps.html#d123e27998)

[Article about functional data analysis](https://www.researchgate.net/publication/227578062_Functional_Data_Analysis)

[R Function for fitting splines](https://link.springer.com/content/pdf/10.1007%2F978-0-387-98185-7_5.pdf)

Fit a B-spline function to the each axis with a spline at each data point. The B-spline is of the 6th order which keeps the original data up to the 3rd derivative (Using Functional Data Analysis\_v1\_april2011).

A roughness penalty is applied to the 4th derivative of the data to smooth the data.

Use the fitted function to produce a high-resolution representation of the trajectory (1000 samples).

Perform the normalization in space by extracting 200 points equally spaced along the Z axis (perpendicular to the screen) from the high-resolution representations.

Since the subject can move backwards the movement is divided to sections according to the movement direction (towards / away from the screen). The 200 points are equally divided along the TOTAL path traveled in the Z axis (if the subject moved 2 forward, 1 backward and 3 forward, the total is 6).

## Trial screening

Test the original data (before preprocessing) and excludes trials that fall within the following criteria:

* Too early – movement initiation started lees than 100ms after target was displayed indicating a predictive response.
* Late response – movement didn't start 320ms after target display.
* Extremely slow movement – movement time was 3SD above the subject's mean, or simply above a preset threshold.
* Short reach distance – distance along the Z axis between first and last sample was shorter than 32cm. Should this be done on the processed traj?
* Too much missing samples – trajectory has more than 100ms of missing samples (usually due to recording issues or obstruction of the marker from the camera's view).
* Short sample – Recorded trajectory is shorter than 100ms.
* Missed targets – The last sample is further than 12cm from either of the targets (on the X,Y plane).
* Bad stimulus duration – the duration of one of the stimuli (fixation, masks, prime, target) deviated by more than 2ms from its designated duration.
* Incorrect – target classification was wrong.
* Subject didn't perform the trials (quit)

## Subject screening

Excludes subjects that fall withing the following criteria:

* Not enough trials – The number of valid trials which also had a PAS rating of 1 is smaller than 60.
* Not enough trials in each condition – The number of valid trials in each condition (congruent /

incongruent) which also had a PAS rating of 1 is smaller than 30.

* Bad performance – subject was at chance level in the target classification task (counts only trials with PAS=1).
* Aware of prime – prime recognition was above chance indicating the subject is aware of the prime.

## Parameters extraction

### MAD

Maximal absolute deviation.

Locates for each trial the point that is furthest away from the line that connects the start and end points (known as the maximally deviating point, mad\_p).

MAD is the distance of that point from that line.

### Functional data analysis

getRMMeans – calculates the mean trajectory for each subject at each condition.

Fanovan – runs a repeated measures aNOVA analysis at every point along the trajectory.

For an explanation why this doesn't violate multiple comparisons limitations see Craig's document " Using Functional Data Analysis\_v1\_april2011.pdf" section: 5.2 – Statistical violation and functional interpretation.

Main point is that we don't conclude the diff along the whole trajectory is significant from seeing that a single comparison was significant, we just conclude that the difference at that point is significant.

Subject and left/right are used as random factors.

### Reach area calculation

Calculates the area circumscribed between the average trajectory to the left target and the average trajectory to the right target.

Does so for each condition separately.

Area calculation:

~~Trim one trajectory's Z values to be within the range of the other trajectory.~~ Isn't relevant since they share Z values.

Finds the minimal X value and draws a line at that value parallel to Z axis.

Computes the area between each trajectory and this line and subtracts the results, thus receiving the area between the trajectories.

To avoid negative area values after the trajectories intersect, they are split to section at their intersections and the area is calculated separately for each section.

## Averaging within subject

Averages trials withing each participant, excluding invalid trials or trials whose PAS isn't 1.

Averages:

* Trajectories
* Response time
* Reaction time
* Movement time
* Prime recognition – Includes most invalid trials, \*Excludes only\* unperformed trials or trials with bad

stimuli duration.

* MAD
* Maximally deviating point.
* Total STD of the X coordinates – collapses the STD across time.

Computes:

* STD (between trials) of the x coordinates at each point along Z.
* Number of trials with each PAS rating.
* Difference between average trajectory in the congruent and incongruent conditions.

## Sorting and averaging between subjects

Averages the following values (after excluding the bad subjects):

* Trajectory
* RT
* Reaction time
* Movement time
* Prime recognition
* Number of trials with each PAS rating.
* MAD
* Maximally deviating point.
* Reach area
* STD of the x coordinates at each point along Z.
* Total STD of X

## Formatting to R

### Reach area

Define 'M', which is the minimal amount of valid trials any subject has in a single condition.

For each subject we compute 1000 average left and right trajectories for each condition by randomly sampling (with replacement) 'M' trials and averaging them.

We use these average trajectories to compute 1000 reach areas for each subject in each condition.

## Modeling

### Diff in X value between conditions along the trajectory

We computed the difference between each subject's average congruent and incongruent trajectories in the "averaging within subject" section (Did so for left and right sides separately).

We now plot the average difference and it's confidence interval, this gives us a "t-test" along time. We look if at any point in time the difference is significantly greater than zero.

Chart

Description automatically generated

Chart, surface chart

Description automatically generated

### Reach Area

We previously generated 1000 reach area observations for each subject.

We enter all these observations from all the subject into a LMM with condition as the predictor, reach area as the predicted, and subject as a random factor.

We then compare it to an "empty" model that contains only an intercept and subjects as a random factor.

Text

Description automatically generated with low confidence

### MAD

Model MAD as a function of condition with subjects as a random factor.

Use actual values for each subject, not the average MAD.

A screenshot of a computer

Description automatically generated with medium confidence

### X Deviation

Model X position as a function of condition with subjects as a random factor.

Does so for each point along the trajectory.

A screen shot of a computer

Description automatically generated with low confidence