## 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:**

* Write:
  + What is it? (from references)
    - 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

**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

Yuval-Greenberg, S., and Heeger, D. J. (2013). Continuous flash suppression modulates cortical activity in early visual cortex @@@ Check it contains evidence for reduced signal @@@

Dubois, J., and Faivre, N. (2014). Invisible, but how? The depth of unconscious processing as inferred from different suppression techniques @@@ Check it contains evidence for reduced signal @@@

Neural processing of visual information under interocular suppression: a critical review @@@ Check it contains evidence for reduced signal @@@

)

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
  + Klein, S. B. (2014). What can recent replication failures tell us about the theoretical commitments of psychology?. *Theory & Psychology*, *24*(3), 326-338.
    - Social priming
      * Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action
      * Dijksterhuis, A., & van Knippenberg, A. (1998). The relation between perception and behavior, or how to win a game of Trivial Pursuit
    - Social distance
      * Williams, L. E., & Bargh, J. A. (2008). Keeping one’s distance: The influence of spatial distance cues on affect and evaluation
  + 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 following papers if they fail to show UC effects:
    - Can Item Effects Explain Away the Evidence for Unconscious Sound Symbolism? An Adversarial Commentary on Heyman, Maerten, Vankrunkelsven, Voorspoels, and Moors (2019)
    - Priming in a shape task but not in a category task under continuous flash suppression
  + Action priming
    - Investigating Masked Priming Along the “Vision-for-Perception” and “Vision-for-Action” Dimensions of Unconscious Processing
  + Linguistic category priming – Perceptual effects of linguistic category priming: The Stapel and Semin (2007) paradigm revisited in twelve experiments
  + priming replication and the hardest science
  + Look in reply to Ran Hassin (Hesselmann 2015)
    - Unconscious thought
      * Gonzalez-Vallejo, C., Lassiter, G. D., Bellezza, F. S., and Lindberg, M. J. (2008). “Save Angels Perhaps”: a critical examination of Unconscious Thought Theory and the deliberation-without-attention effect
      * Waroquier, L., Marchiori, D., Klein, O., and Cleeremans, A. (2009). Methodological pitfalls of the Unconscious Thought paradigm
      * Huizenga, H. M., Wetzels, R., Van Ravenzwaaij, D., and Wagenmakers, E. J. (2012). Four empirical tests of Unconscious Thought Theory
      * Meta analysis + replication - Nieuwenstein, M. R., Wierenga, T., Morey, R. D., Wicherts, J. M., Blom, T. N., Wagenmakers, E. J., et al. (2015). On making the right choice: a meta-analysis and large-scale replication attempt of the unconscious thought advantage
      * Nieuwenstein, M., & van Rijn, H. (2012). The unconscious thought advantage: Further replication failures from a search for confirmatory evidence
    - Political
      * Klein, R. A., Ratliff, K. A., Vianello, M., Adams, R. B., Bahnik, S., Bernstein, M. J., et al. (2014). Investigating variation in replicability a “Many Labs” replication project
  + Klein, S. B. (2014). What can recent replication failures tell us about the theoretical commitments of psychology?. *Theory & Psychology*, *24*(3), 326-338.
    - Doyen, S., Klein, O., Pichon, C-L., & Cleermans, A. (2012). Behavioral priming: It’s all in the mind, but whose mind?
    - Social distance
      * Pashler, H., Coburn, N., & Harris, C. R. (2012). Priming social distance? Failure to replicate effects on social and food judgments
    - Intelligent behavior
      * Shanks, D. R., Newell, B. R., Lee, E. H., Ekelund, L., Cenac, Z., Kavvadia, F., & Moore, C. (2013). Priming intelligent behavior: An elusive phenomenon
  + 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.
      * 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.
    - Arithmetic:
      * Moors, P., & Hesselmann, G. (2018). A critical reexamination of doing arithmetic nonconsciously. *Psychonomic Bulletin & Review*, *25*(1), 472-481.
      * Unconscious arithmetic: Assessing the robustness of the results reported by Karpinski, Briggs, and Yale (2018)
    - Semantic:
      * Rabagliati, H., Robertson, A., & Carmel, D. (2018). The importance of awareness for understanding language. *Journal of Experimental Psychology: General*, *147*(2), 190.
      * 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.
      * Frequent Words Do Not Break Continuous Flash Suppression Differently from Infrequent or Nonexistent Words: Implications for Semantic Processing of Words in the Absence of Awareness

**1:**

When a certain aspect of an unconscious stimuli affects a subject's behavior, a conclusion can be drawn that this property can be processed unconsciously. Experiments manipulating properties like semantics, numeric value, integration, yielded much contradicting results.

If a certain type of processing was shown to happen while the subject is kept unaware of the processed stimuli, one can claim UC processing can perform such processing.

UC processing is claimed to perform varies in the subject the deal with, such as semantic processing, arithmetics, integration, and contradictory results can be found in each of them.

In a classic semantic priming paradigm the subject unconsciously views a prime word that primes a certain semantic category, after which he is asked to categorize a target word as belonging or not to the category. Some research have shown the UC processed words affect the response to the conscious prime, making it slower when incongruent, while others haven't found this effect.

The concept of

**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.

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