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## Introduction

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

### Background

Unconscious effects are notoriously small and week. This raises a doubt about the existence of these effects. This has been the topic of a burning debate for the past few years.

@@ quote articles that show priming and the articles that contradict them @@

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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.

@@

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.

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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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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 ones 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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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 (@@ Read abstract and discussion to check if relevant @@ "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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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.

A different test group will be used for each measure to avoid a practice effect.

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

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.

### 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

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

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.
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. 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. 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's answer at classifying the target are found to be at chance level in 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

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 and will cover the central area of the screen where words can appear (approximately ).

@@@@@ Write something about the fact that each word is represented equally in each condition @@@@@

**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 a 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 finger 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.

In the classification task a notification will be given if subjects provided a wrong answer or responded too early (<100ms). "Keyboard" Subjects will be prompted if they responded too late (>740ms) @@ What is the correct timing limitation @@ while "Motion" subjects will be prompted if their movement onset was too late (>320ms) or the movement duration was too long (>420ms). The prime recognition and PAS tasks will not be time constrained.

@@ What are the timing constraints for a regular priming keyboard experiment? @@

**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 test blocks will contain 5-letter words taken from a different list. The word order in the practice blocks Each block will contain 40 trials

The second day will start with a single training block of 40 trials similar to those in the first day but with 5-letter words.

Then the subjects will have a single practice block similar to the actual test blocks, after which they will perform 12 test blocks.

Next the subjects will perform a training block and After which the subjects will perform another training block of target classification similarly to the first day. After which the subjects will perform another practice block which will be similar to the test trials: The words for this task will be taken from but with new words comprised of 5 letters and, after which the subjects will perform a block of target

similar to those used in day 1 but with different 5-letter words.

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

Specify in "materials and stimuli" how you created the trial lists. Then continue writing about the test day. Look in Trello 🡪 pre-reg 🡪 stimuli: read your comment titled "trial randomization"

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On the test day subjects will perform a target classification task, a prime recognition task and a PAS task.

Pas in answered with keyboard in both groups.

\*\* The procedure should describe keyboard exp as well.