**Show some sensitivity! Using motion tracking to improve unconscious measures**

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# Introduction

The scope of unconscious processing is highly controversial (Goldstein & Hassin, 2017; Hassin, 2013; Hesselmann & Moors, 2015; Peters et al., 2017; Peters & Lau, 2015). Although unconsciously processed stimuli have been repeatedly shown to evoke both behavioral and neural changes (Kouider & Dehaene, 2007; Rohr & Wentura, 2021; Van den Bussche et al., 2009), some of these findings have been criticized on different grounds (Avneon, 2018; Pratte & Rouder, 2009; Shanks, 2017; Vermeiren & Cleeremans, 2012) and are generally not easy to detect given the typically weak signals (Greenwald et al., 1996). A prominent complication stemming from this difficulty to detect unconscious effects relates to the most appropriate interpretation for such findings. For example, small positive effects can be attributed to the use of a non-exhaustive awareness measure (i.e., contamination by aware processes) (Eriksen, 1960; Newell & Shanks, 2014; Reingold & Merikle, 1988; Vadillo et al., 2016), while null results can be attributed to the use of a non-sensitive performance measure (Xiao et al., 2015). Such contradicting interpretations make the field highly debated (Newell & Shanks, 2014; Quilty-Dunn, 2019; Shanks, 2017; Sklar et al., 2021).

The goal of our research is accordingly to look for ways to enhance the measured signals and obtain more robust effects. To do so, we examine the usage of motion tracking as a performance measure, and ask if it is superior to the widely-used keyboard response and response time (RT) measure. Continuous motion tracking allows to capture fluctuations in the decision as it formulates (Cressman et al., 2007; Freeman et al., 2011; Friedman & Finkbeiner, 2010; Gallivan & Chapman, 2014) and can accordingly be used to uncover cognitive conflicts stemming from an unconscious stimulus (Almeida et al., 2014; Finkbeiner et al., 2008; Finkbeiner & Friedman, 2011; Schmidt, 2002; Xiao & Yamauchi, 2014, 2015, 2017). However, a direct comparison between the strength of the effects evoked by motion tracking as opposed to a typical RT experiment is missing; only one study included such a comparison, yet the awareness measures there were somewhat liberal, and the response method was not natural (Xiao et al., 2015). Thus, in the current experiment we will reexamine this question while using rigorous awareness measures and a more intuitive reaching response. Intuitive responses are less effortful and can thus be considered more likely to express decision fluctuations in the trajectory (Burk et al., 2014; Moher & Song, 2014). In previous motion tracking pilots we conducted, we found a larger effect size than those reported in similar experiments using a keyboard. We now seek to confirm that motion tracking can indeed evoke stronger effects than a typical RT task, in a direct comparison between the two.

## Hypothesis

We hypothesize that motion tracking will be more sensitive to cognitive conflicts than a keyboard response. Therefore, we expect the congruency effect found when using motion tracking to be larger than that found while using a keyboard response.

# Methods

## Design

IV:

1. **Congruency:** a within subject variable of two levels.
2. Congruent: prime and target are the same word.
3. Incongruent: prime and target are a different word from a different semantic category that do not share letters in common locations.
4. **Response measure:** a within subject variable of two levels.
5. Motion tracking: the participant chooses an answer by reaching and touching it on the screen.
6. Keyboard response: the participant chooses an answer by pressing "E" / "Y" accordingly.
7. **Item type:** a within subject variable of two levels. Item type is manipulated during the task but is not a variable of interest for the analysis.
8. Natural: target and / or prime describe a natural item (e.g., "Plant", "Cloud").
9. Artificial: target and / or prime describe an artificial product (e.g., "Radio", "Phone").

DVs:

All confirmatory and exploratory DVs will be calculated on *valid trials* only(see "Exclusion Criteria" below).

1. **Reach area:** in the motion tracking session, two average trajectories will be computed for each condition (congruent / incongruent); one for reaches made to the left side when the correct answer was on the left and one for reaches made to the right side when the correct answer was on the right. Then, the area between a participant's average reach to the left and average reach to the right will be defined as his reach area (Figure 1; see further details in the "Reach Area Calculation." section below).

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Figure . Depiction of reach area. The dark and light red lines represent a single participant's average trajectory to the left and right accordingly. The pink area represents a single participant's reach area.

1. **Response time:** in the keyboard session, the average timing of keyboard presses in the target task in the congruent and incongruent conditions. It is defined as the time from target presentation up until "E" / "Y" are pressed.

Exploratory DVs:

Beyond the above measure, on which we will perform a confirmatory analysis, we will also explore additional measures to see if the yield a stronger effect in the motion tracking task (thus, all the measures below refer to the motion tracking session):

1. **Reaction time:** time from stimulus presentation up to movement initiation. Movement initiation is detected once the Euclidean distance from the starting point is greater than 1cm.
2. **Movement duration:** time from movement initiation until the screen is reached.
3. **Deviation from center:** the distance of every point along the average trajectory from the center line, which is drawn between the starting point and the middle of the screen (Figure 2).

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Figure . Depiction of Deviation from center. Each red dot represents a single sample along the movement trajectory. The dashed grey line represents the center line and the blue arrows represent each sample's deviation from the center.

1. **Movement variation:** the standard deviation of the "Deviation from center" measure (3). The standard deviation will be computed over the trials.
2. **Heading angle:** first, a tangent is evaluated for every point along the trajectory by connecting it to the previous point. The "Heading angle" is confined between the tangent and a line perpendicular to the screen (Figure 3). Angles will be considered negative if the extension of the tangent meets the screen on the side opposite to the chosen answer. Finally, the angles are averaged across trials for each participant.

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Figure . Depiction of the heading angle measure. Dots are samples along the movement trajectory and the heading angle is estimated for the one colored in green. The grey arrow is the tangent to the green dot. The heading angle is confined between the dashed perpendicular line and the tangent line. Since the tangent meets the screen on the side opposite to the final response, the heading angle will be negative.

1. **Changes of mind (COM):** the frequency of goal changes during a movement, defined as the number of changes in implied goal (the side, left/right, where the current tangent to the trajectory meets the screen) along a single trial's trajectory.
2. **Total distance traveled:** the sum of Euclidean distances between samples along the trajectory of a single trial (Figure 4).

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Figure . Depiction of total distance traveled. Each red dot represents a single sample along the movement trajectory and the grey arrows represent the Euclidean distance between each pair of consecutive dots. The sum of the grey arrows is the total distance traveled.

## Planned Sample

All participants will be right-handed, native Hebrew speakers who have normal vision or corrected-to-normal vision. Only participants declaring that they have no neurological, attentional, or mental disorders, and are not taking psychiatric medicines, will be included. Data will be collected at Prof. Liad Mudrik's lab for high level cognition in Tel-Aviv University, from students or other young adults at the ages of 18-35, in a 90 minutes session. Participants will be reimbursed with course credit or cash payment.

## Sample Size Estimation

The semantic priming effect of the reaching task was estimated in two pilots ran in the lab. The average effect size was 0.88 (Cohen's dz). We estimated the keyboard task's effect size to be around 30% smaller (Cohen's dz = 0.61), in line with our hypothesis for a smaller RT effect, and in accordance with a previous study (Xiao et al., 2015, d=0.65, though see Dehaene et al., 2001, where the effect size was 0.8). To find such effect with a power = 95% and a sample of 30 participants is needed, based on G\*Power (Faul et al., 2007, 2009).

## Exclusion Criteria

The following trials will be considered invalid and thus excluded from the main analysis:

1. Trials with visibility rating higher than 1.
2. Trials in which there was a technical malfunction with the setup or recording:
3. Over 100ms of missing samples in the trajectory.
4. Less than 100ms of existing samples in the trajectory.
5. Stimulus presentation duration deviated from the desired by more than 2ms.
6. Trials in which the response meets one of these criteria, suggesting a potential problem:
7. Short reach distance: the distance on the *Z* axis between *reaching onset* and *reaching offset* was shorter than:

*Onset variation* is a 3cm error margin that compensates for small variations in the location of *reaching onset*.

1. Missed targets: touching point on screen is more than 12cm away from either target.
2. Bad timing: in the keyboard task, key press was too early (less than 100ms after target), or too late (more than 740ms after target). In the reaching task, movement started too early (less than 100ms after target display, implying a planned response) or too late (more than 320ms after target display). Slow movements (movement duration longer than 420ms) will be included in the analysis if they are within 3 STDs from the average movement duration of the participant across trials that were properly recorded (were not excluded due to criteria 2-i,ii and 3-i), started on time (not too late or too early) were completed on time (with a movement duration shorter than 420ms), and were answered correctly.
3. Wrong answer when classifying the target.
4. No response given via the keyboard.

Participants will be excluded according to the following criteria:

1. Had less than 25 valid trials in each condition (congruent / incongruent).
2. Their target classification accuracy among trials that were completed in time (i.e. not "Too early" or "Too late") was significantly lower than 70% according to a binomial test. In the reaching task, only trials that had no missing data, were the target was not missed and the reaching distance was not short will be examined for performance.
3. Their priming recognition accuracy among incongruent trials was significantly better than chance (50%) according to a binomial test.
4. Had a reach area larger than 0.07m2 (Figure 5). Such value is highly unlikely and will thus indicate incorrect execution of the experiment or a problem with the recording.

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Figure . Depiction of the maximal reach area. This figure presents a hypothetical situation that will produce a very large reach area. This will occur if a participant first moves in the direction of the chosen answer (left / right) and then advances toward the screen. The red lines represent this participant's average paths to the left and right targets and the pink area represent the large reach area that is defined as the maximal reach area.

## Apparatus

The stimulus will be displayed on a VPIXX monitor (VIEWPixx /3D Lite LCD display and data acquisition system, version 3.7.6287) using Matlab R2020b (9.9.0.14677003) (*MATLAB*, 2020) and Psychtoolbox 3.0.18 – Flavor: beta, Corresponds to SVN Revision 12779 (Brainard, 1997). The monitor will be set to 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 stimulus display to the screen's refresh rate. A Perspex cover will be placed over the screen to protect it. The cover will be spray painted with a light layer of transparent matte lacquer to avoid reflections. The participants will sit approximately 60cm away from the screen and place their index finger on a marked starting point which will be located on the table 35cm away from the screen, in line with its center. The stimulus will be displayed 24cm above the table and the classification answers will be displayed on each side of it, 20cm apart (Figure 6). Participants will wear a Velcro ring with a marker at the tip of their index finger. A touch will be registered when the marker is 0.7cm away from the screen or closer. A system of 6 OptiTrack Flex 13 cameras by NaturalPoint, Inc. will track the marker's location using Motive 2.3.0 software (*Motive*, 2021) at a sampling rate of 120Hz. The coordinates will be broadcasted online to a NatNet client (*NatNet SDK*, 2021) and recorded with Matlab.

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Figure . Setup. A participant placing his finger on the starting point which is located 35cm away from the screen. The target is positioned 24cm above the starting point and the answers are placed on each of its sides, 20cm apart. Z axis maps the path to and from the screen. X axis maps the left and right directions. Y axis maps the up and down directions.

## Materials and Stimuli

One hundred 5-letter words will be used as primes and targets. All words will be imageable nouns with a frequency of at least 10 per million (Frost & Plaut, 2005). One half will describe artificial products (e.g., radio, train) and the other 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 which covers the central area of the screen where words can appear (approximately ). Forty words will be used for the practice blocks and the remaining sixty will be used in the test blocks.

## Procedure

Each participant will perform a reaching session and a keyboard session, and their order will be counterbalanced across participants. Each session will include a practice block and six test blocks of forty trials each (i.e., 40 practice trials and 240 test trials per session, 560 trials total). Breaks will be allowed between blocks. Throughout the experiment, half the trials will be congruent and half incongruent, and half the targets will be natural and half artificial. Stimuli order will be dictated by two lists that will be randomly sampled (without replacement) out of twenty pre-composed lists of trial condition and stimulus. One list will be assigned to the reaching session and the other to the keyboard session. The practice lists will be similarly sampled out of a different set of ten lists. In each list, the order of words is pseudorandom, with the following constraints: (a) Each word is equally frequent as a target at the congruent and incongruent conditions; (b) All words are used as targets the same number of times; (c) A target never repeats in the same block; (d) In the congruent condition the prime Is identical to the target word; (e) In the incongruent condition, a prime which doesn't share letters in common locations with the target is selected from the alternative category (artificial/natural). For example, in the congruent condition "phone" can be preceded by "PHONE", while in the incongruent condition it can be preceded by "GRASS". Each prime is further paired with a random distractor from the same category (artificial/natural) to be used in the prime recognition task. The distractor shares no letters in common locations with the prime, so seeing one letter only would suffice for correct discrimination.

The procedure closely follows the one used in Dehaene et al. (2001). Every trial will consist of a fixation cross (1000ms), a first mask (270ms), a second mask (30ms), a prime word (30ms), a third mask (30ms) and a target (500ms). Once the target is displayed, participants will classify the target word as describing a natural / artificial item by selecting the side of the screen that contains the appropriate category (Figure 7). In the reaching task the participants will touch the appropriate side of the screen. Here, responses are bound to movement onset time and movement duration constraints; onset is the time from target presentation until the participant's finger moved 1cm away from the starting point (Euclidean distance). It must be longer than 100ms to prevent predictive movements but shorter than 320ms to prevent prime dilution. Inaccurate timing will be immediately replied with a "Too Early" / "Too Late" feedback accordingly. Movement duration starts once the finger leaves the starting point and ends when it is 0.7cm away from the screen or closer (on the Z axis). Movements longer than 420ms will be replied with "Too Slow" feedback once they are completed. In the keyboard task participants will use "E"/"Y" keys to select the left / right side accordingly. Response must be given within a time window of 100-740ms from target display; otherwise "Too Early" / "Too Late" feedback is given. After Classifying the targets, the participant will be asked to recognize the prime as an objective measure of prime awareness. Participants will be presented with two words – the prime and another word from the same category. Response will be given in an identical fashion to the target classification task, within a 7 seconds response window. Finally, a subjective measure of prime awareness will be taken, using the Perceptual Awareness Scale (PAS) (Sandberg & Overgaard, 2015). Participants will use the keyboard numbers 1-4 to rate how well did they see the prime (1 – "Didn't see anything", 2 – "Saw something vaguely, but can't say what it is", 3 – "Saw part of the prime clearly", 4 – "Saw the whole prime clearly"). Finally, in the reaching session participants will have to return their finger to the starting point after each response.

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Figure . Stimuli presentation order. Each trial is composed of a fixation cross (1000ms), a first mask (270ms), a second mask (30ms), a prime word (30ms), a third mask (30ms), a classification task (100-740ms, out of which the target is displayed for 500ms), a recognition task (100-7000ms) and a PAS task (no time limit). The blue circles appearing on the screen are presented as markers for the subjects to know where they should touch in order to make their response. They appeared also in the Keyboard session.

# Analysis Plan

## Trajectory Preprocessing

The preprocessing procedures will follow those described in Gallivan & Chapman (2014). Missing values will be interpolated with the inpaint\_nans (D’Errico, 2022) function to fill gaps in the trajectory, which will then be filtered with a low pass butterworth filter (2nd order with cutoff at 8Hz) to reduce noise. The axis' origin will be set at the first sample of each trial. To locate *reaching onset*, a low pass butterworth filter (2nd order with a 10Hz cutoff) will first be applied to the 3D velocity. *Reaching onset* and *reaching offset* will be defined differently from movement onset and offset; onset will be indicated by four consecutive samples having a velocity greater than 20mm/s and a total acceleration of at least 20mm/s^2. *Reaching offset* will be determined as the point along the trajectory that is closest to the screen. The movements will be normalized to the traveled distance along the axis perpendicular to the screen (Z axis). To do so, a B-spline of the 6th order with a roughness penalty on the 4th derivative will be fitted to each axis with a spline at every data point. The fitted function will be used to produce a high-resolution representation of the trajectory (1000 samples) from which 200 points equally spaced along the total distance traveled on the Z axis will be extracted (e.g., if the participant moved 2cm forward and 1cm backward, the total distance traveled is 3cm). These points will represent the proportion of path traveled.

## Dependent Variables Extraction

### Reach Area Calculation.

A participant's reach area in each condition will be calculated in three stages (Figure 8). First, a line perpendicular to the screen will be drawn at the lowest X value amongst the participant's average trajectories to the left and to the right targets in a single condition. Then, the area between both the right and the left average trajectories and the perpendicular line will be computed (Figure 8, left and middle panels, respectively). The results will be subtracted from each other (Figure 8, right panel), and their absolute value will be used as the reach area. To avoid negative area values, the trajectories will be split at their intersections and the area will be calculated separately for each section.

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Figure . Reach area calculation. The average trajectories of a participant to the right (light red) and left targets (dark red) are produced. Then a line perpendicular to the screen (black) is plotted at the minimal X value among both trajectories. The area between each trajectory and that line is computed and the results are subtracted from each other giving the participant's reach area.

## Confirmatory Analysis

A paired t-test will be conducted between the congruent and incongruent conditions for each DV. Multiple comparisons will be corrected for using the Tree-BH method (Bogomolov et al., 2021) based on the tree structure described in Figure 9. The "effectsize" package (Ben-Shachar et al., 2020) will be used to evaluate Cohen's dz and its confidence intervals for each of the DVs. Non overlapping confidence intervals between the reach area and the keyboards RT measures will indicate an advantage for one measure over the other. In the event that an exploratory DV of the reaching task will produce a larger effect size than reach area, it will be used instead of reach area. The normality of the difference score of each DV will be examined with a qq-plot; in case of a violation, we will use a t-test with permutation to estimate the congruency effect. Similarly, if there will be outliers located more than one and a half inter quartile ranges from the average reach area or keyboard RT, we will use a robust t-test using R's WRS2 package (Mair & Wilcox, 2020) and its "APK" effect size will used instead of Cohen's dz.

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Figure . Tree-BH architecture. Nodes represent statistical tests. Deviation from center and STD of x have multiple points for each trial, therefore a permutation and clustering procedure is used to extract the significant clusters, and only those will be included in the exploratory analysis.

## Expected Results

In the reaching task, we expect to find a bias for the incorrect answer in the incongruent condition. A tendency to deviate toward the side opposite to the final correct answer will increase the total distance traveled, the AUC and the maximal absolute deviation from the optimal path but decrease the deviation from the center. The bias will also curve the average path towards the center, which will make the reach area smaller. In addition, an incongruent prime will evoke a cognitive conflict which is expected to increase the time it takes to reach a final decision. This will manifest in longer movement duration as well as in higher movement variation.

In the keyboard task, we expect longer reaction times in the incongruent condition. Finally, we expect effect sizes to be larger in the reaching task than in the keyboard task.

# Project Data Collection

Data collection started on the 12th of May 2022 and will end on the 30th of October 2022.

Up to this point in time, 26th of June 2022, data was collected from 2 participants.

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