### Introduction

#### What is unconscious processing

Our brain continuously processes information. It receives inputs via our senses and processes it in various ways, for a variety of stimuli and using different modalities [ref]. For example, upon seeing a ball flying our direction, we process its trajectory and the likelihood of it hitting us. The produced results can lead to a change in behavior – like ducking the ball in this case [ref] – and/or to internal changes, like the induction of fear [ref]. Some of these processes are also accompanied by conscious experiences [ref]: I perceive the flying ball, and I experience the sense of fear. But this is not always the case: I might miss the ball altogether, for example if I am extremely occupied by a different engaging task [ref]. Importantly however , I might still duck the ball following some automated response triggered by unconscious processing [ref]. What differentiates between such conscious and unconscious processing?

In the lab, studies trying to answer this question have used different methods to render the stimulus invisible (for review, see [ref] ). One possibility is to degrade the physical properties of the stimulus (e.g., contrast, resolution, volume, duration) [ref]. Another is to suppress the stimulus by presenting a much more salient stimuli concurrently with the critical stimulus or at close temporal proximity to it (e.g., masking, CFS), hereby rendering it invisible [ref]. Invisibility can also be achieved by diverting attention away from the stimulus [ref].

All three methods, and others (for reviews, see REF) typically decrease the visibility of the stimulus, but also evoke weaker neural responses to the stimulus [ref]. Such weak signals usually translate to small behavioral changes that are hard to detect [ref]. As a result, the field abounds with contradicting findings [ref], which in turn evoke an ongoing controversy about the scope of unconscious processing (ref).

#### Contradicting findings

One point of disagreement concerns the extent of semantic processing without awareness [ref. Among other paradigms, this has often been studied using priming, [ref] where a participant is asked to perform a certain task on a target stimulus (e.g., classify as word/non-word). Preceding this target, a related/unrelated invisible prime stimulus is presented. Typically, the subject's response is either facilitated or inhibited according to the congruency between the prime and the target. Such a congruency effect is often taken as evidence the prime was indeed processed (e.g., ref). To ensure that the prime was indeed invisible, a subjective and / or objective measure of prime awareness is typically administered [ref]. A subjective measure quarries the participant about her vision of the prime by asking her to rate how well did she see it on a scale that moves from "did not see anything at all" on one end to "saw the prime clearly" on the other. Using a subjective measure allows to detect awareness on a trial-by-trial basis. An objective measure forces the participant to recognize the prime between few possible choices, and the proportion of correct responses across trials reveals whether the participant saw it. This type of task is intended to tackle the criterion problem [ref].

While some semantic priming found that invisible words can be processed up to the semantic level [ref], other studies failed to show semantic effects and claimed that processing only reaches the lexical level [ref]. Moreover, other studies have not found any congruency effects [ref]. Similar controversies involve other types of processing: claims for arithmetic computations being performed without awareness [ref] were challenged by failures to replicate [ref], and a similar mixed picture emerged also for studies of processes like integration [ref].

#### Explaining The discrepancy between findings

How can these contradicting results be explained? One option, that is explored in this thesis, is that they stem from methodological limitations of some of these studies. For example, the way consciousness is measured might strongly affect the obtained results: if the awareness measure is not sensitive enough to discover residual awareness, the researcher might falsely ascribe unconscious processes to conscious processing [ref]. Such insensitivity can stem from several factors: the objective task might probe features of the stimulus that are irrelevant to the tested feature (note that this could also lead to overestimation of awareness; REF) [ref]. In addition, introducing a long delay between the presentation of the stimulus and the awareness measure might cause subjects to forget that they had some experience of it [ref]. Underestimation of awareness can also occur if the subject uses a very strict criterion when judging whether she saw the prime [ref]. Finally, if the objective task is too difficult, subjects can be at chance even if they do see the stimulus, or parts of it, and their motivation to perform the task on invisible stimuli can also be hindered, leading to worse performance [ref].

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

The above issues might lead to overestimating unconscious processing, due to contamination by conscious effects. On the other hand, one might underestimate unconscious processing, due to insensitive measures of the unconscious effect. The most prominent measure for probing unconscious effects are reaction times (RTs), as measured using keyboard presses (e.g., comparing RTs in the congruent vs. incongruent condition) [ref]. However, for invisible primes this effect is usually very small [ref]. Also, it only indexes the end result of the response, and does not provide insight on the process of formulating the final decision, as it unfolds over time [ref].

#### Motion tracking vs keyboard

Both these problems can be solved using motion tracking, which has become a popular tool for unraveling cognitive processes [ref], and might prove to a be a powerful tool for detecting effects evoked by unconscious processes. Contrary to keyboard RTs, which produce a discrete value for each trial, motion tracking provides a continuous set of values which is better suited for tracking ongoing cognitive processes. This was previously used in other fields of research (e.g., unraveling the temporal dynamics of speech comprehension, to show that words are processed in an incremental manner [ref]). Such online tracking of movement as the cognitive processes take place provides further insight on their development over time. For example, when studying syntactic speech processing, researchers used motion tracking to demonstrate that multiple syntactic interpretations of a sentence are processed simultaneously as opposed to serially [ref]. Similarly, motion tracking allows one to compare movement patterns associated with simultaneous conflicting goals and serially occurring goals [ref]. Finally, of the rich, continuous data afforded by motion tracking can be curated for various parameters that are not available when using non-continuous measures, and might reveal an effect that goes unnoticed in the latter case. One such parameter is velocity which was used to inspect subjects' confidence in their answers [ref]. Another parameter is Changes Of Mind (COM), that are not possible to detect when responding with a keyboard, but are reflected in the trajectory when using motion tracking [ref].

#### Prev papers with motion tracking

The ability to unravel cognitive conflicts and observe COM might be beneficial when studying unconscious processing, especially in priming paradigms that evoke conflicts between the prime and target. This was indeed done in a handful of studies: two studies probed the level at which unconscious images are processed by asking subjects to classify a target image preceded by an invisible prime as a person / animal in a reaching response, while movement was tracked. When the prime was incongruent with the target, reaching trajectories tended to deviate towards the incorrect answer [ref], therefore indicating that the semantic meaning of prime images was processed unconsciously [ref]. In a similar experiment digits or letters were primed before classifying a target stimulus as one of them, and here too the trajectories were affected by the congruency between the prime and the target [ref]. Finally, another study used motion tracking to demonstrate the role of attention in facilitating priming [ref]: when participants judged a target digit as larger or smaller than 5, longer reach trajectories were observed when this target was preceded by an incongruent prime (compared to a congruent one), and this effect was larger when the subjects attended to the prime [ref].

#### Prev papers with motion tracking and keyboard

Thus, motion tracking can be used to unravel unconscious processing as it unfolds. But are these effects indeed stronger than keyboard-RT ones? This question has hardly been studied. Two studies combined motion tracking and keyboards RTs, yet without directly comparing between them. In the first, a prime arrow pointing to the left/right/neutral direction was rendered invisible with meta-contrast masking, and participants were asked to choose which side was the mask pointing to. The task was first performed with a keyboard, revealing that prime-target congruency affects the response speed, and a second time with stylus tracking. In the stylus session the stimulus was presented only after the participants initiated a movement towards the center, forcing participants to correct their movement mid-flight. The correcting movement's onset, length and velocity were influenced by the prime-target congruency which gave rise to the conclusion that subliminal stimuli can influence the ongoing execution of an already-prepared target-directed movement [ref]. In the second study, the effect of unconscious dorsal – as opposed to ventral – processing on decisions was examined using a subliminal priming paradigm. Primes and targets were images of animals/tools that belonged to the same/different semantic category and had a similar/different shape (i.e., elongated / round) and therefor similar/different affordances. When responses were given via a keyboard, semantically congruent primes improved the response speed to their targets. While keyboard responses reflected a semantic priming effect, reaching movements, which were assumed to depend more heavily on dorsal processing, were used to examine if the dorsal stream elicits subliminal shape related effects. Indeed, blob-like animal primes caused a larger deviation from the elongated tool target than did elongated animals. Hence the researchers concluded that dorsal-stream processing contributes grasp related information to decision making processes [ref].

#### Xiao + reaching vs mouse

To date, only one study directly compared the strength of the effects revealed by keyboard presses and motion tracking [ref]. In this study, participants classified two digits as identical/different by either pointing to the correct answer with the mouse or choosing it with the keyboard. The target digits were preceded by a positive/negative subliminal image which facilitated same/different responses respectively. Critically, this effect was marginally significant when probed with a keyboard, but robust when measured via mouse tracking. Although this study indeed reinforces the above assumption, according to which motion tracking might be beneficial for unraveling unconscious processes, it also suffers from several limitations. First, awareness assessment was done in a separate block after the main task, with no online assessment of prime visibility on a single trial level. This is especially important since the visibility ratings of many participants were above zero, suggesting that the effect might have been driven by some conscious processing. In addition, performance was not tested against chance, and instead shown not to correlate with the congruency effect – a method that has been widely criticized [ref]. Finally, the number of trials in the awareness task was 96, which might be underpowered for detecting awareness [ref].

Notably, this study used mouse tracking, which might be less sensitive than reaching movements. Using a mouse requires subjects to remap the real-world representation into 2D. Such 2D mapping constrains free movement [ref], which can affect the trajectory and timing of the movements [ref] and suppress the expression of cognitive conflicts. Indeed, when both measures were compared, reaching produced shorter movement durations, larger curvatures, faster velocities and most importantly, it responded faster to changes of mind [ref]. Reaching movements are also more intuitive than using a mouse, making them less effortful and possibly more likely to express fluctuations in the decision [ref]. These properties accordingly suggest that reaching movements might be optimal for detecting fast and short-lasting processes such as unconscious priming effects [ref].

#### Current Research

The current study was aimed at testing the above hypothesis that motion tracking might be superior to the commonly used keyboard responses measure in detecting effects of unconscious processing. This was tested in a series of four studies, with rigorous awareness measures to ensure residual awareness is not mistaken for unconscious processing. Three exploratory studies were aimed at finding the optimal conditions for discovering an unconscious effect when using reaching responses. A fourth confirmatory study directly compared between motion tracking and keyboard responses as a means to examine if one measure has an advantage over the other. All four studies used a priming paradigm following a classical study by Deheane and colleagues [ref], in which participants were presented with a masked prime word followed by a visible identical/different target word. This task was chosen as it was supposed to evoke strong effects, in a fairly simple design which probes identity priming. The participants were asked to perform a semantic judgment on the target word, and determine if it describes a natural or artificial item. In the first three experiments, I expected to find evidence for a congruency effect with motion tracking, so that the average reaching trajectories of the incongruent trials would deviate towards the incorrect answer further than would the trajectories of the congruent trials. In the fourth experiment, I expected this congruency effect to be larger than the one extracted from the keyboard-RT.

### Exp 1

The first experiment's purpose was to produce a first dataset to experiment with. The end goal was to troubleshoot the experiment and the motion tacking system and establish an encapsulating analysis environment that can extract meaningful parameters from the recorded trajectories. We were hoping to locate a congruency effect in at least one of the parameters and tweak the experiments that followed to maximize its size (e.g., change the RT or training length).

#### Methods

##### Participants

Ten participants (eight females) between the ages of eighteen and thirty-five were recruited for the study (M = 24.2, SD = 2.57). All participants were 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, were included. All participants signed a consent form and were explained that they can stop the experiment at every point if they wished to do so. They were reimbursed with course credit or cash payment. The experiment was approved by the Tel Aviv University ethics committee.

##### Stimuli

One hundred 5-letter words were used as primes and targets. All words were imageable nouns with a frequency of at least 10 per million [ref]. One half described artificial products (e.g., radio, train) and the other natural items (e.g., fruit). Target words were written in typescript while prime words were written in handwriting font. Masks were 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 were used for the practice block and the remaining sixty were used in the test blocks.

##### Apparatus

The stimulus was displayed on a VPIXX monitor (VIEWPixx /3D Lite LCD display and data acquisition system, version 3.7.6287) using Matlab R2020b [ref] and Psychtoolbox 3.0.18 [ref]. The monitor was 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 was placed over the screen to protect it. The cover was spray painted with a light layer of transparent matte lacquer to avoid reflections. The participants sat approximately 60cm away from the screen and placed their index finger on a marked starting point located on the table 40cm away from the screen, in line with its center. The stimulus was displayed 24cm above the table and the classification answers were displayed on each side of it, 20cm apart (Figure 6). Participants wore a Velcro ring with a marker at the tip of their index finger. A touch was registered when the marker was 3cm away from the screen or closer. A system of 6 OptiTrack Flex 13 cameras by NaturalPoint, Inc. tracked the marker's location using Motive 2.3.0 software [ref] at a sampling rate of 120Hz. The coordinates were broadcasted online to a NatNet client [ref] and recorded with Matlab.

A picture containing text, device

Description automatically generated

Figure 1. Setup. A participant placing his finger on the starting point which is located 40cm 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.

##### Procedure

Each session included a practice block and twelve test blocks of forty trials each (i.e., 40 practice trials and 480 test trials). Breaks were given between blocks. Half the trials were congruent and half incongruent, and half the targets were natural and half artificial. Stimuli order in the experimental blocks was dictated by a list that was randomly sampled (without replacement) out of ten pre-composed lists of trial condition and stimulus. An additional practice list was used for all participants. In each list, the order of words was pseudorandom, with the following constraints: (a) Each word was equally frequent as a target at the congruent and incongruent conditions; (b) All words were used as targets the same number of times; (c) A target never repeated in the same block; (d) In the congruent condition the prime was identical to the target word; (e) In the incongruent condition, a prime which doesn't share letters in common locations with the target was selected from the alternative category (artificial/natural). For example, in the congruent condition, the word "phone" could be preceded by "PHONE", while in the incongruent condition it could be preceded by "GRASS". Each prime was further paired with a random distractor from the same category (artificial/natural) to be used in the prime recognition task. The distractor shared no letters in common locations with the prime, so seeing one letter only sufficed for correct discrimination.

The procedure closely followed the one used in Dehaene et al. [ref], yet in a motion tracking setup. Every trial consisted 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 was displayed, participants classified the target word as describing a natural / artificial item by reaching the side of the screen that contains the appropriate category (Figure 7). Responses had to be provided within a 1500ms time window from target presentation. Movement duration was defined as the time between target onset and the point when the finger was 3cm away from the screen or closer (on the Z axis). Responses slower than 1500ms were followed by a "Move faster" feedback. After Classifying the targets, the participants were asked to recognize the prime as an objective measure of prime awareness. Participants were presented with two words – the prime and another word from the same category. Response was given in an identical fashion to the target classification task, within a 5 seconds response window. Finally, a subjective measure of prime awareness was taken, using the Perceptual Awareness Scale (PAS) [ref]. Participants used 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, participants were asked to return their finger to the starting point.

Diagram

Description automatically generated

Figure 2. Stimuli presentation order of experiment one. Each trial was 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 (0-1500ms, out of which the target was displayed for 500ms), a recognition task (0-5,000ms) 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.

##### Trajectory preprocessing

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

##### Variables extraction

The congruency effect was estimated with eight reaching parameters: (a) reach area, defined as the area confined between the average trajectory to the left side when the correct answer is on the left and the average trajectory to the right when the correct answer is on the right; (b) reaction time, defined as the time from stimulus presentation up to movement onset. Movement onset and movement offset were distinguished from reaching onset and offset. *Movement onset* was detected once the Euclidean distance from the starting point was greater than 2cm. Movement offset was recognized once the distance from the screen on the Z axis was shorter than 3cm; (c) movement duration, defined as the time from movement onset until the screen was reached; (d) deviation from center, defined as the distance of every point along the average trajectory from the center line, which was a line drawn between the starting point and the middle of the screen; (e) movement variation, defined as the standard deviation of the "Deviation from center" measure. The standard deviation was computed over the trials; (f) heading angle, defined as the angle confined between a tangent at every point along the trajectory and a line perpendicular to the screen. An angle was considered negative if the extension of the tangent met the screen on the side opposite to the chosen answer; (g) changes of mind, defined as the number of changes in implied goal along a single trial's trajectory. The implied goal was indicated by the side where the current tangent to the trajectory met the screen; (h) distance traveled, defined as the sum of Euclidean distances between the samples of a single trial.

##### Exclusion criteria

Trials in which either a technical malfunction occurred, or a problematic response was given, as well as trials that had a visibility rating that is higher than one, were excluded from the analysis. A technical malfunction alludes to trajectories that had less than 100ms of existing data or more than 100ms of missing data, or trials in which the stimuli duration was incorrect. Problematic responses include incorrect answers and trajectories that missed the target by more than 12cm, as well as reaching movements that were shorter – when measured along the z axis – than the distance between the starting point and the screen, minus a three-centimeter allowance that accounts for small variations in reaching onset. Finally, slow movements were disqualified if they were located more than 3 SD from the average movement duration across the participant's correctly answered trials that did not have missing data.

#### Results

The responses to the recognition task on the congruent condition do not represent the objective visibility since the prime and target words are identical which biases the responses. Therefore, only the responses in sthe incongruent condition were used to estimate prime visibility. When participants rated the prime as invisible, they were not better than chance at recognizing it, M = 50.6%, SD = 3.4, t(9) = 0.59, p = 0.56, 95% CI = [48.2, 53]. The distance traveled on the congruent (M = 1.01, SD = 0.006) and incongruent (M = 1.01, SD = 0.007) conditions did not differ (t(9) = -0.94, p = 0.36, 95% CI [-0.003, 0.001], Cohen's dz = -0.29) and neither did the COM frequency (Mcon = 0.21, SDcon = 0.06, Mincon = 0.2, SDicon = 0.08, t(9) = 0.3, p = 0.76, 95% CI [-0.03, 0.04], Cohen's dz = 0.09). Reach area was marginally smaller in the incongruent condition (Mcon = 0.028, SDcon = 0.0047, Mincon = 0.027, SDincon = 0.0050, t(9) = 2.22, p = 0.053, 95% CI [-0.00001, 0.0021], Cohen's dz = 0.703) while reaction time was marginally longer in the incongruent condition (Mcon = 433.9ms, SDcon = 125.2, Mincon = 441.8ms, SDincon = 125.8, t(9) = -2.07, p = 0.067, 95% CI [-16.5, 0.7], Cohen's dz = -0.656). Movement time didn't differ between the conditions (Mcon = 558.1ms, SDcon = 80.7, Mincon = 557.9ms, SDincon = 81.6, t(9) = 0.07, p = 0.93, 95% CI [-6.9, 7.4], Cohen's dz = 0.024).

#### Discussion

### Experiment 1 was conducted to establish an experimental environment capable of capturing unconscious effects with motion tracking. In contrast to our expectations, no robust unconscious effect was found in any of the motion tracking measures, and although a trend was found in some of them, it was never significant. Nevertheless, this trend was most prominent in the reach area variable, which implies it might be the optimal variable for probing the unconscious effect. Interestingly, although the movement duration was similar in both conditions, there was a trend to longer reaction times in the incongruent condition. This pattern of results might imply that the conflict created by the prime in the incongruent condition is resolved before the movement starts which might explain why an unconscious effect was hardly seen.Exp 2

For an unconscious effect to be reflected in the reaching trajectories, the conflict that it produces has to be present while the reaching is performed. The longer reaction time for incongruent trials in experiment one implied this was not the case. Therefor in experiment two, movement onset was restricted, and movement duration was decreased.

Since quicker responses were required, a second training block was added. The results were expected to reflect a greater unconscious effect than experiment one seeing that an overlap should exist between the decision-making process and the reaching movement.

#### Methods

##### Participants

15 participants (11 females) were recruited for the study (M=24.78, SD=3.68) in a recruitment procedure identical to experiment 1. Six participants were disqualified from the analysis. Three of them had less than 25 valid trials in each condition [see exclusion criteria of exp 2] and two performed significantly worse than 70% correct answers in the classification task according to a binomial test. The sixth participant was excluded because the experiment crashed during her session.

##### Stimuli

Stimuli was identical to that used in experiment one.

##### Apparatus

The set up was identical to that used in experiment one except that the starting point was 35cm away from the screen and the size of the blue circle beneath each target was slightly increased so that hitting it will be easier.

##### Procedure

In this experiment before performing the practice and test blocks, the participants completed an initial practice block that did not include a prime. The order of trials in this block was drawn from an additional list of trial condition and stimulus. Other than that, all the lists were the same. Timing was also adjusted so that movements had to start before 330ms had passed and last no longer than 430ms. Movement started when the finger was 2cm away from the starting point (Euclidean distance) and ended when it was 3cm away from the screen (on the Z axis). Late initiations and long durations were followed by a "Too late" and "Too slow" feedbacks respectively. Recognition responses were given within a 7 second response window. The rest of the design was identical to experiment one.

Diagram, schematic

Description automatically generated

Figure 2. Stimuli presentation order of experiment 2. Each trial was 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 (0-760ms, out of which the target was displayed for 500ms), a recognition task (0-7,000ms) 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.

##### Exclusion criteria

Additional restrictions were placed on the participants' reaching movements, limiting their reaction time and movement duration. Movements that started less than 100ms or more than 320ms after target display were excluded. In addition, movements that lasted more than 420ms were excluded if they were located more than 3 SD from the participant's average movement duration among correct trials that were not too short, had no missing data and were completed in time (i.e., started between 100ms and 320ms after target display and lasted no longer than 420ms). *Valid trials* were those that were not excluded due to any exclusion criteria.

#### Results

When participants rated the prime as invisible, they were not better than chance at recognizing it, M = 50.2%, SD = 2.57, t(8) = 0.30, p = 0.77, 95% CI = [48.27, 52.24]. Similarly to experiment one a congruency effect was not reflected in the traveled distance (Mcon = 1.01, SDcon = 0.004, M­­incon = 1.02, SDincon = 0.004, t(8) = -0.83, p = 0.42, 95% CI [-0.008, 0.003]), frequency of COM (Mcon = 0.26, SDcon = 0.08, M­­incon = 0.27, SDincon = 0.12, t(8) = -0.4, p = 0.69, 95% CI [-0.11, 0.07]), reaction time (Mcon = 140.4ms, SDcon = 34.2, M­­incon = 144.2ms, SDincon = 33.2, t(8) = -1.192, p = 0.26, 95% CI [-11.2, 3.5]) or movement duration (Mcon = 416.5ms, SDcon = 60.5, M­­incon = 423.9, SDincon = 45.4, t(8) = -1.192, p = 0.26, 95% CI [-21.7, 6.9]). Similarly, but unlike experiment one, the difference between the reach area in the congruent (M = 0.00015sec, SD = 0.0000289) and incongruent (M = 0.00013sec, SD = 0.0000646) conditions was far from significant, t(8) = 0.667, p = 0.523, 95% CI [-0.0000281, 0.0000511], Cohen's dz = 0.222. The average number of valid trials among included and excluded participants was 91.64 (SD = 57) out of 240 in the congruent condition and 84.57 (SD = 54.8) in the incongruent condition. On average, 118 trials were excluded due to late responses and 31 due to early responses, while 67 trials were excluded due to incorrect answers.

#### Discussion

### Experiment two was expected to produce an unconscious effect since prime dilution [ref] was diminished by further limiting the participants' response time in comparison to experiment one. However, none of the dependent variables showed any difference between the conditions, including reach area which was marginally significant in experiment one. An examination of the reach area distribution shows a that a single subject had an opposite trend to the rest of the sample which might explain why a significant unconscious effect could not be found [ref to graph of reach area]. However, the failure to find a congruency effect could also be the product of the strict timing limitations. It is possible that participants did not properly perform the task because the required responses were too quick. This notion is supported by the high proportion of trials that were excluded due to late or early responses (30.9%). Being unable to keep up with the fast pace of the experiment could also result in rash and incorrect answers, as did happen in 13.9% of the trials, which is unexpected in such a simple classification task [ref to % of incorrect answers a similar semantic priming exp].Exp 3

Having a large proportion of excluded trials could explain why significant effects were not found in experiment two. Since many of the trials were excluded due to bad timing, experiment three incorporated a long practice session a day before the test session. Once the response time had improved, the task was expected to become easier. Thus we anticipated less incorrect answers and inappropriate timing responses, and a large congruency effect.

#### Methods

##### Participants

17 participants (10 females) were recruited for the study (M = 25.5, SD = 3.7) in a recruitment procedure identical to experiment 1. Four participants were excluded since they did not arrive to the second day of the experiment. One more participant was excluded because he had less than 25 valid trials in each condition, and five other participants were excluded since they achived significantly less than 70% correct answers in the classification task according to a binomial test. Overall, seven subjects were included in the analysis.

##### Stimuli

Sixty 4-letter words were used as primes and targets on the practice day. All words followed the same criteria as in the previous experiments. The stimuli on the test day remained the same as in the previous experiments.

##### Procedure

The procedure on the test day was identical to experiment two except for a few minor changes. The maximal movement onset and movement duration were reduced by 10ms to 320ms and 420ms respectively. Recognition of movement onset and offset was also adjusted, movement started when the finger was 1cm away from the starting point (Euclidean distance) and ended when it was 1.5cm away from the screen (on the Z axis). In addition, "Too early" feedback was given if the participant responded less then 100ms after target presentation. The purpose of the "Too early" feedback was to prevent predictive responses, i.e., responses that are planned before the stimuli is displayed and are therefore less affected by it. The above changes also applied to the six practice blocks participants completed on the practice day. The stimuli on the practice day were drawn from a set of ten pseudo random lists of condition and stimulus order that followed the same constraints as the test session lists.

##### Exclusion criteria

Exclusion criteria was identical to experiment two.

#### Results

When participants rated the prime as invisible, they were not better than chance at recognizing it, M = 47.4%, SD = 3.4, t(6) = -1.94, p = 0.1, 95% CI = [44.26, 50.65]. Contrary to experiment two, a congruency effect was reflected in the traveled distance which was shorter in the congruent (M = 1.01, SD = 0.005) than in the incongruent condition (M = 1.02, SD = 0.007), t(6) = -3.76, p = 0.009, 95% CI [-0.008, -0.001], Cohen's dz = -1.422. In accordance with shorter movements, movement duration was also marginally shorter in the congruent (M = 391.9ms, SD = 32.9) than in the incongruent condition (M = 403.3ms, SD = 25.4), t(6) = -2.41, p = 0.051, 95% CI [-22.9, 0.1], Cohen's dz = -0.91. A significant difference was also detected in the reach area which was larger for the congruent condition (Mcon = 0.0002, SDcon = 0.00003, Mincon = 0.0001, SDincon = 0.00002, t(6) = 3.02, p = 0.02, 95% CI [0.000006, 0.00004], Cohen's dz = 1.14). On the other hand the frequency of COM (Mcon = 0.2, SDcon = 0.13, Mincon = 0.2, SDincon = 0.15, t(8) = -0.4, p = 0.69, 95% CI [-0.1, 0.1]) and the reaction time (Mcon = 164.4ms, SDcon = 26.1, Mincon = 175.9ms, SDincon = 15.4, t(6) = -2.22, p = 0.067, 95% CI [-24, 1.1]) did not demonstrate any congruency effect. Surprisingly, the average number of valid trials among included and excluded participants was 87.61 (SD = 34.69) in the congruent condition and 77.84 (SD = 36.23) in the incongruent condition, which did not differ significantly from experiment two (t(25) = -0.3, p = 0.76, 95% CI [-83.5, 62](. However, trends were found when analyzing each exclusion criteria separately. The amount of late responses decreased (M3 = 52.84, SD3 = 30.83, M2 = 118, SD2 = 128.16, t(25) = -1.78, p = 0.08, 95% CI [-140.4, 10]), while the number of short trajectories (M3 = 57, SD3 = 40.7, M2 = 18.5, SD2 = 18, t(25) = 3.2, p = 0.003, 95% CI [13.8, 63.1]), slow movements (M3 = 77.5, SD3 = 44.3, M2 = 60, SD2 = 50.4, t(25) = 0.95, p = 0.34, 95% CI [-20.3, 55.2]), early responses (M3 = 54.3, SD3 = 50.6, M2 = 31.5, SD2 = 36.5, t(25) = 1.35, p = 0.18, 95% CI [-11.9, 57.6]), and incorrect answers (M3 = 91.2, SD3 = 57.13, M2 = 67, SD2 = 36.1, t(25) = 1.32, p = 0.19, 95% CI [-13.4, 61.7]) increased.

#### Discussion

Experiment three incorporated an additional practice session that was intended to decrease the proportion of excluded trials. Interestingly, although the overall number of excluded trials did not change, a trend was seen in the proportion of each exclusion reason. It seems that late responses became less prominent at the expanse of having more short reaches, slow movements, early responses, and incorrect answers. Seeing that late responses were the most prominent cause for failure in experiment two, it possible that participants in experiment three mainly focused on reducing their response time, causing them to respond too quickly and have short trajectories. If these hasty responses were executed before adequate processing of the target was done, they were more likely to result in an incorrect answer. Consequently, the probability for corrective movements increased which accounted for the higher rate of long movement durations. Even though the expected decrease in excluded trials did not occur, the results of experiment three did demonstrate the anticipated congruency effect. The conflict between the invisible prime and the target was reflected in the trajectory's bias towards the incorrect answer in the incongruent trials. This bias was expressed as a decrease in the reach area and an increase in the traveled distance for incongruent trials. The similar reaction time between the conditions and longer movement duration in the incongruent condition indicated that the conflict was processed during the movement, not before.

### Exp 4

The purpose of the current study was to examine whether motion tracking is preferable over keyboard response when studying unconscious processing. Experiment four was designated to answer this question by comparing the sensitivity of both measures on an identical task. Since experiment three have shown that additional practice does not improve the number of valid trials, a separate training day was not included in experiment four and only one practice block was used for each measure. The two measures were used in two consecutive sessions and the number of trials for each was reduced in half to prevent fatigue. In accordance with previous findings [ref to Xiao, but see ref to dehaene] we expect that the reach area variable in the reaching session would produce a larger congruency effect than the RT variable in the keyboard session.

#### Methods

##### Participants

To estimate the required sample size we calculated the average semantic effect in experiment two and three when using only half of the trials in each experiment. 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 α=0.05 a sample of 30 participants was needed, based on G\*Power [ref to GPOwer]. One participant was excluded since a reflective object that she wore interfered with the motion tracking system's recordings. Another participant was excluded since the program crashed in the midst of her experiment due to unexpected reason. Another one because she quite before completing the training.

##### Stimuli

The stimuli was identical to that used in experiment one.

##### Procedure

Each of the two sessions included a practice block and six test blocks (i.e., 40 practice trials and 240 test trials) which were run consecutively, and the order of the sessions was counterbalanced between subjects. Breaks were given between blocks. Half the trials were congruent and half incongruent, and half the targets were natural and half artificial. Stimuli order in the experimental blocks was dictated by a list that was randomly sampled (without replacement) out of twenty pre-composed lists of trial condition and stimulus. For the practice blocks a list was drawn from a different set of ten lists. The order of words within each list followed the same constraints as in experiment one. Every trial consisted 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 was displayed, participants classified the target word as describing a natural / artificial item by selecting the side of the screen that contains the appropriate category. In the reaching task this was done by touching the appropriate side of the screen. Reaching responses were bound to the same movement onset and duration constraints as in experiment three. However, here movement ended when the finger was 0.7cm away from the screen (on the Z axis) and the "Too slow" feedback was given after a movement was completed. In the keyboard task participants pressed "E"/"Y" keys with the left/right hand to select the left/right side accordingly. Response had to be given within a time window of 100-740ms from target display, otherwise "Too Early"/ "Too Late" feedback was given. After Classifying the targets, the participants were asked to recognize the prime out of two words as in previous experiments. Response was given in an identical fashion to the target classification task, within a seven second response window. Finally, a subjective measure of prime awareness was taken, using the Perceptual Awareness Scale (PAS) [ref].

##### Exclusion criteria

The exclusion criteria in the reaching session was identical to that used in experiment two. Additional exclusion criteria were used in the keyboard session where trials were excluded if no response was given or if it was given less than 100ms or more than 740ms after target display.

#### Results

Discussion

### General Discussion

We set out to examine if motion tracking can serve as a solution for the small effect sizes that are usually found in the field of unconscious processing. Increased sensitivity to unconscious effects will allow to settle the long lasting debate about the extent of unconscious processing. To do so we used a classical semantic priming paradigm that was previously used by Dehaene and colleagues [ref] and was proven to exhibit extensive unconscious effects. Our first experiment required participants to make a semantic judgment regarding a target stimulus that was preceded by a congruent/incongruent subliminal prime. Analysis of the results revealed a hint of unconscious processing only in the reach area variable which was smaller for incongruent trials. Since this experiment allowed for relatively slow responses, it was suspected that the prime's activity is diluted before the movement is initiated, which explains why a robust congruency effect was not observed. Supportive evidence for this assumption was provided by the longer movement onset times in incongruent trials, but not movement durations. For the unconscious effect to be reflected in the movement trajectory instead of the movement onset, it is preferable that the cognitive conflict between the prime and the target will overlap with the reaching movement. For this reason, the participants' response window in the second experiment was diminished and limitations were placed on their movement onset time and movement duration. Unfortunately, the strict timing constraints resulted in many excluded trials and therefore a significant congruency effect was not found. To solve this problem, an additional training day was added in experiment three, which was intended to improve the participants' response speed and increase the amount of valid trials. Although the proportion of excluded trials did not decrease in the third experiment, the proportion each exclusion reason took did change; Interestingly the number of late responses decreased while the number of early, slow and incorrect responses increased. This pattern of results served as an indication of an undesired training effect: the participants mainly focused on hastening their responses, at the expense of proper timing and performance in the task. Therefor in the fourth experiment the additional training day was discarded. The goal of the fourth experiment was to examine if motion capture is superior to keyboard-RT when probing unconscious processing, consequently the experiment was comprised of a reaching session and a keyboard session that were run consecutively.

@@@ Write the results of experiment 4 @@@@