### 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 without changing the stimulus, 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. 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, an objective and / or subjective measure of prime awareness is typically administered [ref]. SHORTLY DESCRIBE WHAT THESE MEASURES ARE

While some semantic priming found n that invisible words can be processed up to the semantic level], although 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], or unconscious thought [ref], have similarly exhibited both successful and failed experimental investigations. Finally, failed replications have also been demonstrated when studying the priming of behavioral patterns, namely social distancing and intelligent behavior [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: f the awareness measure is not sensitive enough to discover residual awareness, the researcher might falsely ascribe conscious processes to unconscious 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 UC 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

**1:**

Both these problems can be solved using trajectory 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 UC 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 UC 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 UC [ref]. In a similar experiment the concept of digits or letters was 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 movement tracking to demonstrate the role of attention in facilitating priming [ref]: subjects were asked to judge a target digit as larger or smaller than 5, and exhibited longer reach trajectories 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 movement tracking and keyboards RTs, yet without directly comparing between them. In the first, DESCRIBE THE STUDY: WHAT DID SUBJECTS DO? keyboard responses were affected by prime-target congruency, and motion tracking showed that it also affected the ongoing execution of the motor response. This served as basis for the conclusion that the motor response is based on feedforward processing that is first evoked by the prime, and then corrected once the target becomes available [ref]. In the second study, the effects of UC processing in the dorsal stream was tested. AGAIN, DECRIBE., Alongside the keyboard-RT effect, motion tracking was held to index dorsal – as opposed to ventral – processing, under the assumption that reaching movements are more heavily dependent on dorsal processing than button presses [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]. AGAIN, DESCRIBE WHAT HAPPENED IN THE STUDY. The authors concluded that positive / negative primes facilitate a same / different response accordingly when participants judge the similarity of two digits. 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 XX, which might be underpowered for detecting awareness [ref,.

Other than specifications of the awareness measure worthy of note is also the unintuitive semantic relation between the valence of the primes and the same / different response.

Notably, this study used mouse tracking and not reaching movements, which might be less sensitive. 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 possible 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 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 UC processing. Three exploratory studies were aimed at finding the optimal conditions for discovering a UC 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 subjects 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. They 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 reaching trajectories are … DESCRIBE. In the fourth experiment, I expected to find a larger congruency effect in the motion tracking task than in the keyboard task.

### Exp 1

GIVE A VERY SHORT INTRODUCTION (A FEW SENTENCES) ABOUT THE GOAL OF THIS EXPERIMENT

Methods

#### Participants

Ten participants (XX females) between the ages of eighteen and thirty-five were recruited for the study (M=??, SD=??). 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 (9.9.0.14677003) [ref] and Psychtoolbox 3.0.18 – Flavor: beta, Corresponds to SVN Revision 12779 [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 was dictated by a list that was randomly sampled (without replacement) out of ten pre-composed lists of trial condition and stimulus in the experimental blocks. 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 time 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

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Figure 2. Stimuli presentation order. 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.

#### Results

#### Discussion

### Exp 2

### Exp 3

In exp 3 the training day used 4 letter words.

### Exp 4

### General Discussion

This paper claims averaging trajectories is wrong. Read it before the thesis test:

Wulff (2019). Mouse-tracking: Detecting types in movement trajectories

Check if this paper has some conclusions about "reaching" that can be relevant for your discussion:

Schmidt (2007). Measuring unconscious cognition: Beyond the zero-awareness criterion