### 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 others do not. And so, I might miss the ball altogether if I am extremely occupied by a different engaging task [ref] , yet 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 UC stimuli or at close temporal proximity to it (e.g., masking, CFS) [ref]. Invisibility can also be achieved without changing the stimulus, by diverting attention away from the stimulus [ref].

All three methods decrease the likelihood of evoking awareness by reducing the brain's response to the stimulus [ref]. This weak signal usually translates to small behavioral changes that are hardly detectable in experiments [ref]. As a result, a hot debate is raging regarding the contradicting findings that are common to the field [ref].

#### Contradicting findings

One prevalent paradigm which is prone to such contradicting findings is the priming paradigm which is often used to examine if a certain aspect of a stimuli can be processed UC [ref]. In this paradigm a participant is required to perform a certain task on a target stimulus. Preceding this target, a related prime stimulus is presented in an unconscious fashion. The subject's response is either facilitated or inhibited according to the congruency between the prime and the target. The difference in the response between the congruent and incongruent conditions is called the congruency effect and it is an indication that the prime was indeed processed. To ensure that processing was done unconsciously an objective and / or subjective measure of prime awareness is introduced to the participant [ref]. Studies that applied this paradigm have shown that UC words can be processed up to the semantic level [ref], although similar studies failed to show semantic processing and claimed for lexical processing instead [ref]. Other studies haven't found any congruency effect at all [ref]. The UC processing of numbers has also been examined in a few studies which discovered that simple arithmetic computations can be done unconsciously [ref]. Interestingly, studies trying to replicate the results failed to do so [ref]. Other cognitive functions, such as 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

Do these contradicting findings represent a genuine heterogeneity in unconscious processing, or could they stem from methodological limitations of some of these studies?

##### Underestimation of awareness

**1:**

One source of methodological difference relate to the way consciousness is being measured.

If the awareness measure isn't sensitive enough to discover small markers of awareness, the researcher might be inclined to rule out awareness and falsely deduce UC processing instead [ref].

There are several factors that can cause awareness to be underestimated, that is to conclude awareness doesn't exist when in fact it does. Firstly, a measure that is insensitive to the relevant aspects of the stimuli will not be able to discover awareness of it [ref]. In addition, a long delay between the presentation of the stimulus and inquiry about it might cause subjects to forget that they had some experience of it [ref]. Underestimation can also occur if the subject uses a very strict criterion when judging whether she saw the prime [ref]. Finally, a difficult task could reduce that participant's motivation to perform an exhaustive introspection and thus lead to underestimation of awareness [ref].

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

Another source, conversely, is insensitive measures of the UC effect that promote null findings. The most prominent measure for probing UC effects is the keyboard RT. When participants are asked to perform a task on a target stimulus, it was shown that their RT changes according to the congruency between the target and the prime [ref]. However, this effect is usually very small [ref] and doesn't provide insight on the process of formulating the final decision.

#### Motion tracking vs keyboard

**1:**

The solution for these problems might be provided by trajectory tracking which has become a popular tool for unraveling cognitive processes [ref]. Contrary to keyboard RT which produces a discrete value for each trial, motion tracking produces a continuous set of values which is better suited for tracking ongoing cognitive processes. This property allowed to reveal the temporal dynamics of speech comprehension and show that words are processed in an incremental manner [ref]. Another drawback of the keyboard RT is that it doesn't allow to draw direct conclusions regarding the cognitive processes that lead to the final decision; Since keyboard input is given only after the decision has been made, only retrospective deductions can be made. In contrast, motion tracking captures the movement while the cognitive processes are occurring which is why it directly reflects their development. This advantage was used to probe the syntactic processing of speech and conclude that multiple syntactic interpretations of a sentence are processed simultaneously as opposed to serially [ref]. The different movement patterns associated with simultaneous conflicting goals and serially occurring goals were differentiated using motion tracking [ref].

Another benefit of continuous data is the possibility to extract various parameters of behavior from it that are not available when using non-continuous measures. One such parameter is velocity which was used to inspect subjects' confidence in their answers [ref]. Another parameter is changes of mind that are not possible 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 is beneficial when studying UC processing. The combination of motion tracking and priming paradigms that evoke conflicts between the prime and target can be used to learn about the functionality of UC processing. For example, the level at which UC images are processed was probed by asking subjects to classify a target image as a person / animal while the image is preceded by a prime image. When the prime was incongruent to the target the 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 stimulus as one of them, and here too the trajectories were affected by the congruency between the prime and the target [ref].

Motion tracking can was also be used to corroborate previous findings and confirm that the effect is robust across measuring techniques. The role of attention in facilitating priming [ref] was reaffirmed using this concept when subjects that had to judge a digit as larger or smaller than 5 exhibited longer reach trajectories in the incongruent condition especially when they were attended to the prime [ref].

#### Prev papers with motion tracking and keyboard

It should be noted that applying motion tracking doesn't contradict the usage of keyboard response and in fact can be incorporated in a keyboard experiment to further extend its findings. For instance, when keyboard responses revealed that UC primes influence the onset of motor responses, motion tracking was incorporated to show that it also affects the ongoing execution of the motor response. This enabled the inference that the motor response is based on feedforward processing that first reacts to the prime and only then makes the appropriate corrections once the target becomes available [ref]. In a keyboard response study that examined the properties of UC processing in the dorsal stream, motion tracking was used to prompt dorsal – as opposed to ventral – processing since reaching movements are more heavily dependent on dorsal processing than button presses [ref].

#### Xiao + reaching vs mouse

Although motion tracking seems to be more suitable for UC research than keyboard response, drawing solid conclusion about the advantage of one measure over the other demands a direct comparison between the two. So far, to our knowledge, only one study made such comparison [ref] and concluded that positive / negative primes facilitat 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 probed with mouse tracking. Although this study provides important insights into methodological considerations of UC priming experiments, a few points arise that urge further investigation. Awareness assessment was done in a separate block from the main task, hence obviating the assessment of prime visibility on a single trial level. This is especially important since the visibility ratings of many participants were above zero. In addition, the statistical test that was used to infer awareness was the significance of the correlation between d' and the congruency effect, instead of the comparison of the absolute value of d' to zero. This type of analysis was shown to inflate UC effects [ref]. Finally, as was shown in recent work in our lab [ref], having less than two-hundred awareness trials isn't sufficient for revealing conscious processing of a supposedly UC stimulus.

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.

Regardless of the manipulations used in an experiment, an important aspect to consider is the difference between reaching movements and mouse tracking. Using a mouse requires subjects to remap the real-world representation into 2D. The repercussions of 2D mapping are constraints on 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 are compared, reaching produces shorter movement durations, larger curvatures, faster velocities and most importantly responds faster to changes of mind [ref]. These properties make it optimal for detecting fast and short-lasting processes such as unconscious priming effects.

Lastly, since reaching movements are more intuitive than using a mouse they are also less effortful and can thus be considered more likely to express fluctuations in the decision [ref].

#### Current Research

The current study examined the use of motion tracking as a performance measure and asked if it is superior to the commonly used keyboard response and response time measure. Rigorous awareness measures were applied to ensure residual awareness isn't mistaken for UC processing and the intuitive reaching response was used to promote the expression of UC effects. Three exploratory studies were used to assess the optimal conditions for discovering a UC effect when using reaching responses. A fourth confirmatory study compared between motion tracking and keyboard response as a means to examine if one measure has an advantage over the other. All four studies used a priming paradigm inspired by Deheane [ref] in which subjects were presented with a masked prime, followed by a visible target, on which they performed a semantic judgment – does it describe a natural or artificial item. The first experiment used a rather long RT restriction which was later reduced and divided to onset time and movement duration in the second experiment. In addition, the second experiment also introduced another training block to improve response speed. The third experiment incorporated a whole separate training day to achieve the same goal but was then discarded in the fourth experiment as it caused an "over training" effect. Since we hypothesize motion tracking is more sensitive to cognitive conflicts than keyboard response, we expect that the fourth experiment will yield a larger congruency effect in the motion tracking task than in the keyboard task.

### Exp 1

#### Participants

Ten participants between the ages of eighteen and thirty-five were recruited for the study. All participants were right-handed, native Hebrew speakers who aren't color blind and 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. Data was collected at Prof. Liad Mudrik's lab for high level cognition in Tel-Aviv University in a 90 minutes session. Participants were reimbursed with course credit or cash payment.

#### 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 . 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 allowed between blocks. Throughout the experiment, 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. The practice list was identical for all participants. In each list, the order of words is 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 "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]. 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. Slower responses were replied with "Move faster" feedback. Movement time started once the target was displayed and ended when the finger was 3cm away from the screen or closer (on the Z axis). 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 had to return their finger to the starting point after each response.

Diagram

Description automatically generated

Figure . 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