### Schedule

1. לשלוח לרותי abstract ורשימה של 2-3 בוחנים **עד ה30.8.22**.

לכל בוחן לרשום שורה שמסבירה מדוע התחום בו הוא עוסק רלוונטי לתזה שלי.

1. לאחר קבלת אישור לגבי הבוחנים לעדכן את רותי לגבי הבוחנים והתאריך בו קבענו (פירוט לגבי התאריך בסעיף הבא).
2. הבחונים צריכים לקרוא את העבודה ולתת לה ציון לפני המבחן תזה.

צריך לתאם מועד בחינה על תזה עם הבוחנים כדי שיספיקו לקרוא אותה לפני ולשלוח את הפרטים על המועד לרותי **עד ה15.9** (אחרי זה מתחילים החגים ורותי לא זמינה).

המועד לבחינה עד חודש אחרי הגשת העבודה למזכירות במייל.

1. מבחן תזה (הגנת תזה) יכול להיערך **עד ה18.10.**
2. להסדיר במזכירות את כל ההליכים לקראת סיום לימודים **לפני מבחן התזה**.
   1. מילוי חובות לימודים
   2. הגשת עותק של עבודת הגמר חתומה ע"י המנחה (במייל). הבחינה תתקיים **עד חודש אחרי הגשת העבודה**.
3. צריך למלא טופס העלאת התזה לספריה: [טופס הפקדה של עבודת הגמר לתואר שני](https://sagol.tau.ac.il/yedion/987).
4. למלא [טופס הצהרת הסטודנט על מקוריות העבודה](https://sagol.tau.ac.il/yedion/987).
5. לאחר הבחינה וביצוע התיקונים בעבודה, להגיש למזכירות עותק מוגמר של העבודה בדיסק און קי או CD יחד עם טופס אישור העלאה למאגר הדיגיטלי.
6. לאחר מכן יש להזמין טופס טיולים דיגיטלי במערכת מידע אישי לתלמיד.

### Structure

תבנית לעמוד השער של התזה מופיע במייל "הנחיות לקראת סיום התואר, הגשת התיזה והבחינה עליה".

הנחיות כתיבה:

* לא יותר מ-100 עמודים
* רווח 1.5 פונט 12
* מבנה:
  + דף שער - בעברית ובאנגלית בשני צידי העבודה בהתאם לשפה (דוגמאות בסוף המסמך)
  + תקציר - בעברית ובאנגלית בהיקף של 1-2 עמודים בשני צידי העבודה בהתאם
  + תוכן העניינים
  + מבוא - תיאור מלא של מקורות המידע עליהם מסתמך המחקר, הצגת הבעיה הנחקרת ומהי ההצדקה לחקור אותה
  + היפותזה ומטרות המחקר
  + שיטות וחומרים - פירוט החומרים ושיטות העבודה שננקטו במהלך המחקר
  + תוצאות - פירוט תוצאות הניסויים שנערכו ועיבוד התוצאות לצורך הסקת המסקנות
  + דיון - דיון ממצה ומקיף המציין את המסקנות ואת הסימוכין המדעיים המצדיקים את הסקתן
  + סיכום
  + נספחים (איורים וטבלאות) - אם הם אינם בגוף החיבור
  + רשימת מקורות המצוטטים בחיבור. הרשימה תכלול את הפרטים הבאים: שמות המחברים, שם כתב העת, כרך ועמודים.

### 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]. For the subjective measure, the participant is asked to report about her perception of the prime by rating how well she saw it on a categorical scale that ranges between "did not see anything at all" to "saw the prime clearly" on the other (the Perceptual Awareness Scale; PAS; REF). Using a subjective measure allows to detect awareness on a trial-by-trial basis, yet it is subjected to the criterion problem, where subjects’ ratings might be highly affected by their response criterion (ref). For the objective measure, the participant is asked to make an objective judgement about the prime, typically choosing an answer among several options (i.e., a forced choice question). If the proportion of correct responses across trials (or the overall sensitivity, measured using d’; ref) is higher than chance, the stimuli will be considered as consciously perceived. This measure is less affected by the criterion problem, yet it is held to overestimate conscious perception [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].

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, 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].

#### Previous 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 experiments 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 to which side was the mask pointing. The task was first performed with a keyboard, revealing that prime-target congruency affects the response speed, and then with stylus tracking. In the stylus session, the stimulus was presented only after the participants initiated a movement towards the center, forcing them to correct their movement mid-way. 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 the subsequent 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 compared with elongated animals. The researchers accordingly 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 here in using rigorous awareness measures to ensure residual awareness is not mistaken for unconscious processing. Three pilot experiments were aimed at finding the optimal conditions for discovering an unconscious effect when using reaching responses. A fourth confirmatory experiment 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 Dehaene 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.

### Pilot Experiment 1

The aim of the first experiment was to test the effect of unconscious processing on motion trajectory. This was a pilot experiment where I developed and troubleshooted the apparatus, as well as explored meaningful parameters from the recorded trajectories.

#### Methods

##### Participants

Ten participants (eight females) between the ages of eighteen and thirty-five were recruited for the study (age: 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 in this and subsequent experiments 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. This experiment – and all others reported here – 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 in experiment 1. 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

Prime visibility: overall, 63.93% of the trials were rated as visibility 1, 21.25% as visibility 2, 3.25% as visibility 3 and 0.75% as visibility 4. Since in the congruent condition the prime and target words are identical, responses in this condition are highly biased towards the target therefore, I only analyzed the responses in the incongruent condition to estimate prime visibility. When participants rated the prime as invisible, they were not better than chance at recognizing it, M = 50.6%, SD = 3.40, t(9) = 0.59, p = 0.56, 95% CI = [48.2, 53]. Thus, both the subjective and the objective measures confirm that masking was effective in rendering the stimuli invisible.

Congruency effect: 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) = 0.30, 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, although trends were found for some of them. As the trend was most prominent in the reach area variable, I reasoned that it might be the optimal variable for probing unconscious processing, and accordingly decided to focus on it in subsequent experiments. Interestingly, although the movement duration was similar in both conditions, there was a trend to longer reaction times in the incongruent condition.

### Pilot Experiment 2

Given the results of Experiment 1, an explanation is called for, which explains why a congruency effect did not emerge and how can the paradigm be improved to promote it. A possible explanation for the null result can be given using an evidence accumulation model as was done in [ref]. In this model, which is used to model decision making processes, the presentation of a stimulus initiates / commences an evidence accumulation process in favor of a response that corresponds to the stimulus. When the enough evidence has built up and it crosses a certain threshold, a decision is made. If an opposing stimulus is presented before the threshold is reached, evidence starts to accumulate in the opposite direction, and the threshold crossing and decision making is delayed. This is the case for incongruent trials in a priming paradigm, where the prime and target evoke contradictory evidence. This explains why incongruent trials often yield longer response times compared to congruent trials in priming paradigms [ref to priming experiments?]. However this is not the case for the movement duration in my experiment, which was identical for both conditions. Therefor I assumed that the threshold for making a decision has been reached before the movement started. This was supported by the slightly longer reaction time in the incongruent condition which indicates that the participants first reached their decision threshold and only then initiated their movement, thus preventing the congruency effect from being expressed in the movement itself.

Therefor in experiment 2, movement onset was restricted, and movement duration was decreased.

Since quicker responses were required, a second training block was added to make sure subjects learn to respond within the required time window. The movements were expected to reflect a greater unconscious effect than experiment 1 considering that participants will not have enough time to make a decision before starting their movement.

#### Methods

##### Participants

9 participants (7 females) were recruited for the study (age: M=23.66, SD=2.44) using the same recruitment procedure as in experiment 1. Five additional participants were disqualified from the analysis, as they met two of the following predefined excluded criteria: (a) having less than 25 valid trials in each condition (N=3); and (b) showing performance lower than 70% in the main classification task (N=2; determined using a binomial test). Another participant was excluded because the experiment crashed during her session.

##### Stimuli, Apparatus and

##### Procedure

The methods were identical to those used in Experiment 1, besides the following differences: first, the starting point was now 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. Second, here 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. Third, timing was 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.

##### Exclusion criteria

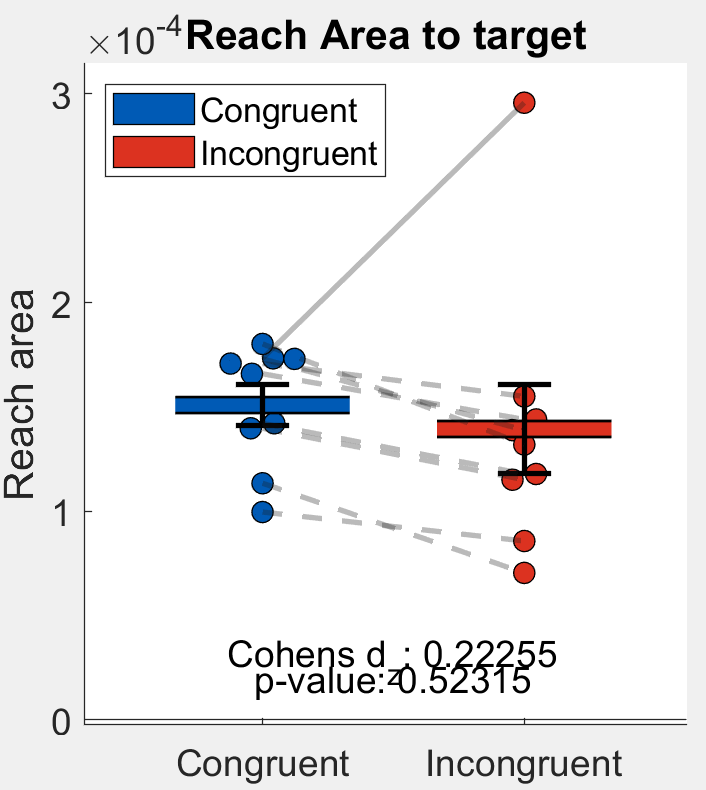
Additional restrictions were placed on the participants' reaching movements, limiting their reaction time and movement duration. Movements that started less than 100ms or more than 320ms after target display were excluded. In addition, movements that lasted more than 420ms were excluded if they were 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

Prime visibility: overall, XX% of the trials were rated as visibility 1, XX% as visibility 2, XX% as visibility 3 and XX% as visibility 4. 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

Since participants in Experiment 2 no longer had enough time reach a final decision before initiating their movement we expected the movement trajectories to reflect the decision making processes and the congruency effect's on it. However, it was not observed in any of the dependent variables. 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 [See reach area graph below]. Expectedly, reducing the allowed response time in this experiment increased the average proportion of late responses (24.58%). Moreover, demanding faster responses might have resulted in rash and incorrect answers, which accounted for the average proportion of early (6.56%) and incorrect (13.95%) responses. Overall Experiment 2 exhibited a large average number of excluded trials (45%).



### Pilot Experiment 3

Given the large proportion of excluded trials, in Experiment 3 the practice session was substantially prolonged into a full session conducted a day before the test session. I anticipated that if participants learn to respond more quickly, there will be less incorrect answers and too-slow timing responses, leading to less exclusions. This in turn was expected to increase the signal-to-noise ratio, and allow the congruency effect to be found.

#### Methods

##### Participants

7 participants (5 females) were recruited for the study (age: M = 25.5, SD = 3.7) in a recruitment procedure identical to experiment 1. Four additional 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 achieved significantly less than 70% correct answers in the classification task according to a binomial test.

##### Stimuli, Apparatus and Procedure

The experimental methods were identical to those used in Experiment 2, besides the following changes: first, the maximal movement onset and movement duration were reduced by 10ms to 320ms and 420ms respectively so as to make sure they do not exceed those use in Gallivan & Chapman [ref]. Recognition of movement onset and offset was also adjusted, so 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). Second, "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, which are planned before the stimulus is displayed and are therefore less affected by it. Third, and most importantly, a longer practice session was run on a separate day before the main experimental session. It included six practice blocks, where a different set of 60 4-letter words was used as primes and targets. All words followed the same criteria as in the previous experiments. These stimuli were drawn from a set of ten pseudo random lists of condition and stimulus order, which followed the same constraints as the test session lists.

#### Results

Prime visibility: overall, XX% of the trials were rated as visibility 1, XX% as visibility 2, XX% as visibility 3 and XX% as visibility 4. 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(6) = -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 response time among included and excluded participants did not improve between the first block of the first day and the second day but rather exhibited an opposite trend (M1 = 446.44, SD1 = 113.36, M2 = 491.97, SD2 = 83.64, t(12) = -1.46, p = 0.169, 95% CI [-113.40, 22.33]). Similarly, 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](. Interestingly however, trends were found when analyzing each exclusion criteria separately. The amount of late responses decreased as expected (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 increased (M3 = 57, SD3 = 40.7, M2 = 18.5, SD2 = 18, t(25) = 3.2, p = 0.003, 95% CI [13.8, 63.1]). In addition, although a significant change was not found, a numerical increase was observed in the amount of 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]).



#### Discussion

Experiment 3 incorporated a prolonged practice session in order to decrease the number of excluded trials and improve the probability of detecting the unconscious effects. The results clearly d on the reaching trajectories, as was evident in the caused a These results are in-line with previous papers that found a larger Area Under the Curve (AUC) [ref] and a larger traveled distance [ref] for incongruent trials.

Contrastingly, but still in line with previous papers [ref], the reaction time was not affected by the prime-target congruency while the movement duration was, which implies that the decision-making process occurs after the movement is initiated.

Interestingly, although the overall number of excluded trials did not change compared to Experiment 2, a trend was seen in the proportion of each exclusion reason. It seems that late responses became less prominent at the expense of having more short reaches, slow movements, early responses, and incorrect answers.

A Possible explanation for this pattern of results can be conceived by reviewing the proportion of each exclusion reason in Experiment 2. Late responses were the most prominent cause for error in experiment 2, and therefore it is possible that in order to diminish their error rate, participants in experiment 3 mainly focused their efforts on reducing their response time. Consequently, quicker responses developed which decreased the number of late responses but increased the number of early responses and short trajectories. These hasty responses left less time to process the target which explains the increase in incorrect answers. Similarly, the probability for corrective movements could have increased as well, which accounted for the higher rate of long movement durations.

### Exp 4

The last experiment included in this thesis was a preregistered one [ref], aimed at examining whether motion tracking is preferable over keyboard responses when studying unconscious processing. To do so, Experiment 4 included both motion tracking and keyboard responses sessions, allowing me to compare the sensitivity of both measures on an identical task. My approach followed the one by Xiao et al. (2015) [ref], but replaced the mouse response with a more intuitive and less effortful reaching response which does not constrain free movement. Additionally, I improved the validity of the unconscious effect by applying a rigorous awareness measure that includes both an objective awareness measure (prime 2-forced-choice recognition) and a subjective trial by trial awareness measure (PAS). Finally, awareness was measured on the same trials as the main task instead of a separate block. Since experiment 3 have shown that additional practice does not improve the number of valid trials, a separate training day was not included in experiment 4, and only one practice block was used for each session. To prevent fatigue, each session included half the number of trials (after testing that the effect found in Exp. 3 is found also when half the trials are used). In accordance with previous findings we expected the effect found in motion tracking (namely, the reach area variable) would produce a larger congruency effect than the effect in the keyboard session (RT variable) [ref to Xiao, but see ref to Dehaene were a larger effect was found using a keyboard].

#### Methods

##### Participants

The recruitment procedure and criterions were identical to those of Experiment 1. 30 participants were recruited (age: M = XXX, SD = XXX) and additional 15 participants were excluded. Five of them were excluded because they had significantly less than 70% correct answers in the target classification task according to a binomial test. Seven participants were excluded since they had less then 25 valid trials in each condition. Three more participants were excluded due to technical issues: one since a reflective object she wore interfered with the motion tracking system's recordings, another participant since the program crashed in the middle of her experiment, and one more quit before completing the experiment. The sample size was determined following a power analysis, calculated on the average effect in experiment 2 and 3, 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]..

##### Stimuli, Apparatus and Procedure

The methods were identical to those used in Experiment 3, besides the following changes: first, the separate practice day was omitted and instead two main sessions were conducted on the same day, one for the keyboard response and the other for motion tracking. Each included a practice block and six test blocks (i.e., 40 practice trials and 240 test trials). They were run consecutively, with the order counterbalanced between subjects. 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. 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. Response in the prime recognition task was given in an identical fashion to the target classification task, within a seven second response window.

##### Exclusion criteria

The exclusion criteria in the reaching session were identical to that used in experiments 2 and 3. 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

Prime visibility: overall, XX% of the trials were rated as visibility 1, XX% as visibility 2, XX% as visibility 3 and XX% as visibility 4. When participants rated the prime as invisible, they were not better than chance at recognizing it, M = 50.9%, SD = 4.3, t(29) = 1.21, p = 0.23, 95% CI = [49.3, 52.5]. A congruency effect was found in both measures, as was evident by the smaller reach area (Mcon = 0.0002, SDcon = 0.00005, Mincon = 0.0001, SDincon = 0.00004, t(29) = 3.7, p = 0.0007, 95% CI [0.00001, 0.00005], Cohen's dz = 0.68 ) and slower keyboard-RT (Mcon = 524.7ms, SDcon = 35.2, Mincon = 545.2ms, SDincon = 32.6, t(29) = -6.5, p = 0.0000003, 95% CI [-26.8, -14], Cohen's dz = -1.19) in the incongruent condition. A bias towards the incorrect answer in incongruent trials was evident in the trajectory from 155ms to 398ms post target onset (%path 17.5-95.5) as was found using a permutation and clustering procedure [ref to trajectory fig with clustering result]. The bias resulted in extended traveled distance (Mcon = 1.013, SDcon = 0.006, Mincon = 1.018, SDincon = 0.008, t(29) = -5, p = 0.00002, 95% CI [-0.007, -0.002], Cohen's dz = -0.9) and prolonged movement duration (Mcon = 412.1ms, SDcon = 29.1, Mincon = 425.7ms, SDincon = 28.1, t(29) = -6.7, p = 0.0000007, 95% CI [-17.7, -9.4], Cohen's dz = -1.2) in incongruent trials. Contrastingly, reaching reaction time (Mcon = 173.1ms, SDcon = 24.1, Mincon = 173.7, SDincon = 24.4, t(29) = -0.31, p = 0.7, 95% CI [-4.2, 3.1]) and the number of changes of mind (Mcon = 0.24, SDcon = 0.12, Mincon = 0.22, SDincon = 0.1, t(29) = 1.12, p = 0.26, 95% CI [-0.01, 0.06]) did not differ between the conditions. As predicted by the previous experiments the number of excluded trials among excluded and included participants in the reaching task was high and exceeded that of the keyboard task (Mreach = 133, SDreach = 32.6, Mkeyboard = 56.2, SDkeyboard = 23.1, t(41) = 15.3, p = 0, 95% CI [66.6, 86.9], Cohen's dz = 2.3), although further inspection reveals this was true for late responses (Mreach = 32.6, SDreach = 22.8, Mkeyboard = 17.1, SDkeyboard = 14.8, t(41) = 4, p < 0.001, 95% CI [7.7, 23.2], Cohen's dz = 0.6), early responses (Mreach = 24, SDreach = 20.1, Mkeyboard = 0.1, SDkeyboard = 0.5, t(41) = 7.9, p = 0, 95% CI [17.8, 30], Cohen's dz = 1.1) and slow movements, but not for incorrect answers which showed an opposite trend (Mreach = 27, SDreach = 18.1, Mkeyboard = 38.9, SDkeyboard = 16, t(41) = -4.4, p = 0.00005, 95% CI [-17.2, -6.5], Cohen's dz = -0.6).

#### Discussion

Experiment four utilized motion tracking and keyboard response to probe unconscious processing. Despite previous criticisms about the robustness and reliability of evidence [ref, take from introduction], a large congruency effect was found using each measure. In the reaching session, movements were clearly biased towards the incorrect answer when primed by an incongruent word, as was evident by the centrally oriented reaching trajectories, as well as the smaller reach area and longer traveled distance and movement duration. The difference between congruent and incongruent trajectories was significant approximately around 155ms to 398ms (%path 17.5-95.5) post target onset ~~325-562ms~~. Surprisingly, the significant effect found in the reaching session was smaller than that of the keyboard session, possible explanations are discussed below.

Papers:

* Finkbeiner 2011 - The flexibility of nonconsciously deployed cognitive processes evidence from masked congruence priming

Congruency effect for repeated primes starts at 375ms (novel starts at 420ms) and remains significant until the end.

Cumulative submovement amplitude (???) is significantly different between 120-340ms for repeated and 160-320ms for novel.

* THE FINGER IN FLIGHT: Real-Time Motor Control by Visually Masked Color Stimuli

Effect is manifested around 250-450ms after prime display (they don't mention numbers it just looks like it from figure).

Subjects seem aware of prime.

Diagram

Description automatically generated

* Moher and Song 2019 - A comparison of simple movement behaviors across three different devices

Subjects move to center and change direction after target is displaced to new location. Target is **supra-liminal.**

Reaction time = 239ms

Movements redirected 206ms after target displacement.

* Scherbaum (2018). Stuck at the starting line: How the starting procedure influences mouse-tracking data

Congruency weight is significant in regression model that predicts trajectory angle between 186-429ms in the dynamic condition and 166-455ms in the static condition.

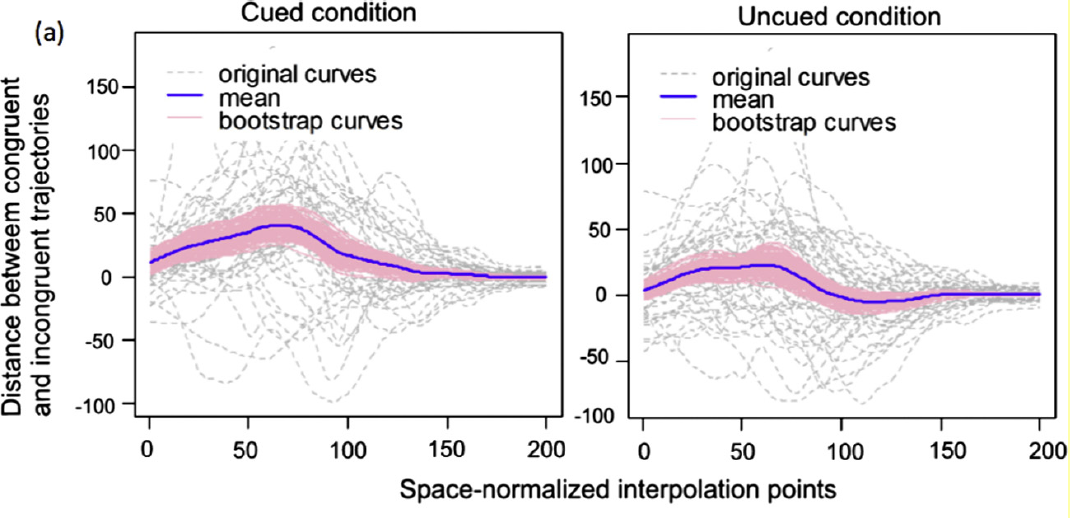
There is no prime! Target appears on the side that is in/congruent to the side of the correct answer.

* Xiao (2017). The role of attention in subliminal semantic processing: A mouse tracking study – when attended to stimulus, the UC prime affects the processing of the target when the SOA (prime onset to target onset) is around 200-500ms. UC effect lasts around 200ms without attention. In "סיכומי מאמרים פריימינג" there are 3 papers with different timing claims.

Chart

Description automatically generated

* Xiao (2015). Subliminal semantic priming in near absence of attention – differences between trajectories appear between 0-50% path traveled.



Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation – The effect in the brain for masked prime doesn't last until 200ms, but the behavioral effect does (exists for 67 SOA and 200 SOA).

Eddy M., Schmid A., Holcomb P.J. Masked repetition priming and event-related brain potentials: A new approach for tracking the time-course of object perception – subjects were aware of the primes as indicated by d'.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D. & Tyler, L. K. 2000 Morphological and semantic effects in visual word recognition: a time-course study – Semantic priming occur only on long SOA (72ms,230ms, prime is probably aware, they don't check). Orthographic (word sound similar) priming occurs on short SOA (43ms)

Micher 2021 On the time course of Conscious and Unconscious Semantic Processing – Findings do not replicate between their two experiments. They find that repetition priming occurs for 83,158,224 SOAs, or only for 224 SOA. Response priming occurs for 83,158,224 or for 158.

Didn't read:

Ferrand, L. & Grainger, J. 1993 The time course of orthographic and phonological code activation in the early phases of visual word recognition

Vorberg (2003). Different time courses for visual perception and action priming

unconscious masked priming depend on temporal attention

Task-induced strategies and near-threshold priming: Conscious influences on unconscious perception

Friedman, J., & Finkbeiner, M. (2010). Temporal dynamics of masked congruence priming: evidence from …

High density ERP indices of conscious and unconscious semantic priming

The semantic origin of unconscious priming: Behavioral and event-related potential evidence during …

Unconscious task set priming with phonological and semantic tasks

Unconscious semantic priming from pictures under backward masking and continuous flash suppression

The anatomy and time course of semantic priming investigated by fMRI and ERPs

The N400 is modulated by unconsciously perceived masked words: further evidence for an automatic spreading activation account of N400 priming effects

Book: https://books.google.co.il/books?hl=en&lr=&id=VH55AgAAQBAJ&oi=fnd&pg=PA2&dq=unconscious+priming+SOA&ots=JDWRtHcohd&sig=m7dij482hMQ9TFo\_SUksIeEAtjc&redir\_esc=y#v=onepage&q=unconscious%20priming%20SOA&f=false There is an episode about priming as function of SOA

Couldn't access:

On the time course of Conscious and Unconscious Semantic Processing

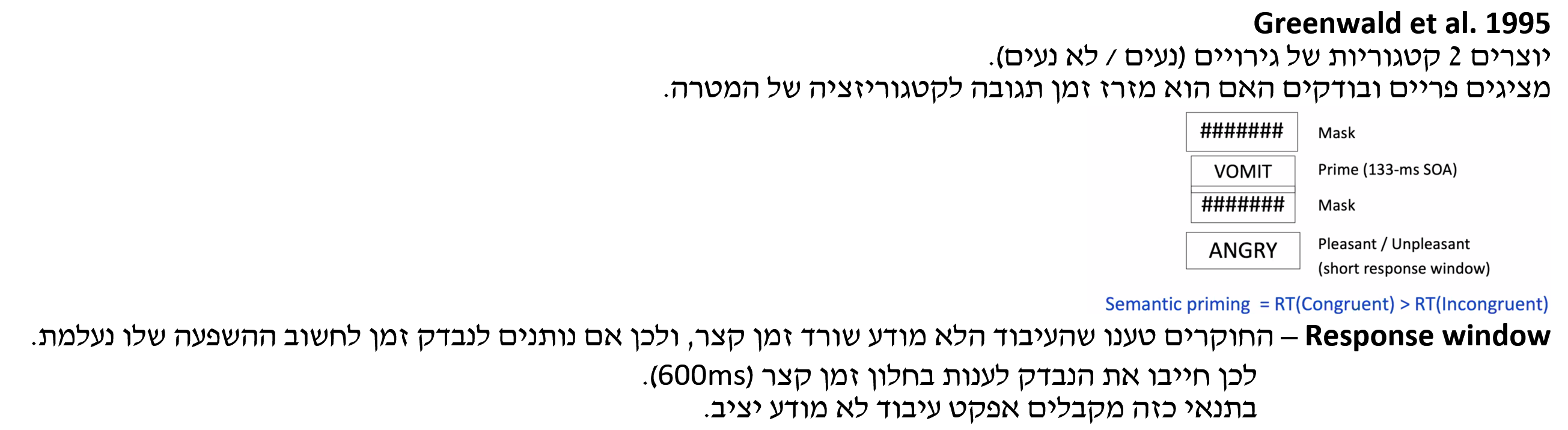
Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2004 – SOA increases response priming

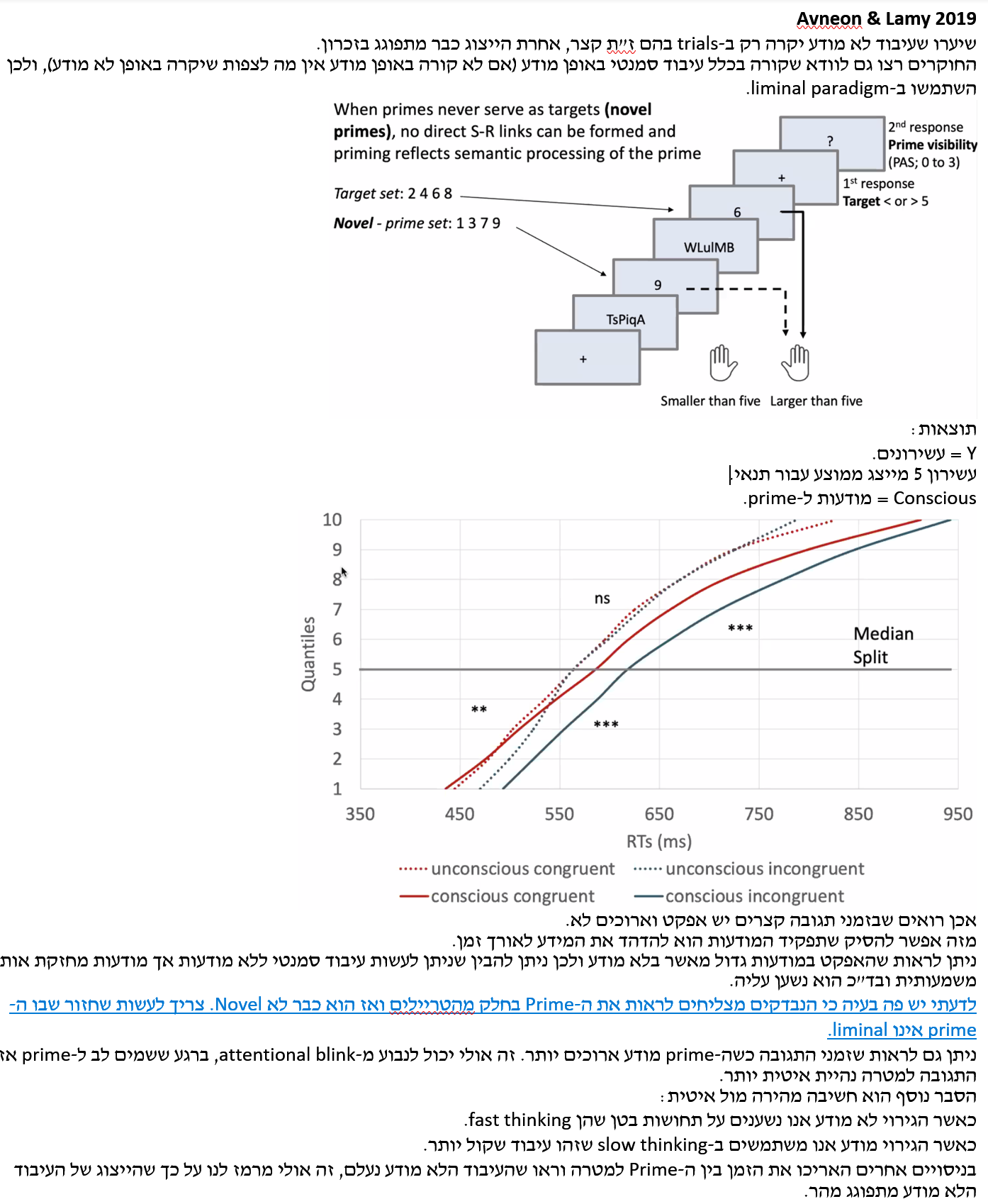
Terms to search:

* temporal characteristics of unconscious effects.
* SOA, delay.
* response window.

UC in EEG Course?

Pitts 2012 - Visual processing of contour patterns under conditions of inattentional blindness (from sicum, look for the activation created by UC stimuli).





Text

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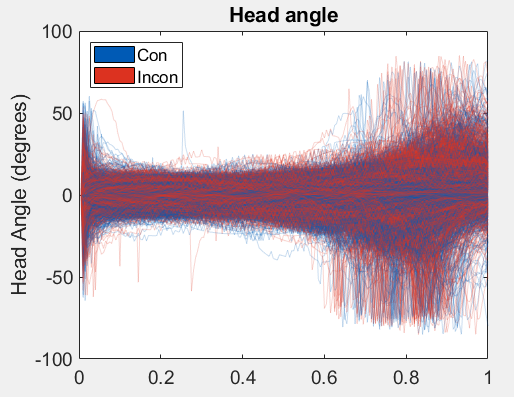
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### General Discussion

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 [ref]. Increased sensitivity to unconscious effects will allow to settle the long-lasting debate about the extent of unconscious processing [ref]. 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 in the reach area variable which was smaller for incongruent trials. Since this experiment allowed for relatively slow responses, it was suspected that the conflict evoked by the prime perishes before the movement is initiated [ref], which explains why a robust congruency effect was not observed. Supportive evidence for this assumption was provided by the longer reaction times in incongruent trials, but not movement durations. Hence, 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 number 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 tracking is superior to keyboard-RT when probing unconscious processing, consequently

both measures were used in two consecutive sessions, both of which yielded robust effects. Since the experiment included stringent awareness measures, criticisms attributing unconscious effects to residual undetected awareness [ref] should not apply for these results. Similarly, although a large number of participants were excluded, this does not imply that the unconscious status of the rest of the participants is a result of measurement error and regression to the mean [ref to shanks 2017] since none of them were excluded due to seeing the prime. In addition, the distribution of the objective awareness measure is centered around 50% correct answers [ref to figure] indicates that the masking manipulation was successful. To conclude, the observed unconscious effect is not easily refuted and therefore provides a solid testimony (advocate / substantiate / testimony / corroboration / validation) in favor of unconscious processing in the debate regarding its existence [ref].

When examining the distribution of heading angles we see that participants mostly make their changes in trajectory after around 60% of the path was already covered. This translates to around 400ms after target onset. This occurs both for congruent and incongruent trials?



Graphical user interface, chart, application

Description automatically generated

How can we explain the discrepancy between our hypothesis and the results? As mentioned in experiment three, the timing demands of this experiment are very high. Since participants have a hard time keeping up with the timing demands, the proportion of disqualified trials is very high.

@

This could be partially due to the incongruent prime which lengthens the movement trajectory and increases the probability for exclusion due to slow movement. This will provide further evidence for the processing of the prime, and can be tested by comparing the proportion of trials that were excluded due to slow movement between congruent and incongruent trials.

@

When averaging the trajectories in a single condition we expect the noise to cancel out and the bias created by the prime to remain. However, when a high number of trials are excluded, the signal to noise ratio decreases and it becomes harder to detect the congruency effect. ~~This is especially problematic here since trajectories are a very noisy measure [ref to std figure]. In contrast to keyboard responses which have only a single degree of freedom to change in (time), trajectories can change in a number of degrees of freedom which is identical to their number of samples, 200 in our case. This is represented in the wide distribution of the deviation from center variable, which is considerably wider than that of the keyboard-RT and even of the reaching movement duration (write the size of the std for each distribution, you need a way to compare std / variation between variables) [ref to figure of distributions]. The large distribution doesn't stem only from the measure but also from the timing constraints.~~ When participants are forced to respond quickly their responses become hasty, and doing so reduces the motor control and accuracy [ref]. Therefore, the movements are less repetitive, ~~which increases the variation and makes it more difficult to locate the bias towards the incorrect answer in the average trajectory. Evidence for that can be seen when comparing the distribution of deviation from center of experiment one which had a long RT allowance, and experiment four which had a much shorter allowance~~.

Explanaitations for small effect:

* ~~More noise (larger STD)~~
* Reaching ends before the conflict is resolved, while keyboard response is given only after it is resolved (correctly of falsely). Thus we capture less of the effect?

The findings of the current research open the results of Xia and colleagues [ref] to debate.

Explain discrepancy between Xia and me:

* They had 240 trials total.
* They did not use any timing constraints (except for dumping RT longer than 3000ms).
* They did not discriminate on trial level, so their effect might stem from conscious trials.

When including conscious trials in our data the results do not change much.

* The mouse d' distribution shows some of the participants are aware of the prime.

The keyboard d' distribution shows two groups, one aware and one not – if a reverse congruency effect occurs when prime images are conscious, perhaps this cancels the effect that exists in the unaware group.

Check these to find out:

* + Pessoa (2005). To what extent are emotional visual stimuli processed without attention and awareness
  + Dell'Acqua (1999). Unconscious semantic priming from pictures
  + Ferrand (1998) Masked repetition and phonological priming in picture naming
  + Faivre (2019). Imaging object-scene relations processing in visible and invisible natural scenes – no behavioral results of diff between conscious and unconscious.
* Different participants participated in the keyboard / mouse tasks.
* They use AUC (taking only the area that exceeds the optimal path toward the incorrect answer).
* Their pre and post masks are 100ms

Although motion tracking did not produce a larger effect, it can still be beneficial to the study of unconscious processes. Unlike keyboard response which is definitive and final, the reaching measure allows participants to change their mind while providing the answer and correct it if necessary. This type of trials is particularly interesting to us because it might be expressing the bias we expect to see created by incongruent primes twards the incorrect answer. In addition, the possibility to regret and correct could be the reason for the lower number of incorrect answers in the reaching session. Another addition that could reduce the number of excluded trials is using a dynamic starting condition, in which the stimuli starts only after participants initiated their response. This might eliminate early response, late response and perhaps slow movement. In my experiment this change will result in a larger number of trials in the reaching session compared to the keyboard session. A previous experiment compared static and dynamic starting conditions [ref "stuck at the starting line…"] when participants were asked to classify a digit as larger or smaller than 5. The digit appeared either on the same side as the correct answer or on the opposite side. The researchers found that a dynamic starting condition, the researchers found ??????benefits?????? for dynamic condition, which might also increase the expression of the unconscious effect.

Ideas for content:

* What advantages does motion tracking still give (clustering)?
* When do significant clusters appear? Why do they appear in that point in time?

Can't draw strict conclusions about the beginning or ending of the cluster (because the permutation might be creating false end/start, התאבכות). Try to find articles that discuss this.

* Diplaying the stimuli after movement was initiated yields greater differences in devation (Scherbaum and Kieslich - 2018 - Stuck at the starting line: How the starting procedure influences mouse-tracking data)

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

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

Linking cognitive and reaching trajectories via intermittent movement control – Friedman's paper that claims that the motor access to the cognitive processes is intermittent instead of continuous. This could affect my experiment.

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

Things to do before sending to Liad:

* Change all number above 9 to numerals.
* Convert all movement duration and reaction time results to ms.

**Exp 4 PAS =1/2/3/4: -----------------------------------------------------------------------------------------------**

------------Reaching RTs------------

----Reaction time

Con: M=171.9914 STD=25.7036

Incon: M=173.4255 STD=26.9333

t-test = -0.82079 df = 30 p-value = 0.41824

CI = [-5.0024, 2.1342] sd = 9.7282

cohens d\_z = -0.14742

----Movement time

Con: M=413.6971 STD=30.9089

Incon: M=426.1632 STD=29.8063

t-test = -6.7582 df = 30 p-value = 1.7124e-07

CI = [-16.2332, -8.6989] sd = 10.2703

cohens d\_z = -1.2138

----Response time

Con: M=585.6885 STD=28.9917

Incon: M=599.5887 STD=29.6772

t-test = -5.9968 df = 30 p-value = 1.4069e-06

CI = [-18.6341, -9.1663] sd = 12.9058

cohens d\_z = -1.0771

---------Prime Forced Choice------------

Con: M=NaN STD=NaN

Incon: M=51.1959 STD=3.4709

t-test = 1.9184 df = 30 p-value = 0.06

CI = [49.9228, 52.469] sd = 3.4709

cohens d\_z = Inf

Warning: Ignoring extra legend entries.

---------Reach Area------------

Con: M=0.00020692 STD=5.2959e-05

Incon: M=0.00017621 STD=5.3382e-05

t-test = 3.6671 df = 30 p-value = 0.00094479

CI = [1.3607e-05, 4.7814e-05] sd = 4.6628e-05

cohens d\_z = 0.65863

---------Num of COM------------

Con: M=0.25187 STD=0.12125

Incon: M=0.21665 STD=0.111

t-test = 1.7445 df = 30 p-value = 0.091318

CI = [-0.0060127, 0.076453] sd = 0.11241

cohens d\_z = 0.31331

---------Total Distance Traveled------------

Con: M=1.0139 STD=0.006838

Incon: M=1.0185 STD=0.0082706

t-test = -4.761 df = 30 p-value = 4.5713e-05

CI = [-0.0066113, -0.002642] sd = 0.0054107

cohens d\_z = -0.85511

--------Keyboard RT--------

Con: M=528.3173 STD=35.6353

Incon: M=548.9396 STD=33.7906

t-test = -6.7018 df = 30 p-value = 1.9977e-07

CI = [-26.9066, -14.338] sd = 17.1327

cohens d\_z = -1.2037

**Exp 4 PAS = 1: ----------------------------------------------------------------------------------------------------------------------**

------------Reaching RTs------------

----Reaction time

Con: M=173.1988 STD=24.1601

Incon: M=173.7655 STD=24.4941

t-test = -0.31486 df = 29 p-value = 0.75512

CI = [-4.248, 3.1145] sd = 9.8586

cohens d\_z = -0.057485

----Movement time

Con: M=412.1677 STD=29.1116

Incon: M=425.7843 STD=28.1205

t-test = -6.7316 df = 29 p-value = 2.188e-07

CI = [-17.7537, -9.4796] sd = 11.0793

cohens d\_z = -1.229

----Response time

Con: M=585.3665 STD=28.4978

Incon: M=599.5499 STD=28.4108

t-test = -5.8475 df = 29 p-value = 2.4222e-06

CI = [-19.1442, -9.2226] sd = 13.2853

cohens d\_z = -1.0676

---------Prime Forced Choice------------

Con: M=NaN STD=NaN

Incon: M=50.9565 STD=4.3116

t-test = 1.2151 df = 29 p-value = 0.23

CI = [49.3466, 52.5665] sd = 4.3116

cohens d\_z = Inf

Warning: Ignoring extra legend entries.

---------Reach Area------------

Con: M=0.00020876 STD=5.0752e-05

Incon: M=0.00017413 STD=4.847e-05

t-test = 3.7506 df = 29 p-value = 0.0007839

CI = [1.5746e-05, 5.3512e-05] sd = 5.057e-05

cohens d\_z = 0.68477

---------Num of COM------------

Con: M=0.24525 STD=0.12902

Incon: M=0.22198 STD=0.10784

t-test = 1.1251 df = 29 p-value = 0.26977

CI = [-0.019027, 0.065559] sd = 0.11326

cohens d\_z = 0.20542

---------Total Distance Traveled------------

Con: M=1.0136 STD=0.0067037

Incon: M=1.0187 STD=0.0080803

t-test = -5.0345 df = 29 p-value = 2.305e-05

CI = [-0.0070845, -0.0029913] sd = 0.005481

cohens d\_z = -0.91916

--------Keyboard RT--------

Con: M=524.7782 STD=35.2285

Incon: M=545.2371 STD=32.6702

t-test = -6.5416 df = 29 p-value = 3.6472e-07

CI = [-26.8554, -14.0624] sd = 17.1302

cohens d\_z = -1.1943