## Introduction

UC processing is a highly controversial subject @Cite@. When processed unconsciously a stimulus can evoke both behavioral and internal changes @Cite@, however these changes would usually be hardly detectable in experiments @Cite@. The difficulty in detecting them complicates reaching unequivocal conclusions. For example, small positive effects can be attributed to the use of a non-exhaustive awareness measure @Cite@, while null results can be attributed to the use of a non-sensitive performance measure @Cite@. The discrepancy between the interpretations makes the field highly debated @Cite@.

The goal of our research is to promote the usage of motion tracking as a performance measure by establishing its advantages over the currently prominent keyboard measure. Previous studies have utilized motion tracking's rich output to uncover cognitive conflicts stemming from UC stimulus @Cite@. However, to date only a single study directly compared motion tracking with keyboard response @Cite@. Our experiment offers a rich exploratory comparison between the two while keeping a rigorous awareness testing procedure to avoid confounds. The continuous motion tracking measure allows to track fluctuations as a decision formulates while the intuitive properties of the reaching movement increase the probability for expression of UC effects @Cite@. Our previous motion tracking pilots have produced an effect size larger than those found in similar experiments conducted with a keyboard, accordingly we expect to see an advantage for motion tracking I the current study.

### Hypothesis

We hypothesis motion tracking will be more sensitive to cognitive conflicts than a keyboard response. Therefore, we expect the congruency effects found when using motion tracking to be significantly larger than those found while using a keyboard response.

## Methods

### Design

IV:

1. Congruency – A within subject variable of two levels.
   1. Congruent: prime and target are the same word.
   2. Incongruent: Prime and target are a different word from a different semantic category that do not share letters in common locations.
2. Item type – A within subject variable of two levels.
   1. Natural: target and / or prime describe a natural item (e.g., "Plant", "Cloud").
   2. Artificial: target and / or prime describe an artificial product (e.g., "Radio", "Phone").
3. Response measure – A within subject variable of two levels.
   1. Motion tracking: The participant chooses an answer by reaching and touching it on the screen.
   2. Keyboard response: The participant chooses an answer on the left / right half of the screen by pressing "F" / "J" accordingly.

DV:

1. *Area under the curve (AUC):* Area between the actual trajectory and the optimal path (a straight line connecting the start and end points). Area central to the optimal path is considered positive, while area lateral to it is considered negative. The area will be evaluated for each trial separately.
2. *Reach area:* Area between the average path to the left target and the average path to the right target in a single condition (congruent / incongruent). The path will be averaged across trials in each condition.
3. *Reaction time:* From stimulus presentation up to movement initiation. Movement initiation is detected once the Euclidean distance from the starting point is greater than 1cm.
4. *Movement time:* From movement initiation up to a screen touch.
5. *Response time:* The time it takes a participant to classify the target as natural / artificial. In the "Keyboard" condition it will be measured from target presentation up until "F" / "J" are pressed. In the "Reaching" condition it will be given by the sum of reaction and movement times.
6. *Maximal absolute deviation:* the point along the trajectory that is furthest away from the optimal path for that trial.
7. *Deviation from center:* Distance of every point along the average trajectory from the center line (a line connecting the starting point and the middle of the screen).
8. *Movement variation:* Standard deviation of the distance of every point along the average trajectory from the center line. STD will be computed for each participant over all the trials in each condition.
9. *Changes of mind (COM):* The frequency of goal changes during a movement. Will be measured by

Number of direction changes between sub-movements (Friedman, J., & Finkbeiner, M. (2010). Temporal dynamics of masked congruence priming: evidence from reaching trajectories.),

Number of changes in implied goal (the side, left/right, where the current tangent to the trajectory meets the screen).

1. *Total distance traveled:* The sum of Euclidean distances between samples along the trajectory of a single trial.

### Planned sample

All participants will be right-handed, native Hebrew speakers who aren't color blind and have normal vision or corrected-to-normal vision using contact lenses. Only participants declaring that they have no neurological, attentional, or mental disorders, and are not taking psychiatric medicines, will be included.

Data will be collected at Prof. Liad Mudrik's lab for high level cognition in Tel-Aviv University, from students or other young adults at the ages of 18-35, in a 90 minutes session.

Participants will be reimbursed with course credit or cash payment.

### Sample size estimation

Previous pilot studies produced an effect size of approximately 0.8. To achieve the same effect we will use a sample of X participants (@@ Cite @@).

### Exclusion criteria

The following trials will be excluded from the main analysis:

1. Trials in which there was a technical malfunction with the setup or recording:
   1. Over 100ms of missing samples in the trajectory.
   2. Less than 100ms of existing samples in the trajectory.
   3. Stimulus presentation duration deviated from the desired by more than 2ms.
2. Trials in which the participant provided a problematic response:
   1. Short reach distance: The length of the processed trajectory as measured on the *Z* axis was shorter than:

"Marker gap" accounts for the variating distance of the marker from the edge of each participant's finger and its value is 1.5cm.

* 1. Missed targets: Touching point on screen is more than 12cm away from both targets.
  2. Bad timing: When using a keyboard, key press was too early (less than 200ms after target), or too late (more than 4000ms after target). When reaching, movement started too early (less than 100ms after target display, implying a planned response) or too late (more than 320ms after target display).

Slow reaching movements (reaching duration was longer than 420ms) will be included in the analysis if they are within 3 STD from the average reaching time of the participant.

* 1. Wrong answer when classifying the target.
  2. No response given via the keyboard.

Participants will be excluded according to the following criteria:

1. Less than 30 valid trials in each condition (congruent / incongruent).

"Valid" trails are those that have a PAS rating of 1 and weren't excluded due to any of the above reasons.

1. Failed to classify the target correctly on at least 70% of the non-excluded trials.
2. Recognized the prime on more than 50% of all incongruent trials except for those with a bad stimulus duration.

### Apparatus

The stimulus will be displayed on a VPIXX monitor (VIEWPixx /3D Lite LCD display and data acquisition system, version 3.7.6287) using Matlab 2018b and Psychtoolbox. The monitor will be set to full brightness at a resolution of 1920 x 1080 and refresh rate of 100Hz with VPIXX's "Scanning backlight" feature turned on which synchronizes the stimulus display to the screen's refresh rate. A Perspex cover will be placed over the screen to protect it. The cover will be spray painted with a light layer of transparent matte lacquer to avoid reflections. The participants will sit approximately 60cm away from the screen and place their index finger on a marked starting point which will be located on the table 35cm away from the screen, in line with its center. The stimulus will be displayed 24cm above the table and the classification answers will be displayed on each side of it, 20cm apart. Participants will wear a Velcro ring with a marker at the tip of their index finger. "Marker gap" defines the maximal distance of the ring from the fingertip and will be set to 1.5cm. A system of 6 OptiTrack Flex 13 cameras @@ cite @@ will track the marker's location using Motive 2.2.0 software @@ cite @@ at a sampling rate of 120Hz. The coordinates will be broadcasted online to a NatNet client @@ cite @@ and recorded with Matlab.

Diagram

Description automatically generated

### Materials and stimuli

**Stimuli Selection**

One hundred 5-letter words will be used as primes and targets. All words will be imageable nouns with a frequency of at least 10 per million (Cite: <http://word-freq.mscc.huji.ac.il/>). One half will describe artificial products (e.g., radio, train) and the other natural items (e.g., fruit). Target words will be written in typescript while prime words will be written in handwriting font. Masks will be composed of a semi-random combination of squares and diamonds whose line thickness is equal to the word's font size and which covers the central area of the screen where words can appear (approximately ).

40 words will be used for the practice blocks and the remaining 60 for the test blocks.

Hebrew letters in typescript and handwriting:

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| א | ב | ג | ד | ה | ו | ז | ח | ט | י | כ | ך | ל | מ | ם | נ | ן | ס | ע | פ | ף | צ | ץ | ק | ר | ש | ת |
| א | ב | ג | ד | ה | ו | ז | ח | ט | י | כ | ך | ל | מ | ם | נ | ן | ס | ע | פ | ף | צ | ץ | ק | ר | ש | ת |

**Trial Lists Generation**

For each participant, two out of 10 lists of stimuli will be randomly sampled (without replacement) and used to set the order of stimuli. One list will be assigned to the "Reaching" condition and the other to the "Keyboard" condition. Once all lists were sampled (after 5 participants), they will all become available for sampling again.

Practice lists will be constant for all participants but differ between the practice blocks.

The order of words within each list will be semi-random with the following constraints:

* Each word will be equally frequent as a target at the congruent and incongruent conditions.
* All words will be used as targets the same number of times.
* In the congruent condition the prime will be identical to the target word.
* In the incongruent condition a prime which doesn't share letters in common locations with the target will be selected from the alternative category (artificial/natural).

For example, in the congruent condition "phone" would be preceded by "PHONE", while in the incongruent condition it will be preceded "GRASS".

Each prime will be paired with a random distractor from the same category (artificial/natural) to be used in the prime recognition task. The distractor will share no letters in common locations with the prime.

**Target Classification**

Participants will classify the target word as describing a natural / artificial item by selecting the side of the screen that contains the appropriate category. In the "Reaching" condition the participants will touch the appropriate side of the screen, but in the "Keyboard" condition they will use "F"/"J" keys to select the left / right side accordingly.

**Prime Recognition**

An objective measure of prime awareness. Participants will have to identify the prime between 2 words. Response will be given in an identical fashion to the classification task.

**Perceptual Awareness Scale**

A Subjective measure of prime awareness. Participants will use the keyboard numbers 1-4 to rate how well did they see the prime from 1 ("didn't see anything") to 4 ("Saw the prime clearly").

### Procedure

Each participant will perform a "Reaching" session and a "Keyboard" session lasting together 90 minutes, and their order will be counterbalanced across participants.

A session will include 2 practice blocks and 6 test blocks of 40 trials each (i.e., 80 practice trials and 240 test trials per session, 640 trials total). Breaks will be allowed between blocks.

Every trial will consist of a fixation cross (1000ms), 1st mask (270ms), 2nd mask (30ms), prime word (30ms), 3rd mask (30ms) and a target (500ms). Once the target is displayed the participant is required to classify it as natural / artificial. "Keyboard" response must be given within a time window of 250-4000ms from target display otherwise "Too Early" / "Too Late" feedback is given.

"Reaching" responses will be bound to onset time and movement time constraints; Onset is the time from target presentation until the participant's finger is 1cm away from the starting point (Euclidean distance). It must be longer than 100ms to prevent predictive movements but shorter than 320ms to prevent prime dilution. Inaccurate timing will be immediately replied with a "Too Early" / "Too Late" feedback accordingly. Movement time starts once the finger leaves the starting point and ends when the participant is 1.5cm away from the screen (on the Z axis). Movements longer than 420ms will be replied with a "Too Slow" feedback once they are completed.

After Classifying the targets, the participant will be asked to recognize the prime. The prime and the distractor will be assigned randomly to each side of the screen and a 7 second response window will be used to reduce the amount of recorded data. Finally, the participant will rate the prime visibility on a PAS scale.

In the "Reaching" session participants will have to return their finger to the starting point after each response.

## Analysis plan

### Trajectory preprocessing

Preprocessing will follow @@ Cite @@ Gallivan, J. P., & Chapman, C. S. (2014). Three-dimensional reach trajectories

Missing values will be interpolated with the inpaint\_nans function to fill gaps in the trajectory, which will then be filtered with a low pass butter worth filter (2nd order with cutoff at 8Hz) to reduce noise. The axis's origin will be set at the first sample of each trial. To locate movement onset a low pass butter worth filter (2nd order with a 10Hz cutoff) will first be applied to the velocity. Onset will be indicated by 4 consecutive samples having a velocity greater than 2mm/s and a total acceleration of at least 2mm/s^2. Offset will be determined as the point along the trajectory that is closest to the screen.

The movements will be normalized to the length of the trajectory along the axis perpendicular to the screen (Z axis). To do so a B-spline of the 6th order with a roughness penalty to the 4th derivative will be fitted to each axis with a spline at every data point. The fitted function will be used to produce a high-resolution representation of the trajectory (1000 samples) from which 200 points equally spaced along the total distance traveled on the Z axis will be extracted (e.g., if the participant moved 2 forward, 1 backward, the total distance is 3).

These points will represent the proportion of path traveled.

### Dependent variables extraction

#### Reach area calculation

The area will be calculated in three stages. First, we will establish a line perpendicular to the screen at the lowest X value. Then we will compute the area between each average trajectory and that line. The results will be subtracted from each other, and their absolute value will be used as the reach area.

To avoid negative area values the trajectories will be split at their intersections and the area will be calculated separately for each section.

### Confirmatory analysis

Analysis will be performed only on trials with a PAS rating of 1.

We will compute each participant's DV separately over congruent and over incongruent trials and a paired t-test will be conducted between the conditions. The p-value will be corrected with Benjamini-Hochberg FDR correction since we conduct a comparison for each of the DV. Cohen's dz and its CI will be examined for overlap between the "Reaching" and "Keyboard" conditions. No overlap will indicate an advantage for one measure over the other. In a separate comparison changes of mind will be compared between correct and incorrect trials.

The difference score of each DV will be tested for normality using the Shapiro-Wilk test. A DV that will fail to keep normality will be tested instead with Wilcoxon signed rank test and its effect size will be given by .

In case of outliers outside the 0.75 0.25 thresholds a robust t-test will be computed using R's WRS2 package.

Computing effect sizes for robust t-test:

Functional Data analysis – Conducts a repeated measures ANOVA at every point along the trajectory with participant

and side (left/right) used as random factors. Tests if the trajectories are significantly different from each other. A conclusion is drawn regarding the whole trajectory as a single unit since treating each point separately violates proper statistical practice by running multiple comparisons.

### Expected results

We expect to see a bias for the incorrect answer in the incongruent condition. A tendency to move toward the side opposite to the final correct answer will increase the total distance traveled, the AUC and the maximal absolute deviation from the optimal path. Conversely, it will decrease the deviation from the center. The bias will also curve the average path towards the center which will make the reach area smaller. In addition, an incongruent prime will evoke a cognitive conflict which is expected to increase the time it takes to reach a final decision. This will extend the RT in the "Keyboard" condition and the movement time in the "Reaching" condition. Furthermore, it will make reaching a final decision more challenging and therefore will increase the movement variation and the changes of mind frequency.

Unlike the motion tracking which captures the decision as it formulates, the keyboard records only a single final response and is thus insensitive to changes of mind. This means fluctuations created by the incongruent prime will only be captured by the motion tracking system which is why we believe it will be more sensitive and yield greater effects.

The frequency of COM will also be compared between correct and incorrect trials. Having more COM in the correct trials will indicate they are mostly corrective (i.e., changing the end goal from the incorrect to the correct answer). This would pose another advantage for motion tracking over keyboard response since the latter doesn't allow COM and would instead discard these kinds of trials.

### Project data collection

Start and end dates @TBD@