## Intoduction

#### Ver1

Unconscious effects are notoriously small and weak, making their existence controversial.

Using more sensitive measures could tip the scale of that debate.

Motion tracking is richer than keyboard response.

* Implicit measure for unconscious effects.
* Many parameters can be extracted: movement time, onset time, velocity, acceleration, position in time, deviation from optimal path, number of changes in direction, timing of changes in direction, area difference from optimal path.
* Continuous cognitive processes need a continuous measure.
  + Conflicts between internal processes are reflected by @deviations in trajectory@ on the way to the final

response.

* + captures the fluctuations in confidence.

Motion tracking has been used before to probe unconscious effects.

* semantic priming – Exp 1 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming

Temporal dynamics of masked congruence priming: evidence from reaching trajectories,

**Exp1,2** in: Engaging the motor system with masked orthographic primes: A kinematic analysis,

Conceptual priming – Exp 2 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming

* Response priming – Subliminal semantic priming in near absence of attention: A cursor motion study,

The role of attention in subliminal semantic processing: A mouse tracking study

Some researchers have even used both motion tracking and keyboard response measures.

* On-line control of pointing is modified by unseen visual shapes
* Exp 4 in: Grasping with the eyes: The role of elongation in visual recognition of manipulable objects

However, to date, only 1 study made a direct comparison between them, and showed an advantageous effect size for mouse tracking.

* Assessing Masked Semantic Priming: Cursor Trajectory versus Response Time Measures

unconscious images of positive / negative items facilitate same / different response accordingly when judging the similarity between two digits.

Pitfalls:

* Only objective measure
* Separate from main session
* Less trials (96) than minial requirement for discovering a awareness of the prime (200, as shown in recent unpublished work in our lab).
* No evaluation of d', only its correlation with performance measure which has been shown to inflate unconscious effects (Correlation analysis to investigate unconscious mental processes: A critical appraisal and mini-tutorial)
* Examination of d' reveals many subjects were aware of the prime
* Unituitive semantic connection between positive stimuli and "same" response.
* Mouse tracking requires remapping of stimuli representation from real world to 2d. places constraints on movement (read paper if you want this point @@ Moher and Song 2019🡪 Palluel-Germain, Boy, Orliaguet, & Coello, 2004 @@).
* Reaching has faster movement time, larger movement curves, faster velocities, reponds faster to changes of mind (optimal for discovering fast and short lasting unconscious effects).
* Changes of mind are less likely to occur when a motor demand is high, thus incongruent effects might be less frequent (@@ Read this @@ Moher and Song 2019🡪 Burk, Ingram, Franklin, Shadlen, &Wolpert, 2014; Moher&Song, 2014).

#### Ver2

Unconscious effects are notoriously small, and thus controversial.

Using a more suitable and sensitive measure could tip the scales of that debate.

Cognitive processes are continuous, thus need a continuous measure.

Motion tracking (provides) is a continuous and rich measure, that yields multiple analyzable parameters.

The path of movement while a decision formulates, reflects the underlying competing processes and captures fluctuations in confidence.

~~As a decision formulates, the concurrent movement path reflects underlying competing processes and captures fluctuations in confidence.~~

~~Its continuous nature allows to track the formulation of decisions.~~

~~Conflicts between underlying processes are reflected by deviations in it.~~

* ~~Implicit measure for unconscious effects.~~
* ~~Many parameters can be extracted: movement time, onset time, velocity, acceleration, position in time, deviation from optimal path, number of changes in direction, timing of changes in direction, area difference from optimal path.~~
* ~~Continuous cognitive processes need a continuous measure.~~
  + ~~Conflicts between internal processes are reflected by @deviations in trajectory@ on the way to the final~~

~~response.~~

* + ~~captures the fluctuations in confidence.~~

Motion tracking has been used to probe unconscious semantic, conceptual and response priming effects.

* semantic priming – Exp 1 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming

Temporal dynamics of masked congruence priming: evidence from reaching trajectories,

**Exp1,2** in: Engaging the motor system with masked orthographic primes: A kinematic analysis,

Conceptual priming – Exp 2 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming

* Response priming – Subliminal semantic priming in near absence of attention: A cursor motion study,

The role of attention in subliminal semantic processing: A mouse tracking study

Some researchers have even used both motion tracking and keyboard response measures.

* On-line control of pointing is modified by unseen visual shapes
* Exp 4 in: Grasping with the eyes: The role of elongation in visual recognition of manipulable objects

However, to date, only 1 study showed a direct advantage for mouse tracking over keyboard response when investigating unconscious effects.

* Assessing Masked Semantic Priming: Cursor Trajectory versus Response Time Measures

unconscious images of positive / negative items facilitate same / different response accordingly when judging the similarity between two digits.

Future research is necessary that includes stricter measures of awareness, clearer semantic manipulations and a more natural response method.

Pitfalls:

* Only objective measure – susceptible to criterion bias.
* Separate from main session
* Less trials (96) than minimal requirement for discovering awareness of the prime (200, as shown in recent unpublished work in our lab).
* No evaluation of d', only its correlation with performance measure which has been shown to inflate unconscious effects (@Do you know why it inflates?@Correlation analysis to investigate unconscious mental processes: A critical appraisal and mini-tutorial)
* Examination of d' reveals many subjects were aware of the prime
* Unintuitive semantic connection between positive stimuli and "same" response.
* Mouse tracking requires remapping of stimuli representation from real world to 2d. places constraints on movement (read paper if you want this point @@ Moher and Song 2019🡪 Palluel-Germain, Boy, Orliaguet, & Coello, 2004 @@).
* Reaching has faster movement time, larger movement curves, faster velocities, reponds faster to changes of mind (optimal for discovering fast and short lasting unconscious effects).
* Changes of mind are less likely to occur when a motor demand is high, thus incongruent effects might be less frequent (@@ Read this @@ Moher and Song 2019🡪 Burk, Ingram, Franklin, Shadlen, &Wolpert, 2014; Moher&Song, 2014).

## Methods

This pilot includes only a motion tracking group while a future version will also include a keyboard response group.

Based Dehane's XXX exp.

N = 13 (two of which were disqualified for a low number of valid trials (13 and 16).

Training day: 240 trials, without prime.

Test day: 40 practice trials w/o prime, 40 practice trials with prime, 480 test trials.

Which subs are bad?

Do you check category chance level at plotting section? Is that test the same as in the subScreening?

Is the test for prime awareness in the plotting section identical to that in the subScreening?

Diagram

Description automatically generated Graphical user interface, diagram

Description automatically generated

Diagram

Description automatically generated

reaching area derived from 3D motion tracking of reaching movements. Subjects will perform a semantic classification task (does the target describe an "natural" / "artificial" item) in which the target word will be preceded by an unconscious prime that can be congruent / incongruent to the target's category. Next, the subject will be asked to recognize the prime in a two forced choices task, and finally they will rate the prime's visibility in a PAS scale (from 1 for "Didn't see anything" to 4 for "Saw the prime clearly"). In an unreported pilot study we found out subjects have a hard time providing correct answers in the short time constraints of the task, thus the experiment will be comprised of two sessions in two consecutive days. The first day includes only a training session without primes and its purpose is to allow subjects to hasten their responses in the reaching task while keeping their accuracy high. The second day includes a short training and a test session.

A different test group will be used for each measure to avoid a practice effect.

## Results

How many subs?

How many excluded? Why?

How many excluded trials?

Avg traj of all subs. 🡪 Show reach area on it, or on a similar graph.

Reach area comparison graph.

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

-----------------------------------------------------------------------------------------------------------

The difficulty could be due to the measure being used.

Trajectory tracking has become a popular tool for revealing the development of cognitive effects and may be the answer for that. Some studies have utilized the rich nature of the data it produces to probe different cognitive processes.

One aspect of richness could be the temporal domain. Regular measures usually produce a discrete value for each trial, while the cognitive process they measure might be continuous. For example (Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors) used trajectory analysis to show that a distractor word that shares phonetic properties with the target word's beginning delay the point when the answer is selected, concluding that spoken words are processed incrementally, creating multiple possible representations in every step along the way.

Another example could be inspecting the development of evolving semantic processes. (Farmer et al., 2007a,b).

Motion tracking can even be used to reveal private / hidden attitudes. For example (The action dynamics of overcoming the truth.) showed a difference in trajectory between truthfull answers and lies. Another example is revealing stereotypical thinking with motion tracking (Motions of the hand expose the partial and parallel activation of stereotypes).

A slightly different directin is using trajectory to perform online confidence monitoring (Dotan 2018 - Online confidencemonitoring during decision making). Motion tracking enabled to inspect the unfolding of the decision but also the fluctuations (instead of a single discrete value @put more emphasis on this in the sentence@) in the confidence as the decision is being made. Another advantage is the fact that this measure of confidence is implicit.

Maybe in the introductions of these papers there would an explanation for why trajectory analysis is good, and a citation of papers showing that:

Dotan 2019 - Track it to crack it Dissecting processing stages with finger tracking

Dotan 2013 - How do we convert a number into a finger trajectory

Dotan 2016 - On the origins of logarithmic number to position mapping

Papers showing the usefulness of trajectory analysis:

Dotan 2018 - Online confidence monitoring during decision making

Gallivan & Chapman 2014 - Three-dimensional reach trajectories as a probe of real-time decision-making between

Freeman et al. - 2011 - Hand in Motion Reveals Mind in Motion (good information in my abbreviation).

@@

When considering keyboard response, it can be understood that it represents only the final decision after the subjects have already made up their mind.

In contrast, when using motion tracking subjects can start moving before making their final choice and correct their trajectory on the fly. The changes in trajectory will reveal the cognitive conflicts on the way to formulating the final response (Freeman et al. - 2011 - Hand in Motion Reveals Mind in Motion).

If so, trajectory tracking might be a preferable venue for researchers studying unconscious processing.

-----------------------------------------------------------------------------------------------------------

Indeed, some articles have utilized trajectory tracking to investigate unconscious processing.

In an interesting paper (Exp 1 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming.) who ever wrote it used motion tracking to reveal unconscious semantic processing of images (see also: Temporal dynamics of masked congruence priming: evidence from reaching trajectories, **Exp1** in: Engaging the motor system with masked orthographic primes: A kinematic analysis, **Exp2** in: Engaging the motor system with masked orthographic primes: A kinematic analysis). The writers presented participants pictures of animals / persons and ask them to categorize the images accordingly by reaching the appropriate category. Each image was preceded by an unconscious prime image of an animal / person, which when incongruent to the target caused deviations from the optimal path to the target.

Others have demonstrated conceptual priming by asking participants to reach the appropriate category (digits / letters) of the target stimuli which was preceded by an unconscious prime. Incongruent primes caused greater deviation in the trajectory to the target (Exp 2 in: The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming.).

Response priming has been replicated with motion tracking in an exp by (Subliminal semantic priming in near absence of attention: A cursor motion study, The role of attention in subliminal semantic processing: A mouse tracking study) where subjects had to judge a target digit as smaller / larger than 5 by pressing the correct side of the screen. When the target was preceded by an incongruent prime digit, the trajectory length was bigger. A common measure, used also in that paper is Area Under the Curve (AUC) which measures the area between the optimal path and the actual path, where areas central to the optimal path indicates a conflict between the possible decisions and is considered positive, while areas lateral to the optimal path are considered negative. A larger AUC indicates a greater effect of the prime on the trajectory.

-----------------------------------------------------------------------------------------------------------

Some have even included both keyboard and trajectory analysis measures in their research.

(On-line control of pointing is modified by unseen visual shapes) used keyboard response to show that unconscious primes influence the onset time of motor responses, and then used motion tracking to expand the finding and show that unconscious prime also influenced the ongoing execution of the motor response. This indicated that the movement trajectories were processed in a feed forward manner, initially influenced by an unconscious prime and then by the target when it became available.

(Exp 4 in: Grasping with the eyes: The role of elongation in visual recognition of manipulable objects) has shown an unconscious semantic priming effect once using a keyboard and again using motion tracking. Congruent prime pictures of animals / tools facilitated the RT in the keyboard experiment, in the motion tracking experiment incongruent primes caused a larger AUC than congruent ones. That being said, this experiment used a small set size of stimulus and as mentioned by the authors the effect found could be explained by the shape of the items instead of their semantic category.

-----------------------------------------------------------------------------------------------------------

However, to date, in the context of unconscious effects, only one study made a direct comparison between this measure and a classic dichotomous keyboard response measure.

(Assessing Masked Semantic Priming: Cursor Trajectory versus Response Time Measures) has shown that unconscious images of positive / negative items facilitate same / different response accordingly when judging the similarity between two digits. Critically, this effect was marginally significant when recorded with a keyboard, in contrast to a strong effect when using the AUC parameter in a mouse tracking version of the experiment.

However, this study did not use a subjective measure of awareness in every trial, but rather an objective measure in a separate session from the test session. This means the prime visibility in a single trial level cannot be assessed. In addition, the number of awareness trials (96) didn't reach the minimal required threshold (200) for discovering conscious processing of supposedly unconscious stimuli (as shown in recent work in our lab). Finally, the measure used by the authors to evaluate awareness of the prime was checking for a correlation between d' and the size of the priming effect. This measure has been shown to inflate unconscious effects (Correlation analysis to investigate unconscious mental processes: A critical appraisal and mini-tutorial). They didn't statistically evaluate the absolute value of d'. When examining the single subject's d' it seems it is larger than zero for a large number of subjects, meaning they were actually aware of the prime.

The conclusion in the paper about semantic priming might also be put into question considering the unintuitive semantic connection claimed to exist between positive / negative stimuli and same / diff responses.

One more aspect to be taken into consideration is the comparison between natural movements of reaching and limited movements while using mouse tracking to probe cognitive processes. Responding with a mouse requires subjects to remap the representation of the stimuli in the real world into the 2D screen representations, this transformation could affect the trajectory and timing (@@ read this @@ Moher and Song 2019🡪 Palluel-Germain, Boy, Orliaguet, & Coello, 2004 @@) and place constraints on the subjects movement (@@ Make sure it appears in these papers @@ Moher and Song 2019🡪 Desmurget, Jordan, Prablanc, & Jeannerod, 1997; Desmurget, Prablanc, Jordan, & Jeannerod, 1997; Palluel-Germain, Boy, Oliaguet, & Coello, 2004) and inhibit process which might be of interest to us from being expressed in the motion.

Indeed, when comparing it to reaching for an answer in the real world, reaching has been shown to have faster movement times, larger movement curvatures (@@ Read abstract and discussion to check if relevant @@ "larger curvature represents uncertainty about predicted target position" Reaching for known unknowns: Rapid reach decisions accurately reflect the future state of dynamic probabilistic information), faster velocities and most importantly to respond faster to changes of mind, which makes it optimal for detecting fast and short lasting processes such as unconscious priming effects. Even more importantly, it has been shown that changes of mind are less likely to occur when a motor demand of a task is higher (@@ Read this @@ Moher and Song 2019🡪 Burk, Ingram, Franklin, Shadlen, &Wolpert, 2014; Moher&Song, 2014), this means incongruent effects might occur less frequently.

-----------------------------------------------------------------------------------------------------------

In the current research we will compare two measures of unconscious processing: response time given via a keyboard and reaching area derived from 3D motion tracking of reaching movements. Subjects will perform a semantic classification task (does the target describe an "natural" / "artificial" item) in which the target word will be preceded by an unconscious prime that can be congruent / incongruent to the target's category. Next, the subject will be asked to recognize the prime in a two forced choices task, and finally they will rate the prime's visibility in a PAS scale (from 1 for "Didn't see anything" to 4 for "Saw the prime clearly"). In an unreported pilot study we found out subjects have a hard time providing correct answers in the short time constraints of the task, thus the experiment will be comprised of two sessions in two consecutive days. The first day includes only a training session without primes and its purpose is to allow subjects to hasten their responses in the reaching task while keeping their accuracy high. The second day includes a short training and a test session.

A different test group will be used for each measure to avoid a practice effect.

-----------------------------------------------------------------------------------------------------------

We used the previous studies results and compared their keyboard response time measure and their trajectories measures.

Almeida et al. – 2014:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure** | **Parameter** | **Contrast type** | **Mean difference**  **Congruent – incongruent**  **Mean (SEM)** | **t-value** | **Cohen's dz** |
| Keyboard | RT (ms) |  | 9 (3) | 2.86 | 0.53 |
| Reach | AUC (mm2) |  | 2.3 (1.4) | 2.334 | 0.38 |
| Keyboard | RT (ms) |  | 16 (6) | 2.55 | 0.47 |
| Reach | AUC (mm2) |  | 3 (1.3) | 2.252 | 0.37 |
| Keyboard | RT (ms) |  | 13 (6) | 2.06 | 0.38 |
| Reach | AUC (mm2) |  | 2.4 (1.2) | 2.4 | 0.39 |

* t=tool, a=animal, .=oblong, \_=elongated
* Cohen's dz calculated using t-value.
* Keyboard RT – N=29
  + Con-incon 1: mean diff (SEM of diff), 9ms (3), t = 2.86,

Cohen's dz = 0.53

* + Con-incon 2: 13ms (6), t = 2.06,

Cohen's dz = 0.38

* + Con-incon 3: 16ms (6), t = 2.55,

Cohen's dz = 0.47

* AUC – N=37
  + Incon-con 1: 2.3mm2 (1.4), t = 2.334,

Cohen's dz = 0.38

* + Incon-con 3: 2.4 mm2 (1.2), t = 2.4,

Cohen's dz = 0.39

* + Incon-con 2: 3mm2 (1.3), t = 2.252,

Cohen's dz = 0.37

Cressman et al. – 2007:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure** | **Parameter** | **Congruent Mean (SE)** | **Incongruent**  **Mean (SE)** | **Cohen's dav** | **Hedge's gav** |
| Keyboard | RT (ms) | 333.2 (9.5) | 389.9 (7.1) | 2.16 | 2.06 |
| Motion tracking | MT (ms) | 515 (12.1) | 571.7 (10.9) | 1.53 | 1.47 |
| Motion tracking | Correcting movement onset (ms) | 277.3 (4.4) | 333 (4.6) | 3.91 | 3.74 |
| Motion tracking | Correcting movement length (mm) | 70 (SD=15.3) | 79.2 (SD=14.9) | 0.6 | 0.58 |
| Motion tracking | Correcting movement velocity (mm/s) | 475.7 (SD=38.9) | 533.3 (SD = 64.8) | 1.11 | 1.06 |

* Keyboard RT – Cohen's dav = 2.16, Hedge's gav = 2.06
  + Congruent: mean (SE), 333.2ms (9.5)
  + Incongruent: 389.9ms (7.1)
* Reach MT – Cohen's dav = 1.53, Hedge's gav = 1.47
  + Congruent: 515ms (12.1)
  + Incongruent: 571.7ms (10.9)
* Correcting mvmnt onset – Cohen's dav = 3.91, Hedge's gav = 3.74
  + Congruent: 277.3ms (4.4)
  + Incongruent: 333ms (4.6)
* Correcting mvmnt length – Cohen's dav = 0.6 , Hedge's gav = 0.58
  + Congruent: 70mm (SD=15.3)
  + Incongruent: 79.2mm (SD=14.9)
* Correcting mvmnt velocity – Cohen's dav = 1.11, Hedge's gav = 1.06
  + Congruent: 475.7 mm/s (SD = 38.9)
  + Incongruent: 533.3 mm/s (SD = 64.8)

~~Indeed it shows that trajectory measures bring about a greater effect size.~~

~~This supports our hypothesis.~~

@@ When writing your thesis @@ @@ Explain about our pilot studies, how did we start, what did we change in each one and why, how does it help us produce greater effects @@

### Hypothesis

In-line with previous comparisons between motion tracking and keyboard responses, we expect motion tracking to detect a greater incongruency effect (when comparing the effect size of both measures).