Perceptual decisions for different movement effectors

PROJECT DRAFT

Definitions:

Movement target selection: A process that determines which object becomes the target of a movement.
Evidence accumulation: A pattern in neural activity in which activity increases till a threshold is reached. Evidence accumulation is driven by incoming (sensory) information.
Motor plan: A selected movement that accomplishes the task goal and is directed to the movement target.

Introduction:

Goal directed interaction with the world requires accurate perception of the environment and a decision-making process to select from a huge set of potential actions one that is most promising to accomplish current goals. One crucial step in this process is the selection of a movement target, towards which the movement itself is executed. The overall decision-making process is successfully described as a drift diffusion model in which evidence for motor goals is accumulated, until a threshold is reached (Ratcliff, 2008; Wong, Haith, & Krakauer, 2015). Such models provide an accurate fit to behavioural studies and are therefore widely used in decision making research (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006). The neural correlate of evidence accumulation is a gradual increase in firing rate in brain regions linked to perception and action, such as Frontal Eye Fields (FEF), Posterior Parietal Cortex (PPC), and Motor Cortex (Heekeren, Marrett, & Ungerleider, 2008; Ploran et al., 2007). The process selecting the movement target based on individual goals and sensory input, but independent of the movement effector has not yet been localised (Brody & Hanks, 2016; Magri, Fabbri, Caramazza, & Lingnau, 2019).

Claims, that target selection is not different from motor planning (Wolpert & Landy, 2012), are recently being contradicted (Wong & Haith, 2017). For the oculomotor system, target selection and motor planning are likely distinct and serial processes (Lisi, Solomon, & Morgan, 2019). In hand movements, target selection also happens before the movement is initiated, but in contrast to eye-movements reaching trajectories are still controlled by visual input after the movement is launched (Chapman et al., 2010; Dotan, Pinheiro-Chagas, Al Roumi, & Dehaene, 2019). These are obvious differences between motor plan selection at hand-movement and eye-movement level, but the selection of movement targets is still assumed to be effector independent (Heekeren et al., 2008).

A region in the brain that acts as evidence accumulator to select a movement target should meet the following criteria (adapted from Brody and Hanks 2016):

(1) The graded value of the accumulator should be encoded in that region’s neural activity.
(2) Inactivation or perturbation during temporally specific periods that coincide with the evidence accumulation period should impact performance.
(3) The accumulation is modulated by top-down processes.

If this accumulator is independent of the effector, then

(4) The effects described above are present regardless of the movement required by the task.

In the following paragraph, I will argue that those criteria are met by perceptual systems, specifically by the visual system. Eventually, I will present a paradigm to test prediction 2 and 4.

(1) *A graded value of the accumulator is encoded in the neural activity of the visual system.* Neurons in Frontal Eye Fields and Superior Colliculus show increases in firing rates that correlate with target selection and the execution of a saccade (Purcell, Schall, Logan, & Palmeri, 2012; Schall, 2019). These signals might be purely visual or have direct impact on the saccade execution (Costello, Zhu, Salinas, & Stanford, 2013). EEG signals recorded in a face/house discrimination paradigm shows early response components (~170 ms) after stimulus presentation as well as later response components (~300 ms) after stimulus presentation (Philiastides & Sajda, 2006). These components have been linked to the perceptual decision process, and their contribution to low-level feature discrimination and object-level recognition is discussed (Johnson & Olshausen 2003).

(2) *Inactivation or perturbation during temporally specific periods that coincide with the evidence accumulation period impacts performance.*
A brief interruption of evidence accumulation in the visual system delays saccade responses (Reingold & Stampe, 2002). This phenomenon is known as saccadic inhibition and has recently been linked to the evidence accumulation process and to conscious detection of stimuli (Salinas & Stanford, 2018; White & Rolfs, 2016).
When the interruption of eye movements stems by newly presented information arises from a temporal stop in an effector independent target selection mechanism, we would expect similar effects for hand movement.

(3) The accumulation is modulated by top-down selection.
One crucial aspect of target selection is that the target is selected voluntarily. Any accumulation signal suited for target selection must be modulated by task goals – i.e. when a given stimulus is the target of an action, we should see the accumulating activity in that integrator while at the same time we wouldn't see it when the stimulus is processed, but not an action target.
Visual input is top-down modulated by attention (Carrasco, 2011; Rolfs, 2015). This modulation is closely linked to target selection across hand- and eye-movements (Baldauf & Deubel, 2010).

(4) *The response of the accumulator is independent of the effector.*
In the early stages of the visual system, information uptake is driven by stimuli in the environment and gradually shifts to a representation driven by task-goals and attentional selection (Wong et al., 2015). If we are looking for an independent mechanism for target selection, it makes sense to start looking in the visual system and work "forwards", till clear difference between movements effectors are seen.

If the target selection happens in the sensory system rather than in the motor system, we would expect differences over modalities. In a set of two studies, Van Vugt and colleagues used EEG (vanVugt, Simen, Nystrom, Holmes, & Cohen, 2012) and iEEG (van Vugt, Beulen, & Taatgen, 2016) to look at accumulator patterns during decision making tasks. They found accumulation patterns (up-ramping of responses between stimulus presentation and response) when the task involved a perceptual (visual) decision. However, when the same task was conducted in a memory-based paradigm, the up-ramping response was absent. The differences between these two tasks suggest that movement target selection is driven by processes not shared by visual processing and memory recall – potentially the sensory processing itself.

Evidence accumulation in behavioural paradigms:

In most behavioural paradigms, target selection is mixed up with perception and motor planning. In order to isolate target selection, the researcher needs a high degree of control over the incoming stimulus (Waskom, Okazawa, & Kiani, 2019). Previous studies have manipulated the perceptual decision-making process in go-before-you know paradigms (Stanford, Shankar, Massoglia, Costello, & Salinas, 2010). In these studies, participants are asked to generate a random motor plan and are presented with information relevant to target selection while the motor plan is already forming. The time window in which freshly presented information can still influence the movement plan is considered the time to accumulate evidence for target selection. While Stanford and Salinas concluded that this process can be as short as 30ms, Rüter et al argued that the actual integration of evidence is not captured by this approach. Introducing noise in a Vernier tasks, they demonstrated that evidence is integrated over a time window of more than 80 ms (Rüter, Sprekeler, Gerstner, & Herzog, 2013).

Integrating noise or uncertainty about the stimulus over time is a powerful tool, because it allows for a reverse correlation, linking presented data to decision outcome (Ohl, Kuper, & Rolfs, 2017). Lisi et al reverse correlated the target of a saccade (left or right) and the saccade landing position (deviation from centre of stimulus location) to noise stimulus location and luminance (Lisi et al., 2019). They found that the target selection (left/right) and the motor plan selection (landing position) are influenced by noise in different time windows. Target selection was influenced by earlier time windows than motor plan selection.

The review above is not complete, but reveals promising manipulations to experimentally segment movement target selection from other influences on reaction time:

1. Noise in the stimulus that allows for reverse correlation.
2. Speeded decisions that force the observer to integrate over short periods of time.
3. Perturbation of the accumulation process by presenting new evidence.

Here, I suggest a study to establish the independence of target selection from the movement effector. The study should replicate the results reviewed above not only in eye- but also in hand movements.

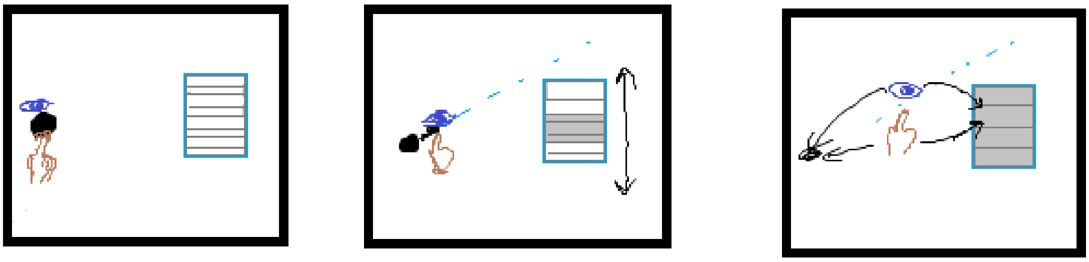


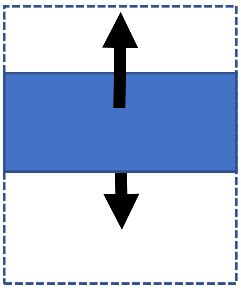
Figure 1 Experimental Setup 1: The participant is instructed to move their finger/eye to the target (light blue box) when they think the moving stimulus (black circle) will hit the target. In the first screen, the participant fixates on the start point (both finger and eye). Next, the target appears on the screen. Only a small fraction of the target is shown (3/7 parts, light grey). This fraction appears to "shake", i.e. moves up and down within the target.
In screen 2, the stimulus starts moving, the observer is required to track the stimulus with hand/eye.
Finally, the moving stimulus disappears. This is the signal to either move the hand/eye to the target (if the stimulus will intercept) or move them back to start (if the stimulus passes by).

This study builds on the "EyeStrike" paradigm (Fooken & Spering, 2019) but introduces noise and an additional response modality (eye movements).
The participant sees a moving stimulus that will either intercept a target or pass by. The target is not revealed at once, but gradually, in a noisy process. The observer needs to make their decision based on incomplete data about the true location of the target and we expect decisions to be driven by the noise integrated in the time window relevant for target selection (Lisi et al., 2019).

The target: The target is a rectangular box (the ground). The outline of the ground is only fully visible at the end of the trial and invisible during the rest of the experiment. The box is divided in 7 equally sized compartments. In the beginning of each trial, three adjacent compartments will be revealed to the observer. During the trial, the visible part of the target will either move one compartment up or down at a high frequence (~ 15 Hz). The visible area stays within the boundaries of the ground. This results in the impression of a "shaking" target. The ground is always upright, aligned with the vertical edges of the screen. The exact vertical location is drawn randomly with each trial. The horizontal location is restricted to be more than 15 degrees away from the screen centre.

The moving stimulus: The moving stimulus (attacker) is a filled circle with a diameter of 1-2 degrees visual angle. Its vertical location is random at each trial, its horizontal location is 30 degrees visual angle apart from the target.
The attacker is launched after the participant "fixates" with an angle that will either produce a clear hit of the target, a hit close to the edges of the target or will clearly miss or closely miss the target (4 launch angels in total, see Fooken and Spering 2019).
After a defined flight time, the attacker will become invisible (or change colour?). The observer tracks it till it disappears, then makes a movement either to the ground (if the ground is hit by the attacker) or back to the start (if the attacker passes by).

Instruction: Your task is to defend your ground from an attack.
The attacker (black ball) will move towards your ground, sometimes it will hit it, sometimes it will miss it. You must only defend your ground by looking at it (or moving your finger towards it), when the attacker hits it.
But be aware: Things in this game are not always as they appear.



1. You will only see a small fraction of your ground. The fraction you see will move during the trial, everything that is highlighted is a part of your ground. The size of your ground will not change during the experiment.
Imagine your ground like shown here:

The dashed lines mark the true size of your ground.
The solid box is what you will see of your ground.
The arrows indicate shifts in the visible area during the trial.

2. Once moving, the attacker will become invisible after some time. But don't worry, it won't change direction.

How to play: Place your finger on/look at the black circle on the screen. Your ground appears and the attacker will start moving from the same spot where you are fixating. Follow the attacker with your hand/eyes till it disappears. Now move your eyes either to your ground, if you think the attacker will hit it (the full ground counts, not only the visible fraction) or back to the start when you think it will miss.

Expectations

1. Prediction based on Lisi et al: The decision whether to move towards the target or not should be influenced by information revealed in early time windows. Eye movement endpoints should correlate with later time windows. If the target selection works identically in hand movements, the time window in which the hit/pass decision is made should be identical to the eye movement condition. After the target selection, we expect hand movements to be controlled continuously (and not serially like saccades), the time windows in which the target position influences the endpoint of the movement can be different for different effectors.

2. Predictions based on Fooken and Spering: higher eye velocity at pursuit initiation correlates with a better prediction of the attacker trajectory and faster pursuit maintenance associated with a more accurate timing decision. These effects could be lower/absent here because they are specific to the tracked target and this task contains a second, uncorrelated source of uncertainty. Eye-movements in the hand-tracking task should predict the decision before the hand moves. We can also test here, if a classifier trained on the data from the eye-movement task can predict the decisions in the hand-movement task. (Should be the case unless eyes move very differently when they occur together with hand-movements).

3. Predictions based on Dotan 2019: For hand movements, velocity correlates with uncertainty. The initial velocity of the movement should correlate with the distance between the attacker and the target. During the trial, the velocity might adapt. Because hand-movements are controlled online and can be modified after launched, we should also see adjustments in the hand trajectory when the target moves clearly in one direction (3 steps in one direction in a row).

4. Predictions from general evidence accumulation literature: Overall reaction times should be faster when the trajectory clearly misses/hits the target than when it closely misses/hits it. Reaction time should also be shorter when the target has been revealed evenly (full target shown before decision).

Explorative idea without clear prediction:

The attacker disappears after some time. This gives the task a memory dimension (remember how the attacker moved). Maybe parts of the target that are shown WHILE the attacker is visible will have a stronger weight on the decision, because they are easier comparable. To check this (also as a sanity check) we should make sure that the attacker disappearance is jittered (not temporally correlated with task onset) and could check later if the target shown before attacker disappearance has significantly more impact on the decision than targets shown after tracker disappearance.

Key Conclusions:

The time window for target selection in hand and eye movements is the same. This is evidence for the claim 4. After the target is selected, both effectors are controlled differently, with the hands being continuously updated by the perceptual system, while the eyes are not.

The decision is correlated with the gradually delivered information, incomplete information will lead to a wrong assumption about the ground location and impair the evidence accumulation/performance. This is evidence for claim 2. A follow-up study that specifically interrupts evidence accumulation is the next logical step.

My critique/questionmarks:

I miss a stronger argumentation that the target selection happens in the visual system. The time window in which information is integrated for a decision can be a hint – the earlier it happens, the more likely the selection is taking place early on. A second hint is the difference between the end of the target selection window and the execution of the movement – the hand movement should start later than the eye movement because the motor cortex is further away from the visual system than FEF.

There is another paper by Lisi (Lisi & Cavanagh, 2017) showing that hand and eye movements rely on different spatial maps. This is a strong contradiction to the claim here because I would assume that the selection of a target can only happen on a spatial map (and that this map should consequently be shared across movement effectors).

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