Angular distance between targets and non-targets influences the direction of early deviation in stylus-based hand trajectories

Master's Thesis in Cognitive Artificial Intelligence

Author: *Christal Gadiot* (3365557)
Supervisor: *Stefan van der Stigchel*
Second corrector: *Chris Paffen*
Third corrector: *Gerard Vreeswijk*

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Research into saccadic eye trajectories has revealed much about the attentional mechanisms underlying target selection and distracter suppression. Previous research has supported the notion that a system based on population vector coding may explain both the behaviour of saccades and targeting hand movements. While studies have been conducted with reaching and grasping, no studies to date have explored the behaviour of stylus-based hand movements on tablet computers. Tablets could become a useful tool for quick diagnostics in a clinical setting, once our operative behaviour can be quantitatively linked to the processes of attention. In this study, stylus-based hand movements on a tablet were observed in a task similar to those used in saccadic eye movements. It was found that the angular distance between the target and distracting element was most informative in determining the direction of the deviation. Shorter distances (20°) led to relatively more attraction (deviation) towards the distracter as compared to longer distances (40° and 65°). The pattern found with regard to angular distance between target and distracter as well as distance between the hand and the distracter, is suggestive of an interaction between the attention and inhibition not unlike what is seen in saccade research.

An integrated model of knowledge regarding the mechanisms behind attention in humans can be beneficial for many aspects of society and science. Examples include the development of attentional structures in robots and other agents and the development of software and tools that function as an extension of human capabilities (*e.g.* support systems in military defence, layout design of control systems of transport vehicles, devices that integrate the digital and real world). With tablets being one of the recent big trends in commercial technology, understanding how attention is reflected in the stylus-based movements of the hand can be beneficial both for the advancement of new technology as well as the development of diagnostic tools in a clinical setting.

Introduction

Rapid eye movements called saccades support our everyday visual perception. Over three decades of research into saccadic eye movements have revealed a great deal about the behavioural and neurological aspects of attention. The trajectory of saccades, which is generally curved, has shown to be informative of a number of processes that underlie behaviour, specifically with regard to attention (Van der Stigchel, 2010). As a result, many studies have used saccade trajectories and saccade deviation to measure aspects of attention, such as its allocation in space, the activity of distracting elements, and top-down control and inhibition (*ibid.*).

While experimental designs may vary a great deal, many share a number of basic elements, of which the features most relevant to the present study will be briefly discussed here. Virtually all experiments make use of a fixation point to ensure an equal starting point for the eyes in all trials (Van der Stigchel, Meeter & Theeuwes, 2006). Secondly, a target (abruptly) appears elsewhere in the visual field and the goal is to make a saccade from the fixation point to the target (*ibid.*). Often, distracting elements (distracters) are placed in the visual field to observe their influence on saccade trajectories and, indirectly, attention (*ibid.*).

In the presence of distracters, the saccade trajectory typically shows deviation relative to trials in which no distracter is present. The deviation observed in these trajectories is most commonly explained in terms of neuronal population coding, an idea first put forward by Steven Tipper and colleagues (Tipper, Howard, & Jackson, 1997; Tipper, Howard, & Houghton, 2000; McSorley, Haggard & Walker, 2004; Van der Stigchel, 2010). According to this view, every neuron in a motor map codes for an individual vector, which in turn encodes the movement towards a specific location. These vectors are averaged resulting in a single direction which determines the direction of the next saccade[1].

As a single saccade can have but a single goal, a visual scene in everyday life is expected to evoke some sort of selection process. It has been found that groups of neurons coding for different elements in a visual scene may compete, resulting in an average direction to an intermediate location (McPeek et al., 2003; Port and Wurtz, 2003; Van der Stigchel, 2010). When this competition remains unresolved at the time of saccade initiation, the saccade is often seen to deviate *towards* the competing non-target (McPeek et al., 2003; Van der Stigchel, Meeter & Theeuwes, 2006). When this competition is resolved by top-down mechanisms, such as the inhibition of one of the elements, deviation *away* from the distracter may be observed (Van der Stigchel, 2010).

Various aspects may influence the extent of inhibition and thus the extent to which deviation away from a non-target is observed. Factors that increase the amount of attention at the location of the distracter generally require stronger inhibition of the distracter, producing stronger deviation away

[1] This paper provides only a concise account of the theory behind saccadic deviation. For an extended review, please refer to Van der Stigchel, Meeter & Theeuwes (2006) and Van der Stigchel (2010).

(Van der Stigchel, 2010). Examples include distracter salience, distracter activity, and short distance between target and distracter (*ibid*.). Additionally, top-down inhibition appears to exert its effects more strongly with longer latencies (Mulckhuyse, Van der Stigchel & Theeuwes, 2009). Saccades with reaction times shorter than 200 ms tend to deviate towards the distracter, while deviations away are only observed for the longer latencies (McSorley, Haggard & Walker, 2009). Furthermore, manipulations such as providing prior knowledge of the distracter location give the inhibitory processes more time to build influence, resulting in deviations away from the distracter even for shorter latencies (Walker, McSorley & Haggard, 2006).

The neural substrate of the population-coded motor map is generally thought to lie in the superior colliculus (SC), a midbrain structure whose intermediate layers contain a retinotopically organised map (Sparks & Hartwich-Young, 1989; Schall, 1991; Van der Stigchel, Meeter & Theeuwes, 2006). The SC receives input from various areas including the frontal eye fields, the supplementary eye fields, the posterior parietal cortex and visual areas in the occipital lobe (Van der Stigchel, Meeter & Theeuwes, 2006; Bosch, Neggers & Van der Stigchel, 2013).

Activity in the SC determines the intended saccade goal through weighted averaging of the vectors in its motor map (Robinson, 1972; Wurtz et al., 1980; McPeek and Keller, 2001; McPeek & Keller, 2004; Van der Stigchel, Meeter & Theeuwes, 2006), although contributions from other areas (*e.g.* frontal eye fields) appear to be involved in this selection as well (Schlag-Rey, Schlag & Dassonville, 1992; Bosch, Neggers & Van der Stigchel, 2013; Van der Stigchel et al., 2013). During saccade preparation, localised activity can be observed in the SC at all sites competing for target selection. The saccade is then initiated to the weighted average of activity in the SC (*e.g.* Lee, Rohrer & Sparks, 1988; Van der Stigchel, 2010).

In principle, the SC codes for the initial saccade goal and not the path towards it, although evidence exists that its influence extends beyond merely the initial direction of a saccade (Quaia et al., 1998; Goossens & Van Opstal, 2000; Bergeron et al., 2003; Van der Stigchel, Meeter & Theeuwes, 2006). Adjustments to the saccade trajectory after the initial launch are thought to be made primarily by the cerebellum, for example when at a later time point a different location wins the competition (Quaia, Lefevre & Optican, 1999).

Besides (or complementary to) its involvement in the preparation of saccades, the SC is closely related to the mechanisms of attention (*e.g.* Ignashchenkova et al., 2003; Müller, Philiastides & Newsome, 2004). In mammals, its function appears to be related to gaze shifts and orienting of the eyes, head, as well as reaching movements of the arm (Klier, Wang & Crawford, 2001; Lünenburger et al., 2001). As attention is not likely to be a process of the visual modality alone, the question arises whether the other modalities make use of the same mechanisms, such as (areas that provide input to) the SC or top-down inhibitory mechanisms. This domain-unspecific view of attention is supported by the finding that it is impossible to direct attention to a discrimination target while making a saccade to another target; even when the two targets are spatially close (Deubel & Schneider, 1996). This coupling is also found for pointing movements, suggesting that a common attentional mechanism underlies both saccadic ("selection-for-perception") and pointing ("selection-for-action") movements (Deubel, Schneider & Paprotta, 1998).

Studies into hand movements have been subject to a great variety of experimental setups, tasks, and points of focus. Types of hand movements used include pointing, reaching[2], and grasping movements, while targets and distracters may be physical or simulated objects. This variation may make comparisons challenging at times. For this reason, this brief discussion will limit itself to studies using pointing movements and simulated elements, as the present study deals with stylus-based hand movements on a tablet computer. These movements can be seen as analogous to the pointing movements described in the literature.

In a study by Lee (1999), it was found that reaching (pointing) movements preceded by a central or peripheral cue were often directed to the cued location for short (< 200 ms) latencies, to an intermediate location between target and cue for intermediate (200-300 ms) latencies, and to the target only for the longest latencies. This prompted other researchers to investigate whether the global effect, commonly found in saccadic eye movements, may also be observed in hand movements (Sailer et al., 2002). The global effect is a term for the phenomenon where saccades land in a position intermediate between a target and distracter, when their locations are spatially close (within 20 or 30° angular distance) (Coren and Hoenig, 1972). It is thought to reflect incomplete target selection, a process that is likely part of a more domain-unspecific mechanism of attention, as supported by findings that the global effect may also be observed in pointing movements of the hand[3] (Sailer et al., 2002). The idea of a domain-unspecific mechanism for target selection is further maintained by results from a study in which hand movements deviated towards a distracter, even when the distracter could never be a target (Chang & Abrams, 2004).

This does not mean that the motor responses in different domains need to be the same. For example, it has been shown that an identical experimental paradigm resulted in opposite deviations for hand and eye movements (Lee, 1999; Van der Stigchel, Meeter & Theeuwes, 2007b). Inhibitory processes involved in target selection may also have a more general (domain-unspecific) and a domain-specific component. Evidence exists that both eye and hand movements are affected by inhibitory mechanisms of attention (Howard & Tipper, 1996), but the execution in these different motor domains appears to be somewhat different. Inhibition of return (IOR) for example, a process whereby a previously attended location is inhibited for a subsequent visit (Posner & Cohen, 1984), was found to consist of two processes: one specific to the oculomotor system, and one more general to

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[2] The term 'reaching' is often used interchangeably with the term 'pointing' in many research articles.

[3] Sailer and colleagues (2002) propose that separate (but intercommunicating) target representations exist for eye and hand, fed by parallel processes of response selection and inhibition. However, their findings may also be explained by the existence of a more central attentional process of target selection and inhibition, whose input is modulated differently at a later stage by the mechanisms of each domain.

visual processing (Fischer, Pratt & Neggers, 2003). As observed by the latter study, this more general process was also involved in pointing movements.

It has been proposed that exactly the same selection processes takes place for targeting hand and eye movements, namely through averaging of population vectors (Tipper, Howard & Paul, 2001). This means that deviations of hand trajectories can be compared to the pattern of deviations known for saccadic eye movements. The reason for the observed differences between studies of hand and eye movements (*e.g.* Van der Stigchel, Meeter & Theeuwes, 2007b) may be due to the fact that "different action systems require different frames of reference", as Tipper and colleagues eloquently stated it (2001). Their study shows that the trajectory of the saccade is affected by whether a reach to the target is also initiated, and they interpret this as competition between different frames of reference: one perception-based and one action-based (Tipper, Howard & Paul, 2001). This action-based frame is centred on the hand that is used to make the movements, rather than the fovea for saccadic eye movements (*ibid.*). This may cause elements closer to the targeting hand to generate stronger responses (vectors) than those farther away from it (*ibid.*), something that needs to be taken into account when comparing the targeting behaviour of manual and ocular systems.

Thus, both targeting eye and hand movements may be explained by a system based on population vector coding, although this information may be used differently by each motor domain. The present study aims to investigate the link between attention and stylus-based hand movements on a tablet computer, which can be considered an analogue of pointing. Tablets have become a common consumer product and can be seen as a more mobile form of the traditional computer. This makes them an excellent tool for use in a clinical setting, as patients may perform quick diagnostic tasks from their hospital bed if necessary. The purpose of the present research is to explore the behaviour of stylus-based hand movements for an attentional paradigm similar to those used in saccade research. A first experiment was conducted to see how such movements are affected by the presentation of a distracter at different degrees of distance from the target (section 1). A second experiment investigated whether decreasing the distance between the hand and the distracter would increase distracter activity, as implied by Tipper and colleagues (2001) (section 2). Finally, a third task experimented with cueing of the distracter, to observe the temporal dynamics of distracter inhibition for these movements (section 3).

1. Tablet task 1

The purpose of the first experiment was to see if stylus-based hand movements on a tablet computer show the same type of response to a distracter as saccadic eye movements in a similar attentional paradigm. In particular, attention was given to reaction times (cf. saccade latencies), initial angular deviation (cf. initial direction of a saccade), and the difference in direction between high and low reaction times (recall that inhibition was found to be stronger at longer saccade latencies (McSorley, Haggard & Walker, 2006; Mulckhuyse, Van der Stigchel & Theeuwes, 2009).

In this pilot test, the paradigm was kept as basic and as similar to the eye-tracking experiments as possible. Firstly, the fixation point corresponds to a starting box, which is –unlike with saccades– at the bottom centre of the screen to allow for longer hand trajectories. The saccade target becomes the target box in the pilot task, positioned in one of four positions at the top of the screen. Thirdly, the distracter corresponds to the distracter box which needs to be avoided.

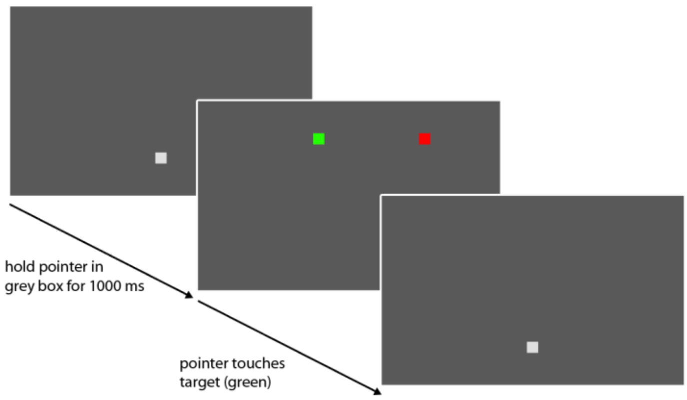
1.1 Methods

Participants

Eleven healthy subjects in the age range of 20 to 33 year participated in the experiment (8 males; mean age = 25.5, SD = 4.46). All participants reported to have normal or corrected-to-normal visual acuity and were right-handed.

Materials

The task, which was specifically designed for the present experiment, was executed on a 12.1" ASUS *Slate EP121* touch-responsive tablet operating on Windows 7. Screen resolution was 1280 × 800 pixels. A stylus from the same brand was used to operate the tablet, mimicking the use of a pencil. During the experiment, the tablet was set to only respond to the accompanying stylus, not to touch.



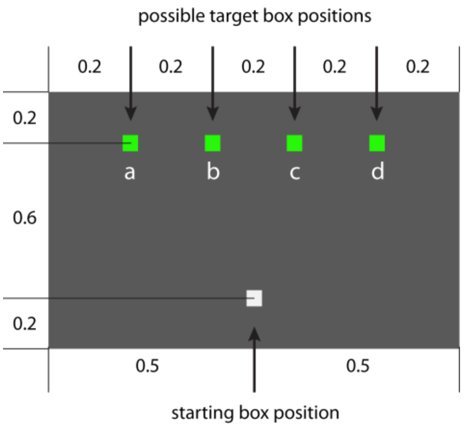


Figure 1. *Left*: illustration of a sample trial with distracter in task 1. *Right:* overview of the four possible positions (*a*, *b*, *c*, and *d*) of the boxes relevant to hand trajectories. Numbers correspond to relative distance (1 equals total width or total length of the screen).

General procedure

The experiment took place in a normally lit room. Participants were given the tablet and asked to position themselves in a way that they found comfortable to sustain for at least ten minutes, to ensure the most natural hand movements during the experiment. Before the task was attempted, the procedure was briefly explained. Participants were instructed to position the stylus on the grey starting box in the bottom centre of the screen, and when it disappeared, to move the stylus to the green target box swiftly but accurately. The red distracter box that appeared on some trials had to be avoided. Furthermore, subjects were specifically instructed not to lift the stylus from the screen while moving from the starting box to the target box.

A typical trial started with the presentation of a single grey (starting) box at the centre bottom of the screen (*fig.* 1, left panel). When the tip of the stylus was positioned inside of the grey square for exactly 1 second, the grey square disappeared and a green target box of equal size appeared at any of four equally spaced positions at the top of the screen (see *fig.* 1, right panel). In most cases, a red distracter box (also of equal size) was presented simultaneously alongside the target at variable distance, but at the same height as the target (*fig.* 2). When the stylus was moved to the target box, both target and distracter disappeared and the grey starting box reappeared at the bottom of the screen, signalling the start of the next trial. While the grey box was visible, no data was recorded, and while the pointer was not inside the grey box, it would be presented indefinitely. Therefore, subjects consciously started each trial. An example trial is illustrated in figure 1 (left panel).

The experiment consisted of 240 trials, of which exactly half presented the target in the right half of the screen. 75% of trials included a distracter alongside the target. In one third of these trials, the angular distance between target and distracter was 20° (relative to the starting box), in one third it was 40° and in the remaining third the distance was 65° (*fig.* 1, 2). This resulted in a total of 8 conditions: baseline (without distracter), 20°, 40°, and 65° angular distance, each for both left and right presentation of targets (see *fig.* 2). Total duration of the experiment was approximately 10 minutes.

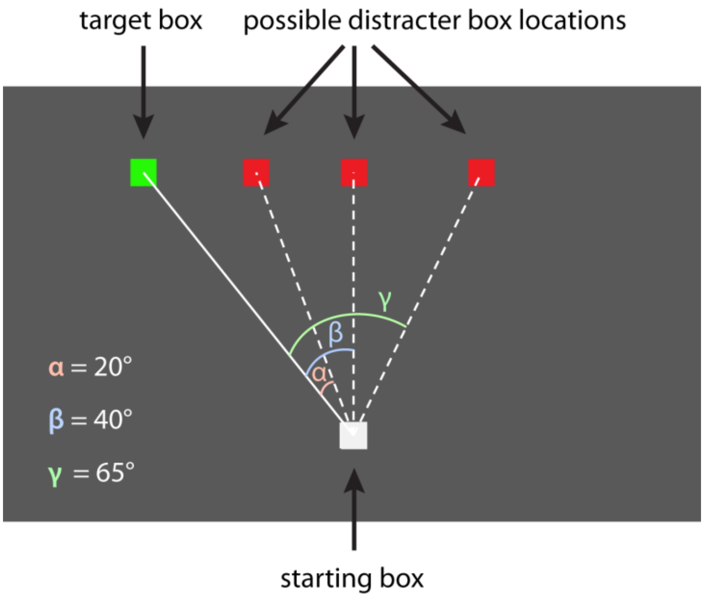


Figure 2. Example of the possible positions of the distracter box given the position of the target box.

Analysis

The experiment followed a repeated measures design, with each participant supplying data for all of the conditions within the task. Data were analysed using MATLAB and statistically evaluated using STATISTICA.

Reaction times

Data were analysed per condition to yield reaction times, defined as the time taken from the onset of the trial (*i.e.* disappearance of the starting box and appearance of the target) to movement of the cursor outside of the starting box. As the interval between two successive data points was 30 ms on average (due to apparent computational limitations of the tablet), the mean of the last time point inside the starting box and the first time point outside of it was used as the reaction time for a trial.

Reaction times lower than 100 ms or higher than 1000 ms were treated as outliers, as well as reaction times that were further than 2.5 standard deviations removed from the condition mean for that participant. Reaction times that were too low were deemed likely to be reflections of false starts and other undesired events. Alternatively, they could be caused by movement near the edges of the starting box before a trial. The cursor may then slowly move out of the box in the period after the trial had started but before the participant has consciously initiated the movement towards the target (this was observed in some cases). Reaction times that were too high are likely due to inattentiveness or distraction.

Statistical analysis of reaction times was done using a 3×4 repeated measures analysis of variance (ANOVA). The first factor is defined as *distance*, corresponding to the angular distance between target and distracter as measured relative to the starting box. Distance has three levels: 20°, 40°, and 65°. The second factor is defined as *location*, corresponding to the location of the target – recall that targets can be positioned in any of four equally spaced positions at the top of the screen (see *fig.* 1, right panel). Influence of the distracter on reaction times was calculated by comparing the means for the grouped experimental conditions to baseline conditions in a t-test.

Initial deviation

Initial angular deviation was calculated as follows. First, only trials in which the participant left the starting box in an upward or sideways direction were used in the analysis. Secondly, trials for which the reaction time fell within the exclusion criteria (as outlined in the section above) were not used in this analysis either. All values pertaining to initial deviation were calculated 3 time points (approximately 90 ms) after the cursor left the starting box. Baseline deviation was calculated by subtracting the angle made by the participant from the angle made by a straight line to the target. Angular deviation for all experimental conditions was calculated relative to baseline conditions. The angle made by the participant was subtracted from the angle made by an ideal straight line to the target (as in baseline deviation), and this result was subtracted from the mean baseline deviation. Trials with targets on the left side of the screen were always analysed using the baseline mean for trials with targets on the left side, and vice versa. In all calculations, positive deviations correspond to movements towards the distracter, while negative deviations symbolize movements away from it.

These initial angular deviations (referred to as *initial deviation* in the remainder of this paper) were grouped into means per condition, or were split based on their associated reaction times before being grouped into condition means. In the latter case, reaction times were labelled as either high or low relative to the mean reaction time of the participant for each specific condition.

Statistical analysis of the initial deviation was done using a 3×4 ANOVA. The first factor is again *distance*, defined in the same way as in the case of reaction times. The second factor is defined as *location*, corresponding to the location of the target – targets can be positioned in any of four equally spaced positions at the top of the screen (see fig. 1, right panel). Analysis of the initial deviation split by reaction time differed only in the addition of a third factor, namely *reaction time*, producing a $3 \times 4 \times 2$ ANOVA. Reaction time has two levels – low and high. Unless stated otherwise, all ANOVAs in this text refer to repeated measures ANOVAs.

1.2 Results

Exclusion criteria resulted in 4.0% excluded trials, of which 1.0% was due to participants leaving the starting box in a downwards direction (the remaining 3.0% fell outside the criteria set for reaction times).

Reaction times

A 3×4 ANOVA (distance × location) on the reaction times revealed a significant main effect for location, *i.e*. the position of the target box ($F(3, 30) = 17.30$, $p < 0.001$). Figure 3 shows the mean reaction times for each target box position. Subsequent t-testing revealed these means to be significantly different between all target locations, with the exception of positions *b* and *d* (see *fig.* 1, right panel). These results are displayed in table 1. Comparing each individual target position with the grouped other three positions yielded significant results for locations *a* ($t(10) = 5.558$, $p < 0.001$) and *c* ($t(10) = 5.437$, $p < 0.001$). No significant differences between experimental and baseline conditions were found.

Initial deviation

A 3×4 ANOVA (distance × location) on the results for the initial deviations showed a significant main effect for distance between target and distracter ($F(2, 20) = 20.51$, $p < 0.001$), as well as a significant interaction between distance and target location ($F(6, 60) = 3.46$, $p = 0.005$). Post-hoc t-testing revealed the difference for distance to be mostly between the 20° and 40° conditions ($t(11) = 7.087$, $p < 0.001$), and the 20° and 65° conditions ($t(11) = 4.705$, $p = 0.001$). In the 20° conditions,

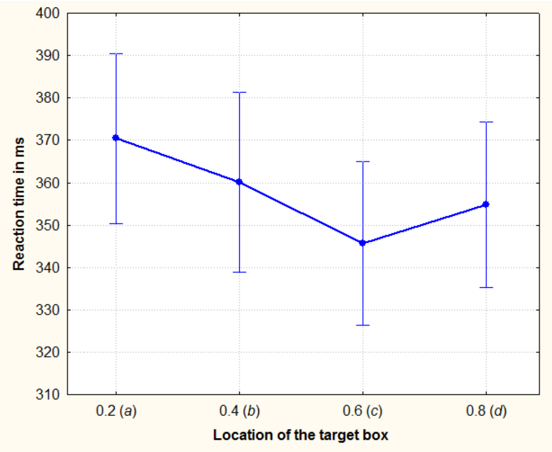


Figure 4. Mean reaction times for the four target box locations. Vertical bars denote CI95.

position	mean	SD	*t*	df	*p*
a b	370 360	29.89 31.58	3.2086	10	0.009
a c	370 346	29.89 28.80	6.4909	10	< 0.001
a d	370 355	29.89 29.06	4.1146	10	0.002
b c	360 346	31.58 28.80	3.5350	10	0.005
b d	360 355	31.58 29.06	1.6161	10	0.137
d c	346 355	28.80 29.06	3.4180	10	0.007

Table 1. T-test results for the mean reaction times (in ms) for the four target positions (*a*, *b*, *c*, and *d*). (*SD* = standard deviation; *t* = t-value; *df* = degrees of freedom, *p* = p-value.)

there was almost no deviation relative to baseline; while for the 40° and 65° conditions, deviation away from the distracter was observed in the averaged totals (*fig*. 4, left panel).

The interaction effect between distance and target location seems to be produced primarily by the data for the leftmost (*a*) target location. T-tests comparing the values for the four target locations in each distance condition had two significant outcomes. In the 20° distance condition, results for the leftmost (*a*) and rightmost (*d*) target location were considerably different ($t(11) = 3.402$, $p = 0.007$). In the 65° distance condition, the results for the leftmost (*a*) and second rightmost (*c*) target locations differed substantially ($t(11) = 3.903$, $p = 0.003$). On their own, these results may not appear relevant, but a closer look at figure 4 (right panel) reveals that the results for target locations *b*, *c* and *d* show a similar pattern, whereas only the results for target location *a* show a different pattern, indicating that this location may be somehow unique (see also the discussion in section 4).

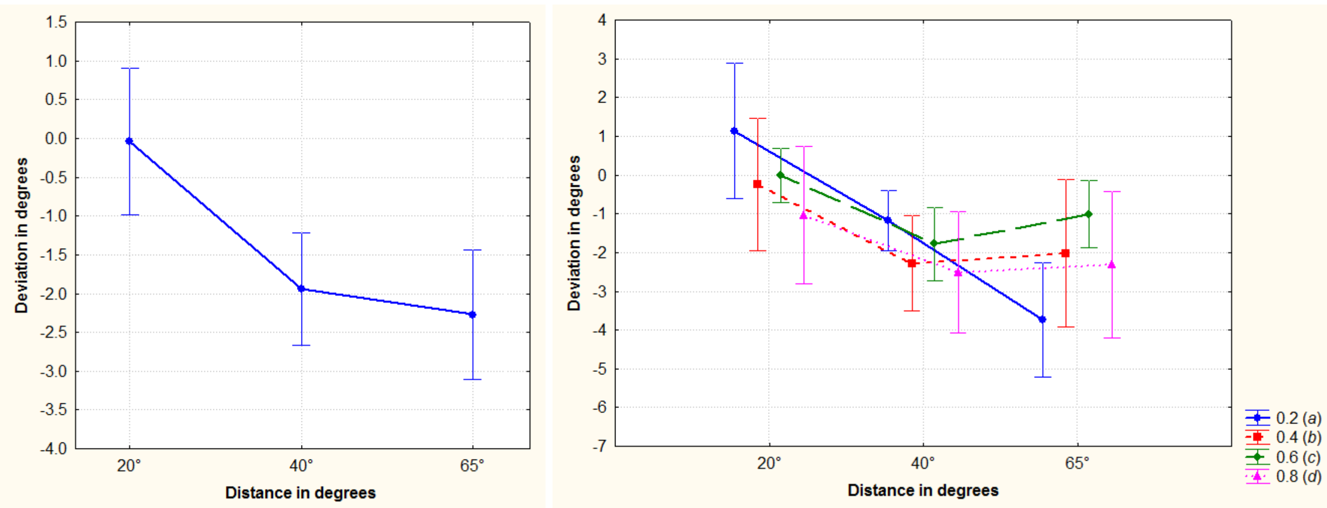


Figure 3. *Left:* Mean initial deviation for the three distances between target and distracter. *Right:* Mean initial deviation for the distances between target and distracter, separated by target location (see legend in bottom-right corner). In both panels, negative values correspond to deviation away from the distracter. All values were calculated relative to baseline conditions. Vertical bars denote CI95.

Finally, splitting the initial deviation data on reaction times in a 3 × 4 × 2 ANOVA (distance × target location × reaction time) revealed significance for distance between target and distracter ($F(2, 20) = 16.69$, $p < 0.001$), reaction time ($F(1, 10) = 8.19$, $p = 0.017$), and again the interaction between distance and target location ($F(6, 60) = 3.30$, $p = 0.007$). Deviation away from the distracter was observed for both low and high reaction times, although for short reaction times, this deviation was much stronger. With regard to distance, the split data showed similar deviation as described in the previous paragraph.

2. Tablet task 2

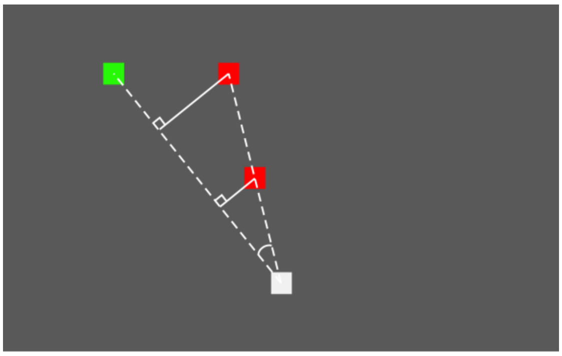


Figure 5. Lowering the vertical distance between starting point and distracter also decreases the distance between the distracter and a straight path towards the target.

Having seen in the first experiment that the distance between target and distracter strongly influences the initial direction of hand trajectories, the purpose of this second experiment was to see how an altered spatial placement of the distracter influences these trajectories. By placing the distracter in the middle of the screen rather than at the top, said distracter becomes closer to the (ideal) path that had to be taken to reach the target (*fig.* 5; *fig.* 6) as well as spatially closer to the hand, which should increase distracter activity (Tipper, Howard & Paul, 2001). Additionally, it would be interesting to see if the difference for the target locations is replicated in this second experiment.

2.1 Methods

Participants

Ten healthy subjects in the age range of 18 to 35 year participated in the experiment (4 males; mean age = 27.6, SD = 6.47). Four of these had also participated in the previous task. All participants reported to have normal or corrected-to-normal visual acuity and were right-handed.

Materials

The same materials were used for the second task as for the first, with the exception of the task used. Differences between the second and first task will be outlined in the following subsection.

General procedure

For a description of the procedure, please refer to the explanation outlined in the methods section of task 1. The task for the second experiment was slightly adjusted. The distracters were no longer presented at the same height as the targets, but on an imaginary line halfway across the screen (*fig.* 6, right panel), in an attempt to increase their distracting influence. Additionally, a progress bar was added to give participants an idea of the remaining amount of trials, as many subjects in the previous task expressed the desire to know the remaining duration of the experiment. Figure 6 (left panel) illustrates a sample trial.

Analysis

Data were analysed in exactly the same way as for the previous task. For the details, please refer to the methods section of task 1.

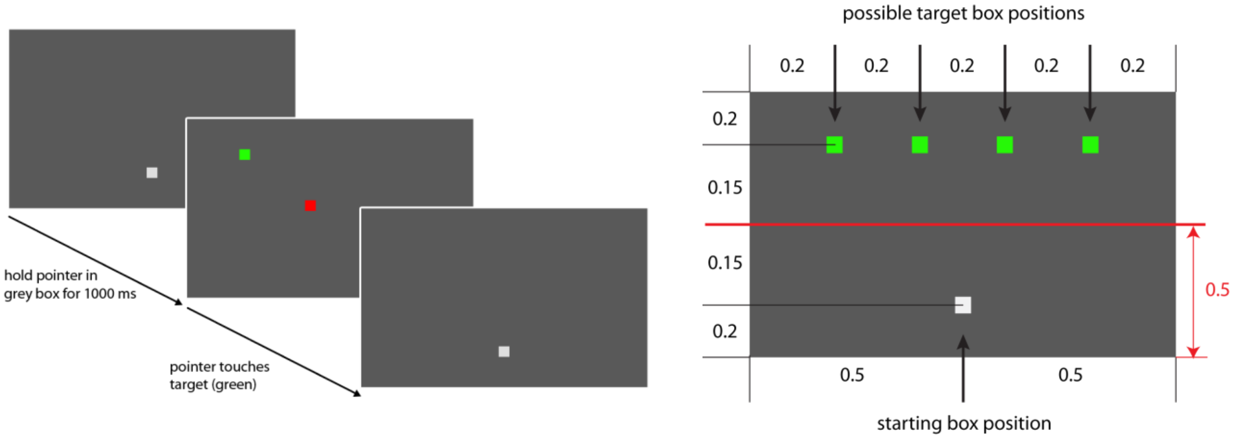


Figure 6. *Left*: illustration of a sample trial with distracter in task 2. *Right:* overview of possible positions of the boxes relevant to hand trajectories, as well as an indication of the vertical position of the distracter (red horizontal line). Numbers correspond to relative distance (1 equals total width or total length of the screen).

2.2 Results

Exclusion criteria led to the loss of 3.5% excluded trials, of which 1.2% was produced by participants leaving the starting box in a downwards direction (the remaining 2.4% fell outside the criteria set for reaction time).

Reaction times

A 3 × 4 ANOVA (distance × location) on the reaction times again revealed a significant main effect for location, *i.e.* the position of the target box ($F(3, 27) = 7.209$, $p = 0.001$). Figure 7 shows the mean reaction times for each target box position. Subsequent t-testing revealed these means to be significantly different for all target locations except those for positions *b* and *d* and for positions *a* and *d* (see *fig.* 1, right panel). These results are displayed in table 2. Comparing each individual target position with the grouped other three positions again yielded significant results for target positions *a* ($t(9) = 3.133$, $p = 0.012$) and *c* ($t(9) = 5.158$, $p = 0.001$). Despite attempts to increase distracter activity, no significant differences were found between experimental and baseline conditions. Overall, these results are very similar to the ones obtained in the first experiment.

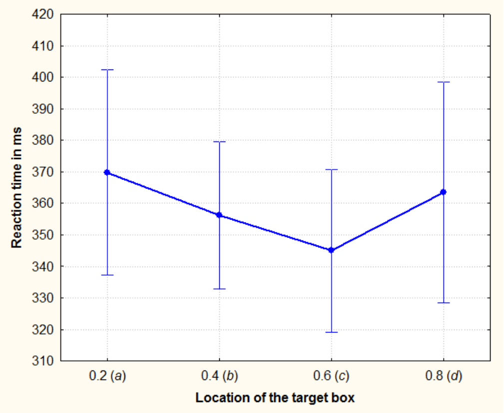


Figure 7. Mean reaction times for the four target box locations. Vertical bars denote CI95.

position	mean	SD	*t*	df	*p*
a b	368 355	44.88 34.79	2.7863	9	0.021
a c	368 345	44.88 36.00	4.9117	9	0.001
a d	368 362	44.88 49.42	0.8413	9	0.422
b c	355 345	34.79 36.00	3.9843	9	0.003
b d	355 362	34.79 49.42	1.2773	9	0.233
d c	362 345	49.42 36.00	2.8750	9	0.018

Table 2. T-test results for the mean reaction times (in ms) for the four target positions (*a*, *b*, *c*, and *d*). (*SD* = standard deviation; *t* = t-value; *df* = degrees of freedom, *p* = p-value.)

Initial deviation

A 3 × 4 ANOVA (distance × location) on the results for the initial deviations showed, again, a significant main effect for the distance between target and distracter ($F(2, 18) = 13.58$, $p < 0.001$). The interaction between distance and target location found in the previous task was no longer present. Post-hoc t-testing revealed significant differences for distance between all three conditions: between 20° and 40° conditions ($t(10) = 3.115$, $p = 0.012$), between 20° and 65° conditions ($t(10) = 4.249$, $p = 0.002$), and between 40° and 65° conditions ($t(10) = 3.040$, $p = 0.014$). Whereas in the previous task average deviations for each distance condition were neutral or negative (away), in the second task shorter angular distance corresponds to deviation towards, while longer angular distance corresponds to deviation away (see *fig.* 8, left panel). Note that the shape of the graph remained relatively consistent.

Splitting the initial deviation data on reaction times as before in a 3 × 4 × 2 ANOVA (distance × location × reaction time) revealed significance for distance ($F(2, 18) = 15.46$, $p < 0.001$). Unlike in the previous task, reaction time and the interaction between distance and target location were no longer significant. There seemed to be, however, a trend for the interaction between distance and reaction time ($F(2, 18) = 3.37$, $p = 0.057$). The related graph (shown in *fig.* 8, right panel) indicates that longer reaction times seem to produce more deviation away in the 65° distance condition, although t-tests reveal no significant difference between these two groups.

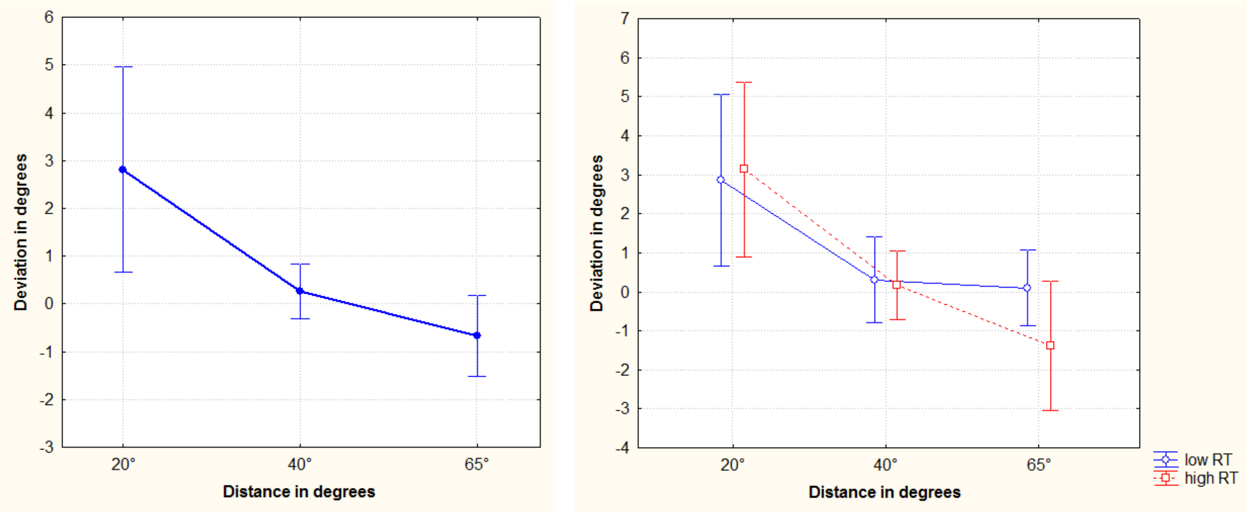


Figure 8. *Left:* Mean initial deviation for the three distances between target and distracter. *Right:* Mean initial deviation for the distances between target and distracter, separated by reaction time (see legend in bottom-right corner). In both panels, negative values correspond to deviation away from the distracter. All values were calculated relative to baseline conditions. Vertical bars denote CI95.

3. Tablet task 3

The previous experiments have shown that the (angular) distance between target and distracter can be consistently correlated to the degree of deviation, with shorter distance corresponding to relative deviation towards, and longer distance to relative deviation away from the distracter. Reducing the (linear) distance between the hand and the distracter led to a positive (upwards) translation of the corresponding graph (compare *fig*. 3, left panel and *fig*. 8, left panel), indicating relative deviation towards the distracter. These results may be interpreted in a similar fashion as is done for saccades, namely as being the result of the interaction of a bottom-up competition of salience and a top-down mechanism of inhibition. However, whether the same mechanisms underlie these deviations remains uncertain. An important problem in the comparison is the inherent temporal difference between the initiation of a saccade and the onset of a hand movement. To explore the temporal dynamics of the hand movements used in this study, a third task intended to pilot the effects of a distracter cue on deviation behaviour. This cue, which appeared on most trials, signalled the location of the upcoming distracter. Half of these trials were preceded by a short cue of 150 ms, while the other half presented the cue for 1000 ms. It was expected that this would provide a glimpse of the temporal dynamics of the underlying behavioural mechanisms, as well as indicate whether these mechanisms are similar or separate from those implied in the literature discussed below.

Cueing at the location of a target or distracter is a form of exogenous cuing, where the cue draws attention via bottom-up processes (as opposed to endogenous cuing) (Jonides, 1981). This direction of attention facilitates visual processing in the cued area for a couple hundred ms before turning into suppression of that area, a process which is called inhibition of return (IOR) (Posner and

Cohen, 1984; Klein, 2000). Exogenous cueing also appears to be able to induce saccade deviations away from the cued location, likely through a mechanism that is separate at least to some degree from the process of IOR (Godijn & Theeuwes, 2004). While the effect of saccade deviation is thought to arise from inhibition at the level of the saccade map (SC), the effect of IOR results from inhibition at a level previous to this, possibly in the parietal cortex (Klein, 2000; Godijn & Theeuwes, 2004). The parietal cortex plays an important role in exogenous visual orienting, spatial working memory, manual responding, and is profusely interconnected with the SC, making it a good candidate for the origin of IOR signals (Klein, 2000). Since this area is not solely connected to the pathways of saccade control but reflects a more general attentional mechanism, it is possible that similar inhibition effects may also be observed for the stylus-based hand movements used in the present study.

In the third task, the distracter is cued to attract attention to it before its actual presentation. All cues in the experiment are valid, but the cue-target onset asynchrony (CTOA) is manipulated. Cues can be either short (150 ms CTOA) or long (1000 ms CTOA), which allows for differentiation of the results based on temporal dynamics. IOR is known to become optimal only after a delay of several hundred milliseconds (about 800 ms in saccade research: Godijn & Theeuwes, 2004), such that IOR effects, if any, are only expected for the long cues. In that case, one may see a lessened influence of the distracter (*e.g.* shorter latencies, deviation comparable to baseline conditions). For the short cues, one may expect to see the effects of more transient inhibitory processes, or perhaps of insufficient inhibition.

3.1 Methods

Participants

Ten healthy subjects in the age range of 18 to 35 year participated in the experiment (4 males; mean age = 24.8, SD = 5.73). One subject had also participated in the first task, two subjects previously participated in task 2, and four subjects had participated in both previous tasks. All participants reported to have normal or corrected-to-normal visual acuity and were right-handed.

Materials

The same materials were used for the third task as for the second task. The task differed in that the distracters were now preceded by a cue in 80% of cases (*fig.* 9), to explore the temporal dynamics of inhibition for stylus-based hand movements.

General procedure

For a description of the procedure, please refer to the explanation outlined in the methods section of task 2. Differences between the procedure outlined there and those used in the present task will be discussed below.

The instruction before the task mentioned that on some trials, a cue would appear that would signal the position of the distracter. This cue always appeared *before* the presentation of the target and distracter boxes. See figure 9 for an illustration of the cue and a sample trial.

In each of the experimental conditions as described in the procedure for the first task (*i.e.* 20° left, 20° right, 40° left, 40° right, 65° left, 65° right), 80% of trials were cued. Of these trials, approximately half were heralded by a short cue (150 ms), and the other half by a long cue (1000 ms).

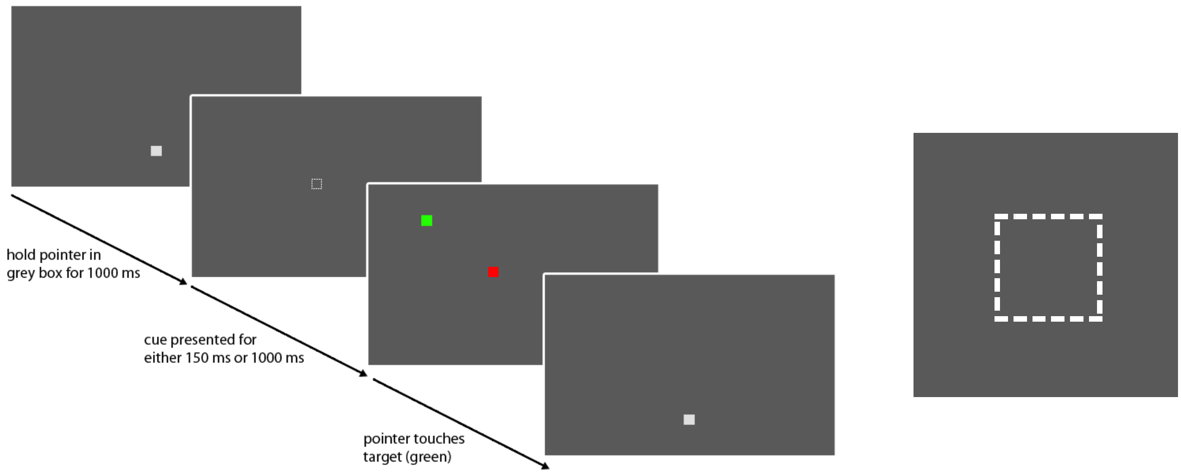


Figure 9. *Left*: illustration of a sample cued trial in task 3. *Right*: illustration of the cue as participants saw it.

Analysis

Data were analysed in mostly the same way as for the previous tasks. For the general idea, please refer to the methods section of task 1. Differences will be outlined below.

Statistical analysis of reaction times was done using a 4 × 3 ANOVA. The first factor, *location,* is defined equally as in the previous tasks. The second factor is defined as *cue* and has three levels: *uncued*, for trials presented in the manner that characterised task 2; *short cue*, for trials preceded by a short cue; and *long cue*, for trials preceded by a long cue. Distance was omitted as a factor because splitting the data on multiple levels left some categories without data, and the rest with relatively little. This was deemed insufficient for reaching relevant conclusions from statistical analysis. Furthermore, the factor distance has not shown any significant effects in the previous two experiments, making it very unlikely to be of influence in a third experiment with mostly the same setup. By factoring out *distance*, more data would be available to produce the category averages, resulting in better statistical performance.

Statistical analysis of the initial deviation was done using a 3 × 2 × 3 ANOVA, with the first factor (*distance*) defined in the same way as for the previous tasks. The second factor (*left-right*) was defined as the location of the target relative to the middle of the screen. Essentially it groups together locations *a* and *b* on the left, and *c* and *d* on the right. This was done to prevent excessive splitting of the data that would leave some categories with little or no data. As the factor location showed no significant effects in the previous task, it was deemed unlikely to do so in the third task (which differed only in the addition of cues), making it the best alternative to factor out. The third factor (*cue*) was defined as described in the previous paragraph.

For the same reasons as stated above, no analysis of the data split by reaction time could be made. The previous task achieved no relevant significant results by splitting the data. To correct for the possibility that grouping the target locations together in two clusters (left-right) somehow had an effect on the results, this factor was removed completely in a third analysis, producing a 3×3 ANOVA. It was expected that neither the left-right grouping nor the complete removal of the factor location would produce any significant differences.

3.2 Results

Exclusion criteria resulted in 4.9% excluded trials, of which 1.0% was due to participants leaving the starting box in a downwards direction (the remaining 3.8 % fell outside the criteria set for reaction times).

Reaction times

Somewhat surprisingly, a 4 × 3 ANOVA (location × cue type) on the reaction times yielded no significant effects. The graph of reaction times plotted against the target locations, however, had a similar shape as in the previous experiments (see *figs.* 4 and 7). While not significant in the ANOVA, locations *a* and *c* ($t(9) = 3.977$, $p = 0.003$) as well as *c* and *d* ($t(9) = 2.403$, $p = 0.040$) differed substantially in a t-test. Similarities with the previous tasks notwithstanding, the influence of target location on reaction times was much less evident in the cued experiment as compared to the two previous experiments. Finally, there were no significant differences in reaction time between experimental and baseline conditions.

Initial deviation

A 3 × 2 × 3 ANOVA (distance × left-right × cue type) on the results for the initial deviations showed, once more, a significant main effect for distance ($F(2, 18) = 28.24$, $p < 0.001$). Furthermore, a main effect was found for cue type ($F(2, 18) = 9.37$, $p = 0.002$) (*fig.* 10, right panel). Post-hoc t-testing revealed significant differences for distance between all three conditions: between 20° and 40° conditions ($t(10) = 3.115$, $p = 0.012$), between 20° and 65° conditions ($t(10) = 4.249$, $p = 0.002$), and between 40° and 65° conditions ($t(10) = 3.040$, $p = 0.014$). Like for the second task, shorter angular distance corresponds to deviation towards, while longer angular distance corresponds to deviation away (*fig.* 10, left panel). Note that the shape of the graph remained relatively consistent across all three tasks. For cue type, significant differences were only found between uncued and short cue conditions ($t(10) = 3.101$, $p = 0.013$), as well as between short and long cue conditions ($t(10) = 3.783$, $p = 0.004$). Interestingly, deviation in the short cue condition was less than for uncued and long cue conditions.

As splitting the data on both cue type *and* reaction time would leave very little data per category, it was not deemed worthwhile to perform this analysis. Moreover, no new observations were made using the split data in the previous experiment. Instead of splitting the data further, the location component was collapsed entirely to provide more data per category, and therefore potentially better statistical performance. A 3 × 3 ANOVA (distance × cue) revealed the exact same effects *and* significance as for the data with the factor *left-right* included, and so did post-hoc t-tests. It can therefore be concluded that positioning the target on the right or left side of the screen has no (or perhaps opposite) influence on initial angular deviations.

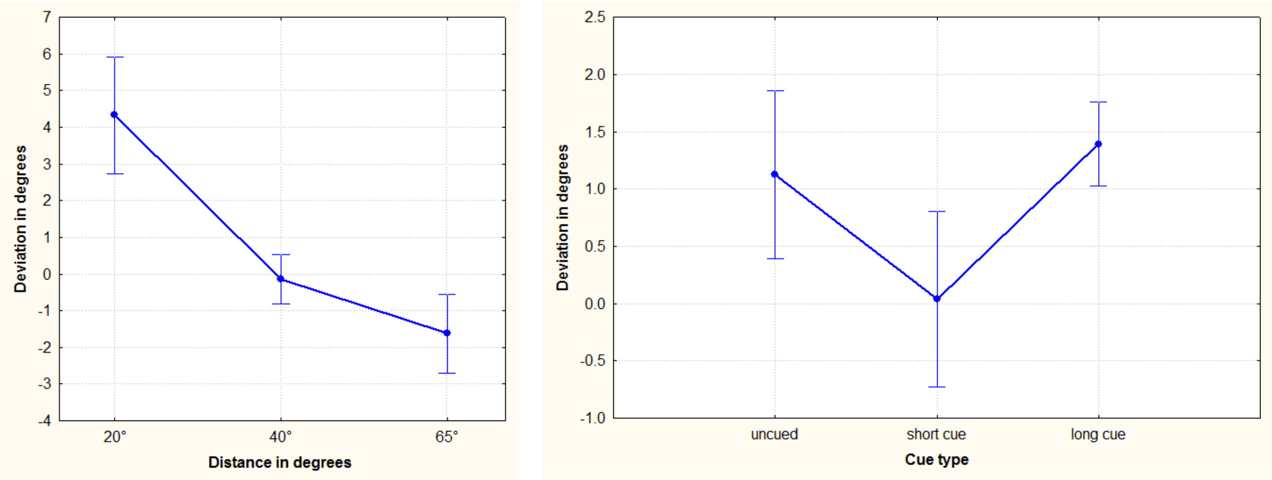


Figure 10. *Left:* Mean initial deviation for the three distances between target and distracter. *Right:* Mean initial deviation for the three cue conditions: uncued, short cue, and long cue. In both panels, negative values correspond to deviation away from the distracter. All values were calculated relative to baseline conditions. Vertical bars denote CI95.

4. Discussion

The purpose of the present study was to investigate whether saccadic eye movements and stylus-based hand movements show behavioural similarities in a comparable attentional paradigm, particularly with regard to deviation in the early part of the trajectory. To this end, three experiments were performed. In the first experiment, it was investigated how hand movements react to a distracter placed alongside a target at varying angular distances. A second experiment assessed the influence of increasing distracter activity by placing the distracter closer to the starting point (*cf.* fixation point), thereby also decreasing the distance between the hand and the distracter. A third and final experiment intended to explore the temporal dynamics of deviation behaviour in hand trajectories by cueing the distracter at short or long intervals before the presentation of the target and distracter. The most prominent result emerging from these experiments was that the distance between target and distracter appears to systematically influence the direction of initial deviations in hand movements. The following paragraphs will further discuss this and other observations made with regard to the results of this study.

Reaction times

The most striking result with regard to reaction times is the consistent difference between the four target locations. While only statistically significant in the first two experiments, all three tasks produced a similar pattern of reaction times (*fig*. 12, left panel). No straightforward explanation for this could be found. One could speculate that the hand and arm movements that had to be made to reach the target locations were perhaps more 'natural' for some locations than others. This may be seen in the distribution of reaction times, where targets on the left side of the screen take some 10 ms longer to react to than those on the right side of the screen. Alternatively, and more in line with the notion of an action-based reference frame centred around the hand (Tipper, Howard & Paul, 2001), it may be that target position *c* (see fig. 1, right panel) is closest to the hand in the action-based representation of the situation (*fig*. 11). Positions *b* and *c* are spatially closest to the hand, but positions *c* and *d* may be functionally closer than *a* and *b*, because movement to these locations is most natural and effective (*i.e.* ingrained through experience). This concept is illustrated in figure 11, where the circles represent isolines of attentional closeness. Together, spatial proximity for the middle two and functional salience for the right two target locations

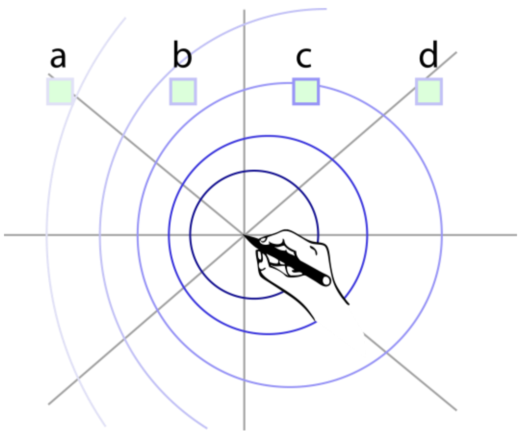


Figure 11. Conceptual illustration of an action-based attentional grid centred on the hand. Circles represent isolines of attentional closeness. Boxes represent target locations.

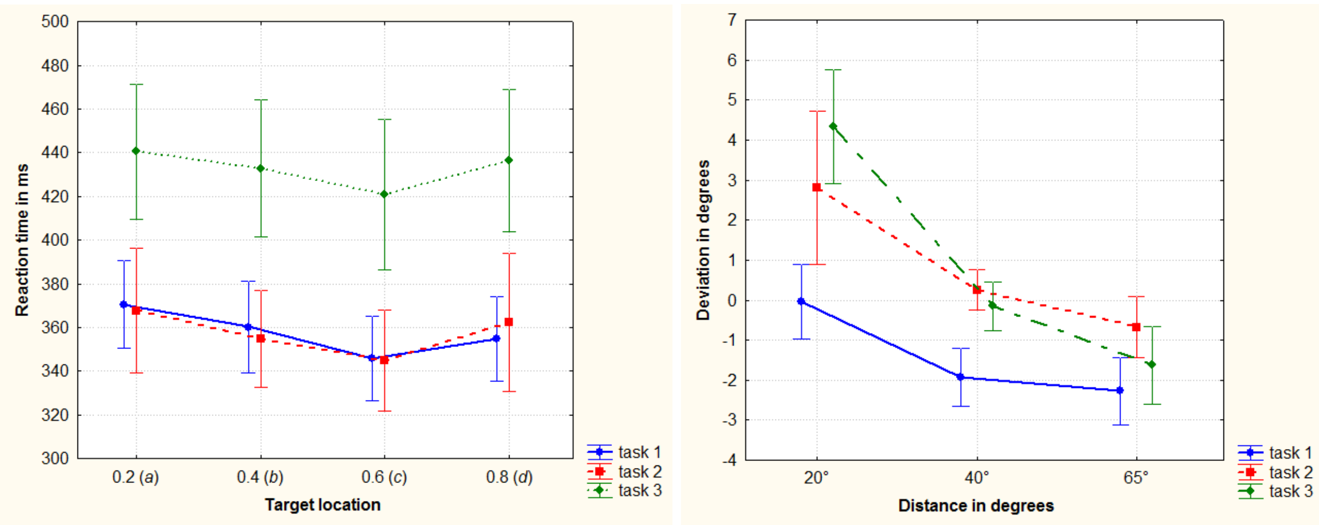


Figure 12. *Left:* Mean reaction time (ms) for each of the four target locations, for each of the three experiments (see legend in bottom-right corner). *Right:* Mean angular deviation for the three distance conditions, for each of the three experiments (see legend in bottom-right corner). All deviation values are calculated relative to baseline conditions. Error bars represent CI95.

may produce the pattern seen in figure 12 (left panel), with *a* being the furthest away and having the highest latency, and *c* being the closest and having the smallest latency (see also *fig*. 11).

The influence of the distracter was not seen in the reaction times. This was rather unexpected, as the distracter clearly influenced deviation behaviour. One possible explanation for this is the lack of control for swift movements to the target upon presentation of the target and distracter boxes. Previous research has emphasised the need for speeded movement in producing distracter interference effects (Tipper, Howard & Jackson, 1997). While subjects were indeed instructed to make their movements as fast and as accurate as possible, observation showed that participants tended to perform the experiment at their own pace. This may have contributed to the apparent lack of influence of the distracter.

As is evident from the graph in figure 12 (left panel), absolute reaction times were similar for the first and second experiment, while latencies for the third experiment were on average some 80 ms longer. The longer reaction times in task 3 may have been related to increased variability of the target onset. In the first two tasks, target and distracter reliably appeared exactly one second after positioning the cursor in the starting box. In the third task, target onset could be after 1 second for uncued trials, after 1 second and 150 ms for short cue trials, or after 2 full seconds for long cue trials. It is possible that the regularity of target onsets in the first two experiments enabled participants to respond more quickly over time through subconscious internalisation of the task rhythm. Furthermore, the cueing led to an increase in false starts, which could have made participants more cautious. Instead of making a movement as soon as the trial started, they might be inclined to wait to see if the presented element is really the target or just a cue.

Initial deviation

The results for the initial deviations show that angular distance between target and distracter reliably influences the amount of deviation towards or away from the distracter. Shorter distances (20°) in the last two experiments produced significantly more deviation towards the distracter than the longer distance conditions (40° and 65°). Longer distance, in contrast, produced more deviation away from the distracter than shorter distances (20° and 40°). The same pattern could be observed in the first experiment, although deviation for all distance conditions curved away and only the difference between the shortest and two longest conditions was significant. Figure 12 (right panel) illustrates this – the graphs for all three experiments follow the same pattern, but the graph for the first experiment is translated downwards.

The finding that distracters closer to the hand (and/or a straight path to the target) generate relatively more attraction than distracters further removed from it could be due to the amount of attention allocated to the location of the distracter. Shortening angular distance between target and distracter may increase attraction at the distracter location, and so may placing the distracter closer to the hand, as can be observed in the difference between experiment 1 and 2. Together with the top-down intent to avoid the distracter, a similar relationship may be found here as is seen with saccades:

increased allocation of attention to the distracter leads to deviation towards, while sufficient inhibition leads to deviation away. This would indicate a parallel with Tipper and colleagues' population vector coding theory (Tipper, Howard & Jackson, 1997; Tipper, Howard & Houghton, 2000). An alternative explanation that cannot be ruled out is that the intended goal location of the hand simply follows the location that is presently foveated.

In the first experiment, the interaction effect of distance and target location was primarily produced for the leftmost (*a*) location (*fig*. 1). In the other two experiments, however, this interaction was not significant. If the effect was not due to some peculiarity of the first experiment or its subjects, this interaction may be explained by the idea that the hand movement towards that location is probably the most difficult or unnatural movement to make for a right-handed person, as compared to the other target locations (see also *fig*. 11). For this reason, it might be especially easy to influence these movements, as they may be less fixed and automated than the more everyday movements that can be made to reach the other target locations.

The results regarding the influence of cues on initial hand deviations may be somewhat puzzling at first glance. Uncued trials and trials preceded by a long cue appeared to produce an equal amount of deviation towards the distracter, while trials with a short cue showed no deviation on average. A possible explanation for this finding may be found in the temporal dynamics of exogenous cueing, which include a facilitating effect on visual processing for short latencies and an inhibiting effect (inhibition of return; IOR) for longer latencies (Posner and Cohen, 1984; Klein, 2000). Taking into account the cue-target onset asynchronies for the short (150 ms) and long (1000 ms) cues, Facilitation of visual processing in the short cue condition may contribute to increased distracter activity, which should result in either deviation towards for incomplete inhibition of the distracter, or increased deviation away for complete inhibition. Recall that as distracter activity increases, more inhibition needs to be applied for successful suppression (Van der Stigchel, 2010).

For the longer cues, the mechanism of IOR may be involved. For saccades, IOR becomes optimal after a delay of about 800 milliseconds and appears to have a domain-unspecific component that may be involved in hand movements as well (Klein, 2000; Godijn & Theeuwes, 2004). IOR could explain why long cue trials did not differ from uncued trials. Assuming IOR and more short-acting inhibition have different underlying processes (Klein, 2000; Godijn & Theeuwes, 2004), IOR may decrease the need for the other inhibitory process, effectively decreasing distracter activity.

While it may seem strange that the short cue trials produced hardly any deviation from baseline conditions while the other two cue conditions resulted in deviation towards, the above speculation does hold in terms of relative deviation to each other. The reason that deviation towards is observed rather than deviation away (corresponding to a vertical translation of the graph), may have to do with the idiosyncrasies of the motor domains of hand and eye (see *e.g.* Van der Stigchel, Meeter & Theeuwes, 2007b). Future research is encouraged to further examine the differences between these action domains, such that comparisons with the extensive literature on saccade behaviour can be more easily made.

Concluding remarks

The present study was the first to investigate whether behavioural aspects of attention as found in saccade research may also be seen in stylus-based hand movements, which can be considered an analogue of pointing (reaching) movements. The rationale behind using stylus-based hand movements on a tablet computer was that such devices, equipped with appropriate applications, may make excellent diagnostic tools in a clinical setting due to their ease of use and mobility. The most prominent result to emerge from this pilot study is that the angular distance between target and distracter appears to determine the relative direction of deviation, with short distances leading to relative deviation towards and long distances to relative deviation away. Decreasing the distance between the distracter and the hand's starting position also led to relative attraction. The explanation proposed for this finding is that distracters that are spatially close to the target or hand (or perhaps the complete intended hand trajectory) attract more attention than distracters positioned further away from it. Assuming parallels with the population vector coding theory (Tipper, Howard & Jackson, 1997; Tipper, Howard & Houghton, 2000) and viewed from an action-based perspective centred on the hand (Tipper, Howard & Paul, 2001), the pattern emerging from the data can be likened to that observed in saccade research. Bottom-up salience maps (*fig*. 11) and top-down inhibition interact to produce effective target selection, where incomplete inhibition of distracters leads to deviation towards the distracter and sufficient inhibition to deviation away from it.

However, before any straightforward comparisons can be made, the differences inherent to the action systems of the eye and hand require further elucidation. The present study was but a small-scale pilot into the behavioural aspects of attention with regard to stylus-based movements, and many limitations characterised the design and execution. Firstly, only behaviour at the early part of the movement was considered, leaving the full trajectories and landing points beyond the scope of this study. Secondly, participants were not representative of the general population, nor were they subjected to any pretesting or practice before participating in the experiment. Their position and posture were not standardized or corrected for during the experiment. Furthermore, the distance between target and distracter and hand and distracter was manipulated according to different measures of distance (angular and linear, respectively). While the difference may not appear significant on this scale, depending on how the elements are represented in the mind this may be of influence. It is hoped that future research will be able to address these limitations, such that the complex interplay between attention, eye, and hand movements may be quantified for use in the development of diagnostic and augmentative tools.

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