University of Groningen

Touchscreen Pointing and Swiping

Olthuis, Raimey; van der Kamp, John; Lemmink, Koen; Caljouw, Simone

Published in:
Motor Control

DOI:
10.1123/mc.2019-0096

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2020

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Olthuis, R., van der Kamp, J., Lemmink, K., & Caljouw, S. (2020). Touchscreen Pointing and Swiping: The Effect of Background Cues and Target Visibility. *Motor Control*, *24*(3), 422-434. https://doi.org/10.1123/mc.2019-0096

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 05-06-2022

***Motor Control*, (Ahead of Print)**
https://doi.org/10.1123/mc.2019-0096

Human Kinetics
ARTICLE

Touchscreen Pointing and Swiping: The Effect of Background Cues and Target Visibility

Raimey Olthuis
University of Groningen

John van der Kamp
Vrije Universiteit Amsterdam

Koen Lemmink and Simone Caljouw
University of Groningen

By assessing the precision of gestural interactions with touchscreen targets, the authors investigate how the type of gesture, target location, and scene visibility impact movement endpoints. Participants made visually and memory-guided pointing and swiping gestures with a stylus to targets located in a semicircle. Specific differences in aiming errors were identified between swiping and pointing. In particular, participants overshot the target more when swiping than when pointing and swiping endpoints showed a stronger bias toward the oblique than pointing gestures. As expected, the authors also found specific differences between conditions with and without delays. Overall, the authors observed an influence on movement execution from each of the three parameters studied and uncovered that the information used to guide movement appears to be gesture specific.

***Keywords*:** action, allocentric, egocentric, goal-directed movement, perception, sensorimotor, touch gestures, touchscreen usability, visual information

Spatial abilities are integral to everyday life, affording us the capability to navigate through and interact with our environment and the objects within it. Accordingly, human perception–action has become a topic of interest to researchers in the field of human movement sciences. Pointing tasks are commonly used for studies aimed at understanding how human information–movement couplings facilitate our interactions with the physical world around us (Obhi & Goodale, 2005; see also Culham & Valyear, 2006). The rapidly growing usage of smart phones and tablets brought on by the technology revolution has also made gestures

---

Olthuis, Lemmink, and Caljouw are with the Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands. van der Kamp is with the Department of Human Movement Sciences, Faculty of Behavioral and Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands. Olthuis (r.a.olthuis@umcg.nl) is corresponding author.

that were once aberrant or even strange, such as swiping, commonplace. However, although swiping has become one of the most standard human gestures, research on it is still minimal, especially in comparison with pointing (see, Greenstein & Arnaut, 1988; Milner & Goodale, 2006). In this study, we compare goal-directed pointing and swiping movements on a touchscreen.

The notion of the ventral and dorsal dissociable visual systems (Milner & Goodale, 2006) strongly promoted studies that explored visuomotor aiming functions. Ample evidence supports that immediate pointing movements rely on egocentric (self-to-object) information whereas imposing a delay between presenting the target and moving toward it increases the reliance on allocentric (object-to-object) information. As a result, movement kinematics become contingent upon the visual environment of the target (Bridgeman, Peery, & Anand, 1997; Hay & Redon, 2006; Obhi & Goodale, 2005). This influence has been illustrated by Rossetti (1998) where subjects pointed to targets positioned along an arc surrounding the starting location with a delay between 0 and 8 s. Results revealed that the distributions of endpoints at the shortest delays were aligned with the movement direction and that the effect of the target context became apparent at larger delays (see Figure 1). Most likely, navigation does not rely entirely on either egocentric or

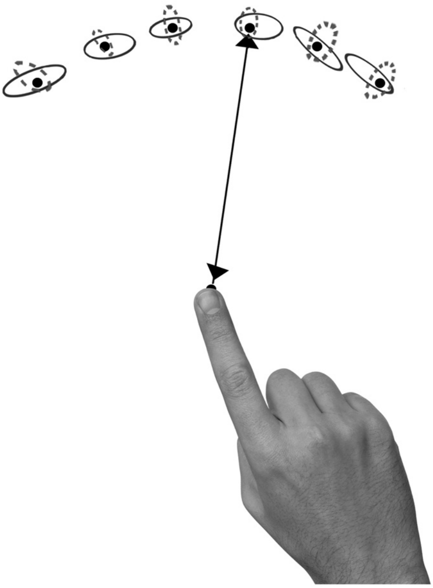

Figure 1 — The confidence ellipses of the pointing scatter endpoints obtained for each target in the 0 s (dashed) and 8 s delay condition (solid). Egocentric localization is indicated when the targeted endpoints are independent of the surrounding visual objects and aligned with movement direction (dashed). In contrast, allocentric localization is indicated by distortions in the direction of other contextual elements within the scene (solid). Adapted from "Implicit short-lived motor representations of space in brain damaged and healthy subjects," by Rossetti, 1998, *Consciousness and Cognition, 7*(3), p. 546.

allocentric information, but rather consists of a combination of each—with the possibility of relative contributions of each lying anywhere along a continuum between the two, depending on the task constraints. Error endpoint distributions typically have an elliptical shape with the orientation of the long (primary) axis indicating the primary direction of error. A primary axis aligned with the movement direction indicates a higher reliance on egocentric information, whereas a primary axis in the target direction infers a higher reliance on allocentric information. The more oblong the ellipse, the greater the disparity between information sources. While the primary information relied on to guide movement can be inferred by the alignment of the endpoint distributions, fluctuations in the shape/alignment of ellipses indicate changes in the relative contributions of allocentric and egocentric information.

Evidence that actions based on visual memory tend to rely more heavily on allocentric information has primarily been evidenced in laboratory studies using active marker motion capture systems to track reaching/grasping and pointing movements (Krigolson, Clark, Heath, & Binsted, 2007; Krigolson & Heath, 2004; Obhi & Goodale, 2005; Westwood, Heath, & Roy, 2000). However, despite the proliferation of touchscreen technology and usage, it is currently unknown if similar localization trends are found for different types of gestures (pointing vs. swiping) on touchscreens. The aim of our study is to extend existing findings on egocentric and allocentric reliance during movement execution to how we locate and move toward targets and objects on touchscreen devices using common interactive gestures. In our study, participants used a stylus to make single, uncorrected pointing and swiping movements on a touchscreen as quickly and accurately as possible to targets located in one of six possible positions displayed in a semicircle on the screen. It is expected that pointing will result in more accurate and precise selections than swiping (Inkpen, Booth, & Klawe, 1996; Kabbash, MacKenzie, & Buxton, 1993; MacKenzie, Sellen, & Buxton, 1991). In line with the previous experiment described by Rossetti, we also hypothesize that delayed gestures will be less accurate and more strongly influenced by the spatial layout of the targets (allocentric influence) than the immediate gestures. Increasing inaccuracies are found when locating objects on noncardinal or “oblique” orientations (oblique effect; Appelle, 1972), movement endpoints of actions directed to these targets tend to cluster toward the nearest 45'-oblique direction between the cardinal axes (Yakimoff, Lansky, Mitrani, & Radil, 1989). Thus, given our experimental setup, within each hemifield, we expect higher endpoint variability with an overall central tendency bias when aiming toward the medial and lateral targets. Meanwhile, movements toward the middle targets should be more precise and accurate, as this target position is closely aligned with the diagonal axis of its quadrant. Furthermore, in line with research suggesting a higher immunity to contextual elements (i.e., pictorial illusion configurations) presented in the right visual hemifield compared with the left visual hemifield (Gentilucci, Daprati, Gangitano, & Toni, 1997; cf. van der Kamp, De Wit, & Masters, 2012), we expect that, especially for the memory-guided movements, the ratio of variable error in the allocentric to egocentric direction will be larger for movements made to targets located on the left (contralateral) side of the screen compared with movements to targets located on the right (ipsilateral) side of the screen. In this study, we add to the existing literature by exploring if the previously reported contextual reliances are apparent in movements on touchscreens and if these movement errors are at least partially dependent on the type of movement gesture.

Methods

Participants

Twelve participants (six females and six males, $M_{\text{age}} = 26.25$ years, age range: 20–41 years) completed the study. A power analysis application (G*Power, version 3.1.9.4; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany [http://www.gpower.hhu.de/]) was used to calculate the a priori sample size sufficient to detect differences using an *F* test (analysis of variance [ANOVA]) within-factors design. For a moderate effect size ($f^2 > 0.25$) and with alpha level set at .05 ($\alpha = .05$), a sample size of 12 was indicated as large enough to provide statistical significance with 95% power (1–β). All participants were right-handed, and all used touchscreen devices on a daily basis (by self-report). All had normal or corrected-to-normal vision and no known history of visual or neuromuscular deficits. All participants were in good health and functionally able to complete the task without fatigue. Participants received no financial compensation for participating in the experiment. Approval from the local ethics committee was granted, and a written informed consent from each participant was acquired after explanation of the task and experimental procedures, in accordance with the guidelines of the local ethics committee.

Apparatus and Task

A fourth-generation tablet (Apple Inc., Cupertino, CA) with retina display (2,048 × 1,536 pixel resolution and 264 ppi) with brightness at 100% was used for this study. The device screen is a 9.7-in. (diagonal) LED-backlit Multi-Touch display with In-Plane Switching technology. The stylus used was an Adonit Jot Pro V3 (Adonit, Austin, TX; Taipei, Taiwan). A custom application that logged all interactions of the stylus with the screen was used for this study. We chose to use a stylus rather than a finger, as we are reporting on movement accuracies and earlier research on pointing, particularly with small targets, shows that movements with styli are more accurate than fingers (Cockburn, Ahlström, & Gutwin, 2012; Lee & Zhai, 2009), the overall pixel accuracy was 0.5. Furthermore, as finger size has been found to affect the reliability of a touch input (Kurosu, 2017), and given the small size of our targets, using a stylus provided more consistent results, but still allowed to compare different kind of arm movements. The full movements were recorded for the swiping conditions with a tracking frequency of 60 Hz, whereas the start and endpoints were recorded for the pointing tasks.

Participants moved the stylus from a home position to one of six possible targets presented on the tablet screen. Specifically, participants held the stylus, like a pen, between their thumb and index finger and moved it on the tablet. The tablet was positioned horizontally and centered in front of them on a table that was approximately 76.2 cm high. The participants were seated comfortably in a chair with their feet touching the ground and their arms were able to move comfortably in all actions required on the tablet.

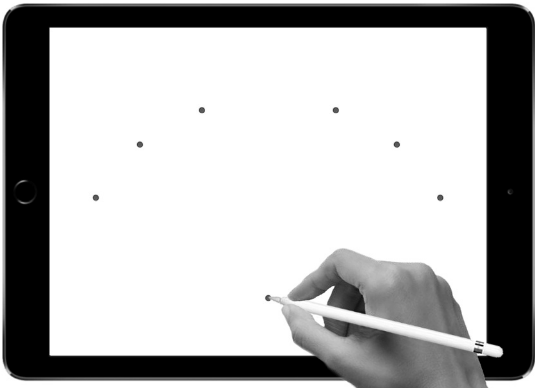

Figure 2 — Complete array, home position (bottom center), and six targets.

When oriented horizontally, the top-left corner of the tablet is the origin (i.e., 0, 0 pixel). In each condition, the start screen showed only the fixed home zone (circle outlined in gray on a white background) in the bottom center of the screen (512, 643 pixel). Once the stylus touched the screen within the home zone, an array of six targets (gray circles) appeared in a semicircle arc (lateral left, middle left, medial left, medial right, middle right, and lateral right) around the home position (Figure 2). The home zone and targets were 3.07 mm in diameter. Each target was equidistance (91 mm) from the home position. After 1.5 s, one of the targets changed color to solid red indicating it as the active target. After appearing active (red) for 500 ms, the entire array (all six targets) disappeared. In the no-delay condition, an audio stimulus ("go signal") sounded simultaneously with visual removal of the targets. In the delay condition, the auditory stimuli occurred 5 s after the offset of the visual presentation. Trials were registered as incomplete if the point or swipe endpoint was >90% of the intertarget distance (>28.5 mm) away from the active target, or if the stylus was lifted off the home position before the auditory start stimulus. In trials with the aforementioned violations, an auditory signal indicated the error, and the trial was aborted.

Procedure and Design

Participants were instructed to place the stylus in the home zone when they were ready to start. They were then told to watch for the red target cue, but to keep the stylus steadily placed in the home zone until the auditory stimuli sounded. Once they heard the tone, they had to move as quickly and accurately as possible to the (remembered) target location in a single, uncorrected movement. If the participants missed the visual cue, they were instructed to tap down (pointing condition) or lift off (swiping condition) the screen just outside of the home area, so the trial would be recorded as a technical error. In the pointing conditions, the participants were told to lift the stylus off the home position and touch down the stylus as near to the remembered target as possible, whereas in the swiping conditions, they were told to keep the stylus in contact with the screen and drag it to the target location, removing contact with the screen only at the (remembered) target location.

The task fitted in a single session of approximately 1 hr. Participants completed four blocks of trials: pointing no-delay, pointing delay, swiping no-delay, and swiping delay. To control for order effects, these four blocks were counterbalanced between participants by means of a balanced Latin Square design. The logic behind presenting the conditions in blocks is that it reduces the risk of carryover effects that can occur in fully randomized setups, thus is more effective in isolating the full effects brought on by each condition. Prior to each experimental block, a familiarization period was performed with the participant completing 12 target practice sessions, with two trials presented randomly to each of the six targets. During the experimental session, each condition was presented within a block. The presentation of the targets within each block was randomized for every set of 60 trials (i.e., for every 60 trials each target would be randomly selected 10 times). In all, within each block (each condition), 30 trials were presented per target, per participant. This led to a total of 180 trials per participant, per condition and 720 trials overall per participant.

Data Collection and Analysis

Before statistically analyzing the means of the dependent variables, technical errors and outliers were excluded. Technical errors were defined as trials where the tablet failed to save the endpoint, or where the distance of the registered endpoint was larger than 90% of the intertarget distance (i.e., 28.5 mm). This may have occurred if the stylus lost contact with the touchscreen during the swipe, if the movement was initiated before the go signal, or if a trial was aborted or aimed at the wrong target. In total, 361 out of 8,640 trials were classified as technical errors and removed from further analysis; three were due to unsaved endpoints and 358 because of participant error. A further 122 trials were classified as outliers because the endpoint was more than three *SD*s away from the mean. Therefore, of the intended 180 trials per person per condition, there was a minimum of 142 trials and a maximum of 177 with an average of 170 trials per condition per participant.

The selection location was defined as the x and y coordinates registered when the stylus touched back down on the screen for the pointing gestures, and as the position of the stylus on the screen immediately before the stylus was lifted from the touchscreen for swiping gestures. Several parameters were calculated. The vector from the active target to the selection location can be expressed in a radial component on the ideal line connecting the start location with the target location (d-ego) and a lateral component perpendicular to this ideal line (d-allo). A positive value of d-ego indicates target overshooting and a positive value of d-allo indicates a deviation toward the more medial targets. We assessed constant error and variable error as well as the ratio of d-allo to d-ego variable error in each condition. As constant error refers to the difference between the mean endpoint locations and the actual target location, this was used to determine whether movements showed a bias. On the other hand, as variable errors indicate the spread of individual responses around the mean action endpoints, the spread in d-allo to d-ego was used to infer the relative influence of target context (i.e., allocentric information) on the fluctuations in the endpoint locations across conditions.

A 3 (Target: lateral, middle, and medial) by 2 (Side: left and right) by 2 (Type: swipe and point) by 2 (Delay: delay and no delay) ANOVA with repeated measures was conducted on each of the measures, and all were subjected to Mauchly's test for sphericity. Whenever the Mauchly's sphericity assumption was violated, the ANOVA results were adjusted using the Huynh–Feldt adjustment for nonsphericity. For post hoc tests on interactions with targets, we performed multiple ANOVAs with target as the repeated measures. Paired *t* tests, with a Bonferroni adjustment of the α level, were used for all other post hoc comparisons.

Results

Egocentric and Allocentric Constant Error

The ANOVA on the constant error in the movement direction (i.e., d-ego) revealed a significant main effect of type, $F(1, 11) = 9.28$, $p = .011$, $\eta_p^2 = .57$, delay, $F(1, 11) = 8.42$, $p < .05$, $\eta_p^2 = .43$, and target, $F(2, 22) = 7.77$, $p \leq .01$, $\eta_p^2 = .41$. An interaction effect of Target × Delay, $F(2, 22) = 4.85$, $p = .018$, $\eta_p^2 = .31$, was also found. No other main or interaction effects were revealed. Participants tended to overshoot all targets, and this error in the movement direction was significantly larger for swiping ($M = .35$ mm and $SD = .21$ mm) than for pointing ($M = .17$ mm and $SD = .12$ mm). The positive error in the movement direction was also larger for trials with a delay ($M = .30$ mm and $SD = .17$ mm) compared with trials without a delay ($M = .21$ mm and $SD = .12$ mm; Figure 3a). As illustrated in Figure 3a, the overshoot for movements gradually increased as the target moved from the lateral to the medial position, particularly in conditions with delay. Subsequent tests confirm significant location-specific distortions in the delay condition, $F(2, 22) = 6.60$, $p = .006$, $\eta_p^2 = .38$, but not in the no-delay condition, $F(2, 22) = 3.91$, $p = .06$, $\eta_p^2 = .26$.

The ANOVA on the constant error in the direction of the other visual targets in the scene (i.e., d-allo) revealed a significant main effect of Side, $F(1, 11) = 5.00$, $p < .05$, $\eta_p^2 = .31$, and interaction effects of Target × Type, $F(2, 22) = 4.70$, $p < .05$, $\eta_p^2 = .001$, Target × Delay, $F(2, 22) = 4.89$, $p < .05$, $\eta_p^2 = .31$, and Side × Delay, $F(1, 11) = 5.00$, $p < .05$, $\eta_p^2 = .31$. No other main effects or interaction effects were

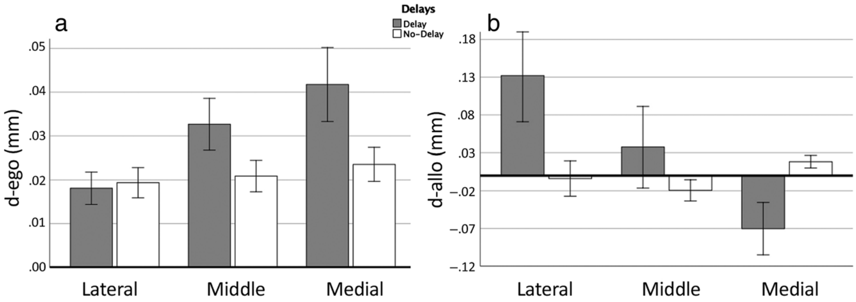

Figure 3 — Mean constant error and *SE* in the movement direction (d-ego) (a) and in the target direction (d-allo) (b) in the delay and no-delay conditions for the three targets.

revealed. Figure 3b depicts the Target × Delay effect and reveals, for the delay condition, a medial bias (positive constant error) when aiming to the lateral targets and a lateral bias (negative constant error) when aiming to the medial targets. The subsequent ANOVAs demonstrated this target effect to be significant for the delay condition, $F(2, 22) = 4.00$, $p = .03$, $\eta_p^2 = .26$. Conversely, a target effect in the no-delay condition was not found, $F(2, 22) = 2.17$, $p = .14$, $\eta_p^2 = .17$. Figure 4 depicts the Target × Type effect and reveals, within the swiping condition, a similar target bias toward the oblique. Indeed, subsequent post hoc ANOVAs showed that the target effect was significant for swiping, $F(2, 22) = 6.00$, $p < .01$, $\eta_p^2 = .35$, but not for pointing, $F(2, 22) = .49$, $p = .62$, $\eta_p^2 = .042$. Figure 5 presents the Side × Delay interaction effect, post hoc tests confirmed that in the presence of the delay allocentric constant errors were larger for movements directed to the right side than when aiming to the left side, with no differences between sides in the no-delay condition.

Ratio of Variable Error in the Allocentric to Egocentric Direction

The ANOVA revealed a significant main effect of side, $F(1, 11) = 6.17$, $p = .03$, $\eta_p^2 = .36$, and delay, $F(1, 11) = 32.73$, $p = 0$, $\eta_p^2 = .75$. There were no other main and interaction effects; however, the target effect was nearly significant with high effect size, $F(2, 22) = 3.38$, $p = .052$, $\eta_p^2 = .58$. A higher proportion of allocentric to egocentric variance in error was found in movements directed to targets on the left side ($M = 1.02$ and $SD = .10$) when compared with targets on the right side ($M = .91$ and $SD = .17$). As expected, the ratio of allocentric to egocentric variance in error increased in the delay condition ($M = .1.09$ and $SD = .16$) compared with the no-delay condition ($M = .83$ and $SD = .12$). This indicates that in the presence of a delay the reliance on allocentric information is higher than for the same movements without a delay.

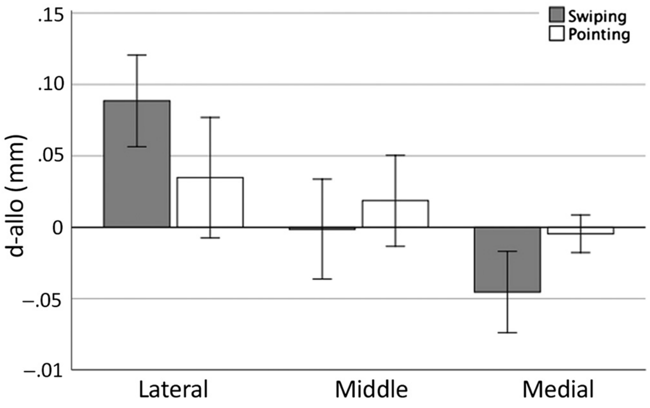

Figure 4 — Mean constant error and *SE* in the target direction (d-allo) in the swiping and pointing conditions for the three targets.

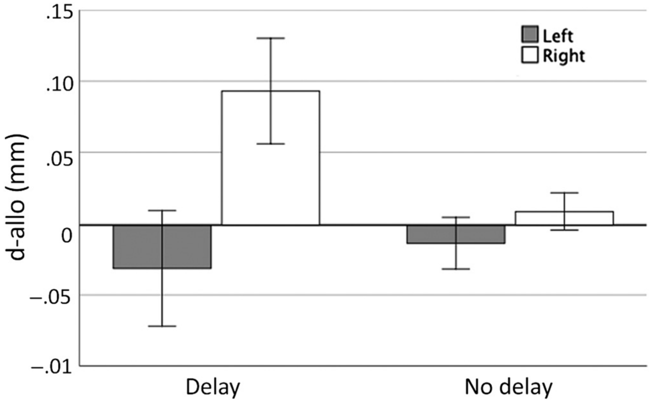

Figure 5 — Mean constant error and *SE* in the target direction (d-allo) for the left and right sides in the delay and no-delay conditions.

Discussion

This study assessed performance differences in target-directed aiming movements between swiping and pointing gestures on a touchscreen with multiple objects. We also compared visually guided and memory-guided movements. To accomplish this, participants used a stylus on a touchscreen, and made single, uncorrected movements as quickly and accurately as possible to targets located in one of six possible positions displayed in a semicircle on the screen. Based on proposals by Goodale and Milner (1992) and Milner and Goodale (2006), we investigated whether the visuomotor system makes more use of allocentric information for memory-guided actions than when vision of the scene is available, and if this reliance is consistent between different types of gestures when using a touchscreen.

Previous studies on constant errors in 2D pointing to targets from a common start location revealed a combination of two types of effects. These include a tendency to undershoot targets (Diedrichsen, Werner, Schmidt, & Trommershäuser, 2004), and an affinity of the movement endpoints to err toward the diagonal of the quadrants containing the targets (oblique effect; Smyrnis, Mantas, & Evdokimidis, 2007)—both effects increase with the introduction of a temporal delay. We did not observe a tendency to undershoot the target; on the contrary, we found an overall tendency to overshoot the target. Interestingly, however, we did find significant differences in the pattern of constant errors between the gestures. Specifically, swiping gestures had a larger overshooting bias than pointing gestures. It is possible that the general tendency to overshoot when swiping is peculiar to our task setup where any early unintentional loss of contact with the screen terminated the trial. However, target overshooting when sliding across a touchpad is also previously reported by Kabbash et al. (1993), which they attributed to the inability to quickly slow down toward the end of the movement. It is also possible that the pattern of errors does not result primarily from mechanical differences. For example, swiping actions require continuous contact with the surface during movement execution, which could influence changes in the control of movements compared with pointing. Further research incorporating different amounts of tactile feedback, such as comparing stylus and finger swiping gestures can further elucidate the influence of tactile information on movement control. Given that our memory-guided trials were accompanied by an increase in systematic error, the overshooting identified in our study is probably more closely related to factors arising within the perceptual component of the task than from mechanical differences. Similar to delayed actions, the overshoot observed in swiping may therefore tentatively suggest that swiping actions also evoke an increased offline mode of control, with planning mechanisms contributing more heavily to swiping than pointing actions. The oblique effect is reported for spatial localization tasks after a delay, where categorization is believed to facilitate the localization of targets in memory-guided movements. In accordance, we observe an oblique effect in the delay condition. Interestingly, we also observed a stronger oblique effect for swiping compared with pointing. This tendency for participants to seemingly underestimate the distance between the target and quadrant diagonal, resulting in errors toward the quadrant diagonal, is aligned with earlier research (Gourtzelidis, Smyrnis, Evdokimidis, & Balogh, 2001). Although the oblique effect may be the result of participants conceptually categorizing the scene into quadrants, it is also possible that the corners of the rectangular tablet used in our study facilitated this diagonal influence and thereby inadvertently influenced the remembered location of the target in this direction. Overall, this suggests, in correspondence with the two visual systems theory, an increased reliance on contextual information for memory guided compared with visually guided movements and also for swiping compared with pointing gestures. Further research is required to determine if this shared characteristic between delayed actions and swiping movements infers that swiping actions are mediated primarily offline. The two visual systems theory postulates that different types of visual information are relevant for visually guided and memory-guided movements (Goodale & Milner, 1992; Milner & Goodale, 2006). Egocentric information (information related to an objects spatial location relative to the performer) is thought to dominate visually guided movements, whereas allocentric information (related to an objects position relative to the other objects) is more heavily relied upon when a temporal delay is present between appearance of a target and the subsequent motor response (Carlton, 1981, 1992; Chua & Elliott, 1993; Heath & Westwood, 2003; Thaler & Goodale, 2011; for review see Elliott, Helsen, & Chua, 2001). In line, it was expected that the introduction of a delay would result in a larger proportion of error in the direction of the other targets (allocentric error) compared with the error in the movement direction (egocentric error; Rossetti, 1998). A higher ratio of allocentric to egocentric variable error was indeed found in the delay condition compared with the no-delay condition. This dispersion of error indicates that over time the relative reliance on allocentric information increases and synchronously the dependence on egocentric information decays.

When aiming movements are made to mirror symmetrically distributed targets in the right and left visual fields we expect, especially for the memory guided movements, a higher immunity to contextual biases when targets are presented in the right visual field compared with the left visual field (Gentilucci et al., 1997). As anticipated, this effect was found as indicated by a higher ratio of allocentric to egocentric variable error for movements made to targets located on the left (contralateral) side of the screen compared with movements to targets located on the right (ipsilateral) side of the screen. Thus, the reliance on allocentric information is seemingly higher in movements directed to targets located in the left visual field than when the same movement is performed for targets in the right visual field, at least for right-handed performers. Seemingly, targets on the left side were more highly influenced by the nearest landmarks than targets on the right side. One explanation for this side effect may be due to the right hemispheric posterior parietal involvement when utilizing allocentric information, as noted in studies using functional magnetic resonance imaging to compare the neural foundations for primarily egocentric and allocentric tasks (Galati et al., 2000; Zaehle et al., 2007).

In conclusion, we were able to identify specific differences in the aiming errors between swiping and pointing gestures. In particular, we found that in goal-directed actions when swiping on touchscreens participants tended to overshoot the target more than when pointing and that swiping endpoints demonstrated a stronger oblique effect than pointing gestures. As expected, we also found specific differences between conditions with and without delays. Interestingly, the effects noted in the swiping actions were also apparent in the delayed conditions where a larger tendency to overshoot targets and tendency to bias actions toward the oblique of the quadrant were observed. A higher ratio of allocentric to egocentric variable error compared with the no-delay conditions was also noted. There was also a higher ratio of allocentric to egocentric variance in movements directed to targets on the left side compared with movements to the right. Overall, our findings on egocentric and allocentric localization during motion on touchscreens supports existing literature for pointing movements and adds that movement error is at least partially dependent on the type of movement gesture, whether or not the target is visible immediately before the movement, and the placement of the other potential targets within the entire scene.

References

Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation: The “oblique effect” in man and animals. *Psychological Bulletin, 78*(4), 266. PubMed ID: 4562947 doi:10.1037/h0033117

Bridgeman, B., Peery, S., & Anand, S. (1997). Interaction of cognitive and sensorimotor maps of visual space. *Perception & Psychophysics, 59*(3), 456–469. PubMed ID: 9136275 doi:10.3758/BF03211912

Carlton, L.G. (1981). Visual information: The control of aiming movements. *The Quarterly Journal of Experimental Psychology Section A, 33*(1), 87–93. doi:10.1080/14640748108400771

Carlton, L.G. (1992). Visual processing time and the control of movement. In L. Proteau& D.E. Elliott (Eds.), *Vision and motor control* (pp. 3–31). Amsterdam: Elsevier Science. doi:10.1016/S0166-4115(08)62008-7

Chua, R., & Elliott, D. (1993). Visual regulation of manual aiming. *Human Movement Science, 12*(4), 365–401. doi:10.1016/0167-9457(93)90026-L

Cockburn, A., Ahlström, D., & Gutwin, C. (2012). Understanding performance in touch selections: Tap, drag and radial pointing drag with finger, stylus and mouse. *International Journal of Human Computer Studies, 70*(3):218–233. doi:10.1016/j.ijhcs.2011.11.002

Culham, J.C., & Valyear, K.F. (2006). Human parietal cortex in action. *Current Opinion in Neurobiology, 16*(2), 205–212. PubMed ID: 16563735 doi:10.1016/j.conb.2006.03.005

Diedrichsen, J., Werner, S., Schmidt, T., & Trommershäuser, J. (2004). Immediate spatial distortions of pointing movements induced by visual landmarks. *Perception & Psychophysics, 66*(1), 89–103. PubMed ID: 15095943 doi:10.3758/BF03194864

Elliott, D., Helsen, W.F., & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin, 127*(3), 342–357. PubMed ID: 11393300 doi:10.1037/0033-2909.127.3.342

Galati, G., Lobel, E., Vallar, G., Berthoz, A., Pizzamiglio, L., & Le Bihan, D. (2000). The neural basis of egocentric and allocentric coding of space in humans: A functional magnetic resonance study. *Experimental Brain Research, 133*(2), 156–164. PubMed ID: 10968216 doi:10.1007/s002210000375

Gentilucci, M., Daprati, E., Gangitano, M., & Toni, I. (1997). Eye position tunes the contribution of allocentric and egocentric information to target localization in human goal-directed arm movements. *Neuroscience Letters, 222*(2), 123–126. PubMed ID: 9111744 doi:10.1016/S0304-3940(97)13366-3

Goodale, M.A., & Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20–25. PubMed ID: 1374953 doi:10.1016/0166-2236(92)90344-8

Gourtzelidis, P., Smyrnis, N., Evdokimidis, I., & Balogh, A. (2001). Systematic errors of planar arm movements provide evidence for space categorization effects and interaction of multiple frames of reference. *Experimental Brain Research, 139*(1), 59–69. PubMed ID: 11482844 doi:10.1007/s002210100767

Greenstein, J.S., & Arnaut, L.Y. (1988). Input devices. In M. Halander (Ed.), *Handbook of human-computer interaction* (pp. 495–519). Amsterdam: Elsevier.

Hay, L., & Redon, C. (2006). Response delay and spatial representation in pointing movements. *Neuroscience Letters, 408*(3), 194–198. PubMed ID: 17027153. doi:10.1016/j.neulet.2006.08.080

Heath, M., & Westwood, D.A. (2003). Can a visual representation support the online control of memory-dependent reaching? Evidence from a variable spatial mapping paradigm. *Motor Control, 7*(4), 349–365. doi:10.1123/mcj.7.4.349

Inkpen, K., Booth, K.S., & Klawe, M. (1996). *Interaction styles for educational computer environments: A comparison of drag-and-drop vs. point-and-click* (Technical report 96(20)). Vancouver, BC: Department of Computer Science, University of British Columbia.

Kabbash, P., MacKenzie, I.S., & Buxton, W. (1993). Human performance using computer input devices in the preferred and non-preferred hands. In *Proceedings of the SIGCHI conference on human factors in computing systems—CHI '93* (pp. 474–481). New York, NY: ACM Press. doi:10.1145/169059.169414

Krigolson, O., Clark, N., Heath, M., & Binsted, G. (2007). The proximity of visual landmarks impacts reaching performance. *Spatial Vision, 20*(4), 317–336. PubMed ID: 17594798 doi:10.1163/156856807780919028

Krigolson, O., & Heath, M. (2004). Background visual cues and memory-guided reaching. *Human Movement Science, 23*(6), 861–877. PubMed ID: 15664677 doi:10.1016/j.humov.2004.10.011

Kurosu, M. (2017). *Human-computer interaction: Interaction contexts: 19th International Conference, HCI International 2017, Vancouver, BC, Canada, July 9–14, 2017, Proceedings. Part II*. Cham, Switzerland: Springer.

Lee, S., & Zhai, S. (2009, April). *The performance of touch screen soft buttons*. Proceedings of the 27th International Conference on Human Factors in Computing Systems, CHI 2009 (pp. 309–318). Boston, MA. doi:10.1145/1518701.1518750

MacKenzie, I.S., Sellen, A., & Buxton, W.A.S. (1991). A comparison of input devices in element pointing and dragging tasks. In S.P. Robertson, G.M. Olson, & J.S. Olson (Eds.), *Proceedings of the SIGCHI conference on human factors in computing systems reaching through technology—CHI '91* (pp. 161–166). New York, NY: ACM Press. doi:10.1145/108844.108868

Milner, D., & Goodale, M. (2006). *The visual brain in action* (Vol. 27). Oxford, UK: Oxford University Press.

Obhi, S.S., & Goodale, M.A. (2005). The effects of landmarks on the performance of delayed and real-time pointing movements. *Experimental Brain Research, 167*(3), 335–344. PubMed ID: 16041512 doi:10.1007/s00221-005-0055-5

Rossetti, Y. (1998). Implicit short-lived motor representations of space in brain damaged and healthy subjects. *Consciousness and Cognition, 7*(3), 520–558. PubMed ID: 9787059 doi:10.1006/ccog.1998.0370

Smyrnis, N., Mantas, A., & Evdokimidis, I. (2007). "Motor oblique effect": Perceptual direction discrimination and pointing to memorized visual targets share the same preference for cardinal orientations. *Journal of Neurophysiology, 97*(2), 1068–1077. PubMed ID: 17122322 doi:10.1152/jn.00515.2006

Thaler, L., & Goodale, M.A. (2011). The role of online visual feedback for the control of target-directed and allocentric hand movements. *Journal of Neurophysiology, 105*(2), 846–859. PubMed ID: 21160005 doi:10.1152/jn.00743.2010

Van Der Kamp, J., De Wit, M.M., & Masters, R.S.W. (2012). Left, right, left, right, eyes to the front! Müller-Lyer bias in grasping is not a function of hand used, hand preferred or visual hemifield, but foveation does matter. *Experimental Brain Research, 218*(1), 91–98. PubMed ID: 22278110 doi:10.1007/s00221-012-3007-x

Westwood, D., Heath, M., & Roy, E. (2000). The effect of a pictorial illusion on closed-loop and open-loop prehension. *Experimental Brain Research, 134*(4), 456–463. PubMed ID: 11081827 doi:10.1007/s002210000489

Yakimoff, N., Lansky, P., Mitrani, L., & Radil, T. (1989). Is the 45-oblique a third dominant direction. *Acta Neurobiologicae Experimentalis, 49*(1), 47–50.

Zaehle, T., Jordan, K., Wüstenberg, T., Baudewig, J., Dechent, P., & Mast, F.W. (2007). The neural basis of the egocentric and allocentric spatial frame of reference. *Brain Research, 1137*(1), 92–103. PubMed ID: 17258693 doi:10.1016/j.brainres.2006.12.044