Crossed Hands Curve Saccades: Multisensory Dynamics in Saccade Trajectories

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Abstract

Crossing one's hands across the midline can interfere with multisensory processing. The current experiment examines this effect in a dynamic framework. Participants were asked to saccade to visual targets in the presence of a manual tactile distraction on the same or opposite side of the target and with hands crossed or uncrossed. Trajectories of the resulting visual saccades were analyzed for curvature. While spatially incongruent trials in an uncrossed position resulted in marginal saccade curvature, the crossed hand condition caused significant curvature when compared to control trials regardless of spatial configuration. Thus, the current study provides evidence that the role of sensory integration in eye movement dynamics is modulated by relative positioning of the hands. Moreover, the findings indicate that saccades can deviate in the presence of crossed-hand stimulation regardless of the spatial configuration of the trial. These results provide an initial link between known multisensory phenomena and saccade trajectories.

Keywords: Embodiment; Saccade trajectories; Multisensory processing; Tactile; Body Position; Crossed hands; Dynamical cognition.

Introduction

We are situated in a complex and multisensory world. While vision is a key source of information, gathering information quickly and promiscuously from our surroundings, the selection of eye movements is mediated by neural regions associated with multisensory integration. Thus, one should expect that saccade trajectories to visual targets can be influenced by information from other modalities. The current study investigates the influence of non-visual information on eye movements by examining the effect of body-position and tactile information on saccade trajectories.

In the 19th century, it was reported that crossing one's hands across the midline leads to decrements in temporal processing of tactile stimuli compared to processing in an uncrossed position (Drew, 1896). Ever since early anecdotal reports, the crossed-hand effect has been demonstrated to be a robust phenomenon (Shore, Spry, & Spence, 2002). In addition to decrements of tactile processing, crossing one's hands has been shown to affect multisensory processing in spatial (see Maravita, Spence, & Driver, 2003 for a review) and non-spatial tasks (Holmes, Sanabria, Calvert, & Spence, 2006). The crossed-hand effect may be related to the perception-action interface where perception is goal-directed and action-motivated (Hommel et al., 2001). Consistent with this view, crossed-*tool* effects have been observed where uncrossed hands yielding tools that cross the midline result in similar performance decrements to the crossed-hand effect (Maravita et al., 2002).

Thus, the process of moving the right hand into left space and vice versa has a diverse and widespread effect on perceptual processing and may be related to the perception-action interface. However, studies to date have not examined on-line patterns of behavior which may provide a dynamic view into processing differences under crossed-hand conditions. The present study is the first to expand the multisensory effects of crossed-hand phenomena into this dynamic framework by examining the effect of crossed-hand stimulation on saccade trajectories.

In the last dozen years, a variety of studies have provided evidence that eye movements are a rich and informative measure of continuous cognitive activity (Spivey & Dale, 2006). Patterns of eye movements have revealed the temporal dynamics of cognitive processes in speech perception (McMurray, Tanenhaus, & Aslin, 2002), spoken word recognition (Allopenna, Magnuson, & Tanenhaus, 1998), syntactic processing (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), visual search (Zelinsky & Sheinberg, 1997), visual memory (Richardson & Spivey, 2000) and even problem solving (Grant & Spivey, 2003).

However, the majority of such studies have focused on a small subset of eye activity. Natural eye activity is characterized by cycles of variable fixation on specific objects and seemingly ballistic saccades, or large movements, between objects (Schall, 1995). While the above studies have focused on patterns of fixation, a variety of recent studies have examined influences on saccade trajectories that link these patterns of fixation. This work has demonstrated that saccade trajectories are influenced by the presence of information in the environment (e.g. Doyle & Walker, 2001) as well as a result of remembered information (Theeuwes, Olivers, & Chizk, 2005); saccades to visual targets have also been shown to curve in the presence of both auditory and tactile distractors (Doyle & Walker, 2002). Saccade trajectories can deviate from straight lines in a variety of tasks (see Van der Stigchel, Meeter, & Theeuwes, 2006 for a review). Thus, Van der Stigchel et al. (2006) suggest that a reasonable analogy for saccade trajectories is not like a ballistic missile, as previously thought, but more similar to a flight path of a plane. In this analogy, the start and end points of the path are fixed, however, the trajectory between these points can experience deviations depending on the environment such as airplane traffic or weather conditions. This analogy emphasizes that despite lasting less than a hundred milliseconds saccade trajectories are dynamic and permeable to external influences much like fixation patterns.

The current experiment applies this dynamic perspective to the study of the crossed hand phenomenon by examining the effect of task-irrelevant stimulation of either crossed or uncrossed hands on saccades trajectories to visual targets. One previous study demonstrated that saccade trajectories could be affected by a crossed hand position. Groh and Sparks (1996) asked participants to saccade to somatosensory targets on their hands while in a crossed or uncrossed position. Saccades to these manual targets deviated towards the uncrossed position, e.g. saccades to a right hand crossed into left space curved towards the right despite the left location of the hand. However, in the current experiments, participants are asked to saccade to visual targets not to somatosensory targets as in Groh and Sparks (1996). Thus, the tactile information is the distractor rather than the target. Previous research has shown that saccade trajectories deviate in the presence of tactile distractors to uncrossed hands (Doyle & Walker, 2002). However, given the robust effects of the crossed hand position on processing, we predict that tactile stimulation to crossed hands will result in more curvature to visual targets than tactile stimulation when in the uncrossed position

Methods

Participants

Eight participants (6F, M = 24.4; SD = 4.7) were recruited to participate for $10/hour at the University of British Columbia. All participants had self-reported normal or corrected to normal vision and no known neurological disorders. Critical for the current study, all participants reported right hand dominance. Ethical approval for this study was granted by the Clinical Research Ethics Board at the University of British Columbia.

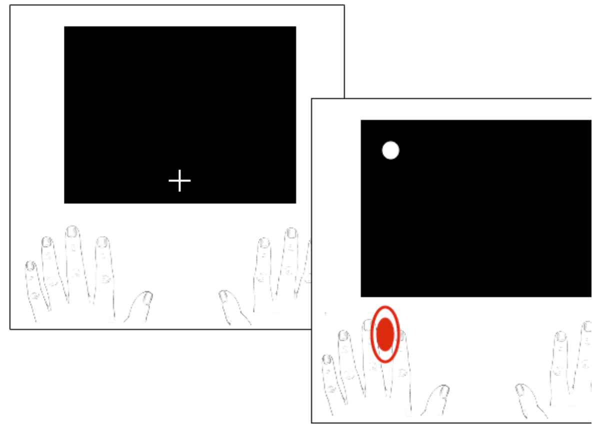

Figure 1: The current trial depicts a spatially congruent, uncrossed hand trial, where there is simultaneous stimulation to the left, uncrossed hand while the participant saccades to the left visual target.

Materials

Visual materials consisting of a fixation cross and visual targets were presented on a 15 in. monitor at a resolution of 1280 by 1080 pixels. Both the fixation cross and the visual target were white against a black background. The fixation cross measured 1.2 cm^2 and the visual target was a circle 1.2 cm in diameter. Vibro-tactile devices provided tactile stimulation well above threshold for each participant. The vibro-tactile devices were 2 cm in diameter. Since only one hand received tactile stimulation for each trial, each device was attached to foam hand-rests (consisting of three individual layers of foam) in order to prevent any potential conduction of vibrations to the non-stimulated hand.

Experiment Builder (SR Research Ltd., Mississauga, Ontario, Canada) controlled the visual and vibro-tactile stimulation. A chin rest was utilitzed for all participants. The chin rest was 40 cm from the monitor and centered. After participants were seated, the distance of the vibro-tactile devices and their foam hand-rests were adjusted to comfortable arm distance. While the distance of the vibro-tactile devices and their rests depended on arm length of each participant, the devices were always 50 cm apart and centered in front of the monitor.

To cover any noise produced by the vibro-tactile stimulation, participants wore foam earplugs and headphones playing auditory noise. The noise consisted of layers of several conversations in multiple languages repeated on loop (Vatikiotis-Bateson et al., 1998).

Procedure

Eye Position Recording horizontal (x) and vertical (y) motions as well as pupil size for the left eye were recorded at 250Hz using the Eyelink II, a head-mounted, corneal infrared eye tracking system (SR Research Ltd., Mississauga, Ontario, Canada). This eye tracking system accurately measures eye position to 0.01 degrees given these recording parameters. Eye position was calibrated using EyeLink II software before the beginning of the experiment and after every 16 trials. In addition, a drift correction procedure was performed after each trial.

Experimental There were two possible visual targets (left and right). These targets were always presented in the same locations. In addition, the hand on the left hand-rest or the hand on the right hand-rest received stimulation for each trial. Participants were instructed to place the vibro-tactile device on their index and middle finger tips. Tactile stimulation was never delivered to both hands simultaneously during a trial. Thus, there were four possible trial types (L/R Target x L/R Tactile Stimulation) within each condition (crossed or uncrossed hand positions).

Twenty (20) trials of each type were presented in random order within tactile/body position condition: hands crossed and hands uncrossed. In the uncrossed-hands condition, participants placed their right hand on the right hand-rest and the left hand on the left hand-rest. In the crossed- hands condition, participants were instructed to place their right hand on the left hand rest and their left hand on the right hand rest. All 80 trials were completed in one condition (crossed or uncrossed-hands) before moving onto the other condition with the order of conditions counter-balanced across participants. See Figure 2 for schematic of trial types and hand position conditions for the left target for both the crossed and uncrossed-hands conditions.

A trial commenced with fixation of the fixation cross. The fixation cross was presented for a variable duration between 1,000 and 1,500ms as in Groh and Sparks (1996). Participants were asked to maintain fixation until the fixation cross disappeared at which time either the left or right target appeared and tactile stimulation commenced. Participants were instructed to move their eyes as quickly and rapidly as possible to the visual target. The visual target and the tactile stimulation were presented until participants successfully fixated on the visual target within 100 pixels. After successful fixation of the visual target, participants completed a drift correction procedure before beginning a new trial. After completing 16 trials, participants were given a self-timed break.

Analysis of Eye Movements

After recording, time points in addition to horizontal (x) and vertical (y) positions were exported using SR Research analysis software and converted to ASCII files using the SR Research Toolbox (Cornelissen, Peters, & Palmer, 2002) using MATLAB (The Mathworks Guide, M.R. Inc., Natick, MA, 1998). The remaining analysis took place in MATLAB.

Recorded eye positions and their time points were separated by tactile condition first (crossed vs. uncrossed hands) then by trial type (e.g. left visual target and left tactile stimulation). Eye movement trajectories from the fixation cross to the visual target were extracted using a pixel boundary and fixation criteria. Fixations were defined as changes of less than 10 pixels in either the Horizontal (x) or Vertical (y) direction within 16ms.

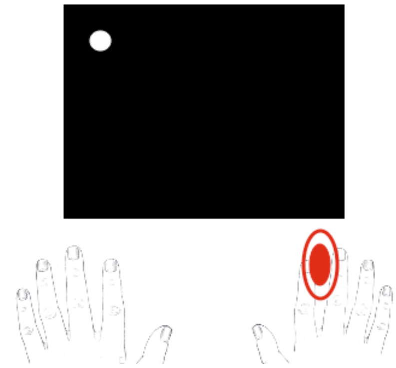

Figure 2a: Spatially incongruent, uncrossed trial to the left visual target.

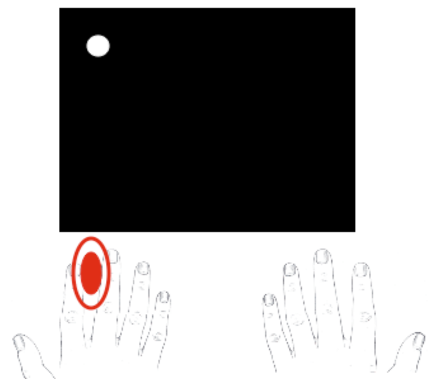

Figure 2b: Spatially congruent, crossed hand trial, where the right hand is in left space while the participant saccades to the left visual target.

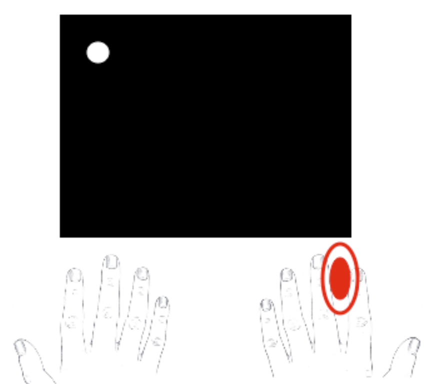

Figure 2c: Spatially incongruent, crossed hand trial, where the left hand is in right space while the participant saccades to the left visual target.

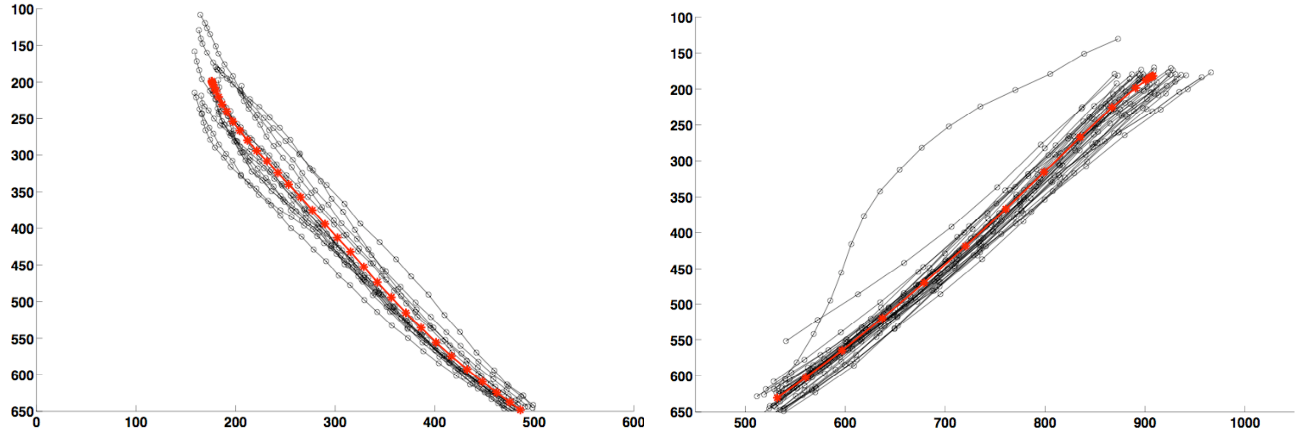

Figure 3: At left, all saccades for a single subject to the left target with tactile stimulation of right hand crossed into left space. At right, all saccades for a single subject to the right target with tactile stimulation of left hand crossed into right space. Average saccade in bold.

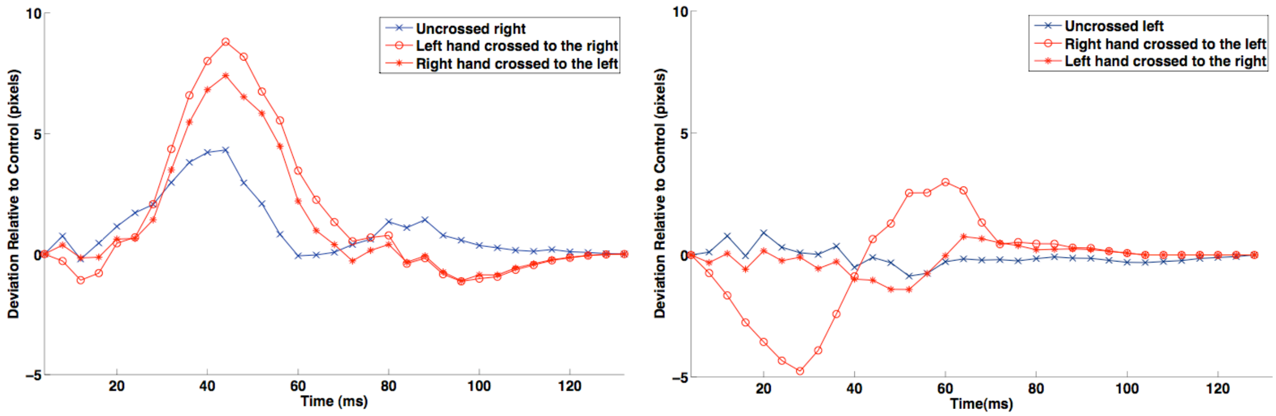

Figure 4: At left, deviations of distractor trials to left visual target. At right, deviations of distractor trials to the right visual target.

In order to measure deviation in continuous saccades to the correct target, strict criteria were used to exclude non-continuous eye movement data. Eye movements that did not start on the fixation cross or end on the target (within 100 pixels) were excluded from analysis. In addition, eye movements that traveled to or began in the direction of the incorrect target were excluded. Saccades that fit either of these criteria were classified as "erroneous". Eye movements from the fixation to the target that included at least one fixation, as defined by the category above, were classified as "multiple saccades". Finally, eye movements that were missing a large number of data points were labeled as "blinks". The above categories of eye movements were excluded from further analysis.

Remaining eye movements were analyzed for both the degree of deviation or curvature as well as the direction of curvature. In order to measure the degree of curvature, the initial time point of the saccade (start point) and the final fixation on the target (end point) were determined for each saccade. A straight trajectory of 100 time points was constructed for each pair of start and end points. For each time point during the saccade trajectory, the Euclidean distance to the nearest straight line co-ordinate was computed in order to determine the magnitude of deviation per time point. Leftward deviations were given a positive value and rightward deviations were given a negative value. Deviations from a straight trajectory were determined for every time point in each saccade. Deviations were averaged for each time point within participants and then across participants. In addition, the maximum deviation of a single time point was determined for each saccade. Deviations were determined and averaged for each trial type in each condition separately. Afterwards, these deviations were compared to the control condition.

The control condition of uncrossed hands and spatially congruent visual and tactile information was compared to performance in the other *distractor* conditions, where either tactile stimulation was spatially incongruent with the position of the visual target in the uncrossed hand condition (e.g. left visual target and stimulation to the right hand in right space) OR in any of the crossed hand conditions (e.g right visual target and tactile stimulation of the left hand crossed into the right side of space). See Figure 2 for a schematic of the distractor trials.

Results

Prior to the analysis, erroneous eye movements were excluded according to criteria described above. Application of these criteria led to the exclusion of 35% of trials (452 out of 1280) in the following categories: erroneous, 53%; multiple saccades, 44%; blinks, 3%. Most (57%) of the excluded saccades were to the left target. Figure 3 presents all analyzed saccades for a single participant in two conditions.

The deviations of the remaining eye movements were analyzed relative to the control trials of congruent stimulation to uncrossed hands. Deviations of the distractor trials were compared to the control trials for both the right and left visual targets (Figure 4). Analyses of deviation of distractor trials from control trials were pooled for every 7 eye position samples, segmenting the duration of the saccades roughly into four quartiles. Thus differences in deviation were analyzed for saccades during the following time windows: 4ms to 28ms; 32ms to 56ms; 60ms to 84ms; and 88ms to 112ms.

For the left visual target (Figure 4, left panel), the only significant deviation from the control trials was in the second time window (32ms to 56ms). In this time window, there is significant deviation of both trials of the crossed-hand condition from the control trials (left target with right hand stimulated in left space, spatially congruent: $t(8)= -2.777$; $p=0.027$; left target with left hand stimulated in right space: $t(8)= -2.550$; $p=0.038$). The difference between control and distractor trials for the uncrossed-hand condition was only marginally significant (left target with right hand stimulated in right space: $t(8)= -2.141$; $p=0.07$).

For the right visual target (Figure 4, right panel), there was no significant or marginally significant deviation of any distractor condition from the control condition in any time window (right target with left hand stimulated in left space: $t(8)= 0.297$; $p=0.774$; right target with right hand stimulated in left space: $t(8)= 0.145$; $p=0.889$; right target with left hand stimulated in right space: $t(8)=0.008$; $p=0.994$). Saccades to the left target from 32 to 56ms after saccade onset during stimulation to the left hand crossed over into right space yielded the maximum deviation of all saccades with an average maximum deviation of 66.8 pixels, 21.29mm or 0.05 degrees of visual angle. Maximum deivation in this time period was similar in the other crossed hand condition (stimulation of right hand crossed into left space: 58.6 pixels, 18.68mm, or 0.05 degrees of visual angle). The maximum deviation in the control condition was 18.6 pixels, 5.9mm, or 0.015 degrees of visual angle. Significant curvature of less than a degree of visual angle has be previously reported (see Theeuwes, Olivers, & Chizk, 2005)

Discussion

We provide evidence that irrelevant tactile stimulation applied to crossed hands can result in significant saccade curvature regardless of the relative spatial congruence of the tactile and visual information. Therefore, the current results indicate that tactile stimulation to crossed hands can have a significant effect on saccade trajectory beyond spatial distraction. It has been well documented that crossed-hand stimulation results in behavioral decrements in multisensory tasks (see Maravita et al., 2003), the current work is an initial link between this known multisensory illusions and saccade trajectories. Further work is necessary to more directly link deviations in saccade trajectories and these behavioral deficits.

Consistent with previous results (Doyle & Walker, 2002), the current study finds that spatially incongruent tactile stimulation of the uncrossed hand results in marginally significant curvature away from the irrelevant tactile information. Also consistent with Doyle & Walker (2002), we report significant curvature in leftward saccades only.

In addition to replicating previous work, the current study expands understanding of the multisensory contribution to saccade dynamics. In addition to reporting saccade curvature away from distractors in an uncrossed-hand condition, there is significant curvature of saccades to the left visual target in the crossed-hand condition in both spatially congruent and incongruent trials (see Figure 4).

As seen in Figure 2, stimulation of the left hand on the right side of space while participants saccade to a left target created a spatially incongruent trial similar to the uncrossed trials discussed above but these trials did not result in equal amount of saccade curvature. Stimulation to the crossed hand leads to significant curvature from control trials, whereas uncrossed spatially incongruent trials resulted in only marginal significance (see Figure 4). Thus, in trials where there are spatially incongruent tactile distractors, distractors applied to crossed hands lead to more curvature than when applied to uncrossed hands.

In addition, significant curvature was reported for the left target when tactile stimulation was applied to the right hand crossed over into left space (see Figure 4). Unlike previously discussed trials where tactile stimulation was spatially incongruent to the visual target, these type of trials were *not* spatially incongruent (see Figure 2c). Despite being the same spatial_configuration as control trials, stimulation of the crossed right hand lead to significant curvature relative to control trials. These findings demonstrate that tactile stimulation to a crossed hand results in significant deviation of a visual saccade to leftward targets. This is true regardless of the spatial congruence of the trial relative to control—a spatially congruent trial can result in saccade curvature if the hands are crossed.

Previous studies have reported that saccades to visual targets tend to deviate away from a tactile distractor presented to an uncrossed hand (Doyle & Walker, 2002). While the current results for the uncrossed-condition replicate the direction of deviation reported by Doyle and

Walker (2002), this pattern of results does not easily extend to the crossed-hand condition where a leftward pattern of deviation is reported for all trials regardless of spatial location of the distractor. While saccade trajectories do not respond uniformly to all distractors (reviewed in Van der Stigchel et al., 2006), this heterogeneity is typically seen with studies employing different distractors and vastly different experimental procedures and not within subjects and experimental paradigms. However, given that it is well documented that crossed-hand position leads to decrements in spatial processing in multiple modalities (review Maravita et al., 2003), it may not be surprising to find that saccade deviations resulting from crossed-hand stimulation do not adhere to a consistent spatial configuration. Thus, the inconsistent direction of saccade deviation may be a result of the decrements in spatial processing resulting from the crossed-hand position.

We report two major findings: 1) spatial congruence produces the same magnitude of deviation as spatial incongruence when distraction comes from crossed hands (at least for leftward saccades) and 2) the direction of deviation of these saccades is not relative to the position of the hand in space as has been previously demonstrated in an uncrossed hand paradigm (Doyle & Walker, 2002). These findings provide initial evidence that saccade trajectories may be linked to the mechanisms that result in performance decrements resulting from a crossed-hand position (e.g. Maravita et al, 2003).

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