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## No Evidence that Binocular Vision Enhances Online Corrections for Reaches in the Lower-Visual Field

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Kinesiology

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## Abstract

Some work has proposed that an increased density of retinal ganglion cells in the superior hemiretina elicits a functional advantage for goal-directed reaches in the lower visual field (i.e., loVF). Furthermore, reaches performed with binocular stereo-cues exhibit optimized feedback-based trajectory corrections (i.e., online control). The present study examined whether the purported loVF advantage is restricted to binocular reaches implemented via a primarily online mode of control. Participants completed binocular and monocular reaches to loVF and upper-visual field (i.e., upVF) targets. Separate groups were provided vision during response planning and control (i.e., closed-loop group: CL), or during response planning only (i.e., open-loop group: OL). The binocular condition and the CL group exhibited more online corrections than reaches in the monocular condition or OL group. Notably, however, for all experimental conditions loVF and upVF reaches did not reliably differ – a result demonstrating no systemic loVF advantage for online control.

### Keywords:

Lower visual field

Online control

Reaching

Pointing

Binocular

Monocular

Closed loop

Open loop

Perception action model

## Co-Authorship Statement

The current dissertation was completed under the supervision and mentorship of Dr. Matthew Heath. Specifically, Dr. Matthew Heath and Dr. Stephanie Rossit provided valued guidance during the experimental design, data collection and analysis, and manuscript preparation. For this manuscript, Jennifer Campbell was the first author whereas Dr. Matthew Heath and Dr. Stephanie Rossit served as co-authors.

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To my lab mates who provided constant encouragement, feedback, and many laughs along the way – you all made the neurobehavioral lab a joy to be in. The dedication and hard work each of you put towards your own work in the lab was motivational and inspirational. I treasure every moment and thank you for making my final years here at Western exceptionally memorable. I would also like to thank all those who willingly participated in my studies. Your time and patience was greatly appreciated, and this work would not have been completed without you.

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## Introduction

The horizontal axis of the human retina exhibits a well-documented increased density of ganglion cells in the central as compared to the peripheral retina. The functional consequence of this asymmetry is an increased resolution power for stimuli appearing in central vision. A less well-known retinal asymmetry exists in the vertical axis with an increased density of ganglion cells in the superior as compared to the inferior hemiretina (Curcio & Allen, 1990). Given the concave surface of the retina, the superior and inferior hemiretina receive visual information from the lower- (i.e., loVF) and upper-visual fields (i.e., upVF), respectively. Notably, Previc's (1990) theoretical account of primate visual space asserts a loVF advantage for goal-directed actions and an upVF advantage for object search and perception-based visual processing. Moreover, Danckert and Goodale (2003) contend that the loVF elicits a preferential bias for processing visual inputs within the visuomotor networks of the dorsal visual pathway. In turn, the upVF is proposed to be biased toward the processing of visual information via the visuoperceptual networks of the ventral visual pathway. Put more directly, Danckert and Goodale (2003) assert a loVF advantage for processing the high temporal resolution and ego-motion cues required for goal-directed actions (see also Previc, 1990).

Danckert and Goodale (2001) provided the first systematic examination of the behavioural consequence of a vertical visual field asymmetry. In that work, participants performed a Fitts (1954) reciprocal tapping task (index of difficulty (ID): values ranging from 0.3 to 1.5 bits) to targets located in the loVF and the upVF. To manipulate the visual field (i.e., loVF vs. upVF) in which a target appeared, participants fixated on a location either above or below the target so that it appeared in the loVF or upVF, respectively. The authors reported that movement times (MT) for loVF reaches increased in relation to increasing ID; that is, responses adhered to lawful speed-accuracy relations as defined by Fitts' law. In contrast, MTs for upVF reaches did not vary with ID and were less accurate than loVF reaches. Accordingly, the authors proposed that the loVF is optimized for the control of visually guided actions (see also Khan and Lawrence, 2005). Moreover, Rossit et. al., (2013) employed a conjoint grasping and fMRI study to examine the neural correlates associated with the putative loVF advantage. In that study, peak

grip aperture for reaches in the loVF elicited enhanced scaling to target size and reduced variability relative to upVF grasping. Moreover, the authors reported that the loVF advantage was associated with increased activation of the superior parieto-occipital cortex (SPOC) and left precuneus – cortical regions associated with the visuomotor networks of the dorsal pathway and linked to the control of goal-directed actions in peripersonal space.

It is, however, important to recognize that work has not consistently reported a loVF advantage for goal-directed actions. For example, Binsted and Heath (2005) had participants complete a reaching task across a wider range of IDs (i.e., 1.5 to 5.5 bits) than Danckert and Goodale (2001). The basis for including a broader range of IDs was twofold. First, Danckert and Goodale employed target IDs that were not within the range Fitts (Fitts & Peterson, 1964) and more contemporary research has shown to produce reliable speed-accuracy trade-offs (for review see Heath et al., 2011). Second, the very low IDs used by Danckert and Goodale would have entailed reaching responses controlled entirely offline via central planning mechanisms (Schmidt et al., 1979), and would therefore not gauge a possible loVF advantage for visually based trajectory amendments (i.e., online control). As such, the IDs employed by Binsted and Heath entailed movement environments that spanned reaches controlled via central planning mechanisms (i.e., ID = 1.5 bits) and those requiring online trajectory amendments (i.e., ID = 5.5 bits). Results showed that loVF and upVF reaches elicited comparable MT/ID slopes, comparable time in the online correction phase of the response (i.e., time after peak velocity), and comparable endpoint accuracy. The only identified difference was that loVF endpoints were less variable. These findings were attributed to a modest loVF advantage associated with the planning – but not the online control – of goal-directed reaches (see also Brown et al., 2005). In another study, Krigolson and Heath (2006) employed a perturbation paradigm involving a target ‘jump’ at movement onset. The basis for this manipulation was that if the loVF imparts a functional advantage for online corrections then such actions should exhibit corrections with decreased latency and increased accuracy compared to their upVF counterparts. Results showed that loVF reaches elicited decreased endpoint variability (across ‘jump’ and ‘no-jump’ trials) but did not demonstrate an increased rate or effectiveness in online corrections. Once again,

such results provide some evidence of a loVF advantage for movement planning but do not demonstrate an advantage for online trajectory amendments.

An identified feature of the visuomotor networks of the dorsal stream is the processing of visual information at the time of response cuing (i.e., real-time control) (Westwood & Goodale, 2003) and response execution (Pisella et al., 2000; for review see Goodale, 2011). It is, however, notable that previous work examining a loVF advantage for reaching/grasping has not selectively examined the importance of visual inputs during planning *and* control. As such, the present investigation had participant's complete loVF and upVF reaches in conditions that manipulated the availability of visual cues during movement planning and control. In particular, participants completed goal-directed reaches wherein visual input was selectively available during movement planning (i.e., open-loop reaching) or available during movement planning and execution (i.e., closed-loop reaching). Furthermore, the closed-loop and open-loop responses were performed in binocular and monocular environments. The basis for the stereo-cue manipulation is that binocular cues provide retinal disparities, angle of convergence, and ego-motion cues allowing for the computation of depth via stereopsis (Previc, 1998). In contrast, removing binocular depth cues results in the reliance of monocular depth cues such as texture, illumination, perspective, and contextual information. Moreover, evidence suggests that binocular cues are necessary for the normal operations of the dorsal visual pathway, and that reaches performed in a monocular environment are mediated via the visuoperceptual networks of the ventral visual pathway. In support of this view, Marotta et al., (1997) observed that patient DF – an individual with a well-documented visual agnosia arising from bilateral lesions to her ventral visual pathway – was able to precisely scale her grip aperture to object size under binocular visual conditions; however, her responses in a monocular condition exhibited impaired grip aperture scaling commensurate with her documented perceptual deficit. These results suggest that binocular cues support the absolute processing of visual information used for the planning and control of actions. Moreover, in healthy adults it has been shown that binocular and monocular reaches are mediated via distinct control strategies (i.e., online vs. offline). In particular, Heath et al. (2008) had participants complete binocular and monocular reaches to targets located at different eccentricities and quantified online

correction via a regression analysis that examined the relationship between the spatial location of the limb at decile increments of normalized MT relative to a response's movement endpoint (i.e.,  $R^2$  values). The basis for this technique is that reaches controlled primarily online exhibit weak  $R^2$  values at later stages in the trajectory as the unfolding response evokes error-reducing trajectory amendments. In turn, more robust  $R^2$  values are taken to evince a trajectory that is structured offline via central planning mechanisms (for review see Heath et al., 2010). Results showed that binocular reaches produced weaker  $R^2$  values (i.e., at > 50% of MT) and more accurate, less variable endpoints than the monocular reaches – a result taken to evince that binocular visual cues advantage the adoption of an online mode of control. Moreover, Hu and Knill (2011) employed a perturbation paradigm wherein the spatial location of the limb appeared to 'jump' during binocular and monocular reaches. The basis for this perturbation was that an online feedback strategy would correct apparent errors in the trajectory caused by the limb 'jump'. Results revealed that binocular reaches elicited more online trajectory amendments than the monocular counterparts and was a result interpreted to reflect advantaged online corrections in the binocular condition.

The present work examined whether the presence/absence of binocular cues differentially influences the putative loVF advantage for reaching. As in previous work, participants were required to fixate on a location above or below a target object to manipulate the visual field in which it was presented. Moreover, the present work had separate groups of participants complete their loVF and upVF binocular and monocular reaches in environments permitting vision during movement planning and execution (i.e., closed-loop reaching: CL) and when vision was selectively available during movement planning (i.e., open-loop reaching: OL). This manipulation was designed to examine whether a possible loVF advantage is selectively expressed for movement planning or online control (for extensive review see Elliott, et al., 2001). Further, the present work provided detailed trajectory comparison of loVF and upVF reaches. In particular, I employed the  $R^2$  analysis outlined previously to examine whether the stereo-cue (i.e., binocular vs. monocular) and visual feedback (CL vs. OL) conditions employed here differentially influenced the degree to which loVF and upVF reaches were controlled online (see also Elliott et al. 1999; Heath 2005). In terms of research predictions, if the loVF elicits a

behavioural advantage for online control then it is expected that CL binocular reaches in the loVF will produce lower  $R^2$  values and increased response accuracy and precision when compared to their upVF counterpart. If, however, the visual field advantage is related to an improvement in central planning then it is expected that CL and OL binocular reaches in the loVF reaches will show equivalent  $R^2$  values and demonstrate enhanced endpoint accuracy and precision relative to their upVF counterparts. As a third alternative, it is possible that the reported anatomical asymmetry in the vertical retinal axis does not advantage the loVF and therefore contributes to equivalent loVF and upVF control strategies, endpoint accuracy and precision regardless of the stereo-cue and feedback conditions used here.

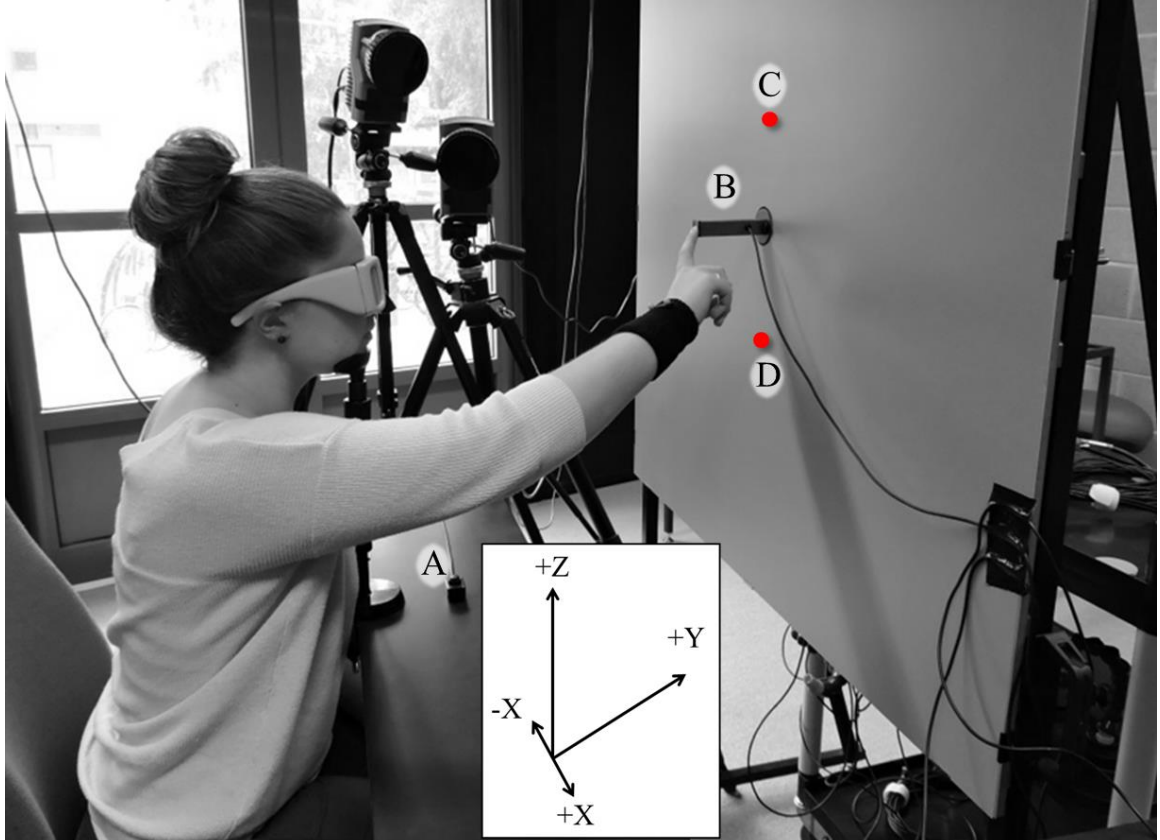
## Methods

### *Participants*

Fifteen participants (12 female: age range = 18 – 36 years) completed CL reaches, and a separate group of fourteen participants (12 female: age range = 19 – 27 years) completed OL reaches (see details of CL and OL conditions below). All participants were right handed according to the Edinburgh Handedness Questionnaire and had normal or corrected-to-normal vision (Oldfield, 1971). Eye dominance was tested using the Hole-in-Card Test, and the participants' non-dominant eye was occluded during the monocular condition (Johansson et al., 2015). All participants had stereoacuties of 120" of arc or better using the TNO test for stereoscopic vision (Walraven, 1972), and values for the CL (35", SD=12) and OL (53", SD=33), groups did not reliably differ ( $t(10) = 1.64, p > 0.05$ ). Participants signed consent forms approved by the institutional ethics committees of the University of East Anglia and the University of Western Ontario, and this work was conducted in conformity with the Declaration of Helsinki.

### *Apparatus and Procedures*

Participants sat at a table (height = 800 mm) with their head placed in a chin rest located 300 mm from the table. A start button was positioned on the table top at the participants' midline and 420 mm from a stimulus board. Targets were affixed to a stimulus board (centred at participants' midline) that was located 550 mm in front of participants with targets located 450 mm in height from the table top surface. Reaches with the right hand were directed to each of three targets (20 mm by 20 mm) set 253 mm, 192 mm, and 53 mm from the back surface of the stimulus board. This manipulation of target eccentricity represents an important manipulation for the current study because it required the trial-to-trial computation of target depth. An LED 10 mm in diameter was located on the face of each target and was illuminated for the duration of a trial. Two fixation LEDs were secured to the stimulus board and were located 150 mm ( $16^\circ$  visual angle) above and below the target (**Figure 1**).



**Figure 1: Image of the experimental set-up from the experimenter's point of view. Participants began each trial by pressing the home button (A) with their right index finger. To manipulate the visual field in which the target (B) was presented, fixation LEDs were located above and below the target. The fixation LED located above the target (C) resulted in a loVF trial, whereas the fixation LED located below the target (D) resulted in an upVF trial. Note: the current image demonstrates the target that was 192 mm in depth from the stimulus board (i.e., the middle target) and was the target position associated with the data analyses presented here. A trial concluded once the participant had quickly and accurately reached forward and placed their right index finger on the center of the target LED.**

The fixation LEDs were used to manipulate the visual field in which the target was presented. For example, when the participant directed their gaze to the fixation LED above the target (i.e., ocular angle of  $16^\circ$ ) it resulted in the target being projected onto their superior hemiretina and a reaching response completed in the loVF, whereas the LED below the target was used to position the target within participants' upVF.

Participants wore liquid-crystal shutter-goggles (e.g., PLATO goggles, Translucent Technologies, Toronto, ON, Canada) to control visual events. A Qualisys Oqus Motion Tracking system (Qualisys AB, Sweden) sampling at 179 Hz tracked the position data of a passive marker affixed to the posterior surface of participants' right index finger. The lights in the laboratory were dimmed to ensure appropriate vision of all LEDs and to minimize background visual cues during data collection.

Each trial began with the goggles set to their translucent state while the experimenter placed the correct target on the stimulus board. Following this, and once the participant depressed the start button with their right index finger, the goggles became transparent and the participant was instructed to direct (and maintain) their gaze on the illuminated fixation LED for the duration of the trial. After a 2000 ms fixation foreperiod, the target was illuminated simultaneous to an auditory imperative that instructed the participant to reach to the target as quickly and accurately as possible (see **Figure 1**). At the end of the trial the goggles were set to their translucent state allowing the experimenter to reset the target in preparation for the next trial. In addition to performing the reaching task, participants completed a simultaneous fixation task to ensure that they remained fixated for the entirety of the trial. The fixation task included 0, 1, or 2 flashes of the fixation LED that the participant was required to report to the experimenter at the end of the trial. The fixation flashes occurred before and during the movement to ensure that the target remained in the appropriate visual field for response duration. Any trial involving a fixation task error was deleted. Thus, all trials analyzed here entailed fixation in the appropriate visual field. The number of trials involving a fixation task error was less than 1%.

As mentioned above, separate groups of participants completed their reaches in CL and OL environments. The separate participant groups were required owing to the number of

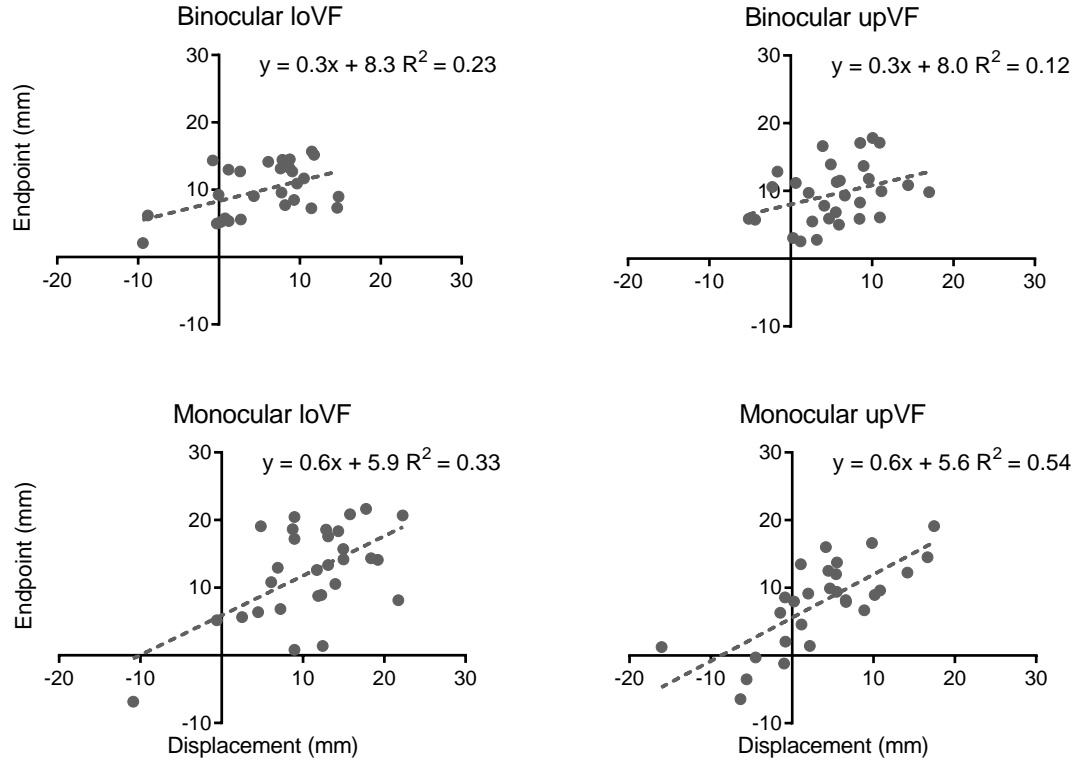


trials used here (see details below). In the CL group, the goggles remained transparent during movement planning and execution. In contrast, in the OL group the goggles were set to their transparent state coincident with the release of the start button and as a result vision was available during movement planning but not during movement execution. CL and OL groups completed their reaches in two stereo-cue conditions (i.e., monocular and binocular). During the binocular condition the PLATO goggles provided vision through both lenses during response planning (i.e., CL and OL) and control (i.e., CL). However, during the monocular condition only the lens associated with the participants' dominant eye became transparent during response planning (i.e., CL and OL) and control (i.e., CL). Each combination of visual field by stereo-cue condition contained 50 trials (i.e., 10 trials to the distal target, 30 trials to the middle target, and 10 trials to the proximal target). The presented study analyzed only reaches to the more frequent middle target and included the distal and proximal targets only as a means to prevent stereotyped actions and to encourage trial-to-trial processing of target-based depth cues. Within each monocular and binocular reaching block the three target positions and two visual field presentations (i.e., loVF, upVF) were randomized. Each experimental session took approximately 90 minutes.

#### *Data Acquisition and Analysis*

Position data of the marker affixed to the index finger were filtered via a dual-pass Butterworth filter employing a low-pass cut-off frequency of 15 Hz. Filtered position data were then used to compute instantaneous velocities via a three-point central finite difference algorithm. Acceleration data were similarly obtained from the velocity data. Movement onset and offset was marked with a velocity criterion of 50 mm/s per frame. Dependent measures included: reaction time (RT: time from auditory imperative to movement onset), movement time (MT: time from movement onset to movement offset), peak velocity (PV: maximum resultant velocity between movement onset and movement offset), percent of time after peak velocity (%TAPV: the % of MT between PV and movement offset), constant error in direction (leftward =  $-CE_x$ , rightward =  $+CE_x$ ), distance (undershoot =  $-CE_y$ , overshoot =  $+CE_y$ ) and depth (undershoot =  $-CE_z$ , overshoot =  $+CE_z$ ) movement axes, and their associated variable errors ( $VE_x$ ,  $VE_y$ ,  $VE_z$ ). In

addition, the proportion of endpoint variance ( $R^2$ ) explained by the spatial position of the limb at proportional increments of MT (20%, 40%, 60%, and 80% of MT) relative to each response's ultimate movement endpoint were computed for each movement axis. Previous work has shown that large  $R^2$  values indicate a response planned primarily in advance of movement onset via central planning mechanisms (i.e., offline), whereas smaller  $R^2$  values demonstrate a response controlled via online corrections (Heath, 2005). **Figure 2** presents spatial correlations for an exemplar participant and demonstrates the computation of  $R^2$  values. This figure demonstrates that monocular reaches were associated with more robust  $R^2$  values than their binocular counterparts.



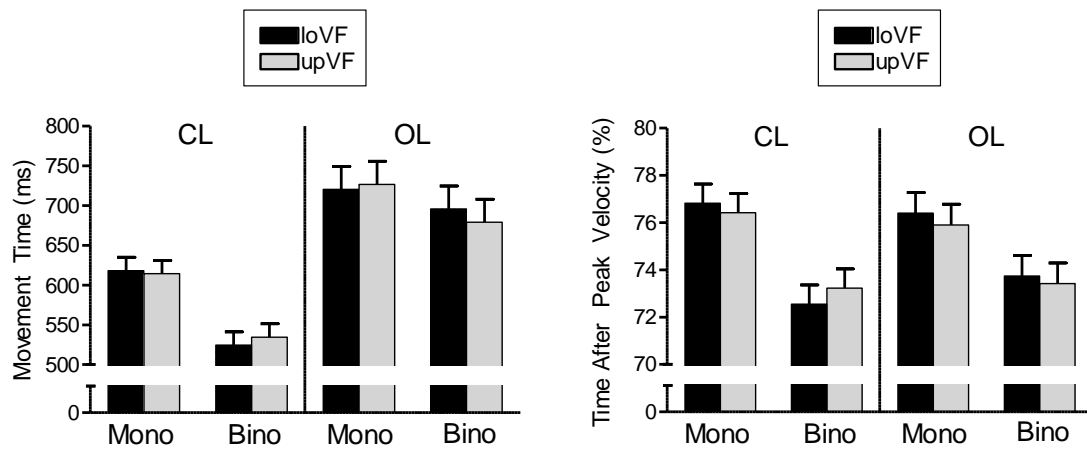
**Figure 2: The proportion of variance ( $R^2$ ) in movement endpoints in the mediolateral axis (i.e., x-axis) explained by the spatial position of the limb at 80% of MT for loVF (left panel) and upVF (right panel) trials performed by an exemplar participant in the closed-loop group as a function of the binocular (top panel) and monocular (bottom panel) conditions.**

Five participants (4 from the CL and 1 from the OL group) were removed due to equipment and signal error. Most dependent variables were analyzed via 2 (feedback group: CL vs OL) by 2 (stereo-cue: binocular vs. monocular) by 2 (visual field: loVF vs upVF) split-plot ANOVA. Simple effects were used to decompose significant interactions. For the  $R^2$  analyses, the variable time (20%, 40%, 60%, and 80%) was added to the ANOVA model. Main effects/interactions involving time were decomposed via power polynomials (Pedhazur, 1997) and simple effects.

## Results

### *Performance and kinematic variables*

The grand mean for RT was 407 ms (SD = 56) and this variable did not elicit any reliable main effects or interactions, all  $F_s(1,22) < 1.39$ ,  $p_s > 0.05$ , all  $\eta_p^2 < 0.06$ . For MT and %TAPV, results yielded main effects of stereo-cue, all  $F_s(1,22) = 27.13$  and  $21.02$ ,  $p_s < 0.01$ ,  $\eta_p^2 = 0.55$  and  $0.49$  for MT and %TAPV, respectively, such that MTs (614 ms SD = 107) and %TAPV (73% SD = 5) for the binocular condition were less than their monocular counterparts (MT: 674 ms, SD = 118; %TAPV: 76% SD = 3) (see **Figure 3**). Further, MT yielded a main effect of feedback group,  $F(1,22) = 15.03$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.41$ , such that MTs for the CL group were less than their OL counterparts (see **Figure 3**). Additionally, MT elicited a feedback group by stereo-cue interaction,  $F(1,22) = 4.62$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.17$ . MTs for CL binocular (529 ms SD = 61) and monocular (616 ms SD = 86) conditions were shorter than their OL counterparts (binocular: 687 ms SD = 75, monocular: 723 ms SD = 117),  $t_s(22) > 2.51$ ,  $p_s < 0.05$ . Moreover, post hoc analyses and inspection of **Figure 3** demonstrates that the CL binocular condition yielded MTs that were shorter than any other experimental condition. In terms of PV, the grand mean was 2009 mm/s (SD = 289) and this variable did not yield any reliable effects or interactions, all  $F_s(1,22) < 3.98$ ,  $p_s > 0.05$ , all  $\eta_p^2 < 0.15$ . Notably, and because of the primary objective of this study, it is important to document that across each of the aforementioned dependent variables neither a main effect of visual field nor any higher-order interactions involving visual field were observed, all  $F_s(1,22) < 3.98$ ,  $p_s > 0.05$ , all  $\eta_p^2 < 0.15$ .



**Figure 3: Mean movement time (MT: left panel) and percentage of time after peak velocity (%TAPV: right panel) as a function of visual field (loVF and upVF) and stereo-cue (binocular and monocular) conditions in closed-loop (CL) and open-loop (OL) groups. Error bars represent 95% within-participant standard deviations**

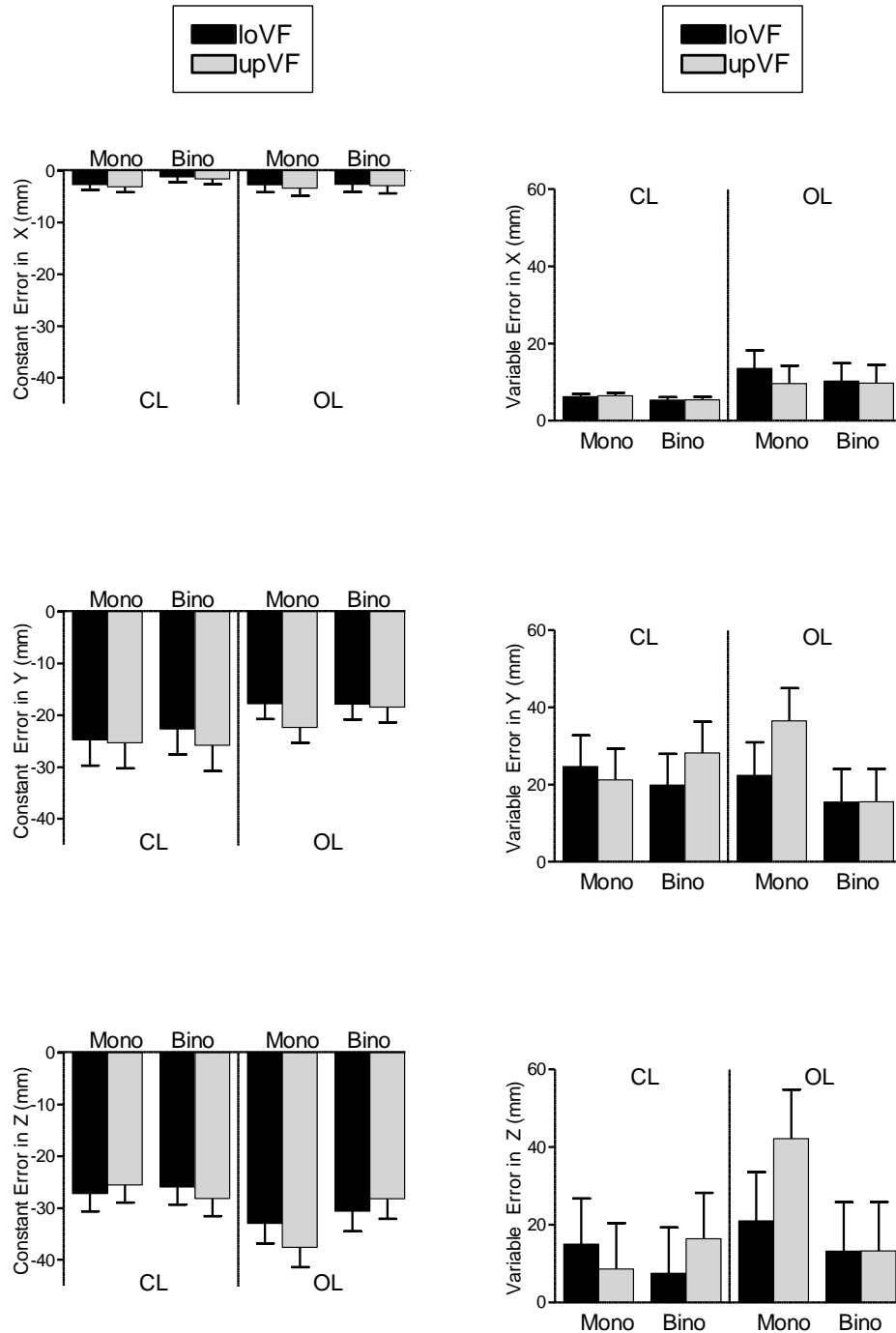
$CE_x$  and  $CE_y$  did not elicit any reliable effects or interactions, all  $F_s(1,22) < 1.07$  and  $3.72$ ,  $ps > 0.05$ ,  $\eta_p^2 < 0.05$  and  $0.15$ , respectively for  $CE_x$  and  $CE_y$  (see **Figure 4**).  $CE_z$  produced a main effect of feedback group,  $F(1,22) = 7.02$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.24$ , and interactions involving feedback group by stereo-cue,  $F(1,22) = 5.25$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.19$ , and feedback group by stereo-cue by visual field,  $F(1,22) = 5.19$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.19$ .

Given the objective of the current study, the highest-order interaction was examined by decomposing the effect of stereo-cue and visual field separately for the CL and OL groups. For the CL and OL groups, **Figure 4** shows that loVF and upVF trials in binocular and monocular conditions did not reliably differ (CL group: all  $ts(10) < 0.91$ ,  $ps > 0.05$ ; OL group: all  $ts(12) < 1.45$ ,  $ps > 0.05$ ); that is, reaching accuracy in the different stereo-cue conditions was not influenced by the manipulation of visual field. Thus, my theoretically motivated post hoc contrasts did not uncover the nature of the interaction. Accordingly, I computed a separate set of post hoc contrasts examining differences between stereo-cue and feedback group separately for each visual field. Results showed that upVF monocular trials in the CL group were more accurate than their OL counterparts,  $t(22) = 3.10$ ,  $p < 0.05$ , whereas loVF monocular trials did not reliably differ between CL and OL groups,  $t(22) = 1.92$ ,  $p > 0.05$ . In turn, results for the binocular condition indicated that neither loVF nor upVF trials reliably varied between CL and OL groups  $ts(22) < 1.60$ ,  $ps > 0.05$  (see **Figure 4**).

$VE_x$  produced a main effect of feedback group,  $F(1,22) = 11.71$ ,  $p < 0.01$ , all  $\eta_p^2 = 0.35$ , such that endpoints for the CL (5.9 mm, SD = 1.6) group were less variable than the OL group (10.8 mm, SD = 7.7) (see **Figure 4**).  $VE_y$  and  $VE_z$  produced interactions involving feedback group by stereo-cue by visual field,  $F_s(1,22) = 5.67$  and  $5.22$ ,  $ps < 0.05$ ,  $\eta_p^2 = 0.21$  and  $0.19$ . The same post hoc approach as used for  $CE_z$  was employed here. **Figure 4** shows that for both variables loVF and upVF trials did not reliably differ in either binocular or monocular conditions, and was a result consistent across CL and OL groups (CL group: all  $ts(10) < 1.78$ ,  $ps > 0.05$ ; OL group: all  $ts(12) < 1.84$ ,  $ps > 0.05$ ). In other words, results did not demonstrate a reliable advantage for loVF trials across any of the experimental conditions used here. Further post hoc analyses of  $VE_y$  revealed that both

upVF and loVF trials in the monocular and binocular conditions did not differ between the CL and OL groups, all  $t(22) < 1.67$ ,  $p > 0.05$  (see **Figure 4**). Additional post hoc contrasts of  $VE_z$  revealed that the nature of the interaction was rooted in the fact that the upVF trials in the monocular condition were less variable for the CL than the OL group,  $t(22) = 2.24$ ,  $p < 0.05$ , whereas loVF monocular values did not reliably vary between groups,  $t(22) = 0.38$ ,  $p > 0.05$ . Results for the binocular condition indicated that neither loVF nor upVF trials reliably varied between CL and OL groups, all  $t(22) < 1.02$ ,  $p > 0.05$  (see **Figure 4**).





**Figure 4: Constant error (CE: left panels) and variable error (VE: right panels) in each cardinal axis presented as a function of visual field (loVF and upVF) and stereo-cue (binocular and monocular) conditions in closed-loop (CL) and open-loop (OL) groups. Error bars represent 95% within-participant standard deviations.**

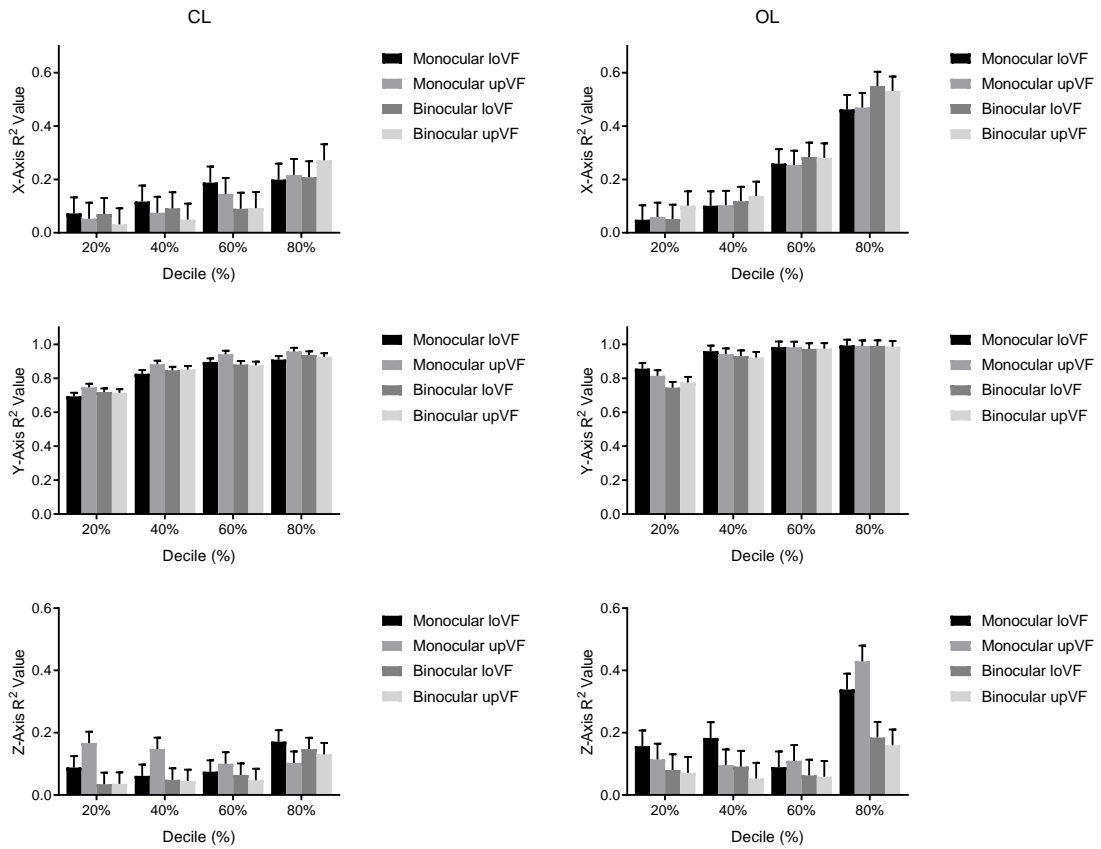
*Spatial correlations ( $R^2$ ) in reaching trajectories*

$R^2_x$  elicited a main effect of time,  $F(3,66) = 92.79$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.81$ , and feedback group,  $F(1,22) = 18.63$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.46$ , as well as interactions involving time by feedback group,  $F(3,66) = 19.46$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.47$ , and time by stereo-cue,  $F(3,66) = 3.32$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.13$ . For CL and OL groups,  $R^2_x$  values increased linearly with increasing MT (only linear effects significant: CL  $F(1,10) = 29.79$ ,  $p < 0.01$ ; OL  $F(1,12) = 157.20$ ,  $p < 0.01$ ). Further, CL and OL groups exhibited equivalent  $R^2_x$  values at 20% and 40% of MT,  $ts(22) < 1.20$ ,  $ps > 0.05$ ; however, at 60% and 80% of MT values for the CL group were less than the OL group,  $ts(22) = 3.34$  and  $5.61$ ,  $ps < 0.01$  (see **Table 1** and **Figure 5**). For the time by stereo-cue interaction, results showed that values for binocular and monocular conditions increased linearly with MT (only linear effects significant: all  $F_s(1,22) = 82.01$  and  $167.08$ ,  $ps < 0.001$ ), and that values for binocular and monocular conditions did not reliably differ at matched points in MT, all  $ts(22) < 2.01$ ,  $ps > 0.05$ . Notably, neither a main effect of visual field nor any higher-order interactions involving visual field was observed, all  $F_s(1,22) < 1.18$ ,  $ps > 0.05$ , all  $\eta_p^2 < 0.05$ .

$R^2_y$  elicited a main effect of time,  $F(3,66) = 28.14$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.56$ , such that values increased linearly with increasing MT (only linear effects significant: CL  $F(1,10) = 10.48$ ,  $p < 0.01$ ; OL  $F(1,12) = 20.31$ ,  $p < 0.01$ ). Notably, neither a main effect of visual field nor any higher-order interactions involving visual field was observed, all  $F_s(1,22) < 2.18$ ,  $ps > 0.05$ , all  $\eta_p^2 < 0.09$  (see **Figure 5** and **Table 1**).

$R^2_z$  elicited main effects of time,  $F(3,66) = 21.70$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.50$ , feedback group,  $F(1,22) = 7.49$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.25$ , and stereo-cue,  $F(1,22) = 16.35$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.43$ , as well as an interaction involving time by feedback group,  $F(3,66) = 5.26$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.19$ . **Figure 5** shows that  $R^2_z$  values for the CL group were lower than the OL group, and that values were lower for the binocular than the monocular condition. In terms of the time by feedback group interaction, CL and OL groups exhibited equivalent  $R^2_z$

values at 20%, 40%, and 60% of MT,  $t_s(22) < 1.46$ ,  $p_s > 0.05$ ; however, at 80% of MT values for the CL group were less than the OL group  $t(22) = 3.04$ ,  $p < 0.05$ . Notably, neither a main effect of visual field nor any higher-order interactions involving visual field were observed, all  $F_s(1,22) < 0.43$ ,  $p_s > 0.05$ , all  $\eta_p^2 < 0.02$ .



**Figure 5: The left and right panels show mean  $R^2$  values in the closed-loop (CL) and open-loop (OL) groups, respectively. Each panel shows mean values at 20%, 40%, 60% and 80% of movement time as a function of each visual field (loVF and upVF) and stereo-cue (binocular and monocular) condition. The top, middle and bottom panels depict  $R^2$  values for the direction (i.e., x), distance (y) and depth (z) movement axes, respectively. Error bars represent 95% within participant confidence intervals.**

	Closed Loop				Open Loop											
	Monocular		Binocular		Monocular		Binocular		Monocular		Binocular					
	loVF	upVF	loVF	upVF	loVF	upVF	loVF	upVF	loVF	upVF	loVF	upVF	loVF	upVF		
20 <sub>X</sub> %	0.07	(0.08)	0.05	(0.06)	0.07	(0.07)	0.03	(0.02)	0.05	(0.05)	0.06	(0.05)	0.05	(0.07)	0.10	(0.11)
40 <sub>X</sub> %	0.12	(0.08)	0.07	(0.09)	0.09	(0.09)	0.05	(0.06)	0.10	(0.10)	0.10	(0.11)	0.12	(0.09)	0.14	(0.15)
60 <sub>X</sub> %	0.15	(0.13)	0.15	(0.15)	0.09	(0.10)	0.09	(0.08)	0.26	(0.20)	0.25	(0.15)	0.28	(0.15)	0.28	(0.18)
80 <sub>X</sub> %	0.15	(0.15)	0.20	(0.20)	0.21	(0.20)	0.27	(0.16)	0.46	(0.21)	0.47	(0.19)	0.55	(0.19)	0.53	(0.18)
20 <sub>Y</sub> %	0.69	(0.40)	0.75	(0.35)	0.72	(0.35)	0.71	(0.36)	0.86	(0.14)	0.81	(0.19)	0.75	(0.26)	0.77	(0.25)
40 <sub>Y</sub> %	0.83	(0.26)	0.88	(0.19)	0.85	(0.23)	0.85	(0.20)	0.96	(0.05)	0.94	(0.07)	0.93	(0.07)	0.92	(0.10)
60 <sub>Y</sub> %	0.90	(0.16)	0.94	(0.09)	0.88	(0.18)	0.88	(0.19)	0.98	(0.02)	0.98	(0.02)	0.97	(0.03)	0.97	(0.03)
80 <sub>Y</sub> %	0.91	(0.19)	0.96	(0.08)	0.94	(0.09)	0.93	(0.14)	0.99	(0.01)	0.99	(0.01)	0.99	(0.01)	0.99	(0.02)
20 <sub>Z</sub> %	0.09	(0.11)	0.17	(0.13)	0.03	(0.03)	0.04	(0.03)	0.16	(0.12)	0.11	(0.19)	0.08	(0.09)	0.07	(0.10)
40 <sub>Z</sub> %	0.06	(0.08)	0.15	(0.14)	0.05	(0.05)	0.04	(0.04)	0.18	(0.14)	0.10	(0.18)	0.09	(0.09)	0.05	(0.04)
60 <sub>Z</sub> %	0.07	(0.07)	0.10	(0.10)	0.06	(0.06)	0.05	(0.06)	0.09	(0.09)	0.11	(0.23)	0.06	(0.08)	0.06	(0.06)
80 <sub>Z</sub> %	0.17	(0.17)	0.10	(0.09)	0.15	(0.17)	0.13	(0.13)	0.34	(0.22)	0.43	(0.26)	0.18	(0.15)	0.16	(0.15)

**Table 1: Mean proportion of variance ( $R^2$ ) explained by the spatial position of the limb for each movement direction as a function of the response's ultimate movement endpoint. Data is presented as a function of feedback condition by stereo-cue by visual field by time. Standard deviations are presented in parentheses.**

## Discussion

The purpose of this investigation was twofold. First, I sought to determine whether binocular vision engenders the expression of a loVF advantage for goal-directed reaching. Second, I sought to determine whether a putative loVF advantage for binocular vision is related to enhanced movement planning and/or control. To address these goals, participants completed loVF and upVF reaches in monocular and binocular conditions wherein vision was available during movement planning and control (i.e., CL group), or when vision was selectively available during movement planning (i.e., OL group).

### *Binocular versus monocular reaches*

Binocular reaches elicited shorter MTs, reduced %TAPV, and lower  $R^2$  values (longitudinal axis only) compared to their monocular counterparts (see also Heath et al., 2008; Hu & Knill, 2011; Marotta et al., 1997; Servos et al., 1992; Servos & Goodale, 1994). Notably, however, I did not observe a reliable between-condition difference in endpoint accuracy or variability (c.f. Heath et al., 2008; Hu & Knill, 2011). This is an important pattern of results because it demonstrates that although similar in endpoint parameters (i.e., equivalent movement effectiveness), monocular trials were less efficient; that is, monocular responses took more time to ‘touch’ the target. Moreover, it is well known the deceleration phase of a reaching response represents the time point wherein participants implement error-reducing trajectory corrections (for review see Elliott et al., 2010). As such, the %TAPV and  $R^2$  values (longitudinal axis) associated with the monocular condition indicates a reduced level of online control compared to the binocular condition. This assertion is consistent with neuroimaging and neuropsychological evidence reporting that monocular reaches employ perception-based cues such as texture, illumination, perspective, and contextual information – visual information that has been shown to render a slow and offline mode of control supported via the visuoperceptual networks of the ventral visual pathway (Rossetti et al., 2005). In turn, the more efficient evocation of binocular reaches evinces that stereoptic depth cues afforded an online mode of control supported via the fast visuomotor networks of the

dorsal visual pathway (Dijkerman & Milner, 1996; Dijkerman et al., 1998; Goodale, 2014; Marotta et al., 1997).

Previous work has generally reported that binocular reaches produce more accurate and less variable endpoints than their monocular counterparts (Heath et al., 2008; Hu & Knill, 2011). Thus, an important issue to address is why my binocular and monocular conditions achieved equivalent endpoint parameters. One possible reason for this discrepancy is that previous work has presented computer-generated target objects. As demonstrated by Hu and Knill (2011) the absence of penumbrae (i.e., shadowing) associated with such images can result in a ‘distrust’ of monocular visual information and therefore render decreased endpoint accuracy. Of course, in the present study, target penumbrae were equated across monocular and binocular conditions. A second possibility is that previous work has involved reaches to targets embedded in the surface of a stimulus-board or projected by a computer monitor. For example, Heath et al. (2008) presented targets embedded into a stimulus-board and thus allowed reaches to be completed without the need for the effector to land within the target boundary; that is, the participant (and not the physical boundary of the target) determined the tolerance for an acceptable level of endpoint precision. In contrast, I employed targets presented in the picture plane (surface of 20 mm by 20 mm) that were disparate in depth from a stimulus board – a manipulation used to increase the reliance on depth cues to support the specification of a movement endpoint. As a result, participants were required to place their finger on the physical surface of a target to complete their reaching response – a manipulation that decreased the potential for observing between-condition differences in endpoint accuracy or variability. In support of this view, it is important to recall that monocular trials were associated with a ‘cost’ such that responses were less ‘efficient’, and my kinematic analyses demonstrated that binocular and monocular reaches were associated with different control strategies (i.e., online vs. offline). Thus, my results demonstrate a difference in the control of monocular and binocular reaches and thereby provide a framework for determining whether the presence/absence of stereo-cues differentially influence the control of reaches performed in the loVF versus the upVF.

*Closed-loop versus open-loop reaches*



The CL group exhibited lower  $R^2$  values (mediolateral and longitudinal axes) than the OL group during the later stage of the response (i.e., > 60% of MT). In addition, the CL group produced shorter MTs than the OL group in binocular and monocular conditions; however, the largest advantage for the CL group was associated with the binocular condition. In other words, binocular reaches performed with online vision resulted in the most efficient reaching response. Regarding, the general difference between CL and OL groups, such results are consistent with a myriad of studies demonstrating that continuous limb and target vision advantages the evocation of error-reducing trajectory corrections (For review see Elliott et al., 2010). Moreover, it has been shown that visual feedback from the late portion of a movement trajectory (i.e., movement deceleration) is more useful than the early stage of the response in effecting trajectory corrections (Carlton, 1981; Chua & Elliott, 1997). In particular, the presence of continuous limb vision has been shown to represent the sensorimotor environment that advantages the adoption of an online mode of control (Heath et al., 2010). In contrast, removing target and limb vision engenders a response that is planned primarily in advance via central planning mechanisms and renders a decrease in movement efficiency (Heath, 2005; Heath et al., 2004; Meyer et al., 1988; Schmidt et al., 1979; for review see Heath et al., 2010). Further, that the MTs for the CL group were shortest during the binocular condition indicates that online corrections specified via binocular cues provided the optimal environment for reaching efficiency. Of course, such a result is important in the context of the present work because it provides a framework for determining whether the optimal environment for reaching efficiency is influenced by the visual field (i.e., loVF vs. upVF) in which a target is presented.

The results for constant error in the depth direction (i.e.,  $CE_z$ ) and variable error in distance ( $VE_y$ ) and depth ( $VE_z$ ) yielded three-way interactions involving group by stereo-cue by visual field. The nature of this interaction did not show any reliable differences between loVF and upVF reaches (see details in following section). Instead, results showed that upVF monocular reaches in the OL group were less accurate and more variable than their matched CL group counterparts, whereas loVF binocular and monocular reaches did not vary between groups. I am unable to offer a theoretically motivated explanation to account for the differences described above. What is more, I

recognize that any such explanation counters my previous assertion that condition-based differences in reaching accuracy were unexpected due to the tolerance demands associated with the target presentation used here. That said, inspection of Figure 4 indicates that the stated difference between the OL and CL group's monocular upVF reaches were modest (i.e., CL vs OL difference score:  $CE_z = 12$  mm and  $VE_z = 34$  mm), and as a result, such a finding may not represent a salient group- and condition-specific difference in the manner that responses were controlled.

*No evidence for a loVF advantage in the planning or online control of goal-directed reaches*

As outlined in the Introduction, the literature examining a loVF advantage for the control of goal-directed reaching/grasping is divided. Some work has reported a reliable loVF advantage for speed-accuracy relations (Danckert & Goodale, 2001) and online trajectory amendments (Khan & Lawrence, 2005; Rossit et al., 2013). In contrast, other work has shown that loVF and upVF reaches exhibit equivalent speed-accuracy relations and efficiency of trajectory corrections (Binsted & Heath, 2005; Krigolson & Heath, 2006). My results support the latter findings in that I did not observe any reliable differences in MT, %TAPV or endpoint properties for loVF and upVF reaches – an effect that was consistent across stereo-cue and visual feedback manipulations. Moreover, analyses of  $R^2$  findings did not evince a difference in the degree to which loVF and upVF reaches were controlled online. In fact, and in spite of findings demonstrating that the CL group exhibited optimized reaching efficiency in the binocular condition, my results demonstrate that this manipulation did not impart a loVF advantage.

In reconciling the results of my study with those reporting a loVF advantage a number of differences in methodology should be considered. Khan and Lawrence (2005) required loVF and upVF reaches to be completed within a movement time criterion of  $400 \pm 10\%$  ms<sup>1</sup>, a range which ensured that reaches were not ballistic and elicited an online mode of control (Elliott et al., 2001). Therefore, it is not likely the information processing

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<sup>1</sup> Khan and Lawrence (2005) did not report movement IDs.

demands – and required online corrections – used here account for the between-experiment discrepancy (Carlton & Carlton, 1987; Crossman & Goodeve, 1983; Howarth et al., 1971; Vince & Welford, 1967; for review see Elliott et al., 2001). As well, both the present study and Khan and Lawrence (2005) presented targets 16 ° above and below the central visual axis – as a result between-experiment differences cannot relate to the eccentricity by which the targets were presented in the vertical retinal axis. It is, however, important to recognize Khan and Lawrence employed upVF and loVF trials in separate blocks. This is an important consideration as a blocked presentation affords participants the opportunity to learn from previous trials (i.e., a strategic adaption and/or offline learning) and therefore may not provide direct evidence of a loVF advantage in online control (Wolpert et al., 1995). In contrast, in my study up- and loVF trials were randomly presented on a trial-by-trial basis such that the depth and location of a target on participants' retina was varied on each trial – a manipulation that required trial-specific sensorimotor transformations (Flanders et al., 1992). Further, in accounting for the between-experiment difference between my work and that of Danckert and Goodale (2001) it is important to note that the latter study employed a very low range of IDs (0.3-1.5 bits) which would have resulted in a ballistic and offline mode of control (Fitts, 1954; see also Gan & Hoffmann, 1988). In contrast, my work employed a target ID of 6.6 bits which is known to elicit reliable speed-accuracy relations and online trajectory amendments. As a result, my study demonstrates that the reported anatomical asymmetry associated with the vertical visual field does not infer an advantage for the online reaching control.

It should be noted that my study is not the first to report a null loVF for online control. Binsted and Heath (2005) as well as Krigolson and Heath (2006) reported a null advantage for online control; however, in those studies it was also reported that the loVF produced less variable endpoints than their upVF counterparts and was a result attributed to enhanced central planning. Again, it should be noted that the studies presenting a loVF advantage for endpoint variability used computer-generated targets or targets embedded in a stimulus board (Binsted & Heath, 2005; Krigolson & Heath, 2006). In contrast, the targets used in the present study were disparate from the stimulus board and

resulted in an equivalent tolerance for loVF and upVF reaches. Given that the present results did not yield a difference between loVF or upVF across any of the performance or kinematic variables reported here I believe it justified to assert that the planning and control mechanisms mediating a reaching response to a depth target are not influenced by the visual field in which the response occurs.

The present results add to an accumulating literature indicating that the increased density of retinal ganglion cells in the upper-hemiretina does not infer a reliable or systematic loVF advantage for goal-directed reaches (Binsted & Heath, 2005; Krigolson & Heath, 2006). Moreover, it is important to recognize that although Curcio and Allen (1990) reported that the superior retina has a 65% increase in the density of retinal ganglion cells at 4 mm beyond the vertical meridian (compared to the inferior retina), the authors also documented considerable between-sample variability and reported that the vertical visual field asymmetry associated with the retinal samples used in their study (i.e., 6 human retinas including two fellow eyes) sometimes diminished when disparities in superior and inferior retinal surface area were equated. Moreover, visual processing areas including the early visual cortex (Liu et al., 2006; Portin & Hari, 1999; Portin et al., 1999) and the lateral occipital cortex (Sayres & Grill-Spector, 2008; Strother et al., 2010) have only shown a loVF advantage in object detection and discrimination tasks which do not reflect neural correlates attributed to a visuomotor advantage. Notably, Rossit et al. (2013) showed increased activation of SPOC and left precuneus when grasping to stimuli in the loVF – cortical regions which are associated with visuomotor networks of the dorsal pathway. It is, however, important to recognize that their task was completed in an open-loop (OL) environment. As stated above, OL actions are not mediated via extensive online corrections and as a result the reported loVF and visuomotor network activation may relate to a process other than advantaged online control. In other words, the anatomical evidence for a vertical visual field advantage is equivocal.

### *Limitations*

It is important to note two potential limitations not foreseen in the design of the present experiment. Firstly, as mentioned prior, utilizing a target with a small surface area that

protruded from the stimuli board limited the effective target boundary and may have resulted in participants producing more accurate reaches. Perhaps future experiments of similar design should still use a 10 mm diameter LED embedded to the target, but should increase the target's surface area. This would extend the effective target boundary and allow participants to conduct reaches with a greater range of acceptable error. However, both the feedback group and stereo-cue manipulations revealed variations in timing to allow greater accuracy in the OL and monocular conditions whereas the visual field manipulation resulted in no timing differences. This suggests that the target used in the present experiment sufficiently allowed for differences, however, lack thereof between visual fields in both accuracy *and* timing leads to the conclusion that there are no visual field differences in online control. Secondly, the two feedback groups had different participants resulting in a mixed ANOVA which decreases the power of my experimental design. Obviously, lack of power can result in lack of differences. However, results revealing greater online control were present with both the feedback group and stereo-cue manipulations which indicate the power of this study was sufficient to produce reliable differences. Additionally, the TNO test revealed stereo-cue abilities were equal across the two feedback groups, allowing the conclusion that any differences were indeed due to the experimental manipulations and not the population sample.

### *Conclusion*

The present study provided the expected demonstration that binocular and closed-loop reaches are more efficient and demonstrate more online corrections than their monocular and open-loop counterparts. Notably, however, I found that the presentation of a target in the loVF or the upVF did not influence the control characteristics associated with my stereo-cue and visual feedback manipulations. In other words, my results did not demonstrate that reaches performed in the loVF elicit advantaged movement planning or online control compared to their upVF counterparts. I believe that such findings add importantly to the literature inasmuch as they demonstrate that a possible vertical field asymmetry in retinal cell density does not consistently or reliably impart a functional advantage for goal-directed actions.

## References

- Binsted, G., & Heath, M. (2005). No evidence of a lower visual field specialization for visuomotor control. *Experimental Brain Research*, *162*, 89–94.
- Brown, L. E., Halpert, B. A., & Goodale, M. A. (2005). Peripheral vision for perception and action. *Experimental Brain Research*, *165*, 97–106.
- Carlton, L. G. (1981). Processing visual feedback information for movement control. *Journal of Experimental Psychology: Human Perception and Performance*, *7*(5), 1019–1030.
- Carlton, L. G., & Carlton, M. J. (1987). Response amendment latencies during discrete arm movements. *Journal of Motor Behavior*, *19*(2), 227–239.
- Chua, R., & Elliott, D. (1997). Visual control of target-directed movements. *Behavioral and Brain Sciences*, *20*(2), 304–306.
- Crossman, E. R. F. W., & Goodeve, P. J. (1983). Feedback control of hand-movement and Fitts' law. *Journal of Experimental Psychology*, *35A*, 251–278.
- Curcio, C., & Allen, K. (1990). Topography of ganglion cells in human retina. *Journal of Comparative Neurology*, *300*(1), 5–25.
- Danckert, J., & Goodale, M. A. (2001). Superior performance for visually guided pointing in the lower visual field. *Experimental Brain Research*, *137*, 303–308.
- Danckert, J., & Goodale, M. A. (2003). Ups and downs in the visual control of action. In *Taking action: Cognitive neuroscience perspectives on intentional acts* (pp. 29–64).
- Dijkerman, H. C., & Milner, A. D. (1998). The perception and prehension of objects oriented in the depth plane.2. Dissociated orientation functions in normal subjects. *Experimental Brain Research*, *118*, 408–414.
- Dijkerman, H. C., Milner, A. D., & Carey, D. P. (1996). The perception and prehension

- of objects oriented in the depth plane I. Effects of visual form agnosia. *Experimental Brain Research*, 112, 442–451.
- Elliott, D., Hansen, S., Grierson, L. E. M., Lyons, J., Bennett, S. J., & Hayes, S. J. (2010). Goal-directed aiming: two components but multiple processes. *Psychological Bulletin*, 136(6), 1023–1044.
- 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.
- Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47, 381–391.
- Fitts, P. M., & Peterson, J. R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology*, 67(2), 103–112.
- Flanders, M., Helms Tillery, S., & Soechting, J. (1992). Early stages in a sensorimotor transformation. *Behavioral and Brain Sciences*, 15(2), 309–320.
- Gan, K., & Hoffmann, E. (1988). Geometric conditions for ballistic and visually controlled movements. *Ergonomics*, 31(5), 829–839.
- Goodale, M. A. (2011). Transforming vision into action. *Vision Research*, 51, 1567–
- Goodale, M. A. (2014). How (and why) the visual control of action differs from visual perception. *Proceedings of the Royal Society B: Biological Sciences*, 281.
- Heath, M. (2005). Role of limb and target vision in the online control of memory-guided reaches. *Motor Control*, 9, 281–311.
- Heath, M., Neely, K. A., Krigolson, O., & Binsted, G. (2010). Memory-Guided Reaching : What the Visuomotor System Knows and How Long It Knows It. In *Vision and goal-directed movement: Neurobehavioural perspectives* (pp. 79–97). Champaign, IL: Human Kinetics.
- Heath, M., Neely, K., & Krigolson, O. (2008). Response modes influence the accuracy of

- monocular and binocular reaching movements. *Motor Control*, 12, 252–266.
- Heath, M., Weiler, J., Marriott, K. A., Elliott, D., & Binsted, G. (2011). Revisiting Fitts and Peterson (1964): Width and amplitude manipulations to the reaching environment elicit dissociable movement times. *Canadian Journal of Experimental Psychology*, 65(4), 259–268.
- Heath, M., Westwood, D. A., & Binsted, G. (2004). The control of memory-guided reaching movements in peripersonal space. *Motor Control*, 8, 76–106.
- Howarth, C. I., Beggs, W. D. A., & Bowden, J. M. (1971). The relationship between speed and accuracy of movement aimed at a target. *Acta Psychologica*, 35, 207–218.
- Hu, B., & Knill, D. C. (2011). Binocular and monocular depth cues in online feedback control of 3D pointing movement. *Journal of Vision*, 11(7), 1–13.
- Johansson, J., Seimyr, G. Ö., & Pansell, T. (2015). Eye dominance in binocular viewing conditions. *Journal of Vision*, 15(9)(21), 1–17.
- Khan, M. A., & Lawrence, G. P. (2005). Differences in visuomotor control between the upper and lower visual fields. *Experimental Brain Research*, 164, 395–398.
- Krigolson, O., & Heath, M. (2006). A lower visual field advantage for endpoint stability but no advantage for online movement precision. *Experimental Brain Research*, 170, 127–135.
- Liu, T., Heeger, D. J., & Carrasco, M. (2006). Neural correlates of the visual vertical meridian asymmetry. *Journal of Vision*, 6, 1294–1306.
- Marotta, J. J., Behrmann, M., & Goodale, M. A. (1997). The removal of binocular cues disrupts the calibration of grasping in patients with visual form agnosia. *Experimental Brain Research*, 116, 113–121.
- Meyer, D. E., Abrams, R. A., Kornblum, S., Wright, C. E., & Smith, J. E. K. (1988). Optimality in human motor performance: ideal control of rapid aimed movements.



*Psychological Review*, 95(3), 340–370.

- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97–113.
- Pedhazur, E. J. (1997). *Multiple regression in behavioral research*. Orlando, FL: Harcourt Brace.
- Pisella, L., Gréa, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., ... Rossetti, Y. (2000). An “automatic pilot” for the hand in human posterior parietal cortex: toward reinterpreting optic ataxia. *Nature Neuroscience*, 3(7), 729–736.
- Portin, K., & Hari, R. (1999). Human parieto-occipital visual cortex: lack of retinotopy and foveal magnification. *Proceedings: Biological Sciences*, 266(1423), 981–985.
- Portin, K., Vanni, S., Virsu, V., & Hari, R. (1999). Stronger occipital cortical activation to lower than upper visual field stimuli. Neuromagnetic recordings. *Experimental Brain Research*, 124, 287–294.
- Previc, F. H. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. *Behavioral and Brain Sciences*, 13, 519–575.
- Previc, F. H. (1998). The neuropsychology of 3-D space. *Psychological Bulletin*, 124(2), 123–164.
- Rossetti, Y., Revol, P., McIntosh, R., Pisella, L., Rode, G., Danckert, J., ... Milner, A. D. (2005). Visually guided reaching: bilateral posterior parietal lesions cause a switch from fast visuomotor to slow cognitive control. *Neuropsychologia*, 43, 162–177.
- Rosit, S., McAdam, T., Mclean, D. A., Goodale, M. A., & Culham, J. C. (2013). FMRI reveals a lower visual field preference for hand actions in human superior parieto-occipital cortex (SPOC) and precuneus. *Cortex*, 49, 2525–2541.
- Sayres, R., & Grill-Spector, K. (2008). Relating retinotopic and object-selective

- responses in human lateral occipital cortex. *Journal of Neurophysiology*, *100*, 249–267.
- Schmidt, R. A., Zelaznik, H., Hawkins, B., Frank, J. S., & Quinn Jr., J. T. (1979). Motor-output variability: A theory for the accuracy of rapid motor acts. *Psychological Review*, *86*(5), 415–451.
- Servos, P., Goodale, A., & Jakobson, S. (1992). The role of binocular vision in prehension: a kinematic analysis. *Vision Research*, *32*(8), 1513–1521.
- Servos, P., & Goodale, M. a. (1994). Binocular vision and the on-line control of human prehension. *Experi*, *98*, 119–127. R
- Strother, L., Aldcroft, A., Lavell, C., & Vilis, T. (2010). Equal degrees of object selectivity for upper and lower visual field stimuli. *Journal of Neurophysiology*, *104*, 2075–2081.
- Vince, M. A., & Welford, A. T. (1967). Time taken to change the speed of a response. *Nature*, 532–533.
- Walraven, J. (1972). *TNO Test for stereoscopic vision*. Lameris Instrumenten, Utrecht.
- Westwood, D. A., & Goodale, M. A. (2003). Perceptual illusion and the real-time control of action. *Spatial Vision*, *16*(3–4), 243–254.
- Wolpert, D. M., Ghahramani, Z., & Jordan, M. (1995). An internal model for sensorimotor integration. *Science*, *269*(5232), 1880–1882.

# Appendices

## Appendix A: University of East Anglia Ethics Approval

### UNIVERSITY OF EAST ANGLIA SCHOOL OF PSYCHOLOGY RESEARCH ETHICS PROJECT DECISION

Project: Monocular and Binocular Influence on Eye Fields: A Reaching Study  
Ref no: 2016-0199-000232  
Decision: Revision: 0  
Decision: accepted  
Date: 19-04-2016

Dear Jennifer Campbell,

Thank you for your application to the committee. I have received detailed reviews from 2 reviewers (see below). One reviewer identified a sentence that should be re-worded for clarity. The application is accepted.

Thank you,  
paul

Dr. Paul Engelhardt  
Lecturer  
School of Psychology  
University of East Anglia

Reviewer 1:  
Recommendation: accept

Reviewer 2:  
Recommendation: minor  
On both the information sheet and the debrief it says "This research is examining the speed and accuracy of a reaching task directed towards a target," suggesting you are examining speed of the tasks, rather than the reaches. Both documents should read "This research is examining the speed and accuracy of reaches directed towards a target".

## Appendix B: University of Western Ontario Ethics Approval



Research Ethics

### Western University Non-Medical Research Ethics Board NMREB Delegated Initial Approval Notice

**Principal Investigator:** Dr. Matthew Heath  
**Department & Institution:** Health Sciences/Kinesiology, Western University

**NMREB File Number:** 108028

**Study Title:** Role of monocular and binocular vision in pointing to a target in the upper- and lower-visual fields

**NMREB Initial Approval Date:** April 29, 2016

**NMREB Expiry Date:** April 29, 2017

#### Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Other	Consent Form - Received April 27, 2016	
Advertisement	Recruitment Poster - Received April 27, 2016	
Letter of Information & Consent	Letter of Information - Received April 27, 2016	
Western University Protocol	Received April 27, 2016	
Other	Debriefing Script - Received April 27, 2016	
Instruments	Handedness and demographic and health questionnaire. Received April 27, 2016	

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

## Appendix C: Participant Information Sheet

School of Psychology

**Study Title:** Monocular and Binocular Influence on Action: A Reaching Study



### PARTICIPANT INFORMATION SHEET

Thank you for your interest in this study. Before you decide whether to take part, please read the following information carefully (this sheet is for you to keep). You may ask me any questions if you would like more information.

#### ***What is this research looking at?***

This research is examining the speed and accuracy of a reaching task directed towards a target. We are particularly interested in any differences in the efficiency of reaching when binocular and monocular vision is manipulated in upper and lower visual hemi-fields. The data from normal healthy subjects will help us understand how vision is used to support goal-directed actions.

#### ***Do I have to take part?***

It is up to you if you want to take part in the study. This information sheet will explain what the study is about, please feel free to ask any questions. If you agree to take part, you'll be asked to sign a consent form. You are free to withdraw from the study at any time without giving a reason. Withdrawing does not affect you in any way.

#### ***What will happen if I agree to take part?***

If you agree to take part in this study, first you will fill out a questionnaire assessing your health. Please note that you may omit answering any question without penalty. We will then ask you to wear some IRED markers on your wrist, thumb and index finger along with the Plato goggles. You will then be sat in front of a vertical board which will have LEDs that will be illuminated. You will have to fixate on a light and then perform a grasping movement while maintaining fixation.

#### ***Are there any problems with taking part?***

You may experience fatigue, but there will be times for you to be able to take a break between tasks and feel free to ask for additional breaks. There are no known risks associated with your participation in this study. However, if you experience any discomfort let us know and we will stop the testing right away.

#### ***Will it help me if I take part?***

While this study will not result in any direct benefit to you, it may help researchers understand how practicing skills can enhance visual and motor preferences.

***How will you store the information that I give you?***

All information which you provide during the study will be stored in accordance with the 1998 Data Protection Act and kept strictly confidential. Any data resulting from your participation will be identified only by anonymised codes, without any reference to your name or personal information. The data will be stored on a secure computer in a locked room. Both the computer and the room will be accessible only to the experimenters. After completion of the experiment, data will be archived on storage disks and stored in a locked room for five years, after which they will be destroyed.

***How will the data be used?***

The data will be kept anonymous and has the potential to be presented at conferences and/or published, participants' names and personal information will remain confidential.

***What happens if I agree to take part, but change my mind later?***

You are free to withdraw at any point to guarantee the anonymity of your data there will not be a link between your name and the data we collect after you complete your involvement. Therefore, once you participation has finished you will not be able to withdraw your data from the study.

***How do I know this research is safe for me to take part in?***

This research has been reviewed by the research ethics committee in order to protect your safety, rights and wellbeing. This research was approved by the Psychology Research Ethics Committee at the University of East Anglia on [date].

**You are under no obligation to agree to take part in this research. If you do agree you can withdraw at any time without giving a reason.**

**If you wish to ask any questions about the research please contact:**

Dr Stephanie Rossit

Jennifer Campbell

**Do also contact us if you have any worries or concerns about this research.**

School of Psychology Ethics Committee:

Head of School Professor Kenny Coventry:

## Appendix D: Consent Form

School of Psychology



### Consent Form

#### Monocular and Binocular Influence on Action: A Reaching Study

Name of Researcher: Jennifer Campbell & Dr. Stephanie Rossit

Please initial all boxes

1. I have read and understand the information sheet and have had the opportunity to questions and have had these answered satisfactorily.
2. My participation is voluntary and I know that I am free to withdraw at any time, without giving any reason and without it affecting me at all
3. I know that no personal information (such as my name) will be shared outside of the research team or published in the final report(s) from this research
4. I agree to take part in the above study

Participant's  
signature.....Date.....

#### Researcher Contact details:

*Dr Stephanie Rossit*

*Jennifer Campbell*

Do also contact us if you have any worries or concerns about this research.

School of Psychology Ethics Committee:

Head of School Professor Kenny Coventry:

## Appendix E: Edinburgh Handedness & Demographic and Health Questionnaires



### EDINBURGH HANDEDNESS QUESTIONNAIRE

#### Monocular and Binocular Influence on Action: A Reaching Study

Participant anonymised initials:

Name of researcher: Jennifer Campbell & Dr Stephanie Rossit

*Please fill in this questionnaire only if you have agreed to take part in our studies and have signed the appropriate consent form. Please note that you may omit answering any question without penalty and that this information will be kept strictly confidential.*

For each of the activities below, please tell us:

Which hand do you prefer for that activity? Do you ever use the other hand for the activity?

	Left (L) or Right (R)	Do you ever use the other hand? Yes or No
Signing		
Writing		
Drawing		
Throwing		
Using scissors		
Using a Toothbrush		
Using a Knife (without a fork)		
Using a Spoon		
Using a Broom (upper hand)		
Striking a Match		
Opening a Box (lid)		
Foot to Kick With		
Bat (swing)		

- Do you consider yourself: (circle appropriate)  
Right-handed                      Left Handed                      Ambidextrous (both hands)
- Is there anyone in your family who is Left-handed? (circle appropriate)    Yes or No  
If yes, who \_\_\_\_\_
- Did you ever change handedness? (circle appropriate)                      Yes or No  
If yes, please explain \_\_\_\_\_  
\_\_\_\_\_
- Is there any activity not on this list that you do consistently with your left hand? If so, please Explain \_\_\_\_\_  
\_\_\_\_\_

### DEMOGRAPHIC AND HEALTH QUESTIONNAIRE

This handedness questionnaire was adapted from: Oldfield, R.C. (1971) The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113.





## Monocular and Binocular Influence on Action: A Reaching Study

Participant anonymised initials:

Name of experimenter: Jennifer Campbell & Dr. Stephanie Rossit

*Please fill in this questionnaire only if you have agreed to take part in our studies and have signed the appropriate consent form. Please note that you may omit answering any question without penalty and that this information will be kept strictly confidential.*

Gender:

Age:

Years of education:

Do you suffer from any vision problems (e.g., cataract, glaucoma, lazy eye, amblyopic)?

YES NO

If yes please describe:

Which of the following best describes your eye sight?

I have normal vision

I wear prescription glasses

I wear contact lenses

Do you suffer from any motor problems (e.g., osteoarthritis, arthritis, paralysis)?

YES NO

If yes please describe:

Have you ever had any stroke, brain injury or other neurological events (e.g., tumour, dementia, epilepsy)?

YES NO

If yes please describe:

Do you suffer from (or have a family history) of psychological/psychiatric conditions (e.g., depression, anxiety)?

YES NO

If yes please describe:

Are you on any medication or have you recently undergone pharmacological treatment?

YES NO

If yes please describe:

Do you suffer from cardiac or respiratory disease?

YES NO

## Appendix F: Debrief

School of Psychology



### Debrief

#### **Monocular and Binocular Influence on Action: A Reaching Study**

**Thank you** for participating in this study. Your time and efforts are much appreciated.

In this experiment, we examine the speed and accuracy of a reaching task directed towards a target. We are particularly interested in any differences in the efficiency of reaching when binocular and monocular vision is manipulated in upper and lower visual hemi-fields. The data from normal healthy subjects will help us understand how vision is used to support goal-directed actions.

If you would like to receive a report of the main findings of the study (or a summary of the findings) when it is completed please contact the researcher, however individual feedback on your results cannot be given.

If you have any questions regarding this study please feel free to ask or contact the researcher or supervisor of this study now, or at a later date.

- Principal Investigator: Jennifer Campbell
- Lead Researchers: Dr Stephanie Rossit

Do also contact us if you have any worries or concerns about this research.

School of Psychology Ethics Committee:

Head of School Professor Kenny Coventry:

**Thank you** again for your participation!

## Curriculum Vitae

<b>Name:</b>	Jennifer Campbell
<b>Post-secondary Education and Degrees:</b>	Western University London, Ontario, Canada Masters of Science Candidate, Kinesiology 2017  Western University London, Ontario, Canada B.A. Kinesiology 2011-2015
<b>Honours and Awards:</b>	Western Graduate Research Scholarship (WGRS) Faculty of Health Science, Western University 2015-2017.
<b>Related Work Experience</b>	Graduate Teaching Assistant School of Kinesiology, Western University September 2015 – April 2017 Exercise Nutrition Movement Neuroscience Introduction to Psychomotor Behaviour
<b>Research Presentations:</b>	<b>Campbell, J.,</b> Heath, M. (2017). No evidence that binocular vision enhances online corrections for reaches in the lower-visual field. Poster. Vision Sciences Society  <b>Campbell, J.,</b> Gillen, C., Heath, M. (2016). No evidence supporting perceptual averaging for auditory pro- and antisaccades. Poster. Canadian Society for Psychomotor Learning and Sports Psychology.  <b>Campbell, J.,</b> Gillen, C., Heath, M. (2015). Perceptual averaging for auditory pro- and antisaccades Poster. Canadian Society for Psychomotor Learning and Sports Psychology.