2014

Can gravitational influences explain endpoint precision between visual conditions?

Chelsea Marie Soebbing
Louisiana State University and Agricultural and Mechanical College

CAN GRAVITATIONAL INFLUENCES EXPLAIN ENDPOINT PRECISION BETWEEN VISUAL CONDITIONS?

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Kinesiology

by
Chelsea M. Soebbing
BScOT, University of Alberta, 2008
May 2014

ACKNOWLEDGEMENTS

I would first and foremost like to thank my mentor, Dr. Jan Hondzinski, for her time and dedication in helping me finish my thesis. She has listened to my ideas and read many drafts that helped me present my project and paper in a neat and orderly way for others to enjoy. I also want to thank my committee members – Dr. Arend Van Gemmert and Dr. Sara Winges – for the many hours they have put in to reading my document and helping me become a better student. Finally, I would like to thank my husband and family for their support. Your support and belief in me reminds me I am capable of succeeding in everything I do.

TABLE OF CONTENTS

ABSTRACT

Reaches to remembered target locations often result in different endpoint precision when compared to reaches to actual (seen) targets. Interestingly, errors are observed whether the reach to the remembered location is performed in an environment with or without allocentric cues (visual cues from the environment) available. People tend to point below remembered target locations in the dark relative to normal room lighting while seated, standing, and reaching with a step. In this study we questioned the effect of gravitational influences on upper extremity reaching and pointing accuracy in dark and illuminated environments. We hypothesized that alterations in body orientation would alter endpoint reaches to final remembered target locations differently for the two visual conditions. Young healthy adults were asked to produce reaching movement in SUPINE and UPRIGHT body orientations or straight arm pointing movements in UPRIGHT and INVERTED body orientations to real and remembered target locations. Three targets directly in front of the midline were presented at shoulder level and shoulder level ±30 cm. Prior to movement participants anchored their gaze on the displayed target before pointing to its real or remembered location. Targets in remembered trials were removed or covered before pointing in normal room lighting (LIGHT) or complete darkness (DARK). At least 6 trials were performed to each target in each body orientation, starting arm position, and visual condition. Endpoint errors, displacement, peak velocity, and movement time were calculated for each participant and compared across target level, body orientation, and visual condition for each starting arm position using repeated measures ANOVAs. In the DARK participants often produced errors corresponding to less displacement and the undershooting of remembered target locations as compared to LIGHT and REAL visual conditions. Control of smaller movement amplitudes observed in darkness primarily with greater movement excursions occurred regardless of muscle activation or body orientation. The present study revealed that the effects of

the gravitational pull for endpoint precision in darkness are minimal at best, thus cannot explain the differences in endpoint accuracy between visual conditions.

INTRODUCTION

Goal-directed upper extremity movements, such as reaching or pointing tasks, are commonly utilized to complete activities of daily living. The seemingly effortless coordination of the eyes, head and upper limbs, as well as the lower limbs when a person reaches while standing upright, masks the detailed sensorimotor transformations required by the central nervous system (CNS) to complete the task accurately. Reaches to remembered target locations, which often result in different endpoint locations when compared to reaching to actual targets (e.g. Hondzinski & Cui 2006), emphasize the subtle differences that can influence CNS control for movement precision.

Interestingly, endpoint errors occur whether the reach to a remembered target location is performed in an environment with or without allocentric cues (visual cues within the environment) (Hondzinski and Cui 2006). Upright participants often reach or point below the remembered target location in a dark environment when compared to an illuminated environment whether seated (Bock and Eckmiller 1986; Bock et al. 1992; Henriques et al. 1998; Henriques and Crawford 2000), standing (Admiraal et al. 2004), or reaching with a step (Hondzinski and Cui 2006). This phenomenon of reaching lower in the dark makes one question the cause for the differences in endpoint position. Significant correlations between vertical hand displacements (i.e. along the gravitational vector) and gaze elevation deviations when stepping and reaching to remembered target locations provide evidence that deviations in gaze direction may help explain this phenomenon (Hondzinski and Cui 2006). However, this explanation is incomplete, as gaze direction does not always precisely match endpoint location (Admiraal et al. 2003; Admiraal et al. 2004) (Henriques et al. 1998; Henriques and Crawford 2000; Hondzinski and Cui 2006).

The errors associated with the phenomenon of pointing or reaching lower in the dark along the vertical axis were in alignment with the gravitational vector. Since reaching to

remembered target locations with eyes closed results in significantly greater negative, thus more inferior, errors for standing than those for the supine or prone body orientations, researchers suggest gravitational influences on endpoint control in the dark (Smetanin and Popov 1997). In contrast, greater errors in the superior direction have been observed in upright relative to supine body orientations for blindfolded participants pointing to targets along the anterior surface of their torso (Spidalieri and Sgolastra 2001). Authors proposed these findings as evidence opposing the influence of the gravitational pull on endpoint accuracy without visual cues available at least when pointing to targets along the body. The contrasting evidence of the gravitational vector's influence on reaching accuracy in darkness likely results from different experimental methodology. For example, pointing to externally placed target locations is different than pointing to egocentrically placed target locations. Furthermore, comparing errors along the longitudinal body axis, which was not always aligned with the gravitational vector, do not offer concrete conclusions about gravitational influences on different endpoint precision in environments with and without allocentric cues. Direct exploration of reaching or pointing endpoint errors that occur in different body orientations and visual conditions specifically along the earth-fixed vertical is warranted to make conclusions about gravitational influences on endpoint accuracy in the dark.

The phenomenon of reaching or pointing lower in the dark has commonly occurred for movements to targets positioned at a further distance from the starting hand position. For targets at shoulder height or higher (i.e. targets located further away from starting hand position at the hip), participants who simultaneously reached while stepping to a remembered target location reached more inferior in the dark as compared to a lit environment (Hondzinski and Cui 2006). For participants in a seated body orientation, under-reaching/undershooting remembered target

locations in the dark occurred for the target that was furthest from the body and start hand position (Henriques et al. 2003). This trend of less movement displacement for reaches in the dark occurs most often for movement excursions for longer distances whether more parallel or perpendicular to the gravitational vector.

Gravitational influence and movement distance are possible factors impacting the phenomenon of pointing lower to a remembered target location in the dark as compared to a lit environment. This leaves one to question, does reaching or pointing below the remembered target location in the dark relative to normal room lighting link to gravitational influences, moving less distance, or both? In order to gain insight to this question the primary purpose of this study was to further investigate the effect of gravitational influences on upper extremity reaching and pointing accuracy in dark and illuminated environments. Alterations in body orientations which influenced the movement direction of the upper extremity in relation to the earth-fixed vertical were used to directly determine whether accuracy differences along the gravitational vector exist for the two visual conditions. Target locations above and below shoulder level as well as different starting arm positions were also utilized to test for the impact of different movement excursions and muscle contraction type on endpoint precision. Based on previous work in which gravitational influences on endpoint accuracy existed for participants reaching to externally placed target locations with eyes closed (Smetanin and Popov 1997), we hypothesized that endpoint accuracy when reaching or pointing in complete darkness would differ for differing body orientations with respect to the gravitational vector. The secondary purpose of this study was to investigate whether participants moved less distance in the dark relative to illuminated environments. Calculation of movement displacement allowed us to determine how far participants moved to each target location in each visual condition to address this purpose. If

endpoint precision was influenced by the gravitational pull, as hypothesized, participants would not always reach less distance in the dark.

METHODS

Experiment 1

Subjects

Seven females and three males who were all right-handed participated in Experiment 1. Ages ranged between 19 and 22 years with an average mass of 67.72±11.3kg, height of 168.42±8.5cm and dominant arm length of 67.69±4.4cm. Participants had no known neurological or musculoskeletal problems to influence task performance and uncorrected or corrected visual acuity better than 20/30. Although acuity for 1 participant was worse than the accepted normal acuity of 20/20, participants had no difficulty viewing targets and were within the accepted acuity of 20/40 for driving in the United States (Owsley and McGwin 1999). Each participant read and signed informed consent prior to participating in the experimental procedures approved by the University's Institutional Review Board (see Appendix).

Experimental set-up

Participants stood UPRIGHT or laid SUPINE with the feet a self-selected comfortable distance apart and the dominant arm bent at the elbow to ~90 degrees (Figure 1A). Reflective markers were placed on specific body landmarks of interest. Figure 1B shows that markers were placed on each shoulder, each ankle, the dominant elbow and wrist, and the tip of a handheld pen. Participants wore a cap equipped with three markers on the top, front and dominant side of the head.

Three targets (1.5cm diameter fishing anchors) were presented individually to participants along the body's mid-sagittal plane at a distance one half arm length (range 30.5-38.1cm) at three different levels: shoulder level and 30cm superior (SUP target) and inferior (INF target) to shoulder level. In the SUPINE body position, the distance between the platform

and the target was 5cm greater than one half the arm length added to the foot length of each participant to account for the slightly forward body position that occurs during stance.

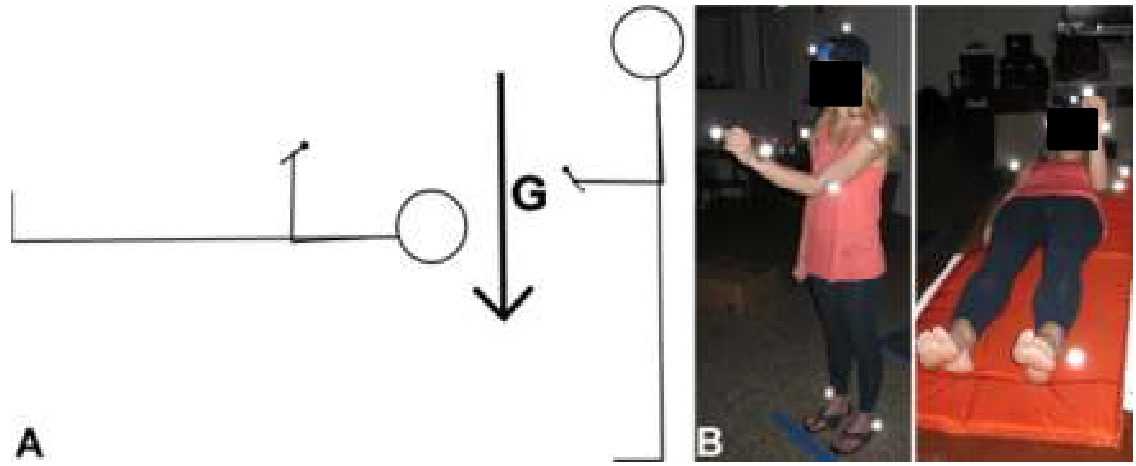

Figure 1: A. Starting position of participants in the SUPINE (left) and UPRIGHT (right) body orientations for Experiment 1. B. Marker placement and end position after reaching to the remembered INF target location in the UPRIGHT (left) and SUPINE (right) body orientations.

Protocol

Prior to movement, a participant would anchor their gaze on a presented target for approximately 2s. After a “ready”, pause (~1s), “go” signal, participants were instructed to make a single reaching movement to place the pen tip just in front of the actual target (REAL) or remembered target locations at a comfortable pace and hold that position for 1-2s until given a “relax” signal. They were instructed to keep their gaze anchored on the REAL target or its remembered location throughout the trial. Movements in remembered trials occurred in normal room lighting (LIGHT) or complete darkness (DARK). Participants were unaware of when the DARK trials would occur as the “ready” signal cued not only manual target removal by an investigator but also lights-out so the participants did not observe target removal or their reach in this condition.

Participants performed three to five practice trials to acquaint themselves with the protocol before performing 54 pseudo randomly ordered reaching movements (6 trials for each visual condition (REAL, LIGHT, DARK) at each target level (shoulder, SUP, INF) for each body orientation (UPRIGHT, SUPINE)) in 2 minute data collection intervals. The trials were pseudo randomly organized into three groups with each visual condition for each target level occurring twice within each group. Trials were repeated when participants did not follow directions (i.e. made obvious movement corrections, moved before the "go" signal, etc). Extra trials were randomly presented and performed in cases when all trials were completed and time was left in the 2 minute data collection interval. Extra trials were utilized to replace substandard trials obtained during collection (i.e., those in which markers were blocked or extra movement occurred that were not observed during data collection). Movements were monitored at 60Hz during task performance using a four camera passive-marker digital video system (Qualysis Medial AB, SE).

Experiment 2

Subjects

Six males and four females between the ages of 18 and 33 years participated in Experiment 2. Nine participants were right-handed and one was left-handed. These participants had an average mass of 72.36±15.5kg and height of 168.01±8.0cm. Participants had uncorrected or corrected visual acuity better than 20/40 (1 participant worse than 20/20), no difficulty viewing targets and no known neurological or musculoskeletal problems to influence task performance. Each participant read and signed informed consent prior to participating in the experimental procedures approved by the University's Institutional Review Board.

Experimental set-up

Participants started in UPRIGHT or INVERTED standing body orientations against a tilt table with the dominant arm extended DOWN by the hip or flexed UP by the ear (Figure 2A). Figure 2B shows that marker placement was similar to Experiment 1 except that participants had one marker placed on their extended dominant fingertip and held no pen. Targets were bright pink dots 1.5cm in diameter located 152cm directly in front of participants on a solid black surface. Target levels along the body midline were the same as Experiment 1.

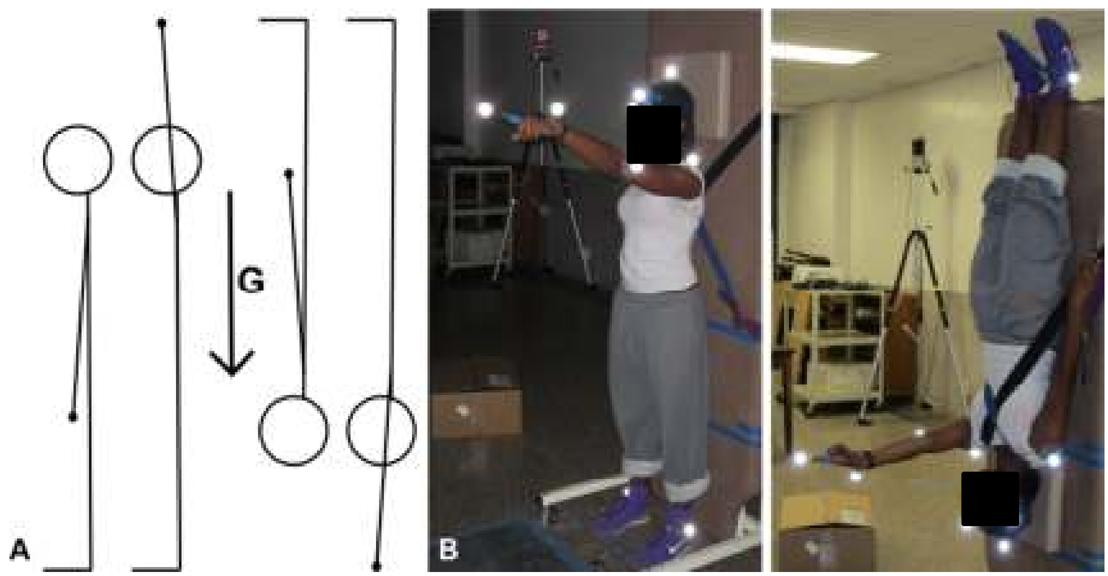

Figure 2: A. Starting positions of participants with arm UP or DOWN in UPRIGHT (left) or INVERTED (right) body orientations for Experiment 2. B. Marker position and final pointing position for UPRIGHT (left) and INVERTED (right) body orientations. Note the flash from the camera lit up the room in the DARK condition. These trials were only used to show experimental setup and not used in analyses.

Protocol

Procedures for this experiment mimicked those of Experiment 1 with the following exceptions. Participants made straight arm pointing movements utilizing primarily the shoulder joint. Targets were covered up with a large black flap that blended with the black background for

remembered target trials. Each group of 54 trials was performed for each start arm position and each body orientation, for which the order was altered across participants (see Table 1).

Table 1: Body orientation and start arm position order for participants in Experiment 2.

Participant	First Position	Second Position	Third Position	Fourth Position
1	UPRIGHT DOWN	INVERTED DOWN	UPRIGHT UP	INVERTED UP
2	UPRIGHT DOWN	INVERTED DOWN	INVERTED UP	UPRIGHT UP
3	UPRIGHT DOWN	INVERTED DOWN	UPRIGHT UP	INVERTED UP
4	INVERTED DOWN	UPRIGHT DOWN	UPRIGHT UP	INVERTED UP
5	UPRIGHT DOWN	INVERTED DOWN	INVERTED UP	UPRIGHT UP
6	INVERTED DOWN	INVERTED UP	UPRIGHT DOWN	UPRIGHT UP
7	INVERTED DOWN	INVERTED UP	UPRIGHT DOWN	UPRIGHT UP
8	UPRIGHT DOWN	UPRIGHT UP	INVERTED DOWN	INVERTED UP
9	INVERTED DOWN	INVERTED UP	UPRIGHT DOWN	UPRIGHT UP
10	INVERTED DOWN	INVERTED UP	UPRIGHT DOWN	UPRIGHT UP

Data Analyses

Trials in which markers of the pen tip for Experiment 1 and fingertip and/or dominant shoulder in Experiment 2 were lost were excluded from analyses and replaced with extra trials when available. Only SUP and INF target levels were included in analyses to include the targets requiring the smallest and largest range of motion by participants and make sure comparisons were for similar shoulder gravitational torques in final pointing positions in Experiment 2.

A 2^{nd} order lowpass Butterworth filter with a 6Hz cutoff frequency was used to filter position data of each marker. The pen tip or fingertip marker position data were differentiated with respect to time to obtain movement velocity. Plots of trial velocity data with a line representing 5% of peak pen tip (or fingertip) velocity allowed for manual identification of the frames at movement onset and end similar to previous work (Gaveau and Papaxanthis 2011). Start and endpoint values correspond to the frame of data just prior to movement onset and after

movement end, respectively. Elevation angles of the shoulder-fingertip line were calculated for the final pointing position in Experiment 2 using the following equations:

$$c = \sqrt{(x_f - x_s)^2 + (y_f - y_s)^2}$$

$$elevation\ angle = atan(z_f - z_s/c)$$

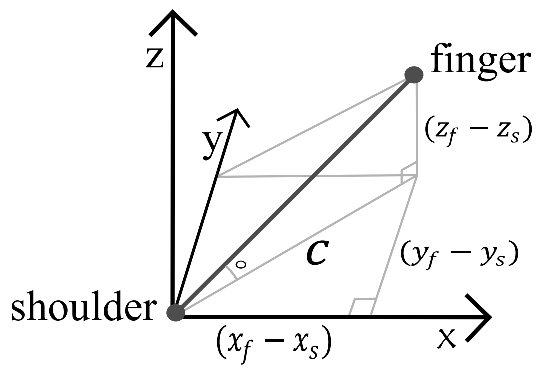

Figure 3: Elevation angle calculation determined in radians for Experiment 2.

where f and s represent the final and starting positions of the finger relative to the shoulder, respectively along the x, y and z axes (medial-lateral, anterior-posterior and superior-inferior, respectively; Figure 3). The primary measure of endpoint errors along the gravitational axis for Experiment 1 (corresponding to the external z-axis) and elevation errors at movement end for Experiment 2 were calculated relative to the mean values of REAL trials (Figure 4) using the following equation:

$$error = trialvalue - avgREAL$$

where trialvalue represents the endpoint z-value of the pen tip (Experiment 1) or elevation error (Experiment 2) for a given trial and avgREAL is the average of corresponding REAL trial endpoint values for a given target level, body orientation and starting arm position. Positive errors represented final endpoints that were more superior than the average location of REAL

endpoints in UPRIGHT and INVERTED body orientations and more anterior than the average REAL endpoints in the SUPINE body orientation.

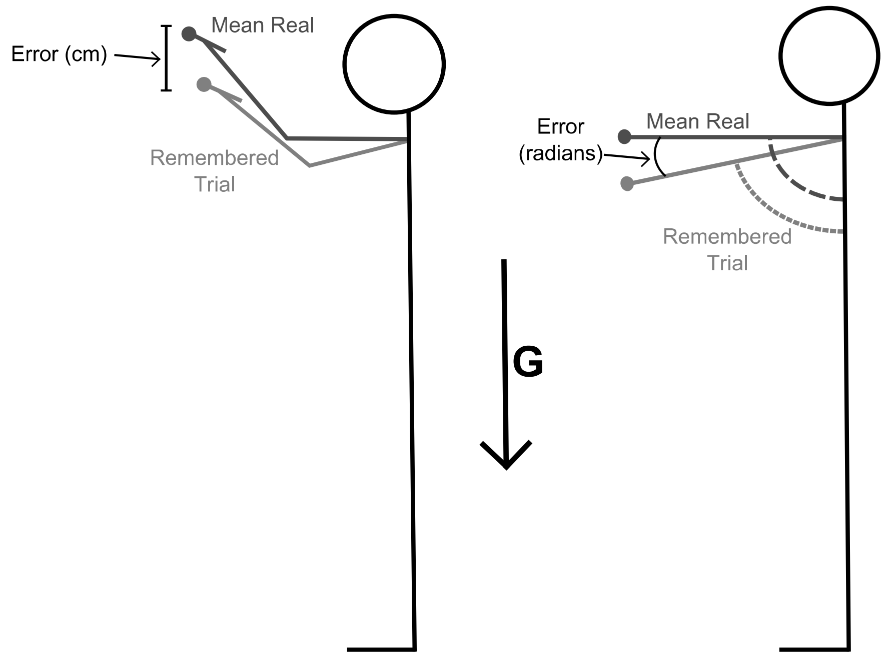

Figure 4. Error calculations for Experiment 1 (left) and Experiment 2 (right). Note that for Experiment 2 overshooting remembered target locations corresponded to positive errors in the arm DOWN starting position and negative errors in the arm UP starting position.

Secondary variables were determined to offer insight to reaching and pointing movements. Displacement (D) for pen tip or fingertip was calculated using the following equation:

$$D = \sqrt{(X_S - X_f)^2 + (Y_S - Y_f)^2 + (Z_S - Z_f)^2}$$

in which X, Y and Z are the 3D values of the pen tip or fingertip and *s* and *f* represent these values at the start and final movement positions, respectively. Movement time (MT) was calculated using the following equation:

$$MT = (frame_{final} - frame_{start})/60$$

where $frame_{final}$ represents the frame of movement in which the movement ended, $frame_{start}$ represents the frame in which movement started, and 60 represents the data collection frequency. Peak velocity (PV) was determined as the maximum velocity during movement of a given trial.

The velocity profile of each pointing or reaching movement was visually inspected to ensure a single movement was used as instructed. Trials without a bell shaped velocity curve indicate sub-movements and were excluded from a secondary analysis of errors using the single movements only in a reduced data set. In order to determine whether precision and movement trends were similar regardless of use of single movements or not, analyses were performed on complete and reduced data sets.

Average values and standard deviations of each variable for each person, target level (SUP, INF), visual condition (LIGHT, DARK), body orientation (Experiment 1: UPRIGHT, SUPINE and Experiment 2: UPRIGHT, INVERTED) and starting arm position were calculated. A 2 x 2 x 2 repeated measures ANOVA determined whether each primary or secondary variable of interest (in complete or reduced data sets) differed according to target level (TARG), visual condition (VIS) and body orientation (ORIENT) for each starting arm position (Experiment 2: DOWN, UP). Tukey's HSD test was used when appropriate. Significance level was set at $\alpha = 0.05$. Additionally, correlations between endpoint errors, displacement, PV and MT were determined for trials from reduced data sets using Pearson's R to offer potential insight to movement control strategies for single goal-directed movements.

RESULTS

Results below are separated by experiment. Because only 61% of trials remained after reducing them for single movements for Experiment 1, we chose to only perform analyses on complete data sets for this experiment. The outcomes of the analysis completed on single movements (reduced data set) follow those on the complete data set for each variable: error, displacement, peak velocity (PV) and movement time (MT) for Experiment 2. Emphasis is placed on significant findings for clarity.

Experiment 1

Endpoint Errors

Figure 5 represents the final positions of the arm/pen tip assembly for one participant after reaching to the REAL or remembered SUP target location in SUPINE and UPRIGHT body orientations. Note that regardless of body orientation, final pen tip position is closer to the starting arm position in the DARK visual condition than the LIGHT visual condition and REAL visual condition.

Table 2 depicts the results for constant and variable errors in the SUPINE and UPRIGHT body orientations. The main effects of TARG and VIS revealed that constant errors in reaching along the gravitational axis were greater for the INF target location (4.13cm) and in the LIGHT visual condition (3.72cm) than for the SUP target location (1.11cm) and in the DARK visual condition (1.52cm), respectively. Errors in reaching were most variable for the UPRIGHT body orientation, however this was only significant for reaches to the INF target location (ORIENT x TARG interaction, Figure 6).

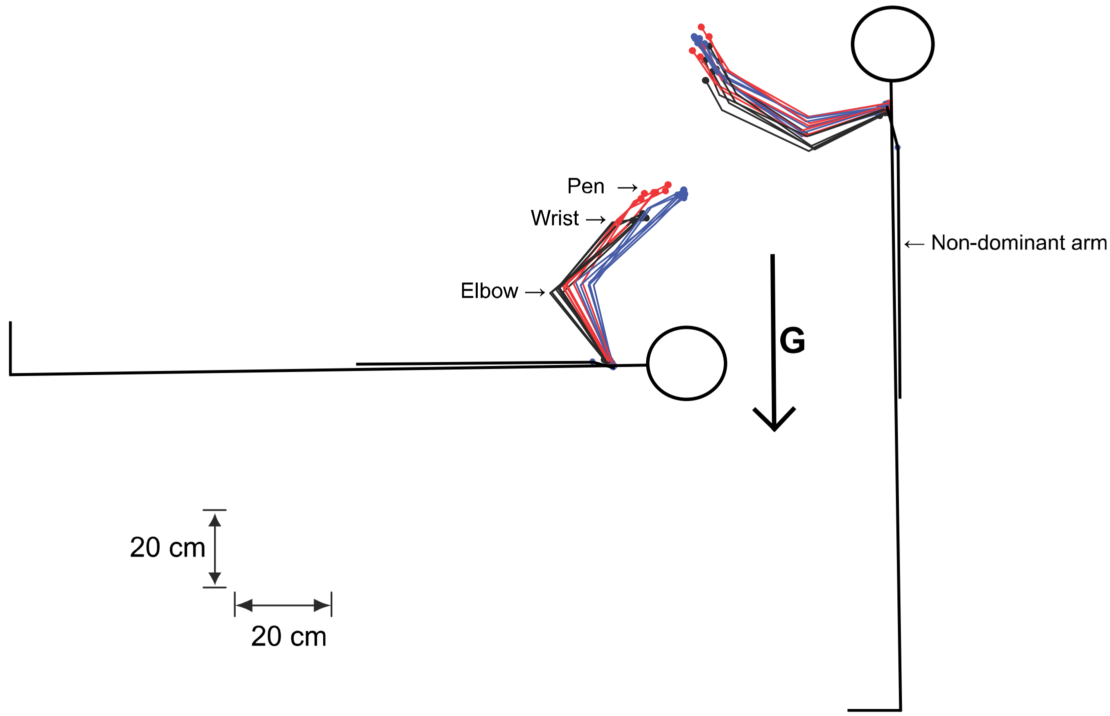

Figure 5: Final shoulder, elbow, wrist and pen tip locations for the SUPINE (left) and UPRIGHT (right) body orientations for the SUP target for one participant. Locations are color coded by visual conditions: red for LIGHT and black for DARK as well as reaches in the REAL condition (blue).

Table 2: Reaching Gravitational Axis Error Results

CONSTANT ERRORS	*F(1,9) value*	*p-value*
TARG	50.49	<0.001
VIS	29.30	<0.001
VARIABLE ERRORS	*F(1,9) value*	*p-value*
ORIENT	8.05	<0.05
ORIENT x TARG	9.70	<0.05

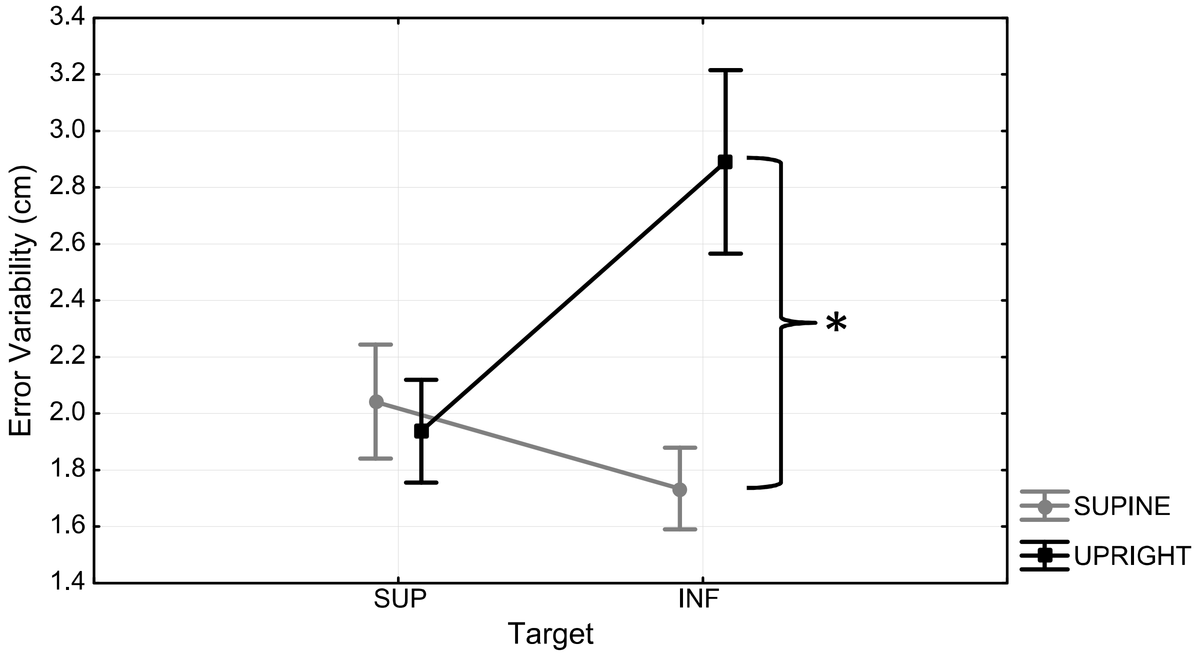

Figure 6: The ORIENT x TARG interaction for variability while reaching. Grey represents the SUPINE orientation and black the UPRIGHT orientation to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level ($p<0.05$).

Displacement

Table 3 depicts the results for mean displacement and its variability. The main effects of TARG and VIS revealed that displacement was greater for reaching movements to the SUP target location (57.1cm) and in the LIGHT visual condition (42.4cm) than reaching movements to the INF target location (25.9cm) and in the DARK visual condition (40.5cm), respectively. The significant ORIENT x TARG interaction revealed differences in displacement between body positions were only significant for reaches to the SUP target location such that displacement for the UPRIGHT body orientation was greater than that for the SUPINE body orientation (Figure 7). The interaction between TARG and VIS revealed differences in displacement between visual conditions were only significant for reaches to the SUP target location with errors in reaching in the LIGHT being greater than those in the DARK (Figure 8). Displacement was also most variable for reaches to the SUP target location.

Table 3: Reaching Displacement Results

MEAN	*F(1,9) value*	*p-value*
TARG	163.43	<0.001
VIS	18.92	<0.01
ORIENT x TARG	15.06	<0.01
TARG x VIS	10.47	<0.01
VARIABILITY	*F(1,9) value*	*p-value*
TARG	6.28	<0.05

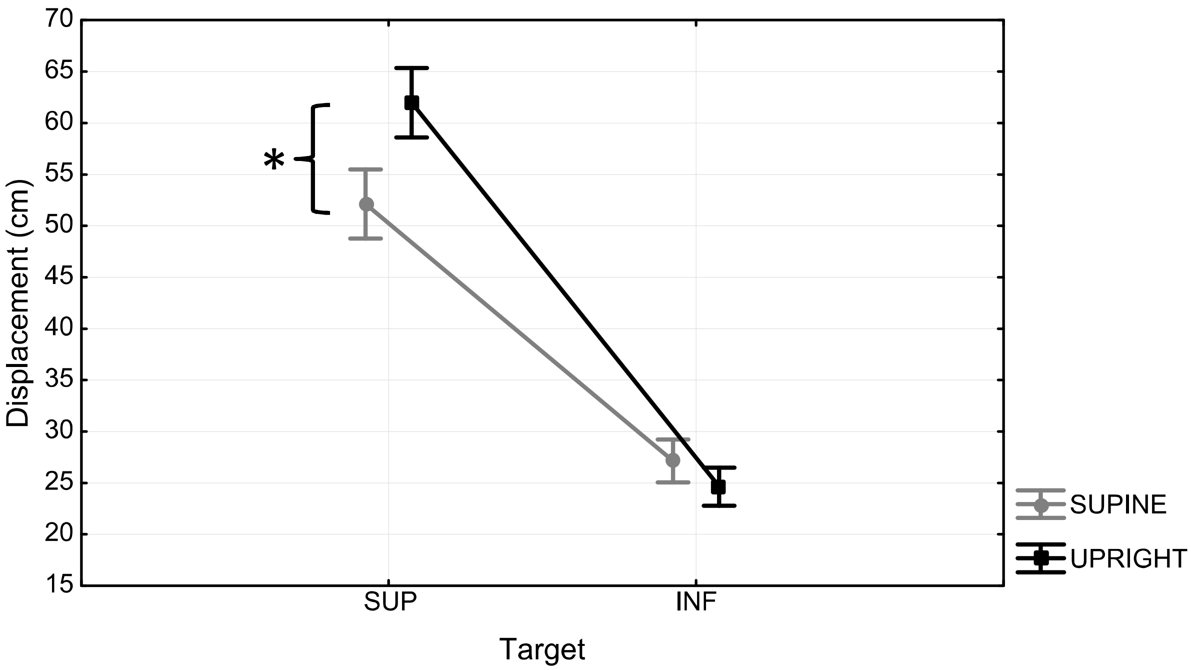

Figure 7: The ORIENT x TARG interaction for displacement of reaching. The grey color represents the SUPINE orientation and black the UPRIGHT orientation to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between body positions for the given target level (p<0.05).

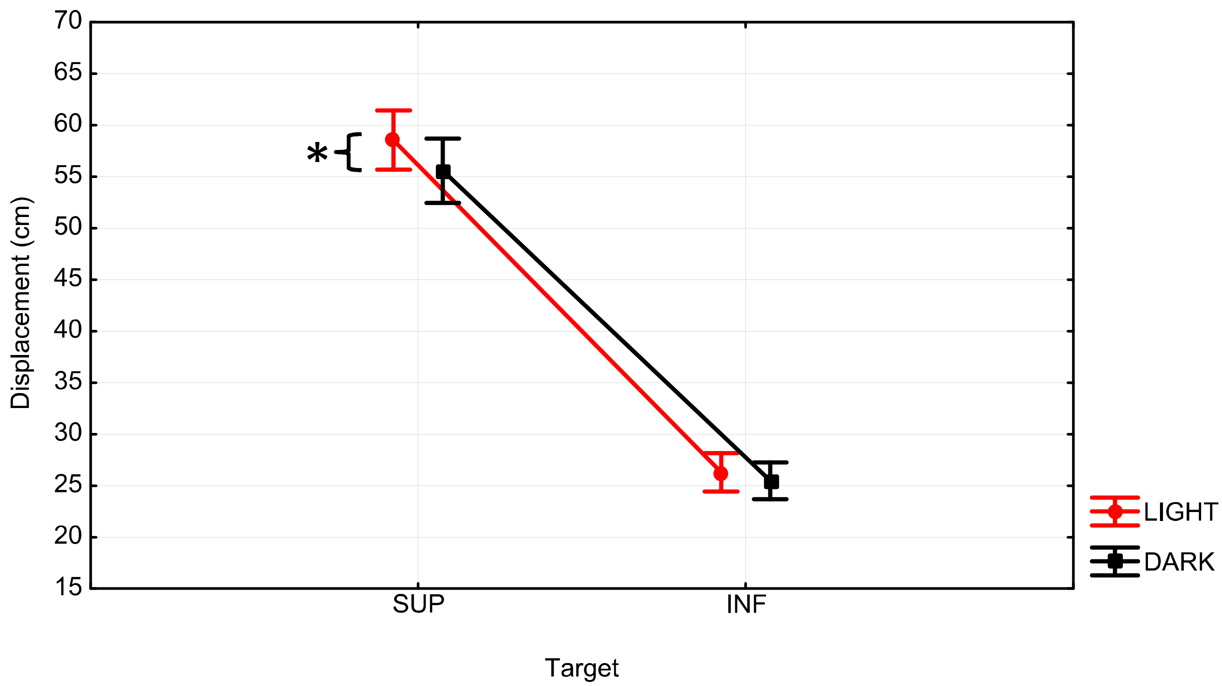

Figure 8: The TARG x VIS interaction for displacement while reaching. Red represents the LIGHT condition and black the DARK condition for reaches to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level ($p<0.05$).

Peak Velocity

Table 4 depicts the significant results for mean PV and its variability. The main effect of TARG indicates that participants produced a greater PV when reaching to the SUP target location (142cm/s) relative to the INF target location (74cm/s). Interestingly, differences in PV between body orientations and visual conditions were only significant for reaches to the SUP target location with the greatest PV occurring for reaches when UPRIGHT (significant ORIENT x TARG interaction, Figure 9) and in the LIGHT condition (significant TARG x VIS interaction, Figure 10). PV was most variable for reaches to the SUP target location, especially when UPRIGHT (significant ORIENT x TARG interaction, Figure 11).

Table 4: Reaching Peak Velocity Results

MEAN	*F(1,9) value*	*p-value*
TARG	51.62	<0.001
ORIENT x TARG	34.31	<0.001
TARG x VIS	18.34	<0.01
VARIABILITY	*F(1,9) value*	*p-value*
TARG	17.23	<0.01
TARG x VIS	8.13	<0.05

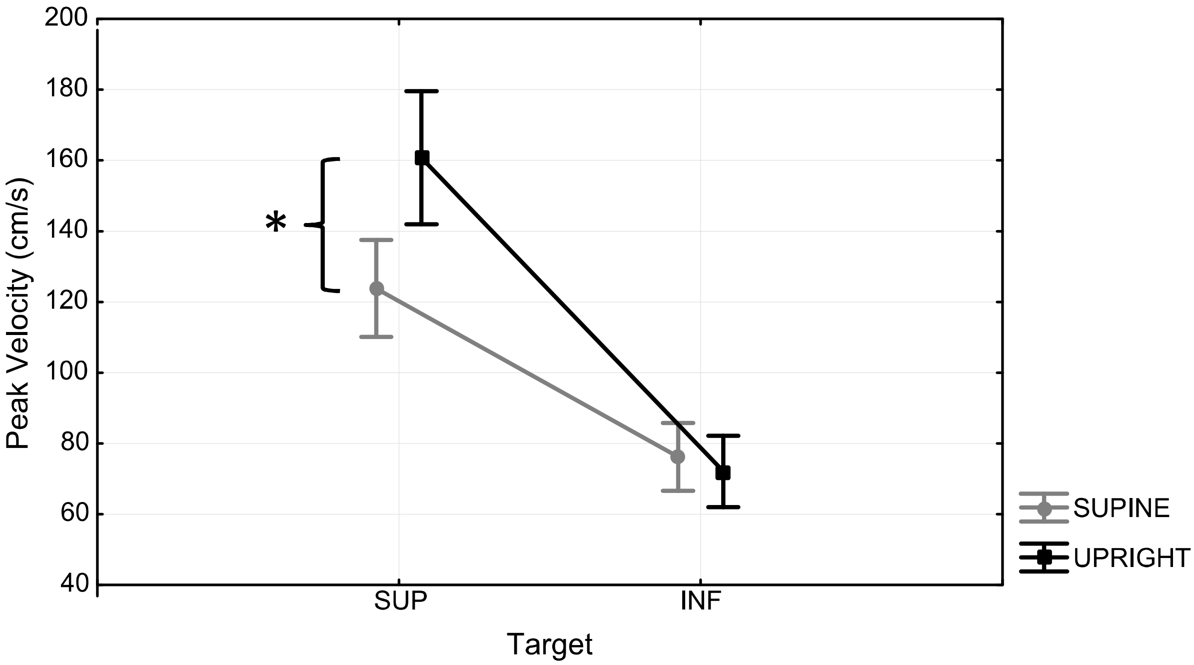

Figure 9: The ORIENT x TARG interaction for PV while reaching. Grey represents the SUPINE orientation and black the UPRIGHT orientation for reaches to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level ($p<0.05$).

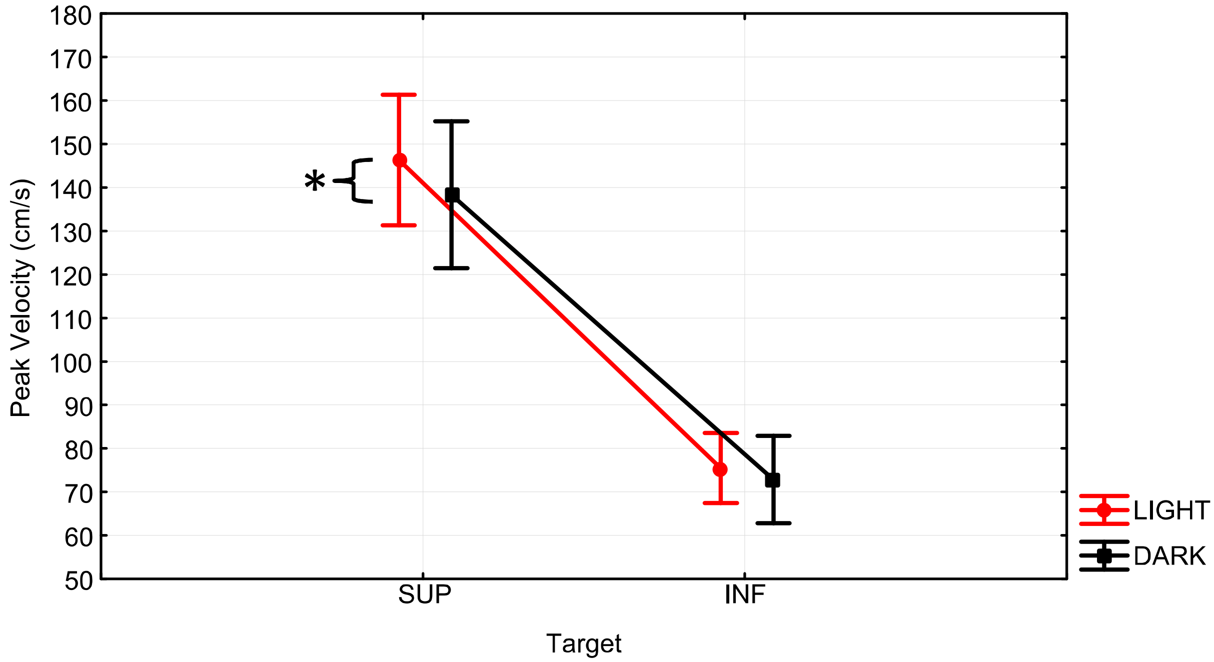

Figure 10: The TARG x VIS interaction for PV while reaching. Red represents the LIGHT condition and black the DARK condition for reaches to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level ($p<0.05$).

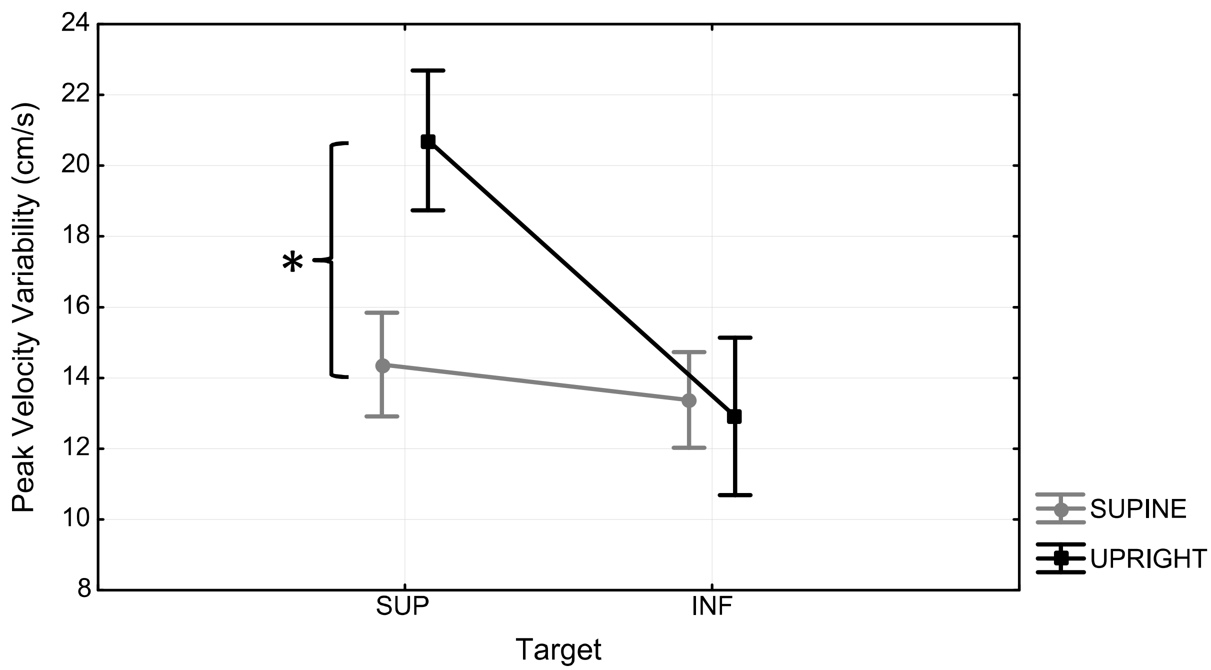

Figure 11: The ORIENT x TARG interaction for variability of PV while reaching. Grey represents the SUPINE orientation and black the UPRIGHT orientation for reaches to the SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level ($p<0.05$).

Movement Time

Analyses on MT revealed few significant outcomes. The main effect of ORIENT on MT ($F_{(1,9)}$ = 7.63, p<0.05) revealed that MT was longer in SUPINE (0.88s) than UPRIGHT body orientations (0.80s).

Experiment 2

Arm DOWN

Endpoint Errors

Figure 12 represents the final shoulder-finger lines of one participant after pointing from the arm DOWN starting position. Final pointing position to the SUP target for both body orientations are shown for the three visual conditions. Note that in the DARK condition, participants commonly pointed more inferior relative to the final locations of REAL and LIGHT conditions.

Table 5 identifies the significant results for the arm DOWN starting position for constant and variable elevation errors before (complete) and after reducing (reduced) the number of trials to only include single pointing movements (reduced equals > 77% of complete trials). Remember that the more positive the errors, the more superior the endpoint position. In the complete data set, the main effects of TARG and VIS revealed that constant elevation errors were more negative for the SUP target (-0.020rad) and in the DARK condition (-0.030rad) than errors for the INF target (-0.005rad) and in the LIGHT condition (-0.002rad). The significant TARG x VIS interaction revealed that for the SUP target location, participants produced more negative errors in the DARK condition than in the LIGHT condition (Figure 13). A trend for similar results was

seen for the INF target but did not reach significance (p=0.08). Finally, elevation errors were most variable in the INVERTED body orientation and DARK visual condition.

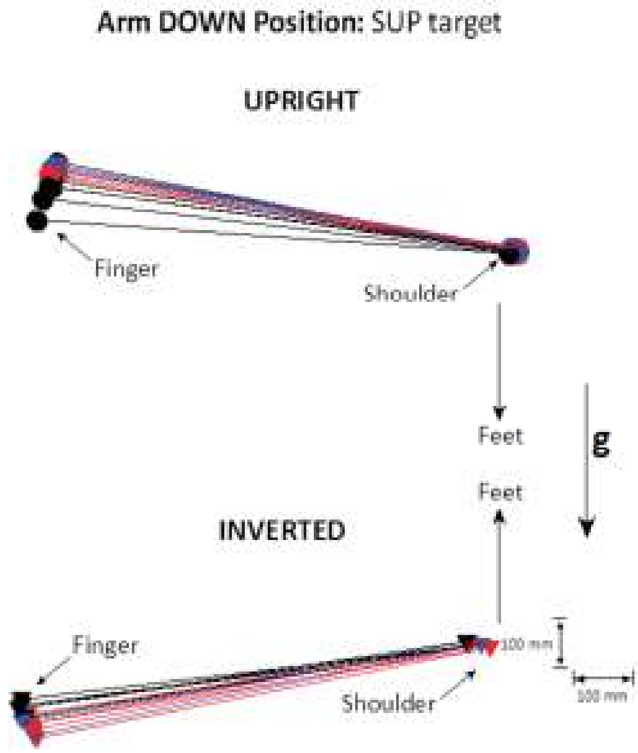

Figure 12: Final shoulder and fingertip locations for the UPRIGHT (circles) and INVERTED (triangles) body orientations for the arm DOWN starting position to the SUP target location for one participant. The shoulder-fingertip lines which connect the markers are color coded by visual conditions: blue for REAL, red for LIGHT and black for DARK.

Table 5: Pointing Elevation Error Results

	Complete		**Reduced**	
CONSTANT ERRORS	*F(1,9) value*	*p-value*	*F(1,8) value*	*p-value*
TARG	14.68	<0.01	6.78	<0.05
VIS	14.02	<0.01	15.44	<0.01
TARG x VIS	13.07	<0.01	7.40	<0.05
VARIABLE ERRORS	*F(1,9) value*	*p-value*	*F(1,8) value*	*p-value*
ORIENT	19.48	<0.01	8.58	<0.05
VIS	56.43	<0.001	44.70	<0.001
ORIENT x VIS			7.43	<0.05

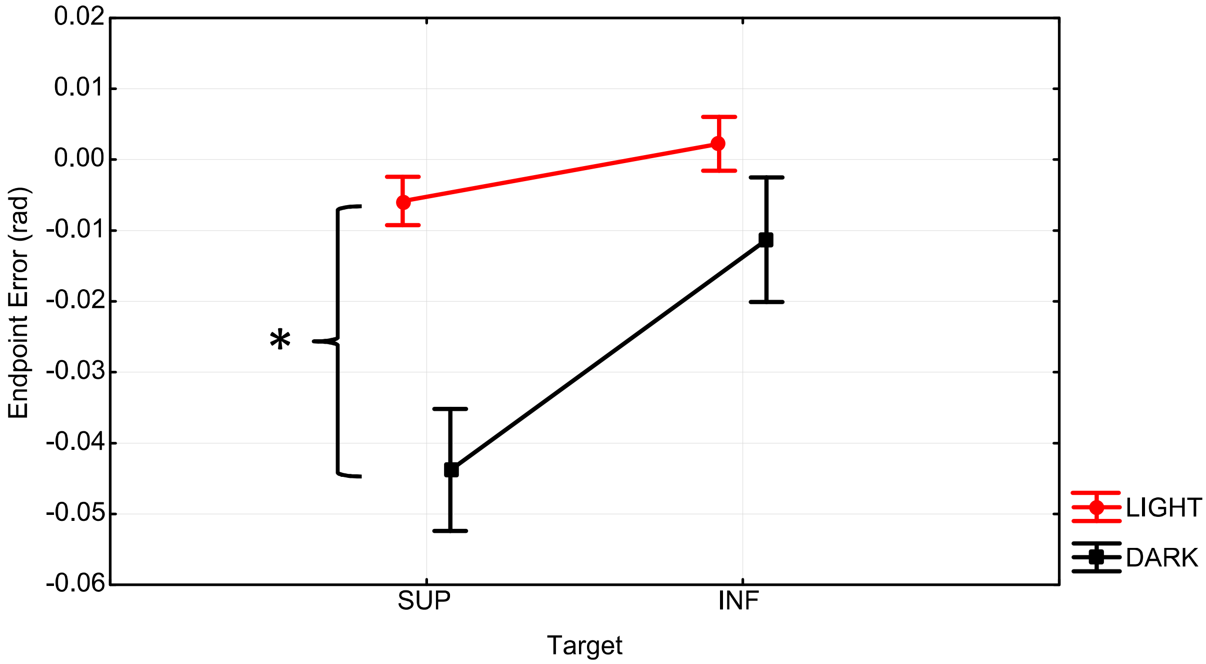

Figure 13: The TARG x VIS interaction for elevation errors in the arm DOWN starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level (P<0.05).

Table 5 also reveals that the complete and reduced data sets result in similar outcomes. The addition of a significant ORIENT x VIS interaction for single pointing movements revealed that participants were most variable while pointing in the INVERTED orientation while in the DARK.

Displacement

Table 6 shows the significant results for displacement in the arm DOWN position. These results revealed a main effect of TARG with greater displacement for the SUP target location (114cm) relative to the INF target location (90cm). These results confirm that the SUP target was the furthest from the starting position of the hand when the arm started in the DOWN position. The main effect of VIS on displacement indicated that participants had longer movement excursions in the LIGHT (103cm) relative to the DARK (101cm). The significant ORIENT x TARG interaction showed that the greatest displacement was to the SUP target while

INVERTED, but that displacement differed more for the INF target despite body orientation (Figure 14). The significant TARG x VIS interaction showed that participants exhibited greater displacement while pointing to the SUP target in the LIGHT visual condition as compared to the DARK (Figure 15). No significant results for variability in displacement for the arm DOWN positions were revealed. The results from the reduced data set paralleled the main effects for mean displacement and the TARG x VIS interaction, yet the ORIENT x TARG interaction was not significant.

Table 6: Pointing Displacement Results

	Complete		**Reduced**	
MEAN	*F(1,9) value*	*p-value*	*F(1,8) value*	*p-value*
TARG	1080.06	<0.001	644.25	<0.001
VIS	17.83	<0.01	13.28	<0.01
ORIENT x TARG	7.306	<0.05		
TARG x VIS	12.90	<0.01	13.07	<0.01

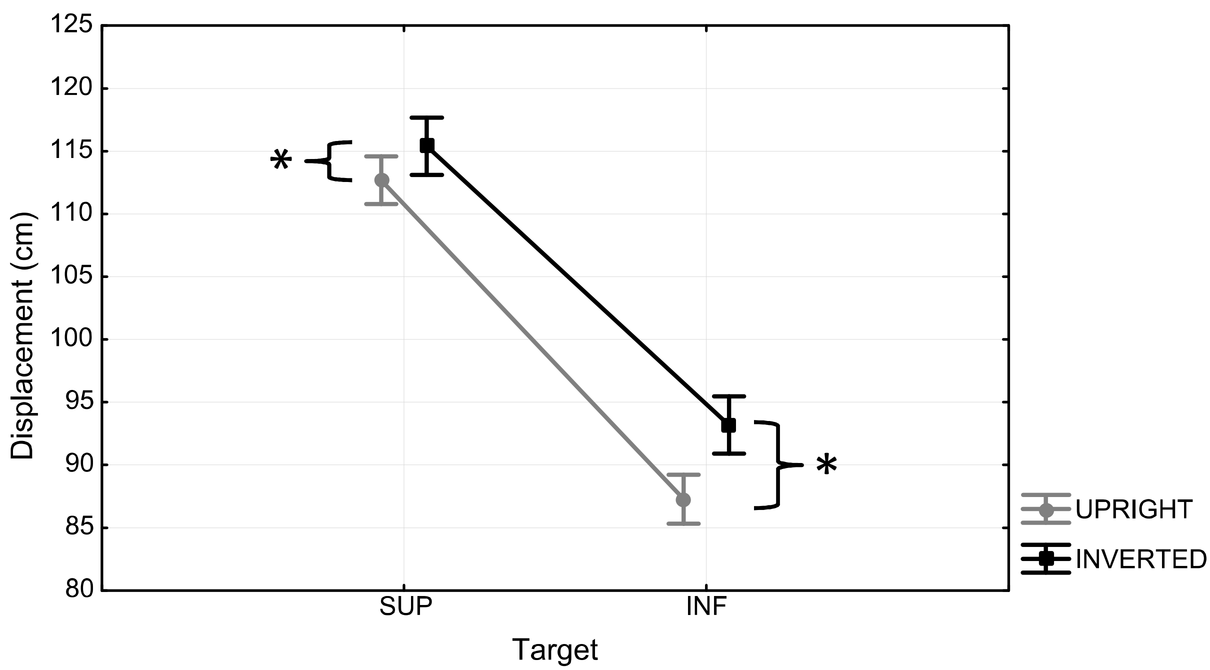

Figure 14: The ORIENT x TARG interaction for displacement in the arm DOWN starting position. Grey represents the UPRIGHT orientation and black the INVERTED orientation for SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between body orientations for the given target level ($P<0.05$).

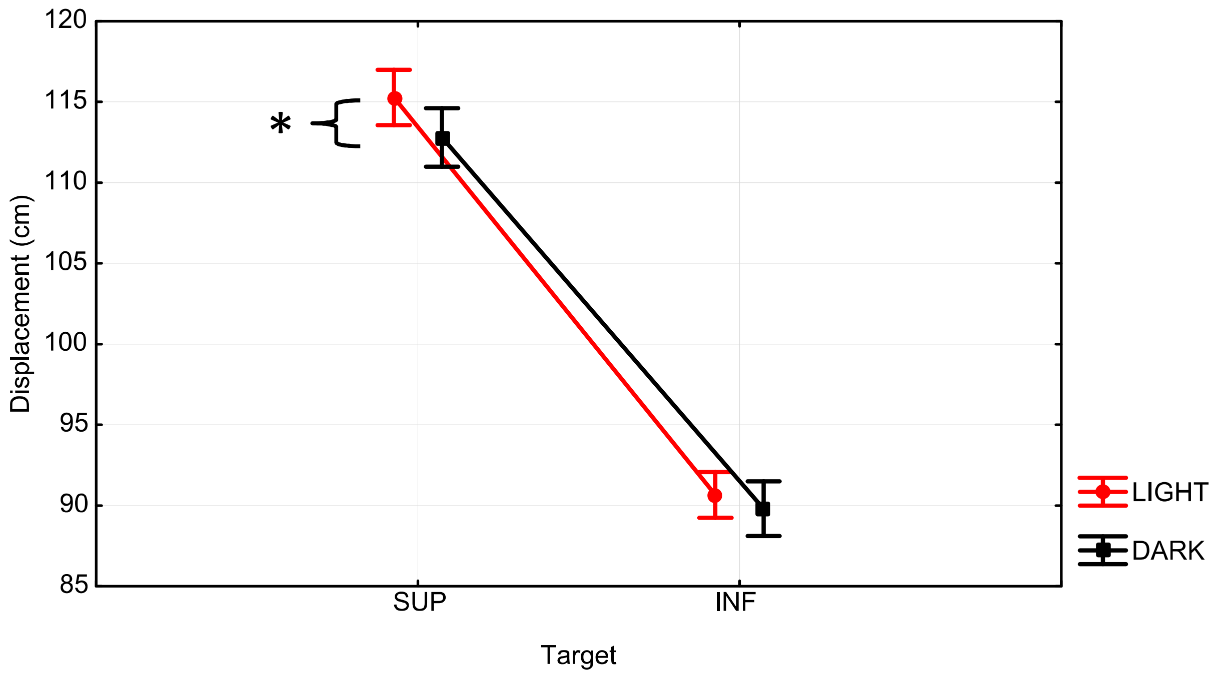

Figure 15: The TARG x VIS interaction for displacement in the arm DOWN starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level (P<0.05).

Peak Velocity

Main effects of TARG ($F_{(1,9)}$=163.85, p<0.001) and VIS ($F_{(1,9)}$=63.55, p<0.001) on PV revealed that participants moved at greater peak velocities during movements to the SUP target location (317cm/s) and in the LIGHT condition (290cm/s) compared to the INF target location (248cm/s) and in the DARK condition (275cm/s), respectively. Figure 16 shows that in the INVERTED body orientation, participants produced greater PVs in the LIGHT condition, however the difference between visual conditions was greatest for the INVERTED body orientation (ORIENT x VIS interaction: $F_{(1,9)}$=11.69, p<0.01). The analysis on variability of PV did not reveal any significant results. The results from the reduced data set paralleled the main effects for mean PV, yet the ORIENT x VIS interaction was not significant.

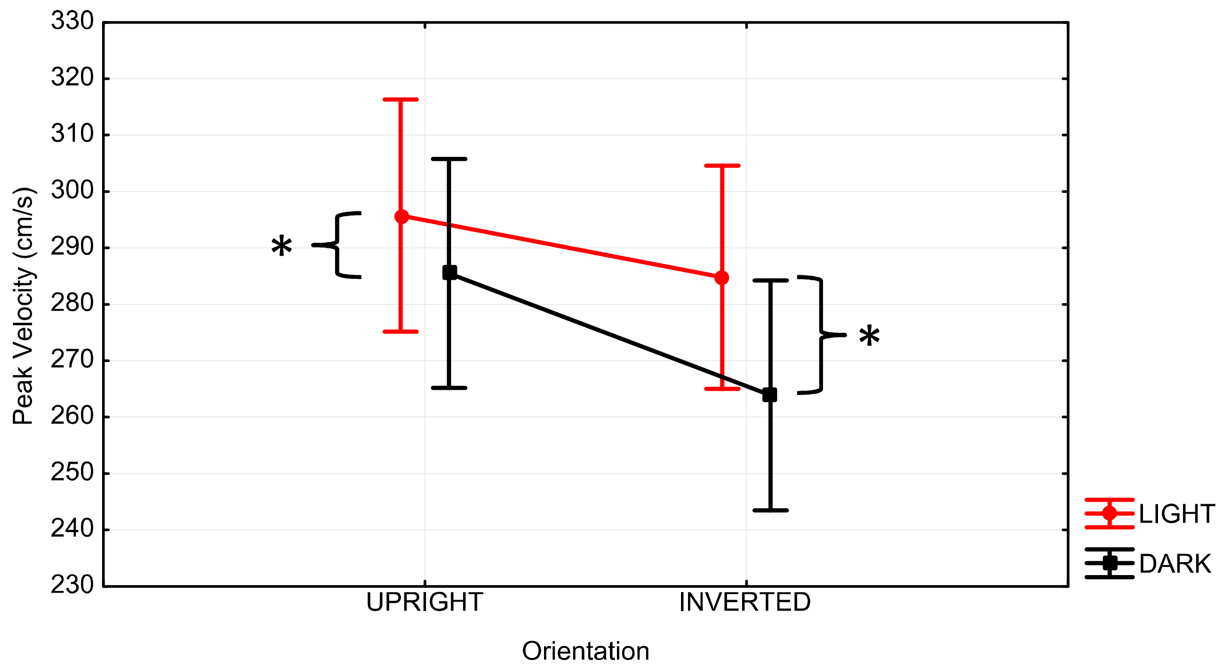

Figure 16: The ORIENT x VIS interaction for peak velocity in the arm DOWN starting position. Red represents the LIGHT condition and black the DARK condition for UPRIGHT (left) and INVERTED (right) body orientations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given body orientations ($p<0.05$).

Movement Time

The main effect of ORIENT on mean MT ($F_{(1,9)}=8.73$, $p<0.05$) and its variability ($F(1,9)=32.23$, $p<0.001$) revealed participants produced the longest (0.84s) and most variable (0.11s) MT while INVERTED compared to UPRIGHT (mean = 0.73s; SD = 0.06s). MT was also greater, thus longer, in the DARK condition compared to the LIGHT condition (main effect of VIS: $F_{(1,9)}=12.30$, $p<0.01$), however this was only significant for the INF target location (TARG x VIS interaction: $F_{(1,9)}=8.46$, $p<0.05$, Figure 17).

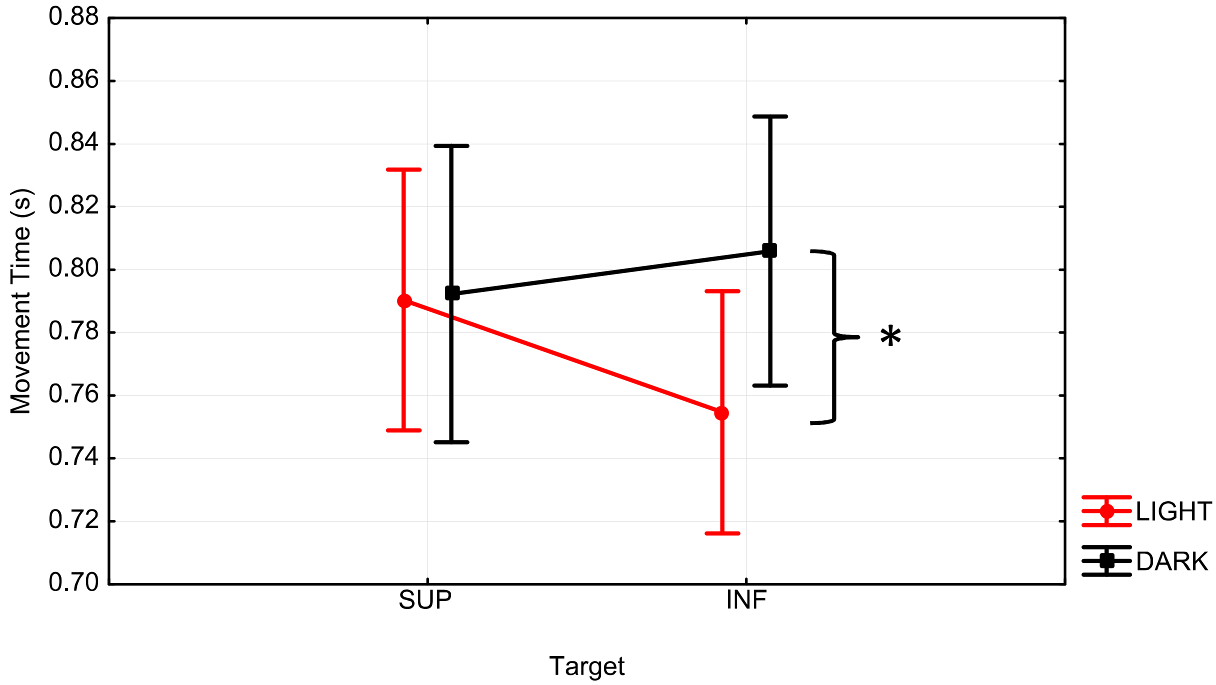

Figure 17: The TARG x VIS interaction for movement time in the arm DOWN starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations. Error bars represent ±1 standard error. Asterisk represents a significant difference between visual conditions for the given target level (P<0.05).

An analysis for MT on the reduced data set revealed several differences from those for the complete data set. The main effect of VIS on MT remained, yet the only other significant finding was the interaction between ORIENT and TARG ($F_{(1,8)}=8.51$, $p<0.05$) such that participants took longer to move in the INVERTED body orientation relative to the UPRIGHT and this difference was greater for the INF target location.

Arm UP

Endpoint Errors

Figure 18 represents the final shoulder-finger lines of one participant after pointing from the arm UP starting position. Note that in the DARK condition, participants commonly point

more superior relative to the final locations of REAL and LIGHT conditions, especially when INVERTED.

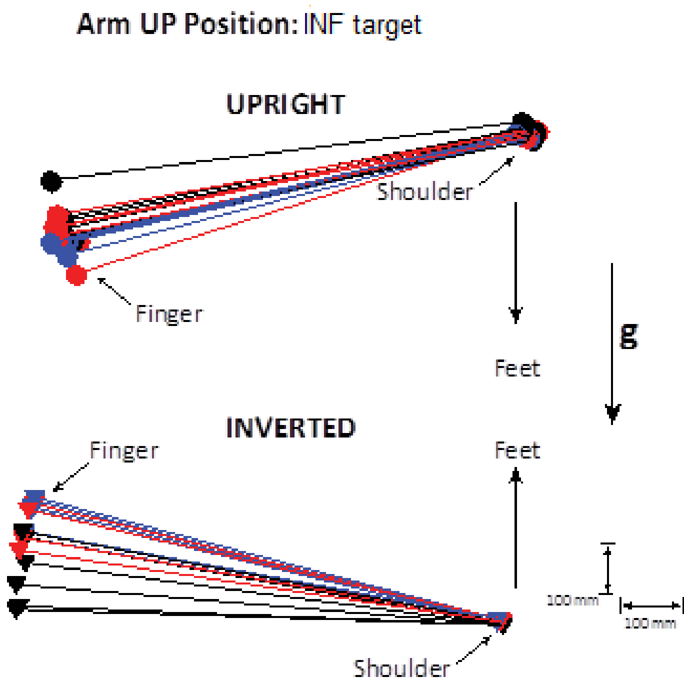

Figure 18: Final shoulder and fingertip locations for the UPRIGHT (circles) and INVERTED (triangles) body orientations for the arm UP starting position when pointing to INF target for participant 1. The shoulder and fingertip markers and the lines which connect these markers are color coded by visual conditions: blue for REAL, red for LIGHT and black for DARK.

Table 7 depicts the results of analyses for constant and variable elevation errors before (complete) and after reducing (reduced) the number of trials based on single movements for the arm UP starting position (reduced equals > 81% of complete trials). Remember that the more positive the errors, the more superior the endpoint position. While INVERTED (0.024rad) participants demonstrated more positive elevation errors than while UPRIGHT (0.006rad, main effect of ORIENT) as well as when pointing to the INF target location (0.024rad) compared to the SUP target location (0.006rad, main effect of TARG). Participants had greater positive error when pointing to the INF target location while INVERTED compared to the both targets for the

UPRIGHT orientation and for the SUP target while INVERTED (significant ORIENT x TARG interaction). The main effect of VIS revealed greater positive errors when performing the task in the DARK condition (0.027rad) relative to the LIGHT condition (0.003rad, main effect of VIS). The significant ORIENT x TARG x VIS interaction revealed that errors between LIGHT and DARK conditions were not significant when pointing to the SUP target while INVERTED (Figure 19). The main effects of ORIENT, VIS and TARG on error variability indicated that participants produced the greatest variability in endpoint error while INVERTED, in the DARK condition and when pointing to the INF target location, accordingly.

Table 7: Pointing Elevation Error Results

	Complete		**Reduced**	
CONSTANT ERRORS	*F(1,9) value*	*p-value*	*F(1,9) value*	*p-value*
ORIENT	17.92	<0.01	15.02	<0.01
TARG	10.32	<0.01	8.52	<0.05
VIS	11.00	<0.01	10.46	<0.05
ORIENT x TARG	13.23	<0.01	12.80	<0.01
ORIENT x TARG x VIS	34.69	<0.001	14.44	<0.01
VARIABLE ERRORS	*F(1,9) value*	*p-value*	*F(1,9) value*	*p-value*
ORIENT	7.05	<0.05		
TARG	11.52	<0.01		
VIS	41.41	<0.001	24.30	<0.001

Results of the reduced data set in the arm UP starting position no longer revealed main effects of ORIENT and TARG on elevation error variability. All other results were consistent with those from the analysis on the complete data set.

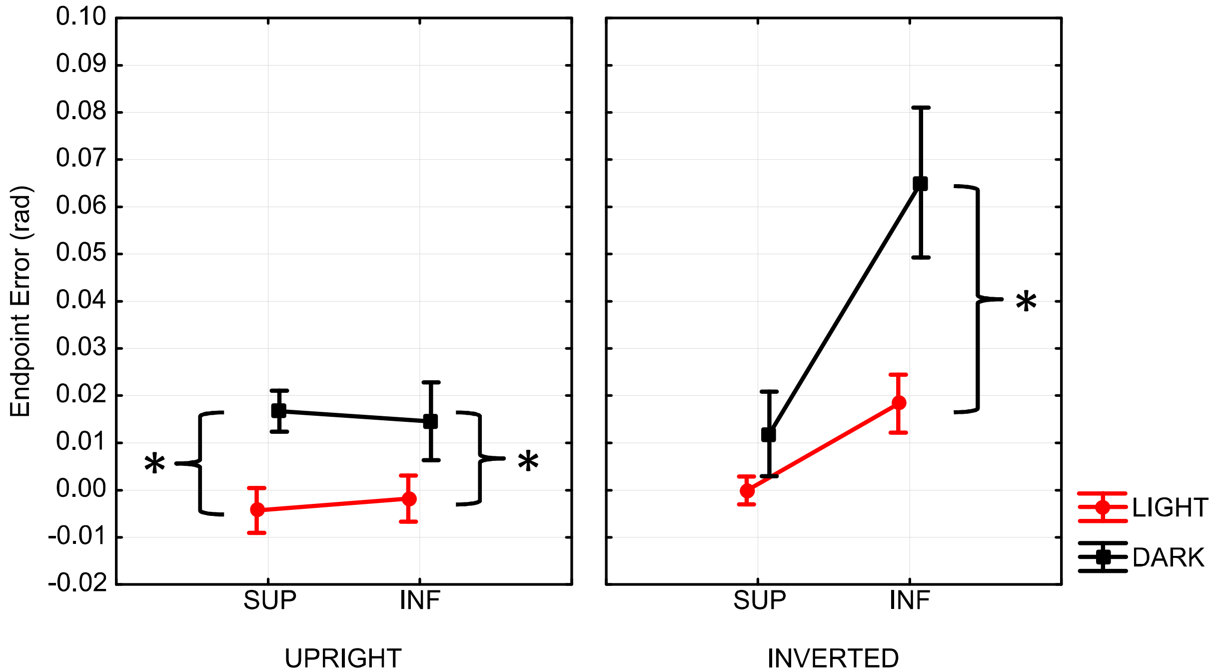

Figure 19: The ORIENT x TARG x VIS interaction for elevation errors in the arm UP starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations within each box. The left box represents endpoint errors for the UPRIGHT body orientation, while the right box represents endpoint errors for the INVERTED body orientation. Error bars represent ±1 standard error. Asterisks represent significant differences between visual conditions for the given target level and body orientation ($P<0.05$).

Displacement

Table 8 displays main effects for displacement in the arm UP starting position for ORIENT, VIS and TARG indicated participants produced greater displacement while UPRIGHT (90.7cm), in the LIGHT condition (84.7cm) and when pointing to the INF target location (97.3cm) relative to the displacements while INVERTED (76.9cm), in the DARK condition (82.9cm) and when pointing to the SUP target location (70.3cm). The significant three-way interaction revealed that participants moved less in the DARK condition than the LIGHT condition when pointing to the SUP target location in the UPRIGHT body orientation and when pointing to the INF target location while INVERTED (Figure 20). Participants produced the most variability in displacement when pointing in the DARK condition. Results of the analysis

on the reduced data set were consistent with the complete data set for mean displacement but did not reveal any significant results for displacement variability.

Table 8: Pointing Displacement Results

	Complete		**Reduced**	
MEAN	*F(1,9) value*	*p-value*	*F(1,9) value*	*p-value*
ORIENT	201.59	<0.001	157.55	<0.001
TARG	732.34	<0.001	730.62	<0.001
VIS	22.02	<0.01	17.60	<0.01
ORIENT x TARG x VIS	13.19	<0.01	9.10	<0.05
VARIABILITY	*F(1,9) value*	*p-value*	*F(1,9) value*	*p-value*
VIS	8.73	<0.05		

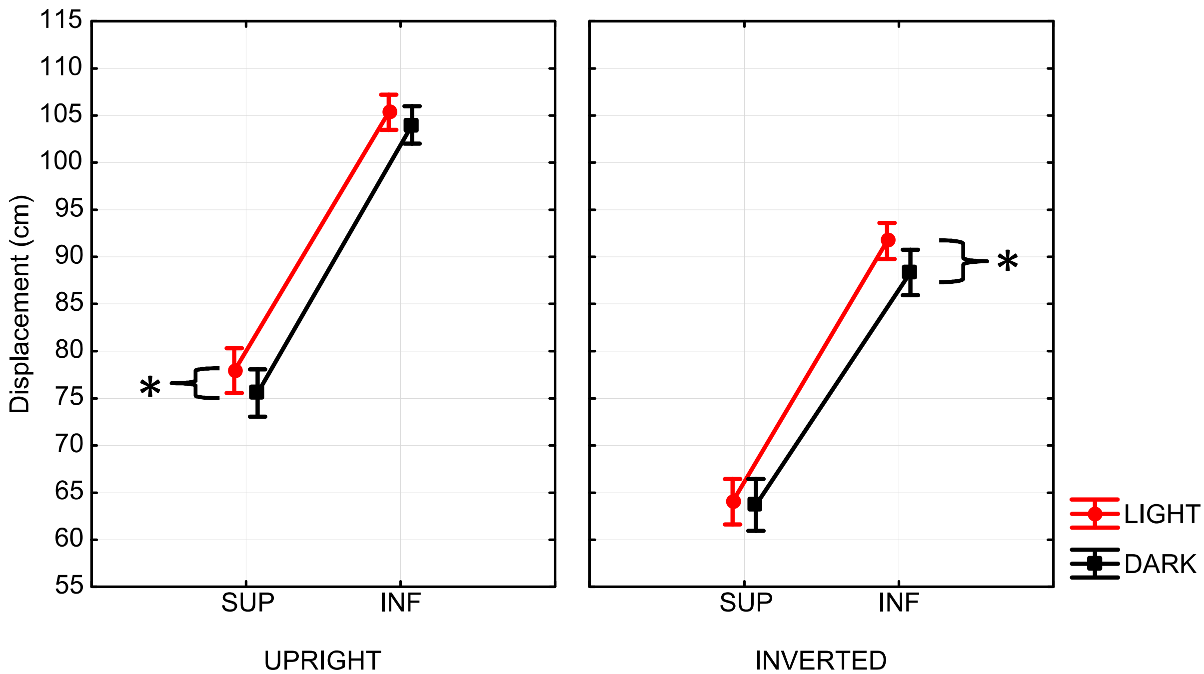

Figure 20: The ORIENT x TARG x VIS interaction for displacement in the arm UP starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations within each box. The left box represents endpoint errors for the UPRIGHT body orientation, while the right box represents endpoint errors for the INVERTED body orientation. Error bars represent ±1 standard error. Asterisks represent significant differences between visual conditions for the given target level and body orientation (P<0.05).

Peak Velocity

In the arm UP starting position, results indicated that participants produced a lower PV to the SUP target location (212cm/s) than the INF target location (277cm/s, main effect of TARG: $F_{(1,9)}=199.61$, $p<0.0001$) and higher PV in the LIGHT condition (249.91cm/s) than in the DARK condition (239cm/s, main effect of VIS: $F_{(1,9)}=8.78$, $p<0.05$). Similar outcomes were found for the analysis of PV in the reduced data set.

Movement Time

Participants took less time to move to the SUP target location (0.70s) than the INF target location (0.76s) from the arm UP position (TARG: $F_{(1,9)}=25.67$, $p<0.001$). A significant ORIENT x TARG x VIS interaction revealed that pointing in the DARK took longer than the LIGHT for the INVERTED condition when pointing to the SUP target location ($F_{(1,9)}=11.24$, $p<0.01$, Figure 21).

Analyses on the reduced data set were very similar to those mentioned for analyses on the complete data set. Additional significant effects revealed that participants took longer to move while UPRIGHT (0.74s) compared to INVERTED (0.66s, ORIENT: $F_{(1,9)}=8.34$, $p<0.05$). A significant TARG x VIS interaction indicated participants produced a longer movement duration when pointing in the DARK as compared to the LIGHT only for the SUP target location ($F_{(1,9)}=14.52$, $p<0.01$).

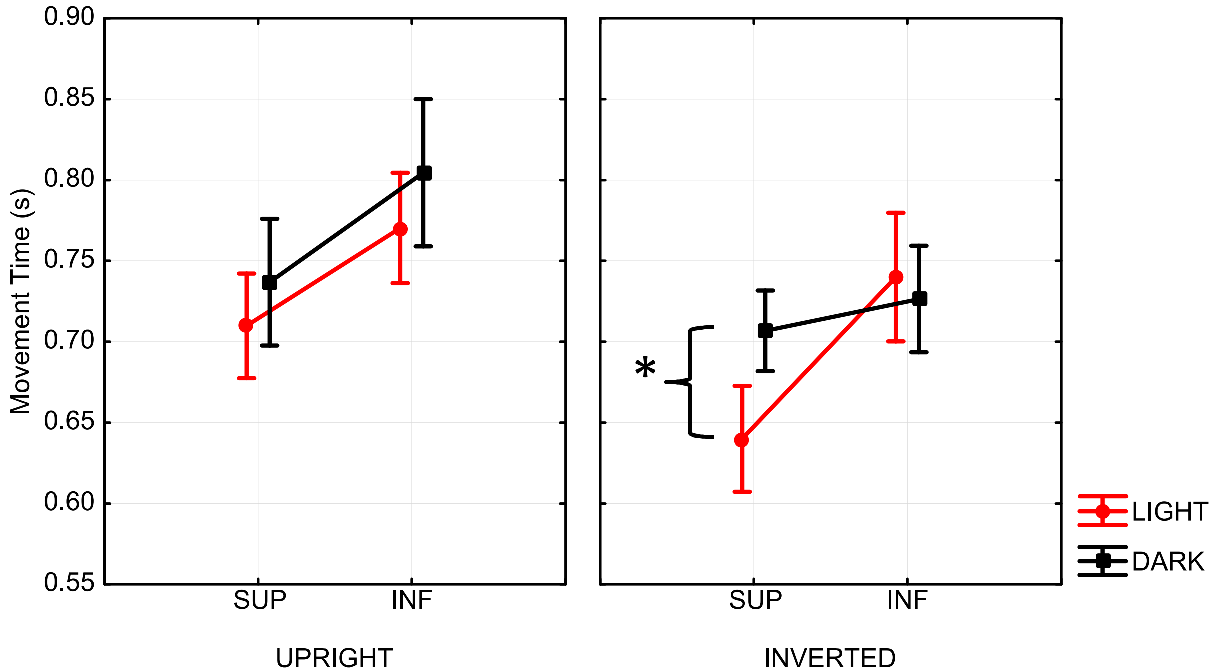

Figure 21: The ORIENT x TARG x VIS interaction for movement time in the arm UP starting position. Red represents the LIGHT condition and black the DARK condition for SUP (left) and INF (right) target locations within each box. The left box represents endpoint errors for the UPRIGHT body orientation, while the right box represents endpoint errors for the INVERTED body orientation. Error bars represent ±1 standard error. Asterisks represent significant differences between visual conditions for the given target level and body orientation ($P<0.05$).

Correlations

Correlation analyses were limited to reduced data sets on single movement trials to maintain a certain amount of homogeneity across trials. These analyses were limited to the data from Experiment 2 due to the large loss of trials from movement corrections that occurred in Experiment 1.

Correlation results of elevation errors with displacement, PV and MT for LIGHT and DARK conditions were performed for SUP and INF target locations separately across and within participants for arm DOWN and arm UP starting positions. Across and within correlations were performed on individual trials. Table 9 shows significant correlation values across participants

and the number of significant within subject correlations between endpoint error and other variables. Significant positive associations were revealed for 7/10 and 8/10 participants for SUP and INF target levels, respectively when participants began with the arm position DOWN and significant negative associations were revealed for 8/10 participants for the INF target location when participants began with the arm position UP. Plots of displacement by error for the SUP target location in the arm DOWN starting position are shown in Figure 22, while plots of displacement by error for the INF target location in the arm UP starting position are shown in Figure 23. Lines of best fit are plotted for all participants (solid thick line) and individual participants (thin dashed lines). These data support the previous findings that endpoint errors were associated with movement excursions to account for the differences in endpoint precision that were not associated with movement time or peak velocity.

Table 9: Experiment 2 Significant Correlations Results

			Displacement	MT	PV
DOWN	SUP	across	R=0.45	NS	NS
		within	7	0	2
	INF	across	R=0.51	NS	NS
		within	8	0	2,-1
UP	SUP	across	NS	NS	NS
		within	-1	0	0
	INF	across	R=-0.63	NS	NS
		within	-8	-1	-5

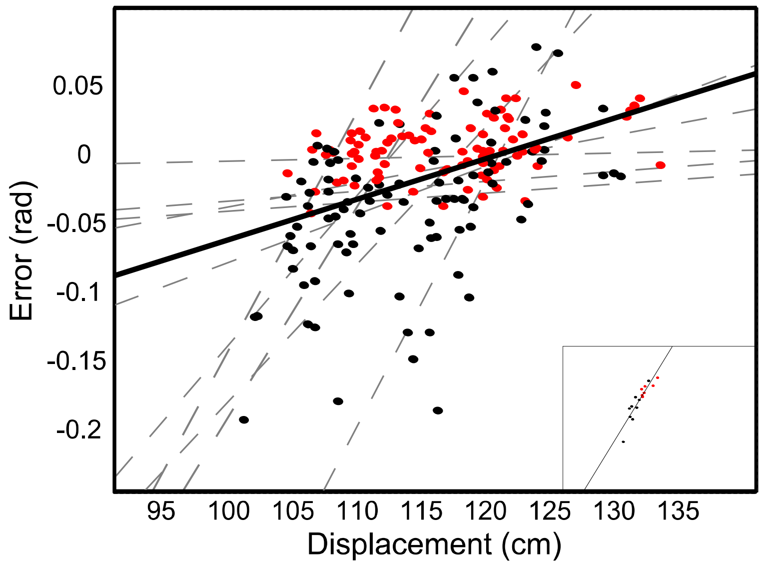

Figure 22: The lines of best fit for plots of endpoint errors with displacement are shown for reaches to the SUP target location for LIGHT (red) and DARK (black) visual conditions. The across subject best fit line is shown with the thick black line and within subject correlations are shown with dashed grey lines. Inset: plots of endpoint errors and displacement and best fit line are shown for one participant.

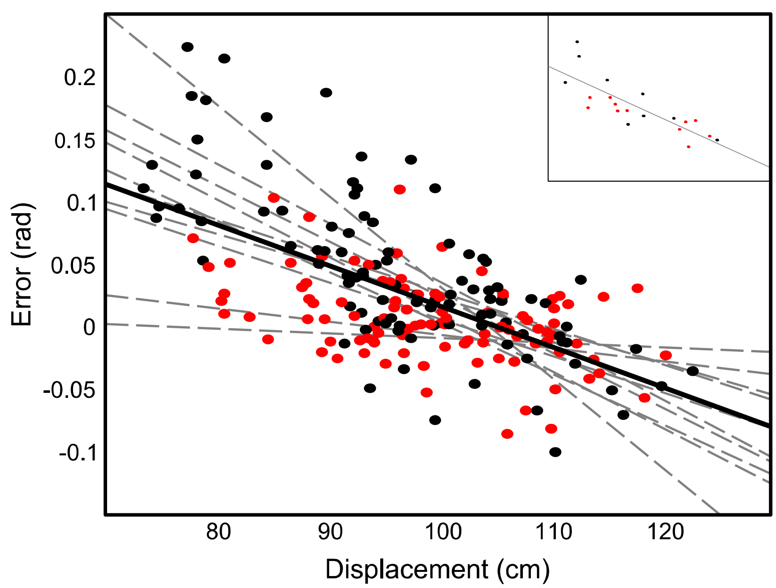

Figure 23: The lines of best fit for plots of endpoint errors with displacement are shown for reaches to the INF target location for LIGHT (red) and DARK (black) visual conditions. The across subject best fit line is shown with the thick black line and within subject correlations are shown with dashed grey lines. Inset: plots of endpoint errors and displacement and best fit line are shown for one participant.

DISCUSSION

The results of the current study for reaching from upright and supine body orientations in Experiment 1 are consistent with the phenomenon of upright participants reaching or pointing below the remembered target location in the dark compared to performances in normal room lighting (Henriques and Crawford 2000; Admiraal et al. 2003; Hondzinski and Cui 2006). Ending below the remembered reach location in a lit environment happens to fall along the gravitational vector for these studies, making the directional pull of gravity a potential explanation for the endpoint error. However, the results of Experiment 2, in which participants completed pointing movements in darkness above and below those in a lit environment depending on body orientation and starting arm position, clearly suggest that differences between endpoint precision for LIGHT and DARK environments cannot be explained by the direction of gravitational acceleration. Results from both experiments indicated that participants frequently produce shorter movement excursions for goal-directed upper limb movements to remembered target locations in darkness. Together these results revealed that less displacement, thus smaller movement excursions, when reaching or pointing in the dark relative to an illuminated environment is to blame for this phenomenon.

Making smaller movement excursions in darkness is common in motor control studies. The phenomenon of moving a shorter distance in the dark has been observed for pointing and/or reaching tasks performed in complete darkness from seated (Henriques et al. 1998; Henriques and Crawford 2000) or standing (Admiraal et al. 2004) body orientations, as well as reaches performed with a step (Hondzinski and Cui 2006). In addition, walking to remembered target locations also displayed this phenomenon, as older individuals with and without neurological deficits due to Parkinson’s disease walked shorter distances in darkness thus undershot target

location (Almeida et al. 2005). Results from the current study suggest that moving a shorter distance in the dark relative to a lit environment occurs most often for relatively large movement excursions regardless of muscle being used, type of muscle contraction (concentric or eccentric) and degrees of freedom involved in the task (reaching and pointing).

The results of the current study also coincide with previous research that revealed the differences in endpoint precision between visual conditions occurred for targets at shoulder level or above, thus those for relatively large hand displacements (Henriques et al. 2003; Hondzinski and Cui 2006). Longer movement excursion in the current study occurred for reaching movements to the SUP target location in Experiment 1 and pointing movements to the SUP target location in the arm DOWN starting position for Experiment 2. In the second experiment longer movement excursions occurred when pointing to the INF target location from the arm UP starting position. Clearly, undershooting the remembered target location occurred most frequently when moving larger distances in darkness as compared to a lit environment. The shorter movement in the DARK explains the greater errors that occur in these situations. These findings are also consistent with evidence that movement excursions decrease for larger movement amplitudes when the arm is not visible (Bock and Eckmiller 1986).

In the current study, there is also evidence for undershooting, or generating a shorter movement excursion, to remembered target locations that required shorter movement distances. In the UPRIGHT body orientation with the arm starting UP by the ear, participants produced movements that corresponded to less displacement to the remembered location of the SUP target location in darkness as compared to in a lit environment. Since overreaching the remembered target location of targets closer to the starting position of the hand in a lit environment is consistent with previous research (Henriques et al. 2003); (Soechting and Flanders 1989);

(Gentilucci and Negrotti 1994); (Tresilian et al. 1999), it is not surprising that undershooting remembered target locations in the dark can result in better endpoint precision (Hondzinski and Cui 2006). Clearly moving less distance in the DARK is not always associated with greater errors.

Previously, it has been hypothesized that different planning processes are likely used for up and down pointing movement trajectories (Papaxanthis et al. 2003). The current study provides some evidence that similar planning processes are likely used for vertical endpoint precision despite movement direction or body orientation. In order to perform the task, participants needed to generate force in the upper extremity through concentric and eccentric muscle contractions. While upright and the arm starting in a down position, the participants concentrically contracted the shoulder flexor muscles, such as the anterior deltoid, to lift the arm to the target location (Papaxanthis et al. 2003). It has been shown that when moving slowly, the same flexor muscles used to lift the arm were the only muscles utilized to slow the arm against the gravitational pull toward movement end (Papaxanthis et al. 2003). This outcome opposes the existence for non-reciprocal inhibition for this movement. Additionally, while participants in the study completed by Papaxanthis et al. (2003) started with the arm up, the anterior deltoid contracted eccentrically to lower the arm with the gravitational pull, like those in the current study in the upright position when starting with the arm UP. One can reason that the opposite holds true when inverted. When the arm started up by the ear, participants would concentrically activate the extensor muscles of the arm, such as the latissimus dorsi, to move the arm against the gravitational pull. Similar to the upright body orientation, these muscles would slow the arm toward the end of movement and would be eccentrically activated when pointing from the arm down starting position. Interestingly, a co-contraction of flexor and extensor muscles during fast

movements was shown regardless of up or down pointing movements (Papaxanthis et al. 2003). Moreover, one would expect greater differences in muscle activity during the multi-joint reaching task used in Experiment 1 with the inclusion of concentric and eccentric muscle contractions around the shoulder and elbow joints. Despite the differences in muscle activation patterns required for each pointing or reaching movements, similar endpoint errors along the vertical axis were displayed for participants in the current study. Although not conclusive, these results suggest some evidence that similar planning processes occur for endpoint accuracy during up and down goal-directed movements.

A previous analysis by Gaveau and Papaxanthis (Gaveau and Papaxanthis 2011) indicated that MT is similar for up and down movements but PV is greater for movements against the gravitational vector (up) than it is for downward movements. MT and PV were also calculated and analyzed in the current study to provide further insight to the differences in pointing accuracy between DARK and LIGHT conditions. In the current study, results from ANOVAs revealed that PV proved to be greater when moving to the target that was furthest from the starting position of the hand (i.e. longest movement excursions) and when the task was performed in an illuminated environment. These results were consistent regardless of task (reaching or pointing), body orientation and starting arm position. The increased PV with longer movement excursions resulted in inconsistent movement times when comparing the DARK and LIGHT conditions. The speed-accuracy trade-off that is often observed for fast discrete movements (Wu et al. 2010) did not hold true for the current experiment in which movement speeds were comfortably paced and self-selected. Movements in darkness with lower mean PV and longer mean MT did not always increase endpoint accuracy. Significant effects of visual condition on MT revealed that movements in the dark frequently took longer, but this was not

consistent across all tasks, body orientations and starting arm positions. Inconsistent results from analyses on MT and PV for the current study did not fully explain the differences in accuracy observed between the light and dark conditions.

As a method to further investigate what factors may contribute to differences in endpoint accuracy, trial data for PV, MT and displacement were correlated with elevation error. For single pointing movements to the target furthest from the starting hand position in Experiment 2, error was associated with displacement for both starting arm positions. The decreased movement excursion of the arm explained the results of participants undershooting the remembered target location in the DARK visual condition. This association between endpoint error and displacement for farther movement excursions is consistent with findings of previous research for a reaching task with a step with and without allocentric cues available (Hondzinski and Cui 2006). The findings from the present study that suggest no links of endpoint precision with PV or MT supports previous research that displayed no significant correlations between endpoint errors and MT of young adults when stepping and reaching toward remembered target locations in normal room lighting at a self-selected comfortable pace (Hondzinski et al. 2010).

Although there was a lack of associations of errors with MT and/or PV, possible explanations for less movement excursion occurring in the dark for faster movements include changes in the relative timing of the phasic co-contraction of the agonist and antagonist muscles , commonly used for fast single pointing movements (Chiovetto et al. 2010). The use of reciprocal inhibition may explain the changes in neural activity corresponding to shorter movement excursions. Although slower movements can use the same muscle to lift and lower the extended arm, faster movements make use of agonist and antagonist muscles (Papaxanthis et al. 2003). Regardless of starting arm position and muscles used, the muscle group opposing the movement

is lengthening. When muscles spindles are stretched or lengthened in the opposing muscle group, reciprocal inhibition is activated causing the antagonist muscles to this group to be inhibited (Crone et al. 1987). The inhibition of these muscles coupled with the excitement of the opposing muscles could cause the participant to create less movement, less displacement, and thus undershoot the final target location. When this lengthening of the opposing muscles occur in the dark, visual feedback, which may override this mechanism to achieve more precise endpoint locations, is not available.

One possible reason participants produce less displacement in the DARK is that the body is utilizing a protective mechanism for optimizing safety (Almeida et al. 2005). It has been noted that less movement excursion could be used as a mechanism to prevent collision with another object or reduce joint stress at extreme ranges of motion to avoid injury (Reid 1988). Although these scenarios were not present in the current study, the control mechanisms may still be applicable for reaching or pointing movements completed in darkness. Future studies to understand the musculature control of the upper extremity movements being utilized for this study may give insight to the mechanism being used to complete the task and if it is protective in nature.

CONCLUSION

Outcomes of this study revealed that greater errors observed in the DARK primarily results from the shorter movement displacement that occurred for longer movement excursions rather than the influences of the gravitational pull. Although different planning processes for up and down pointing movement trajectories exist (Papaxanthis et al. 2003), the present study provides some evidence that similar planning processes occur for goal-directed movements involving endpoint accuracy along the gravitational axis regardless of task (reaching or pointing), body orientation, starting arm position, muscles used and type of muscular contraction.

REFERENCES

Admiraal MA, Keijsers NL, Gielen CC (2003) Interaction between gaze and pointing toward remembered visual targets. J Neurophysiol 90:2136-2148 doi: 10.1152/jn.00429.2003

Admiraal MA, Keijsers NL, Gielen CC (2004) Gaze affects pointing toward remembered visual targets after a self-initiated step. J Neurophysiol 92:2380-2393 doi: 10.1152/jn.01046.2003

Almeida QJ, Frank JS, Roy EA, Jenkins ME, Spaulding S, Patla AE, Jog MS (2005) An evaluation of sensorimotor integration during locomotion toward a target in Parkinson's disease. Neuroscience 134:283-293 doi: 10.1016/j.neuroscience.2005.02.050

Bock O, Eckmiller R (1986) Goal-Directed Arm Movements in Absence of Visual Guidance - Evidence for Amplitude Rather Than Position Control. Experimental Brain Research 62:451-458

Bock O, Howard IP, Money KE, Arnold KE (1992) Accuracy of aimed arm movements in changed gravity. Aviat Space Environ Med 63:994-998

Chiovetto E, Berret B, Pozzo T (2010) Tri-dimensional and triphasic muscle organization of whole-body pointing movements. Neuroscience 170:1223-1238 doi: 10.1016/j.neuroscience.2010.07.006

Crone C, Hultborn H, Jespersen B, Nielsen J (1987) Reciprocal Ia inhibition between ankle flexors and extensors in man. J Physiol 389:163-185

Gaveau J, Papaxanthis C (2011) The temporal structure of vertical arm movements. PLoS One 6:e22045 doi: 10.1371/journal.pone.0022045

Gentilucci M, Negrotti A (1994) Dissociation between perception and visuomotor transformation during reproduction of remembered distances. J Neurophysiol 72:2026-2030

Henriques DY, Crawford JD (2000) Direction-dependent distortions of retinocentric space in the visuomotor transformation for pointing. Exp Brain Res 132:179-194 doi: 10.1007/s002210000340

Henriques DY, Klier EM, Smith MA, Lowy D, Crawford JD (1998) Gaze-centered remapping of remembered visual space in an open-loop pointing task. J Neurosci 18:1583-1594

Henriques DY, Medendorp WP, Gielen CC, Crawford JD (2003) Geometric computations underlying eye-hand coordination: orientations of the two eyes and the head. Exp Brain Res 152:70-78 doi: 10.1007/s00221-003-1523-4

Hondzinski JM, Cui Y (2006) Allocentric cues do not always improve whole body reaching performance. Exp Brain Res 174:60-73 doi: 10.1007/s00221-006-0421-y

Hondzinski JM, Li L, Welsch M (2010) Age-related and sensory declines offer insight to whole body control during a goal-directed movement. Motor Control 14:176-194

Owsley C, McGwin G, Jr. (1999) Vision impairment and driving. Surv Ophthalmol 43:535-550

Papaxanthis C, Pozzo T, Schieppati M (2003) Trajectories of arm pointing movements on the sagittal plane vary with both direction and speed. Experimental Brain Research 148:498-503 doi: DOI 10.1007/s00221-002-1327-y

Reid DC (1988) Prevention of hip and knee injuries in ballet dancers. Sports Med 6:295-307

Smetanin BN, Popov KE (1997) Effect of body orientation with respect to gravity on directional accuracy of human pointing movements. Eur J Neurosci 9:7-11

Soechting JF, Flanders M (1989) Sensorimotor representations for pointing to atrgets in three-dimensional space. J Neurophysiol 62

Spidalieri G, Sgolastra R (2001) Gravitational cues contribute to accurate localisation of mentally represented cutaneous targets. Exp Brain Res 138:274-278 doi: 10.1007/s002210100723

Tresilian JR, Mon-Williams M, Kelly BM (1999) Increasing confidence in vergence as a cue to distance. Proc Biol Sci 266:39-44 doi: 10.1098/rspb.1999.0601

Wu CC, Kwon OS, Kowler E (2010) Fitts's Law and speed/accuracy trade-offs during sequences of saccades: Implications for strategies of saccadic planning. Vision Res 50:2142-2157 doi: 10.1016/j.visres.2010.08.008

APPENDIX

Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

ACTION ON PROTOCOL APPROVAL REQUEST

TO: Jan Hondzinski
Kinesiology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: February 6, 2013
RE: **IRB#** 3076
TITLE: Altered sensory states effects on goal-directed movement control

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Dr. Welsch added as Co-PI; Orthogonal polarization spectral imaging added

Review type: Full ____ Expedited X **Review date:** 2/7/2013

Risk Factor: Minimal X Uncertain ______ Greater Than Minimal______

Approved X **Disapproved** __________

Approval Date: 2/7/2013 **Approval Expiration Date:** 3/11/2013

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 150

Protocol Matches Scope of Work in Grant proposal: (if applicable) N.A.

By: Robert C. Mathews, Chairman ____________________

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

Study Approved By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Approval Expires: 2/13/2014

LOUISIANA STATE UNIVERISTY AND A&M COLLEGE
INFORMED CONSENT FORM

1. **Study Title:** Altered sensory states effects on goal-directed movement control

2. **Performance Site:** Department of Kinesiology laboratories, Louisiana State University and A&M College

3. **Investigators:** The following investigators are available for questions about this study, M-F, 8:30 a.m. - 5:00 pm
   Dr. Jan M. Hondzinski: Office: 225-578-9144; Lab: 225-578-7448; jhondz1@lsu.edu
   Dr. Michael Welsch: Office: 225-578-9143; mwelsch@lsu.edu

4. **Purpose of the Study:** to better understand how the coordination of reaching while standing upright varies under altered sensory conditions.

5. **Participant Inclusion:** Control subjects will be comprised of young and older adults with no known neurological problems. Subjects with Peripheral neuropathy (PN) will also be recruited. All subjects will be: (1) adults at least 18 years old; (2) able to sustain an upright standing posture, independently; (3) able to walk at least 20 yards with or without an assisted device; and (4) willing to participate in the study. Those with PN will present with reduced peripheral sensations.

6. **Participant Exclusion:** All subjects must have no: (1) history or evidence of central nervous system dysfunction; (2) musculoskeletal deformity which influences task performance; (3) history of angina; (4) acute injury which limits task performance; (5) evidence of unstable disease which limits task performance; and (6) cognitive impairment defined as a score of less than 24 on the mini-mental state exam. Control subjects with evidence of peripheral sensory loss relative to normal healthy peers as reported in the literature will be excluded from participation. Women cannot be pregnant.

6. **Number of Participants:** 150. Fewer are needed, however because of individual differences and/or certain equipment requirements some subjects may be excluded if the system will not calibrate to the manufacturer's specifications. This should also account for adherence to inclusion/exclusion criteria.

7. **Study Procedures:** Subjects will schedule 1-3 three visits based on their comfort level and personal schedule. Informed consent, cognitive level, and a medical/personal history will be taken. This will be followed by physiological and functional evaluations of sensory impairment, strength, balance and mobility. Sensory evaluations include foot and hand sensations, proprioception, nerve conduction velocity of the lower limbs, and vision. Lower limb strength will be evaluated. Functional tests of balance, gait, and mobility are also included. Speed of blood

through and the thickness of small capillaries may also be assessed using non-invasive techniques involving orthogonal polarization spectral imaging: the placement of a small plastic tube (size of a pen) against the cheek and nail fold.

Task preparation: You will be fitted with an eye tracker to monitor eye/head movement. Several reflective markers will be placed and taped (medical tape to help prevent skin reactions) over segments of the upper and lower limbs, the trunk, and attached to the head gear to monitor body movements. Note: when standing, it will be on a slightly elevated platform (2"—surface area approximately 4 ft x 4 ft). The platform contains a special scale to measure your natural movement when standing.

Trials: After calibration, which requires subjects target viewing with eye movements only, you will be asked to reach to seen or remembered targets from seated or standing or lying down (horizontally or inverted—strapped while lying on a table tilted so that the body is upside down) positions. Specifically, you will be told to reach to place a pen tip or the fingertip just near the real or remembered target location as accurately as possible. Prior to movement the target will be presented. In remembered trials the target will be moved out of your view prior to movement. You may be asked to move at different speeds or with the lights turned off. In certain cases you may be given external support. Personal assistance is always available for safety. You may rest at any time.

8. **Benefits:** As a volunteer from the college community you may earn extra credit for research participation. As a volunteer from the community you will receive physiological and functional evaluations and their associated outcomes for FREE. Otherwise there are no other direct benefits for you. The information extracted from your performance will be beneficial to future studies involving movement control.

9. **Risks/Discomforts:** There is no known risk to the subject beyond those that occur in daily activity. Every effort will be made to maintain your safety. When inverted you will have breaks every 2-4 minutes and when requested. This requires tilting the table back to horizontal so you are lying down. You will be monitored closely by research personnel during testing. Every effort will be made to maintain confidentiality of your records. Files will be kept in secure cabinets to which only the investigators have access. All vascular assessments involve non-invasive techniques. There are no known risks associated with orthogonal polarization spectral imaging to assess microvascular function (Speed of blood through and the thickness of small capillaries).

10. **Right to Refuse:** Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. **Privacy:** The LSU Institutional Review Board (which oversees university research with

human participants) may inspect and/or copy the study records. Results of the study may be published, but no names or identifying information will be included in the publication. Other than as set forth above, subject identity will remain confidential unless disclosure is legally compelled.

12. **Signatures:** The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about Participants' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

________________________ ________________________

Participant Signature Date

VITA

Chelsea was born in Saskatoon, Saskatchewan, Canada. She was raised by her parents Gordon and Heather and has an older brother. She received her Bachelor's of Science in Occupational Therapy degree from the University of Alberta in June 2008. Chelsea is a candidate for a Master of Science degree in Kinesiology from Louisiana State University in May 2014.