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Effect of Aging and Peripheral Neuropathy on Standing Reaching Precision With and Without Visual Cues

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by

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ABSTRACT

In this study, we examined whether goal-directed reaching movements with and without vision would be influenced by healthy aging declines and reduced lower limb somatosensations associated with Peripheral Neuropathy. Nine subjects with lower limb somatosensory deficits (LLSD), nine older controls (OC), and nine young controls (YC) were asked to produce single goal-directed reaching movements with their dominant arm to three real or remembered target locations. Reaches to remembered target locations were performed in normal room lighting (LIGHT) or complete darkness (DARK). Comparisons between YC and OC subjects to test for aging effects and between OC and LLSD subjects to test for effects of sensory deficits of the lower limb on directional endpoint errors, displacement, movement time, and peak velocity were performed using mixed design ANOVAs. Repeated measures included target level (HIGH, LOW) and visual condition (LIGHT, DARK). Results revealed that OC subjects produced similar endpoint errors, displacements, movement times, and peak velocities to YC subjects. YC and OC subjects produced more variability in the medial-lateral (M-L) direction when reaching in the DARK relative to LIGHT conditions. This was not the case for LLSD subjects, as they produced the greatest error bias in the M-L direction when reaching in the DARK. Although moving less distance in the DARK is common across healthy subjects, especially in the vertical (superior-inferior) direction, ending reaches closer to the dominant hand side signifies that the LLSD subjects moved less distance in this direction in darkness unlike the controls. Since no other visual condition-related differences by group were identified, these differences could not be attributed to movement duration or speed of movements. We conclude that visual cues enhance M-L movements of the upper limb for those with neuropathic induced deficits in lower limb sensations.

INTRODUCTION

Human interaction in a complex and ever changing environment requires the coding, storage, and translation of sensory information in order to complete motor tasks successfully. It is important to note, and unsurprising, that discrete reaching and pointing movements to remembered target locations often have different endpoint precision than those made to actual targets (Flanders, Daghestani & Berthoz, 1999; Berkinblit, Fookson, Smetanin, Adamovich, & Poizner,1995; Darling & Miller, 1993). These differences can be seen when performing reaching tasks in different visual conditions (Hondzinski & Cui, 2006), at different target heights (Huang & Brown, 2013), and for different populations (Hondzinski, Li & Welsch, 2010). The parietal reach region (PRR) is thought to plan visually directed reaching movements (Connolly, Andersen, & Goodale, 2003). The Posterior Parietal Cortex (PCC) controls these reaching movements by integrating sensory input with the motor inputs responsible for inciting muscle activation to create remembered target location representations with respect to the intended reaching direction (Buneo, Jarvis, Batista, & Andersen, 2002). Thus, storage of visual information regarding target location and translation of this sensory input are key aspects used to coordinate different body segments used for goal-directed reaching movements to remembered target locations.

Altered Visual Conditions

Final endpoint accuracy in goal-directed reaching movements can be influenced by the environmental condition in which the task is completed. Removing one sensory input, such as visual cues during a reaching task to a remembered target, requires the use of other compensatory sources of sensory feedback (i.e. proprioceptive cues) to complete the task with a certain amount of success. Previous results showed that subjects reach below remembered target

locations in a dark environment when compared to an illuminated environment (Bock & Eckmiller, 1986; Bock, Howard, Money, & Arnold, 1992; Henriques & Crawford, 2000; Henriques, Klier, Smith, Lowy & Crawford, 1998; Hondzinski et al., 2006; Admiraal, Keijsers, & Gielen, 2004). Additionally, subjects have a tendency to decrease displacement of the hand when reaching in darkness relative to reaches performed in normal room lighting (Hondzinski & Cui, 2006; Henriques, Medendorp, Gielen, & Crawford, 2003). Recently it was shown that reaching lower in the dark is linked to shorter movement excursion in darkness (French, Soebbing & Hondzinski, 2013). Furthermore, since overreaching of target locations located closer to subjects in illuminated settings occurs often in literature (Henriques et al., 2003; Soechting, 1989; Gentilucci & Negrotti, 1994; Tresilian, Mon-Williams & Kelly, 1999), it comes as no surprise that by under reaching in the dark subjects can have great precision bias in some cases (e.g. Hondzinski & Cui, 2006), but often they have greater endpoint errors in dark conditions (e.g., Admiraal, Keiksers & Glielen, 2004) further providing evidence that vision is important in the performance of reaching tasks.

Altered Somatosensations

Reaching tasks from a standing position require inputs not only from the arm proprioceptors and visual system for upper limb control, but also from the visual, vestibular, and lower limb somatosensory systems for postural control (Dietz, Gollhofer, Kleiber, & Trippel, 1992). Damaged or declining feedback from these systems due to injury, disease, or healthy aging can result in greater end-point errors or alterations in movement kinematics during goal-directed reaching movements. One disorder, Peripheral Neuropathy (PN), caused by a progressive degeneration of sensory nerves occurring in a distal to proximal direction, tends to cause balance impairments in patients with the disorder (Resnick et al.,2002), especially with

eyes closed (Akbari, Jafari, Moshashaee & Forugh, 2012). People with PN also tend to have mobility problems and slower gait patterns than healthy adults without PN of similar age (Richardson, Thies, DeMott & Ashton-Miller, 2004). Individuals with lower limb sensory declines associated with PN also produce greater endpoint errors compared to age-matched controls when reaching towards remembered target locations with a step (Hondzinski et al., 2010). Authors blamed these reaching errors on alterations in the lower limb movements while stepping that result from the lower limb sensory deficits for these individuals.

Reaching toward objects from a standing body orientation is common for the performance of daily activities. The neural circuitry involved in postural control has consistently linked lower limb muscle pre-activation to voluntary movements of the arm (Layne & Abraham, 1991; Cordo & Nasher, 1982; Bouisset & Zattara, 1987a). Anticipatory patterns of lower limb muscle activity occur before activation of the upper limb muscles in standing individuals to remain upright by counteracting destabilization of the center of mass that comes from elevating the arm during reaching tasks (Bouisset & Zattara, 1981). Decreased plantar cutaneous sensations of the foot, induced by ice submersion, contribute to postural sway when standing (Hong et al., 2007; Meyer, Oddsson, & De Luca, 2003) and alter the anticipatory adjustments in posture when preparing to step (Lin & Yang, 2011). Evidence shows that these decrements in postural stability due to lower limb sensory reductions cannot be completely compensated by vision, thus remain altered in lighted environments. However, it is unclear whether disease induced (rather than ice induced) sensory deficits in the lower limbs will influence upper limb reaching performance while standing upright without a step.

Age-related Considerations

Age-related declines in the various sensory systems may manifest themselves in different ways than decline due to systems damaged by diseases such as PN. Previous research has identified age-related differences in which reaching endpoint accuracy to a remembered target location in normal room lighting becomes more variable with age with no visual feedback of the movement (Lemay & Proteau, 2003). These results, which required a memory delay of 10 seconds, differ from other work in which the memory delay was much shorter, as no significant age-related differences were reported for endpoint accuracy when reaching to remembered target locations after a few second delay (Hondzinski et al., 2010). Others have shown that for short or long delays prior to reaching to remembered target locations in normal room lighting endpoint errors were not influenced aging (Perrot, Bherer, & Messier, 2012). Natural aging declines do not appear to influence endpoint precision differently from younger adults in illuminated environments when the time between the presentation of target locations and the initiation of movement is relatively short, or visual feedback of the movement is available. However, it is unclear whether differences in age-related endpoint precision exist in complete darkness with short movement delays, as older adults tend to rely on visual cues more than their younger counterparts (e.g., Seidler-Dobrin & Stelmach, 1998).

Purpose and Hypothesis

The purpose of this study was to examine how standing goal-directed reaching precision with and without vision are influenced by deficits due to healthy aging and reductions in lower limb somatosensations. Specifically, young adults, older adults, and older adults with lower limb sensory deficits (LLSD) reached to remembered target locations from standing body orientations in environments with lights on and off. Due to increased postural sway (Hong et al., 2007) and

alterations to anticipatory postural activation during step initiation (Lin & Yang, 2011) that accompany plantar somatosensory declines, we hypothesized that endpoint errors would be greatest in older adults with LLSD when standing in complete darkness.

MATERIAL AND METHODS

Subjects

Two groups of control subjects comprised of 10 young (YC) and 12 older controls (OC) with no known neurological dysfunction, and one experimental group of 12 subjects with lower limb sensory deficits (LLSD) were recruited for participation in this study. Young subjects were students from the Louisiana State University while LLSD and OC subjects were community dwelling adults. The subjects with LLSD had a physician's diagnosis of peripheral neuropathy.

Subjects gave written consent prior to participating in the experiment and the experimental procedures were approved by the University's Institutional Review Board. Exclusion criteria for subjects included history or evidence of central nervous system dysfunction, musculoskeletal deformity that would influence movement performance, history of angina or cardiovascular disease, any evidence of unstable disease which may limit task performance, and no loss of protective cutaneous sensations in their dominant hand (described below). While controls also could not present with loss of protective cutaneous sensations on the plantar surfaces of their feet, those in the LLSD group were only included with evidence of such sensory reduction. Subjects who did not meet inclusion/exclusion criteria or perform movements as requested were excluded from analyses. Table 1.1 reveals the subject characteristics and reason for removal, if applicable. Note that analyses were performed on 9 YC, 9 OC, and 9 LLSD subjects. The mean age of YC, OC, and LLSD groups were 21, 74, and 74 years,

respectively. The mean height and mass ± 1 *SD* of YC subjects were 167 ± 9.1 cm and 75 ± 14.8 kg. The average height and mass of OC subjects were 169 ± 9.1 cm and 73 ± 14.5 kg, and the mean height and weight of LLSD subjects were 176 ± 14.6 cm and 82 ± 19.9 kg. One LLSD, two OC, and one YC subject were left hand dominant, while the remaining subjects were right hand dominant.

All subjects had vision or corrected vision better than $20/30^{(-1)}$, had no difficulties seeing the targets, and had no loss of protective cutaneous sensation in the palmar surface of their dominant hand as evaluated by a touch-test on the tips of the five digits of the same hand using the 3.84 Semmes-Weinstein monofilament (North Coast Medical, Inc, USA). Five plantar sites were tested to confirm LLSD by the evaluation of plantar pressure detection thresholds (PPDT) with the 5.07 gauge Semmes-Weinstein monofilament; the hallux, the base of the first and fifth metatarsals, the heel, and the midsole (Kamei et al., 2005). Each site was tested three times at random by pressing the monofilament at a 90^0 angle against the skin until a bowing was produced for at least 1 s (Eils et al., 2002). The subjects provided a verbal "yes" each time the stimulus was detected on the palmar and plantar surfaces, respectively. The presence of protective cutaneous sensation was determined by two or more correct responses out of three at each site (Hondzinski, Li & Welsch, 2010). PPDT scores were calculated by totaling the number of sites with intact sensation and dividing that score by two, potentially producing a score ranging from 0 to 5. Subjects were categorized as LLSD upon receiving a score less than 5.

Table 1: Subject Characteristics

Subject #	Age	Group	PPDT*	Sex	Visual Acuity[#]	Arm Length (cm)	Reason for removal
1	25	YC	5	F	20/25	68	
2	22	YC	5	M	20/13	71.5	
3	22	YC	5	M	20/13	71	
4	22	YC	5	M	20/10 (-2)	75	
5	20	YC	5	F	20/15 (-2)	70	
6	20	YC	5	F	20/13	71	
7	21	YC	5	F	20/13 (-2)	64	
8	21	YC	5	F	20/15 (-1)	66	
9	20	YC	5	M	20/13	74.3	
10	21	YC	5	F	20/13 (-1)	75	Low PPDT
11	83	OC	5	F	20/20 (-1)	69	
12	65	OC	5	F	20/15 (-2)	74	
13	77	OC	5	M	20/13 (-3)	70	
14	77	OC	5	F	20/20 (-4)	66	
15	76	OC	5	F	20/25 (-2)	66.5	
16	71	OC	5	M	20/20 (-1)	72	
17	79	OC	5	F	20/25	67.5	
18	74	OC	5	M	20/5 (-1)	72.5	
19	67	OC	5	F	20/15 (-1)	71	
20	69	OC	LLSD-4	M	20/20 (-3)	74	Low PPDT
21	64	OC	LLSD-4	F	20/25 (-1)	72.5	Low PPDT
22	66	OC	LLSD-4	F	20/15 (-1)	74	Low PPDT
23	75	LLSD	LLSD-4.5	F	20/15 (-1)	74	
24	67	LLSD	LLSD-1.5	M	20/20 (-1)	80	
25	79	LLSD	LLSD-.5	M	20/20 (-2)	80	
26	77	LLSD	LLSD-4	F	20/20 (-2)	67	
27	79	LLSD	LLSD-3.5	F	20/25 (-1)	72.5	
28	70	LLSD	LLSD-3	F	20/13 (-2)	67.5	
29	74	LLSD	LLSD-0	M	20/15 (-2)	69.5	
30	78	LLSD	LLSD-3	M	20/30 (-1)	80	
31	69	LLSD	LLSD-1	M	20/20 (-1)	75.5	
32	80	LLSD	LLSD-2	F	20/25 (-4)	70	Low hand PDT
33	68	LLSD	5	F	20/25 (-1)	65	High PPDT
34	78	LLSD	LLSD-4.5	F	20/20 (-5)	68.58	Withdrew

*PPDT < 5 indicates reduction in protective cutaneous sensations.
**Hand PDT indicates reduction in protective cutaneous palmar sensations
[#]Visual Acuity: numbers represent the lowest line of correct letters read on a standard Snellen Eye Test chart. Numbers in parentheses represent the number of letters missed on that line.

Procedures

On each trial subjects were asked to produce a single reaching movement to place the handheld pen tip just in front of the real (Control) or remembered target locations. Starting position involved subjects standing comfortably holding their dominant arm flexed at the elbow at a 90° angle against their side with feet shoulder width apart (Figure 1A). Targets made of fishing anchors with a maximum diameter of 1.5 cm were presented at a distance of half arm's length (measured from the acromion process to the tip of the middle finger) directly in front of the body along the midsagittal plane. Target heights were determined based on the subject's estimated shoulder and eye heights based on 82% and 94% of subject height (Winter 1990), respectively. The LOW target was placed at the subject's estimated shoulder height, the middle target was positioned at the subject's estimated eye height, while the HIGH target was positioned at the eye height plus the difference between shoulder and eye heights.

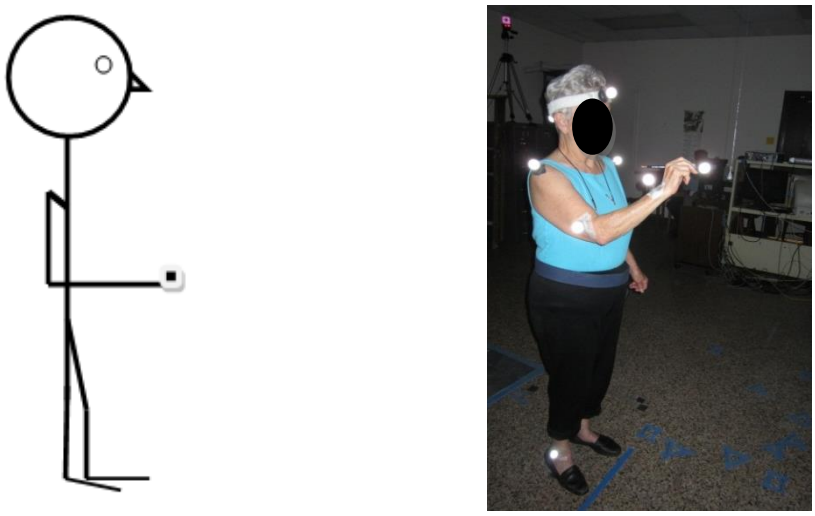

Figure 1. (A) Starting position for subjects. (B) Final reaching position for subjects. Also note marker locations.

Subjects performed reaches to real targets (REAL) or to remembered target locations in normal room lighting (LIGHT) or complete darkness (DARK). After target presentation for about 2 s, the presented target either remained in place (REAL trials) or was manually removed from sight with a "ready" cue. This cue also signaled lights out for DARK trials. Subjects were then asked to make a single reaching movement to place the pen tip directly in front of the target (REAL trials) or remembered target location (LIGHT or DARK trials) at a comfortable pace after a "go" command. Subjects were asked to hold their final position until they were given the verbal "relax" command approximately 1 s later. Two trials for each target in each visual condition were presented at random in three blocks. Trials were repeated if obvious mistakes were made by subjects (i.e., they touched a target in a REAL trial, diverted their gaze during movement, or made an obvious change in movement). Data were collected in two minute sessions, thus extra trials were also collected when extra time remained in the last session. Subjects took a short break between sessions and additional rest was allowed upon request.

Subjects were unaware of when the lights would go out for DARK trials, so for safety purposes, a gait belt was placed around the waist of subjects and monitored by a member of the research team. This person held the belt loosely to provide external assistance, if needed, without providing perceptive tactile feedback to the subject.

Data Collection

Figure 1B shows that eight markers were placed on each subject to track their movements. Two markers were placed on the head (midsagitally) on the front and back of a headband worn by subjects. Two markers were placed laterally on the shoulders and on lateral malleoli of the ankles, and one marker was placed on the elbow, wrist, and tip of the handheld

pen on the dominant hand side. Movements were tracked and recorded at 60 Hz using four cameras of a passive-marker motion capture system (Qualysis Medical AB, *SE*).

Data Analyses

Position data were low-pass filtered at 5 Hz using a Butterworth filter with forward and reverse pass to avoid phase shifts. Tangential velocity of the pen tip was calculated by differentiating position data with respect to time. Each dimension of pen position and tangential pen velocity profiles of each trial were plotted, visually scanned, and marked at movement onset and end using a costumed Lab View program. Movement onset corresponded to the frame just prior to 5% of peak pen velocity during movement acceleration, while movement end corresponded to the frame just following 5% of peak pen velocity during movement deceleration. Velocity plots were also used to determine whether subjects made single reaching movements as requested. Trials with velocity profiles that were not bell-shaped indicating a single reach with no adjustments were discarded. This left us with greater than 87% of the planned trials on which to perform analyses.

Variables of interest included medial-lateral (M-L), anterior-posterior (A-P), and superior-inferior (S-I) 3-dimensional direction errors, pen displacement, peak velocity, and movement time. Position data at movement onset and end were calculated as the average of 5 frames prior to movement onset or after movement end, respectively. The difference between the final pen x (M-L), y (A-P), and z (S-I) and the final mean control location of the pen markers for each subject, target, and body orientation were calculated to determine the final reach errors in cm in the M-L , A-P, and S-I directions, respectively. Positive reach errors for remembered trials were calculated relative to the mean control location and noted as reaching toward the dominant hand in the M-L direction, farther forward in the A-P direction, and above in the S-I direction.

Pen displacement was determined as the distance in cm between start and final pen locations. Peak velocity was determined as the maximum value in cm/s from the velocity profile of each trial. Movement time was calculated in s by dividing the number of frames from the beginning to the end of the movement divided by the data sampling frequency.

A mixed design ANOVA was used to determine *aging effects* on the various measures; if differences in each variable existed based on the between factor of age (YC, OC) and within subject repeated measures of visual condition (LIGHT, DARK) and target height (HIGH, LOW). This analysis was also used to determine effects of *sensory deficits* on the various measures; if differences in each variable existed based on the between factor of sensory deficit (OC, LLSD) and within subject repeated factors of visual condition (LIGHT, DARK) and target height (HIGH, LOW). Tukey HSD post hoc tests were used when appropriate. Results were deemed significant at $p<0.05$.

RESULTS

Results are separated by analyses. Results on sensory deficits between older adults with and without LLSD will follow those on aging between young and older adults. Emphasis is placed on significant findings for simplicity.

Aging Outcomes

Reaching Errors

Figure 2 represents examples of final pen position for one subject. Final pointing positions for the three visual conditions are provided for the HIGH, Middle, LOW targets. Note that in the DARK condition participants commonly pointed more inferior relative to the final locations of REAL and LIGHT conditions.

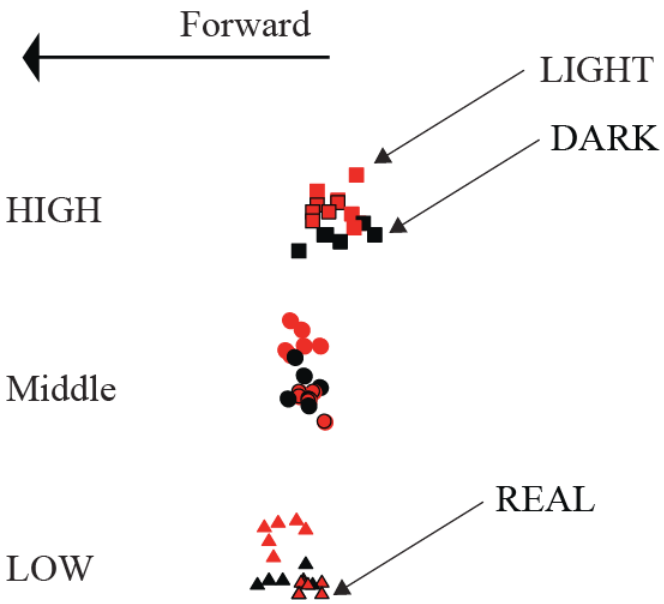

Figure 2. Final pen tip locations for reaches are plotted for a young adult. Final reach locations for HIGH, Middle, and LOW level targets are shown in squares, circles, and triangles, respectively. Locations corresponding to reaches to REAL targets are provided in symbols with red fill and black outlines, while red symbols correspond to reaches to remembered targets with lights on (LIGHT) and black symbols correspond to reaches to remembered targets in complete darkness (DARK).

Table 2 shows the significant constant and variable reaching errors by direction. Note that group differences were only identified in M-L and A-P directions. However, post hoc analyses on the VIS*group interaction for the M-L direction revealed no significant differences. The main effect of VIS condition on M-L variable errors revealed that subjects had greater variability in this direction when reaching in the DARK condition (1.15 cm) with respect to the LIGHT condition (0.67 cm). The significant interaction of TARG*group for the A-P direction revealed that YC subjects reached further (i.e., had greater constant error) when reaching to the LOW target with respect to the HIGH target (Fig. 3). The main effects of target height (TARG) on S-I errors showed greater constant error when reaching to the LOW target (1.13 cm) with respect to the HIGH target (-1.36 cm). The main effects of visual condition (VIS) on S-I

constant errors revealed that subjects had greater errors when moving in the LIGHT condition (1.08 cm) with respect to the DARK condition (-1.31 cm).

Table 2: Significant Constant and Variable Reaching Errors by Direction

	Medial/Lateral (M-L)		**Anterior/Posterior (A-P)**		**Superior/Inferior (S-I)**	
CONSTANT ERRORS	*F value*	*p-value*	*F value*	*p-value*	*F value*	*p-value*
TARG					19.53	0.0005
VIS					29.03	0.0000
TARG*group			7.54	0.0149		
VIS*group	5.98	0.0273				
VARIABLE ERRORS	*F value*	*p-value*	*F value*	*p-value*	*F value*	*p-value*
VIS	24.65	0.0002				

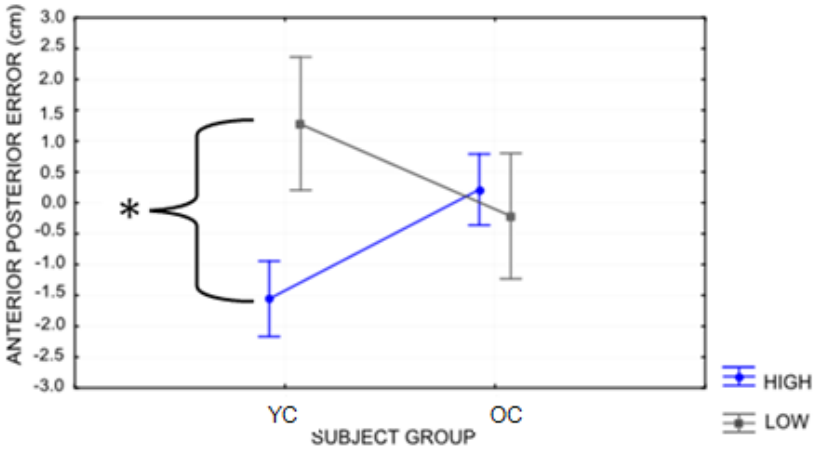

*Figure 3 represents the TARG*group interaction for A-P errors. The blue and grey lines represent data for the HIGH and LOW targets, respectively. Asterisks represent significance differences between corresponding mean values, p<0.05. Error bars represent ±1 standard error.*

Displacement

Table 3 depicts the results for displacement. The main effect of TARG on displacement showed that there was a significant difference between the subject's displacement when reaching to the HIGH (? cm) and LOW (? cm) targets, with subjects having the greatest displacement when reaching to the HIGH target. This was expected as the HIGH target was further away from starting hand position. The main effects of VIS on displacement showed that subjects had a

significantly greater displacement when reaching in the LIGHT condition with respect to the DARK condition, however, the significant TARG*VIS interaction revealed that this was only true when reaching to the HIGH target (Fig 4).

Table 3: Significant Displacement Results

	Displacement	
MEAN	*F value*	*p-value*
TARG	893.69	0.0000
VIS	11.33	0.0037
TARG* VIS	4.55	0.0478

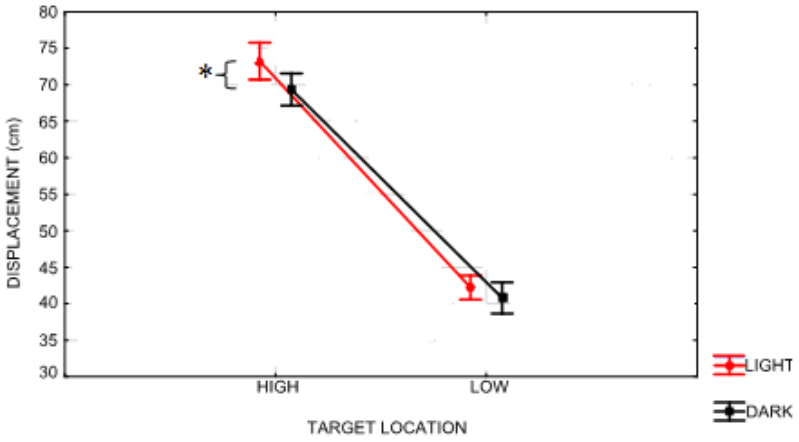

*Figure 4 represents the TARG*VIS interaction for displacement. The red and black lines represent data for the LIGHT and DARK conditions, respectively. Asterisks represent significance differences between corresponding mean values, p<0.05. Error bars represent ±1 standard error.*

Peak Velocity (VEL)

Table 4 depicts outcomes for VEL. The main effects of TARG and VIS on VEL showed that subjects had a higher VEL when reaching to the HIGH target (193 cm/s) with respect to the LOW target (122 cm/s), and when reaching in the LIGHT condition (163 cm/s) with respect to the DARK condition (152 cm/s). The main effect of VIS on VEL variability indicated that subjects had more variability in their VEL when reaching in the LIGHT condition (20 cm/s) with respect to the DARK condition (16 cm/s).

Table 4: Significant VEL Results

	Peak Velocity (VEL)	
MEAN	*F value*	*p-value*
TARG	358.92	0.0000
VIS	8.58	0.0104
VARIABILITY	*F value*	*p-value*
VIS	5.46	0.0348

Movement Time (MT)

Table 5 depicts significant outcomes for MT. Main effects of TARG and VIS on MT showed that subjects had a greater MT, thus took longer time to reach to the HIGH target (0.78 s) with respect to the LOW target (0.73 s) and when reaching in the DARK condition (0.77 s) with respect to the LIGHT condition (0.73 s), respectively.

Table 5: Significant MT Results

	Movement Time (MT)	
MEAN	*F value*	*p-value*
TARG	10.98	0.0047
VIS	6.45	0.0226

The outcomes above revealed that group effects were only identified for reaching errors and not displacement, VEL, or MT, suggesting only minimal aging influences on endpoint accuracy. No other significant outcomes were identified.

Sensory Deficit Outcomes

Reaching Errors

Table 6 reveals the significant constant and variable reaching errors by direction. Note that group differences were only identified in the M-L direction. However, post hoc analyses revealed that the VIS*group interaction for the M-L direction had no significant outcomes. The significant TARG*VIS*group interaction revealed that there were greater constant errors for the

LLSD subjects when reaching in the DARK condition with respect to the LIGHT condition to the LOW target (Fig 5). The main effect of VIS on variable M-L errors showed greatest variability in errors existed when reaching in the DARK condition with respect to the LIGHT condition. However, the significant VIS*group interaction revealed that this was only true for OC subjects (Fig 6). The main effect of VIS on A-P variable errors revealed greater variability in this direction for reaches in the DARK condition (1.76 cm) with respect to the LIGHT condition (1.42 cm).

Table 6: Significant Constant and Variable Reaching Errors by Direction

	Medial/Lateral (M-L)		**Anterior/Posterior (A-P)**		**Superior/Inferior (S-I)**	
CONSTANT ERRORS	*F value*	*p-value*	*F value*	*p-value*	*F value*	*p-value*
TARG					23.40	0.0002
VIS					60.24	0.0000
VIS*group	9.46	0.0072				
TARG*VIS					8.17	0.0114
TARG*VIS*group	6.40	0.0223				
VARIABLE ERRORS	*F value*	*p-value*	*F value*	*p-value*	*F value*	*p-value*
VIS	7.07	0.0179	5.17	0.0380	6.67	0.0208
VIS*group	8.10	0.0122				

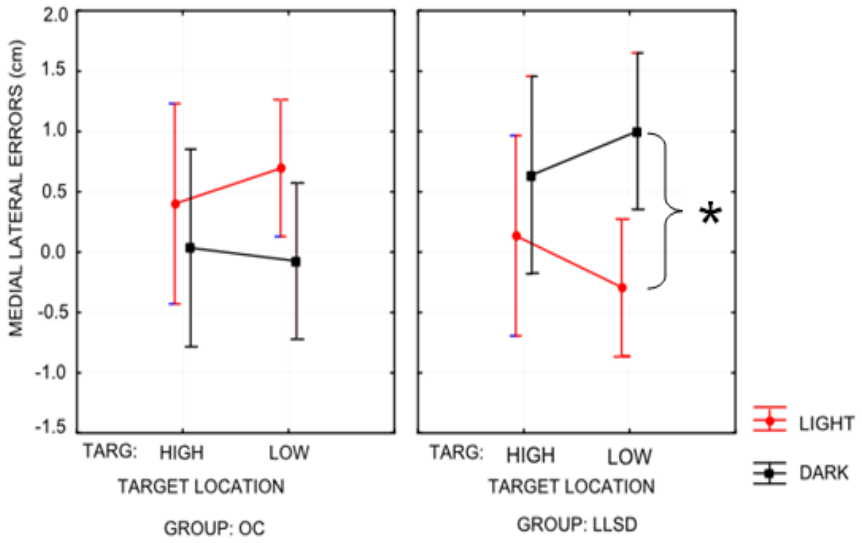

*Figure 5 represents the TARG*VIS*group interaction for M-L errors. The red and black lines represent data for the LIGHT and DARK conditions, respectively. Asterisk represents significant differences between corresponding mean values, p<0.05. Error bars represent ±1 standard error.*

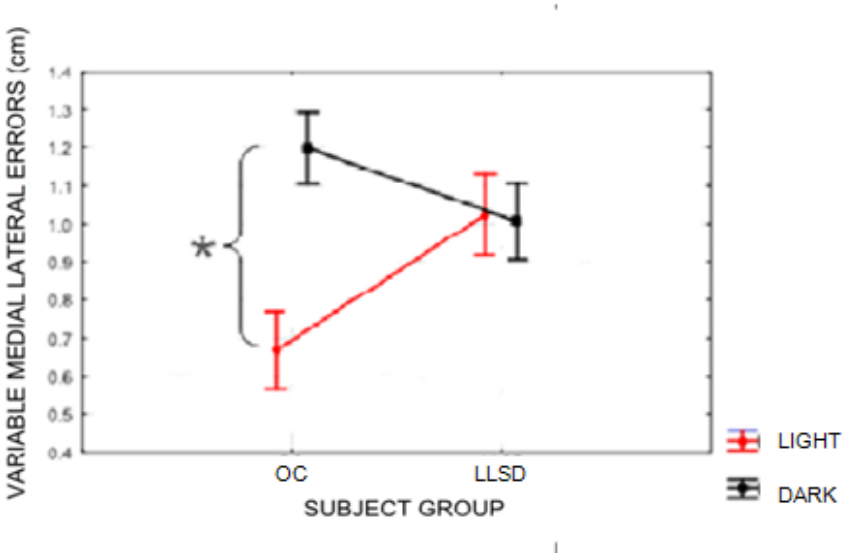

*Figure 6 represents the VIS*group interaction for variable M-L errors. The red and black lines represent data for the LIGHT and DARK conditions, respectively. Asterisk represents significant differences between corresponding mean values, p<0.05. Error bars represent ±1 standard error.*

Along the S-I direction, results for constant and variable errors are presented in Table 5. The main effects of TARG and VIS on S-I constant errors reveal greater errors when reaching to the LOW target (0.83 cm) with respect to the HIGH target (-1.78 cm), and when reaching in the LIGHT condition (0.92 cm), with respect to the DARK condition (-1.88 cm). The significant TARG*VIS interaction revealed that subjects had greater constant errors when reaching in the LIGHT condition to both targets, yet this difference was greater for the HIGH target (Fig 7). Variable errors were greater when reaching to targets in the DARK condition (1.76 cm) with respect to the LIGHT condition (1.42 cm) along the S-I direction (main effect of VIS).

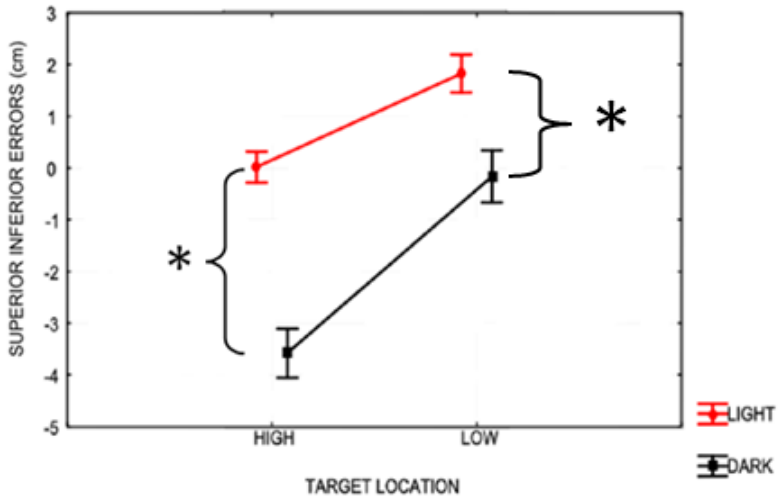

Figure 7 represents the TARG VIS interaction for S-I errors. The red and black lines represent data for the LIGHT and DARK conditions, respectively. Asterisk represents significant differences between corresponding mean values, $p<0.05$. Error bars represent ±1 standard error.*

Displacement

Table 7 depicts the results reaching displacement for the OC and LLSD groups. The main effect of TARG revealed that subjects had greater displacement when reaching to the HIGH target (70.23 cm) with respect to the LOW target (39.89 cm). The main effect of VIS showed

that subjects had greater displacement when moving in the LIGHT condition (56.83 cm) with respect to the DARK condition (53.30 cm).

Table 7: Significant Displacement Results

	Displacement	
MEAN	*F value*	*p-value*
TARG	623.02	0.0000
VIS	19.40	0.0013

Peak Velocity (VEL)

Table 8 identifies the results for VEL. The main effects of TARG and VIS on VEL revealed that subjects produced greater VEL when reaching to the HIGH target (193 cm/s) with respect to the LOW target (123 cm/s) and when reaching in the LIGHT condition (168 cm/s) with respect to the DARK condition (149 cm/s).

Table 8: Significant Peak Velocity Results

	Peak Velocity	
MEAN	*F value*	*p-value*
TARG	138.39	0.0000
VIS	15.24	0.0004

Movement Time (MT)

Table 9 identifies the results for movement time. The main effect of TARG revealed that subjects had longer movement time when reaching to the HIGH target (0.79 s) with respect to the LOW target (0.73 s). Subjects had longer movement times when reaching in the DARK condition (0.78 s) with respect to the LIGHT condition (0.74 s) (main effect of VIS).

Table 9: Significant MT Results

	Movement Time	
MEAN	*F value*	*p-value*
TARG	37.27	0.0000
VIS	5.68	0.0298

DISCUSSION

We wanted to determine how goal-directed reaching precision with and without vision are influenced by deficits due to healthy aging and reductions in lower limb somatosensations. Results revealed significant visual differences in primary measures of constant and/or variable errors in reaching movements for OC and LLSD groups and led us to conclude that reduced lower limb somatosensations do affect performance of this task by causing subjects to end their reaches closer to their dominant hand side in the DARK condition.

Group Effects

Aging Effects

The performance of standing reaches to remembered and real target locations requires the coordination of upper and lower limb segments, as well as the maintenance of postural control (Huang & Brown, 2013). Aging has been associated in the literature with decreased postural stability (Wollacott & Manchester, 1993), increased movement times (Hondzinski et al., 2010), and reduced movement velocities (Carnahan, Vandervoort & Swanson, 1998). In this study, OC subjects produced similar endpoint errors, displacements, movement times, and peak velocities to their younger counterparts. In fact, it was the younger adults who had a tendency to overshoot the LOW target location and undershoot the HIGH target location in the A-P direction, while older adults ended reaches closer to control trials (i.e., mean errors were closer to zero, Fig. 2). Clearly, the well-established effect of movement slowing in older subjects was not observed in this study. These findings on movement time contradict the results of some studies on reaching with a step (Hondzinski et al., 2010), reaching as quickly as possible, and performing reaches from a seated position (Fradet, Lee & Dounskaia, 2008). However, these findings are in line with

others who showed similarities in endpoint accuracy between young and older age groups when delay time between target presentation and movement is relatively short (Hondzinski et al., 2010) or long (Perrot et al., 2012) and visual feedback of the moving limb was provided. Although we reasoned that endpoint errors would differ between the young and older adults if memory delay was increased and visual feedback of the movement was occluded (Lemay & Proteau, 2003), future studies are warranted to determine whether age-related error differences between visual conditions for longer memory delays would exist for three dimensional reaches.

Sensory Deficit Effects

Subjects with LLSD displayed spatial differences in the M-L direction that differed from those for OC subjects when reaching to remembered target locations. It is interesting to note that error differences were observed between visual conditions.

Although OC and YC subjects were more variable in the M-L direction when reaching in the DARK relative to LIGHT conditions, it was the LLSD subjects who ended their reaches closer to the dominant hand side when reaching in the DARK (i.e., more positive errors) relative to the LIGHT condition. This is similar to an upper limb neuropathy subject in the literature who produced greater endpoint errors while reaching with no view of their limb (Messier et al., 2003). However, in the present study the reaching limb was not the affected limb, at least in terms of protective tactile sensations.

The greater variability observed in control subjects corresponds to results in the literature that show greater variability in endpoint precision when reaching in darkness (Hondzinski et al., 2006). The greater endpoint errors toward the dominant hand observed for LLSD subjects when reaching in the DARK to the LOW target suggest that the lack of vision and somatosensations from the lower limbs can affect final reaching bias by causing less movement in this direction.

Smaller movement excursions can correspond to less movement variability, likely explaining why LLSD subjects did not produce greater variable errors in the DARK, similar to the OC subjects. Apparently, the greater M-L endpoint variability that corresponds to M-L variability in step deviations in people with lower limb sensory deficits during a reaching task with a step (Hondzinski et al., 2010) does not differ for LIGHT and DARK visual conditions when the base of support is not moving as observed in this study. Since we did not measure postural sway directly, it is unclear whether those with LLSD in the present study were able to use visual cues to compensate for a greater sway that is often found in this population, especially in the dark and in the M-L direction (Boucher, Tesdale, Courtemanche, Bard, & Fleury, 1995). We reasoned this was not the case because one would expect the greater variability in M-L sway, often observed in this population (Uccioli et al., 1995), to be linked to greater M-L endpoint errors similar to previous observations that linked greater lower limb displacement variability with upper limb endpoint variability (Hondzinski et al., 2010). In an important prospective study looking for predictive factors of falls, researchers also found that measurement of M-L sway was a more sensitive indicator of imbalance than measurement of A-P sway (Baloh, Corona, Jacobson, Enrietto, & Bell 1998). We pose that the postural sway of LLSD subjects was similar in LIGHT and DARK conditions because their base of support was wide; feet were approximately shoulder width apart. After all, subjects in the present study were able to self-select the width of their stance, which has been shown to decrease sway (Wang & Lin, 2008).

Effect of Visual Input

Vision is important in performance accuracy of the simple motor task of reaching to a target. Several differences in error variability did exist between visual conditions, as subjects were often more variable in the DARK relative to the LIGHT condition, similar to previous

research (e.g Henriques et al., 2003), providing additional evidence that vision is an important aspect of good reaching precision. We concluded based on these results that in LIGHT conditions, subjects were better able to integrate visual target information and proprioceptive feedback from their arm to make more consistent reaches to the final target location.

Note in the S-I direction all subjects in the present study tended to reach lower in the DARK condition relative to the light. Without visual feedback, the accuracy involved in reaching to a remembered target in some cases results in greater error bias (see greater DARK M-L errors for LLSD subjects reaching in the DARK, Fig. 4), but this can be linked to reach direction and target location. Similar to previous work in this lab (Hondzinski & Cui, 2006), constant errors when reaching in the DARK were not always greater than reaching to remembered targets in the LIGHT (see DARK condition for LOW target, Fig. 6). However visual use did enhance endpoint precision for M-L direction.

All subjects had a similar pattern of movement duration, moving longer in the DARK condition and when reaching to the HIGH target. Subjects additionally had a greater peak velocity when moving in LIGHT condition and to the HIGH target. The longer distance to the HIGH target explains these results for findings.

Effects of Target Location

In the A-P direction, YC tended to overreach the HIGH target and undershot the LOW target. These later results correspond to those in the literature that reveal overshooting of targets closer to subjects and undershooting those further away (Flanders et al., 1999), as the HIGH target location was located further from starting hand position than the LOW target location. It is unclear why older adults with or without lower limb sensory declines did not use this common strategy.

All subjects had a similar pattern of movement duration and speed between targets. Subjects took longer to move, yet did so with greater peak velocity when reaching to the HIGH target. The longer distance to the HIGH target explains these outcomes. One can easily reason that movement times increases with longer movement excursions, offering longer time to accelerate to a greater peak velocity before decelerating to stop the movement.

Clinical Application

Current treatment for Peripheral Neuropathy (PN) involves drug therapies for neuropathic pain such as opiates, sodium-channel blockers, and tricyclic antidepressants (Woolf & Mannion, 1999). Treatment for PN however, continues to pose a challenge to clinicians in part due to disparateness in neuropathic pain etiology and its influence on physical function (Li & Hondzinski, 2012). Therapist implement compensatory techniques or retrain individuals whose movement has been limited by disease or injury to improve functioning in activities of daily living and facilitate maximal independence in skills for everyday life (Bushby et al., 2005). The findings in this study clearly show that lower limb neuropathy has direct consequences on upper limb precision when standing and reaching. Therapy should teach individuals with PN to compensate for undershooting target locations in the medial-lateral direction in a dark environment to help them *find a light switch in the dark* or *reach a dish on a high shelf.* Retraining reaching precision while standing will also have influences on anticipatory postural muscle activation needed to remain upright (Bouisset & Zattara, 1981), thus potentially decreasing balance impairments and falls.

CONCLUSION

Comparisons between age groups revealed similarities in movement kinematics between older and younger adults without disorder-induced sensory deficits. The well-known effect of

movement slowing in older subjects was not observed in this study and is explained by the short memory delay time between target removal and movement onset, the requirement of using a comfortable reaching speed, and the simplicity of the task. In contrast older adults with LLSD did not produce increased variability in M-L errors when reaching in the DARK relative to the LIGHT like the older and young control subjects. Instead they produced greater endpoint bias towards their dominant hand side, suggesting that the lack of vision and somatosensations from the lower limbs can affect final reaching bias by causing less movement of the upper limb in the M-L direction. These smaller movement excursions explain why LLSD subjects did not produced greater variable errors in the DARK in this direction. Clearly, vision enhances endpoint bias in the M-L direction when those with reduced lower limb sensations due to PN reach from a standing body orientation.

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