**Positive effects of blue light on motor coordination in older adults: A pilot study**

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## Abstract

***Purpose:*** Falls are a risk factor for mortality in older adults. Lighting interventions can improve cognitive and motor task performance, but the effect on postural control with relevance to falling is unknown.

***Methods:*** Sixteen older adults participated in an intervention study with blue-enriched light delivered visually and/or transcranially for 12 minutes. Postural control in three conditions (60s eyes-open, dual-task, and eyes-closed), lower-limb motor coordination, and cognitive function were assessed.

***Results***: Relative to placebo, visual blue-enriched light improved reaction time in the motor coordination task by 0.073±0.035s ($d$=0.77±0.39; p=0.003). Visual exposure decreased Area of Sway relative to the combined ($d$=0.38±0.26; p=0.020) and placebo interventions ($d$=0.47±0.42; p=0.067), with no significant effect on cognition.

***Conclusion:*** Blue-enriched lighting demonstrates a novel approach to positively impact postural control and motor coordination in older adults. By impacting metrics associated with fall risk, light interventions may provide a clinical countermeasure to decrease the human costs of falls.

## 1.0 Introduction

Fall risk is a major economic burden and risk factor for mortality in older adults. The cost of treatment and rehabilitation in all age groups, plus lost economic contribution and human costs, was estimated at almost $50 billion in the USA alone (Florence et al., 2018). In a sample of New Zealanders ≥70 y, a yearly incidence rate of 47 falls per 100 people aged 70 to 74 y was observed, increasing to 122 falls for every 100 people aged ≥ 80 y (Campbell et al., 1990). Concomitantly, advancing age is associated with deteriorations in posturographic measures such as center of pressure displacement (Qiu & Xiong, 2015), which suggests that there is clinical and scientific value in assessing postural control in the ageing population.

It is known that specific short wavelengths of light (~470 nm; blue light) are capable of improving mood, cognitive processing, reaction times, and daily biorhythms with a unique ability to suppress melatonin (Beaven & Ekström, 2013; Cajochen et al., 2005; Chellappa et al., 2011; Ekström & Beaven, 2014). Specifically, non-visual effects of blue light appear to be mediated by the melanopsin photoreceptor expressed by intrinsically photosensitive retinal ganglion cells (Daneault et al., 2016). These ganglion cells in the body that are uniquely sensitive to blue light connect directly to the hypothalamic suprachiasmatic nuclei in the brain, as well as brain areas associated with sleep regulation, emotional processing, and motor activity (Hanifin & Brainard, 2007; Vandewalle et al., 2010). Previous research has demonstrated the efficacy of lighting interventions in improving simple and complex (i.e., including decision making) reaction time tasks (Beaven & Ekström, 2013); however, the effects on gross motor skills, such as balance, are currently unknown.

While blue-enriched light interventions have shown beneficial effects on sustained attention (Chellappa et al., 2011) and psychomotor function (Beaven & Ekström, 2013) among young adults, the effects in an older adult population have received little attention. Given that aging is associated with decreased retinal light transmission (Sletten et al., 2009), it is possible that visual exposure may lose its efficacy. Indeed, differential effects have been reported between the physiological effects of lighting on young and older individuals (Daneault et al., 2016; Gabel et al., 2017). Transcranial light treatment via the ear canal may provide a novel alternative avenue to provide an effective stimulus, and has been reported to improve psychomotor speed (Tulppo et al., 2014) and impact brain regions associated with sensorimotor processing (Starck et al., 2012). Specifically, non-visual phototransduction via the photoreceptor encephalopsin (or panopsin) that is localized in the brain (Blackshaw & Snyder, 1999) has led researchers to speculate that brain tissue may exhibit functionally relevant photosensitivity (Starck et al., 2012). Of note, encephalopsin expression is in the paraventricular nucleus that is known to regulate autonomic function (Blackshaw & Snyder, 1999). Therefore, we sought to investigate 1). Whether the cognitive benefits observed in young adults extend to older adults, and 2). whether visual and transcranial blue-light treatment have the potential to affect motor coordination and balance variables collected from a force platform in an older adult cohort. We hypothesized that the visual lighting intervention would enhance motor coordination.

## 2.0 Methods

### *2.1 Participants*

Based on a moderate effect size for improvement in cognition by light treatment (Beaven & Ekström, 2013), 80% power ($\beta$=0.20) and 5% statistical significance ($\alpha$=0.05), 16 individuals were required for the separate analysis on the four levels of testing (with and without

transcranial light treatment or visual intervention). Therefore, 8 male and 8 female independent, older adults [*Mean* age 74±8.1 y (65 to 82 y)] volunteered after a community-based recruitment effort. The volunteers participated in four randomized and counter-balanced sessions with light delivered visually (Luminette®) and/or transcranially (Human Charger®) for 12 min. Each session was performed on a separate day with at least 48 h between sessions and participants were asked to replicate their pre-session behaviors. Balance, motor function, and cognitive function were assessed before and after the light intervention. The protocol was approved by an institutional Human Research Ethics Committee [HREC(Health)2019#07] and complied with the Declaration of Helsinki. All participants signed informed consent prior to commencing the experimental protocol. All experiments were performed in accordance with the identified guidelines and regulations.

*2.2 Pre-screen*

All participants were pre-screened for visual acuity using a Snellen chart, and health and fall history was collected via a validated questionnaire (Ware et al., 1996) that assesses bodily pain, general health, vitality, and physical functioning. No participants were excluded based on visual acuity (all Snellen scores >0.3) or the health assessment as values were consistent with normative values presented by Ware (1995) for elderly individuals.

*2.3 Balance testing*

After the 12-minute light intervention, the devices were removed and participants performed three balance tasks lasting 60 s each on a multi-axis force platform (AccuGait Optimised$^{TM}$, AMTI, USA) and balance data were collected at 150 Hz using the supplied Balance Clinic software (v.2.03.00). For each task, the participants were unshod, with their feet in a narrow stance with hands by their sides (Romberg Test position). In the first task, participants were instructed to stand as still as possible with their eyes open (OPEN). In the second 'dual-task', the participants repeated the first task while counting aloud backwards from 100 in multiples of 3, restarting at 100 if they reached zero (COUNT). In the final task, the first task was repeated, but with the eyes closed (CLOSED). A reliable center-of-pressure measure of postural stability ($95^{th}$ percentile ellipse area of sway [AoS] in $cm^2$) was obtained for each task before and after the light interventions (Hébert-Losier & Murray, 2020). A researcher was present to ensure that no participants fell while they were on the force platform.

*2.4 Lower extremity motor coordination test*

Following the balance tests, lower extremity motor coordination was assessed using the OptojumpNext® (Microgate, Italy), an infra-red light device with an accuracy of 0.001 s. Participants stood with their hands on their hips and were asked to lift and plant their right leg from a double-leg stance as quickly as possible in response to an unexpected visual cue. A Rapid Step Test has previously been associated with unipedal stance duration, walk errors, and balance confidence (Medell & Alexander, 2000). No instruction was given regarding how high the leg was to be lifted as the focus was on a fast reaction and replanting of the leg. The visual stimulus appeared on a computer screen situated 100 cm from the participant at unpredictable time intervals. Three trials were attempted and the fastest response in milliseconds was recorded for both the reaction time following stimulus presentation and total movement time required to replant the leg on the ground. The fastest time was chosen to represent the maximum physical capacity of the participant.

*2.5 Cognitive function tests*

Immediately after the motor function test, cognitive function was assessed via computer-based Flanker task (response inhibition) and Psychomotor Vigilance Task (PVT) using the Psychology Experiment Building Language: PEBL. The Flanker task was programmed to

present two practice trial repetitions before a 2x3 repetitions experimentation commenced. Participants were asked to press either left or right in response to an arrow presented in the middle of a computer screen flanked by congruent (same direction arrows), incongruent (opposite direction arrows), or neutral symbols (horizontal bar with a small vertical line). The PVT task was a 60 s unprepared reaction time test where the participant was asked to press the space bar on a computer keyboard as quickly as possible after the presentation of a visual cue, with the fastest and mean reaction times recorded. Results of all cognitive tests were recorded in milliseconds.

*2.6 Light interventions*

A single blind, placebo-controlled randomized trial experimental protocol was implemented. Four counterbalanced trials were randomly assigned: 1). Placebo visual and Placebo transcranial light treatment (PLA); 2). Placebo visual and Human Charger® transcranial light treatment (AURAL); 3). Luminette® visual and placebo transcranial light treatment (VISUAL); and 4). Luminette® visual and Human Charger® transcranial light treatment (COMBO). For the visual lighting intervention, a commercially available headset [Luminette®; 2000 lx at the retina; 400-750 nm 'blue-enriched' light or 560-650 nm 'orange' light placebo; Figure 1A] was worn that reflected light to the retina via a diffractive lens positioned approximately 3 cm from the eye (Langevin et al., 2013). The visual light exposure lasted 12 min to correspond with one cycle of the recommended transcranial light treatment intervention. Participants were informed that both visual light interventions were effective in improving balance (i.e. participants were informed that the visual light interventions represented a sunrise or noon day natural exposure). For the transcranial light intervention, the Human Charger® earpieces (Valkee Ltd., Oulunsalo Finland; Figure 1B) were inserted into the ear canal. Previous work has reported that the Human Charger® delivers a light with a peak in the short-wavelength blue region (448 nm), a luminous flux of 4 lumen, an illuminance of 9,542 lux, and irradiance of 2,882 $\mu W/cm^2$ with a photon density of $7.98 \times 10^{15}$ photons/$cm^2$/s at a distance of 1 cm from the light source (Jurvelin et al., 2014). Again, the participants were informed that the aural light intervention was effective in improving psychomotor tasks. For the transcranial light treatment placebo, unbeknownst to the participant, the earpieces were not switched on. The devices were removed before the experimental tasks were performed.


**Figure 1**. Light intervention devices. A: Luminette® headset; B: Human Charger® earpieces

*2.7 Statistical Methodology*

Data from all subjects were included in the analysis. All descriptive statistics are shown as means ±standard deviations. Data from each condition were compared to examine pre- to post differences between trials (Δ). All intervention-induced responses were log transformed for

analysis to reduce non-uniformity of error, and effects expressed as percent changes. Data are presented back-transformed to the original scale. To examine the efficacy of the intervention conditions on performance measures, a two-way RM ANOVA (Condition factor: PLA, AURAL, VISUAL, COMBO and Time factor: pre and post) was performed for each measure separately. Bonferroni post hoc tests were applied if significant effects were detected. Effect size statistics were also calculated to determine the magnitude of pairwise differences between trials. The magnitude of each effect size (Cohen's *d* ±95% confidence interval) was interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for small, moderate, large, and very large (Batterham & Hopkins, 2006; Hopkins et al., 2009). An effect size of <0.2 was considered trivial. Where the 95% confidence limits overlapped the thresholds for small positive and small negative values, the effect was considered *unclear*. In instances where the 95% confidence limits did not overlap the thresholds for small positive and small negative values the effect was deemed *clear* and substantial. Statistical analyses were performed using IBM SPSS statistics (Version 27, IBM Corporation, USA) and effect sizes were calculated using Microsoft Excel using pooled standard deviations. Statistical significance was set at $p \leq 0.05$ for all analyses. Normality of the all data presented was confirmed via Shapiro-Wilk test ($p \geq 0.05$) and visual inspection of boxplot, a residuals Q-Q plot, and Tukey Fence analysis revealed no outliers. Mauchly's tests of sphericity indicated that the assumption of sphericity could not be rejected, hence the assumption had not been violated ($p \geq 0.05$).

## 3.0 RESULTS

### *3.1 Balance*

No participant lost balance during experimentation. No *a-priori* differences were observed between conditions. The AoS balance data is presented in Table 1. The omnibus RM ANOVA revealed no significant interaction effect as a result of the light interventions in the OPEN (p= 0.283), or COUNT tasks (p= 0.925), but the interaction effect on AoS was significant during the CLOSED balance tasks (p <0.001), with a significant effect of light condition (p= 0.039). Post-hoc tests revealed that the decrease in AoS in the VISUAL intervention was *clear* and significantly greater than that observed in the COMBO intervention by 2.0 ±1.6 $cm^2$ (9.3%; *d*= 0.30 ±0.23; p= 0.042). Although not significant, the VISUAL intervention did produce a small but *clear* decrease of 2.2 ±1.9 $cm^2$ (21.2%; *d*= 0.47 ±0.42; p= 0.067) in AoS relative to PLA in the OPEN condition.

### *3.2 Motor coordination*

Motor coordination data is presented in Table 2. No significant interaction effect attributable to lighting was observed for reaction time in the lower extremity motor coordination task. The omnibus RM ANOVA did, however, reveal a significant interaction effect (p= 0.004), a significant effect of time (p =0.075), and a non-significant effect of condition (p= 0.176) on total movement time. Post-hoc testing established that total movement time in the motor coordination task significantly decreased (improved) in the VISUAL relative to the PLA condition (p= 0.003) by 0.073 ±0.035 s (10.6%) with a moderate *clear* effect size (*d*= 0.77 ±0.39; Figure 2).

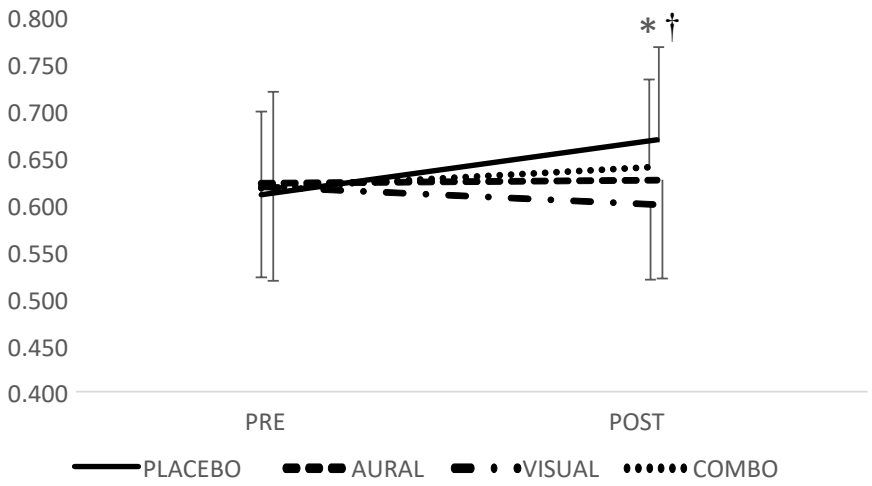


**Figure 2**. Pre-post change in motor coordination in older adults (n=16)

* significantly different to change in PLACEBO; † significantly different to PRE value. PLACEBO Placebo visual and Placebo transcranial light treatment; AURAL Placebo visual and Human Charger® transcranial light treatment; VISUAL Luminette® visual and placebo transcranial light treatment; and COMBO Luminette® visual and Human Charger® transcranial light treatment. Error bars represent standard deviations and the bars for the COMBO and AURAL conditions are slightly offset to avoid overlap.

### *3.3 Cognitive function*

Cognitive function data is presented in Table 3. The RM ANOVA revealed no significant interaction effect for mean, congruent, and incongruent reaction times in the Flanker task (all $p > 0.05$). Similarly, no significant effect of condition was observed for the fastest or mean reaction times in the PVT ($p > 0.05$). An *ad hoc* comparison revealed a significant positive Pearson correlation between the fastest PVT score and motor reaction time ($r = 0.4723$, $p < 0.01$), as well as total movement time ($r = 0.4095$, $p < 0.01$) in the lower extremity coordination task.

## 4.0 DISCUSSION

Compromised mobility, balance, and muscle strength contribute to the likelihood of falling. Falls often result in serious injuries, decreased mobility, and loss of independence. Given the aging population, and statistics showing that almost 1 in 3 adults aged over 65 y will experience a fall every year, effective countermeasures are necessary. Here we present novel data showing that a brief lighting intervention was capable of altering measures with relevance to fall-risk (static balance and rapid motor responses) in older adults. Specifically, the ability to rapidly respond and re-plant the foot following a disturbance could potentially decrease the likelihood of falling (Medell & Alexander, 2000). In contrast, we were unable to extend previous findings in younger cohorts, as we were unable to identify any cognitive benefits in our older adults. The fastest PVT score explained ~20% of the variance in this measure of movement coordination.

An impaired ability to redress postural perturbance is likely a major contributor to falls. Here we show that the time taken to lift a leg in response to an unexpected visual stimulus was enhanced following the VISUAL intervention, with a positive effect on this measure of motor function relative to the PLA condition. Previous research has demonstrated that short-wavelength blue-light is capable of improving reaction times in computer-based tasks (Beaven & Ekström, 2013; Chellappa et al., 2011; Phipps-Nelson et al., 2009). The neurophysiology that mediates the effects of short wavelength light is not well understood, but blue-light has

been shown to affect the superchiasmatic nucleus and high-frequency alpha activity associated with the circadian drive for alertness (Lockley et al., 2006). Currently, strategies for reducing fall risk in older adults use a multifactorial clinical approach including gait and balance assessment, and strength exercises (Bergen et al., 2016). Manipulating the light environment could provide an adjunct approach to reduce fall risk via improved motor coordination. Speculatively, the improvements in motor coordination may also have ramifications for other aspects of human performance and in occupational settings.

Novel balance data showed a significant decrease in postural sway with eyes-closed whereby the visual blue-lighting intervention was superior to the combined exposure. There was also an interesting, albeit non-significant, result whereby the visual intervention decreased the AoS in older adults in the eyes open condition. Greater amounts of postural sway and mean sway area have previously been positively correlated with fall risk (Fernie et al., 1982). The greater AoS in fallers may represent an inferior strategy when attempting to acquire a stable solution with excessive sway responses having been previously suggested to indicate a deterioration in the sensorimotor underpinnings of balance (Maki et al., 1994). Although research has indicated some potential for force plate measures to offer a predictive value of future falls (Johansson et al., 2017), it has been noted that no single measure of postural sway is capable of detecting differences between faller and non-faller groups (Qiu & Xiong, 2015). Currently, there are a wide variety of stance, duration, and other posturographic protocol variables such as surface, as well as a paucity of prospective studies. Thus, it is difficult to make firm conclusions regarding the predictive nature of static force platform-based testing variables on fall risk (Piirtola & Era, 2006).

In contrast to our earlier research in a younger cohort (Beaven & Ekström, 2013), no effect of any light intervention was observed in the measure of cognitive function. The degree to which this null result is due to the elderly cohort assessed is worthy of future research effort given research that has shown a decreased sensitivity in to short-wavelength light in this population (Daneault et al., 2016; Gabel et al., 2017). It is worth noting that the duration of each cycle of testing was approximately 12 minutes and the cognitive task was always performed last. Thus, by the time a participant completed the final PVT test, it had been >10 min since the light intervention. As the persistence of any effect of the current protocols are currently unknown, there is the potential that any modulation of performance effects had dissipated. However, differences in psychomotor performance parameters have been reported to persist for up to an hour after light exposure (Lockley et al., 2006). It is possible that the duration of the PVT utilized (1 min) influenced the results seen, with previous research on the effects of light on sustained attention lasting five minutes (Chellappa et al., 2011).

We also acknowledge that the duration of the VISUAL stimulus may have been sub-optimal, as the duration of exposure was matched with the AURAL exposure that was dictated by the manufacturer's recommendations. Future work may address the optimization of the lighting stimulus and attempt to objectively quantify the persistence of any beneficial physiological effects and we acknowledge that the interpretation and application of the findings are specific to the commercially available devices, durations, and procedures outlined herein. Applicability of outcomes to lighting parameters beyond those of the Luminette® and Human Charger® devices may not be generalizable. We also note that there was no evidence of benefit related to either the individual or combined use of the AURAL intervention, potentially due to sub-optimal timing and/or compromised or inhibitory neural effects relating to the AURAL intervention (Rockland et al., 1997). Furthermore, it is worth noting that force plates can provide numerous posturographic measures, albeit not all measures are considered reliable

(Hébert-Losier & Murray, 2020); thus, other metrics therefore may be worth examining further, including medio-lateral sway (Pizzigalli et al., 2016) and sample entropy (Uiga et al., 2018). Importantly, the brief VISUAL light intervention affected measures associated with the prevention of falls in older adults. Novel lighting interventions may provide a potential countermeasure to decrease the financial and human costs of falls. Additional positive effects via altered lighting environments could include improved mood (Ekström & Beaven, 2014) and sleep quality (Viola et al., 2008). If lighting countermeasures are employed, it is important to consider of the appropriate timing as exposure as evening exposure is known to suppress melatonin and alter circadian rhythms (Hanifin & Brainard, 2007), and reduce slow-wave sleep in the early phase of the sleep period (Kozaki et al., 2005).

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## TABLES

Table 1. Balance (Area of Sway) testing data pre and post intervention

| | Area of Sway: PRE ($cm^2$) | | | Area of Sway: POST ($cm^2$) | | | DELTA ($cm^2$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | OPEN | COUNT | CLOSED | OPEN | COUNT | CLOSED | OPEN | COUNT | CLOSED |
| PLACEBO | 6.61 (3.52) | 6.30 (3.06) | 13.15 (10.08) | 7.76 (4.62) | 6.45 (3.45) | 12.78 (9.16) | 1.14 (3.89) | 0.15 (2.80) | -0.37 (4.86) |
| AURAL | 7.56 (3.29) | 6.31 (3.62) | 11.32 (8.07) | 7.15 (4.54) | 6.78 (4.22) | 11.89 (6.30) | -0.42 (2.90) | 0.47 (3.25) | 0.08 (3.79) |
| VISUAL | 7.65 (4.01) | 5.71 (3.92) | 12.99 (8.70) | 7.12 (4.470 | 6.07 (3.68) | 11.86 (6.93) | -0.54 (2.10) | 0.37 (2.07) | -1.82 (2.96) |
| COMBO | 6.30 (3.36) | 5.53 (2.78) | 10.35 (6.55) | 7.17 (3.51) | 6.24 (2.98) | 10.54 (6.34) | 0.87 (3.03) | 0.71 (2.33) | 0.19 (2.40) |

*Note.* PLACEBO Placebo visual and Placebo transcranial light treatment; AURAL Placebo visual and Human Charger® transcranial light treatment; VISUAL Luminette® visual and placebo transcranial light treatment; and COMBO Luminette® visual and Human Charger® transcranial light treatment.

Table 2. Motor coordination testing data pre and post intervention

| | Motor Coordination Reaction Time (s) | | | Total Movement Time (s) | | |
|---|---|---|---|---|---|---|
| | PRE | POST | DELTA | PRE | POST | DELTA |
| PLACEBO | 0.533 (0.064) | 0.557 (0.063)† | 0.024 (0.030) | 0.614 (0.085) | 0.669 (0.095)† | 0.055 (0.060) |
| AURAL | 0.536 (0.083) | 0.546 (0.083) | 0.009 (0.058) | 0.623 (0.094) | 0.626 (0.098) | 0.003 (0.049) |
| VISUAL | 0.521 (0.080) | 0.520 (0.062) | -0.001 (0.057) | 0.619 (0.094) | 0.601 (0.076)* | -0.018 (0.064)* |
| COMBO | 0.533 (0.079) | 0.546 (0.063) | 0.013 (0.040) | 0.619 (0.101) | 0.640 (0.090) | 0.021 (0.044) |

*Note.* PLACEBO Placebo visual and Placebo transcranial light treatment; AURAL Placebo visual and Human Charger® transcranial light treatment; VISUAL Luminette® visual and placebo transcranial light treatment; and COMBO Luminette® visual and Human Charger® transcranial light treatment. * significantly different to PLACEBO; † significantly different to PRE value.

Table 3. Cognitive testing data pre and post intervention

| | Flanker Mean (ms) | | | Flanker Congruent (ms) | | | Flanker Incongruent (ms) | | |
|---|---|---|---|---|---|---|---|---|---|
| | PRE | POST | DELTA | PRE | POST | DELTA | PRE | POST | DELTA |
| PLACEBO | 543.6 (69.5) | 526.4 (68.9) | -21.8 (35.2) | 520.4 (50.5) | 509.5 (78.8) | -15.7 (43.5) | 588.4 (104.7) | 567.2 (95.2) | -22.1 (62.4) |
| AURAL | 542.1 (71.4) | 530.5 (58.2) | -11.6 (39.2) | 538.4 (75.5) | 504.7 (53.4) | -33.7 (52.7) | 568.7 (85.4) | 575.9 (58.9) | 7.1 (52.2) |
| VISUAL | 548.5 (106.3) | 546.0 (102.0) | -2.5 (34.3) | 538.6 (121.0) | 532.9 (77.2) | -5.8 (62.6) | 604.4 (138.4) | 592.1 (137.8) | -12.3 (66.5) |
| COMBO | 532.3 (57.1) | 546.4 (67.2) | 14.0 (41.1) | 520.7 (57.0) | 533.4 (80.7) | 12.7 (66.6) | 563.5 (92.7) | 581.8 (82.4) | 18.3 (78.6) |

*Note.* PLACEBO Placebo visual and Placebo transcranial light treatment; AURAL Placebo visual and Human Charger® transcranial light treatment; VISUAL Luminette® visual and placebo transcranial light treatment; and COMBO Luminette® visual and Human Charger® transcranial light treatment.

## Figure Legends

**Figure 1**. Light intervention devices. A: Luminette® headset; B: Human Charger® earpieces

**Figure 2.** Pre-post change in motor coordination in older adults (n=16)
* significantly different to change in PLACEBO; † significantly different to PRE value. PLACEBO Placebo visual and Placebo transcranial light treatment; AURAL Placebo visual and Human Charger® transcranial light treatment; VISUAL Luminette® visual and placebo transcranial light treatment; and COMBO Luminette® visual and Human Charger® transcranial light treatment. Error bars represent standard deviations and the bars for the COMBO and AURAL conditions are slightly offset to the right avoid overlap.