Positive Effects of Blue Light on Postural Control and Motor Coordination in Older Adults: A Pilot Study

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Abstract

Purpose: Falls are a risk factor for mortality in older adults. Light interventions can improve cognitive function and performance in motor tasks, but the potential impact on postural control with relevance to falling is unknown. This study aimed to examine the effect of light on postural control, motor coordination, and cognitive functioning.

Methods: Sixteen older adults participated in an intervention study that involved four counter-balanced sessions with blue-enriched light delivered visually and/or transcranially for 12 minutes. Postural control in three conditions (60 s eyes open, dual-task, and eyes closed), lower extremity motor coordination, and cognitive function were assessed. Area of sway (AoS), coordination, and cognitive function were compared between the groups via repeated-measured ANOVA.

Results: Relative to placebo, visual blue-enriched light exposure clearly decreased AoS (d = 0.68 ±0.73; p =0.166) and improved reaction time in the motor coordination task (d = 1.44 ±0.75; p =0.004); however, no significant effect was seen on cognitive function.

Conclusion Blue-enriched light demonstrates a novel clinical approach to positively impact on postural control and lower-limb motor coordination in older adults. By impacting on metrics associated with fall risk, blue-enriched light may provide a clinically meaningful 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 [1]. 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 [2]. Concomitantly, advancing age is associated with deteriorations in posturographic measures such as center of pressure displacement [3], 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 [4–7]. Cells in the body that are uniquely sensitive to blue-light connect directly to the master biological clock in the brain, as well as brain areas associated with sleep regulation, emotional processing, and motor activity [8, 9]. While previous research has demonstrated the efficacy of blue-light interventions in improving simple and complex (i.e., including decision making) reaction time tasks [4], the effects on gross motor skills, such as balance, are currently unknown.

While blue-light intervention has clear beneficial effects on sustained attention [7] and psychomotor function [4] among young adults, the effects in an older adult population have received little attention.

Given that aging is associated with decreased retinal light transmission [10], it is possible that visual exposure may lose its efficacy. Indeed, differential effects have been reported between the physiological effects of blue-light on young and older individuals [11]. Transcranial stimulation may provide an novel alternative avenue to provide an effective stimulus, and has been reported to improve psychomotor speed [12] and impact on brain regions associated with sensorimotor processing [13]. Therefore, we sought to investigate the potential for both visual and transcranial blue-light to impact on balance variables collected from a force platform as well as cognitive function and lower extremity motor coordination. We hypothesized that exposure to visual blue-light would impact on motor coordination.

2.0 Results

2.1 Balance

No participant lost balance during experimentation. No *a-priori* differences were observed between conditions. Area of Sway data is presented in Table 1. A RM ANOVA revealed significant differences in AoS between each of the task conditions (COUNT < OPEN < CLOSED). A RM ANOVA revealed no significant differences as a result of the light interventions in the OPEN (p= 0.106), COUNT (p= 0.489), or CLOSED balance tasks (p =0.166). Although not significant, the VISUAL intervention, did produce a clear and moderate decrease in AoS relative to PLA in the OPEN condition (*d*= 0.68 ±0.73).

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	TASK	CLOSED	OPEN	TASK	CLOSED	OPEN	TASK	CLOSED
PLACEBO	6.61 (3.52)	6.30 (3.06)	13.15 (10.08)	7.76 (4.62)	5.98 (2.97)	12.78 (9.16)	1.63 (3.91)	-0.54 (1.96)	-2.10 (4.42)
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)	0.35 (4.09)
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)	0.32 (2.62)

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

2.2 Motor coordination

Motor coordination data is presented in Table 2. No significant difference attributable to the light conditions was observed for reaction time in the lower extremity motor coordination task; however, the ANOVA did reveal a significant effect of condition on total movement time (p= 0.008). Post-hoc testing established that total movement time in the motor coordination task was significantly enhanced in the VISUAL relative to the PLA condition (p= 0.004) with a large effect size (*d*= 1.44 ±0.75; Figure 1).

Table 2
Motor coordination testing data pre and post intervention

	Motor Coordination (ms)			**Total Movement Time (ms)**		
	PRE	POST	DELTA	PRE	POST	DELTA
PLACEBO	0.533 (0.064)	0.557 (0.063)	0.020 (0.032)	0.614 (0.085)	0.669 (0.095)	0.044 (0.040)
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; AURAL Placebo visual and Human Charger® transcranial; VISUAL Luminette® visual and placebo transcranial; and COMBO Luminette® visual and Human Charger® transcranial.

2.3 Cognitive function

Cognitive function data is presented in Table 3. The ANOVA revealed no significant difference between the conditions for mean, congruent, and incongruent reaction times in the Flanker task (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.

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; AURAL Placebo visual and Human Charger® transcranial; VISUAL Luminette® visual and placebo transcranial; and COMBO Luminette® visual and Human Charger® transcranial.

3.0 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 showed that a brief light 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 decrease the likelihood of falling. 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 large 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 [4, 7, 14] 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 [15]. Currently, strategies for reducing fall risk in older adults use a multifactorial clinical approach including gait and balance assessment, and strength exercises [16]. Optimizing 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, driving, and physical exercise.

The balance data showed an interesting, albeit non-significant, result whereby the visual blue-light 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 [17]. 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 [18]. Although research has indicated some potential for force plate measures to offer a predictive value of future falls [19], it has been noted that no single measure of postural sway is capable of detecting differences between faller and non-faller groups [3]. 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 [20].

Also of note was the lack of negative impact of the COUNT task on the AoS metric, given that postural stability has been shown to be affected by tasks that apply a cognitive load [21]. Bergamin and coworkers [22] demonstrated that a simple backwards counting task had little effect on sway area, while a mental arithmetic task decreased sway area. It is possible that the counting task attenuated the potential for conscious interference of typically automated motor control processes harnessed during postural control. We note that the predisposition for conscious involvement in movement of a given individual, as outlined in the Theory of Reinvestment [23, 24], has the potential to mediate balance task responses [25].

In contrast to our earlier research [4], no effect of any light intervention was observed in the measure of cognitive function. 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 [15].

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 visual stimulus and attempt to objectively quantifying the persistence of any beneficial physiological effects. We also note that there was no evidence to suggest any benefit related to either the individual or combined use of the AURAL intervention. Furthermore, it is worth noting that force plates can provide numerous posturographic measures, albeit not all measures are considered reliable [26]; thus, other metrics therefore may be worth examining further, including medio-lateral sway [27] and sample entropy [21]. Importantly, the brief VISUAL light intervention affected measures associated with the prevention of falls in older adults. Novel light 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 sleep quality [28] and mood [5].

4.0 Materials And Methods

4.1 Participants

Based on a moderate effect size for improvement in cognition by light treatment [4], 80% power (β = 0.20) and 5% statistical significance (α = 0.05), 16 individuals were required for the separate analysis on the four levels of testing (with and without transcranial or visual intervention). Therefore, independent 8 male and 8 female 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. 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.

4.2 Pre-screen

All participants were pre-screened for visual acuity using a Snellen chart, and health and fall history was collected via questionnaire [29]. No participants were excluded based on visual acuity (all Snellen scores >0.3) or health assessment. It is acknowledged that self-reporting of falls may have led to under-reporting [30].

4.3 Balance testing

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 (95th percentile ellipse area of sway [AoS]) was obtained for each task before and after the light interventions [26]. A researcher was present to ensure that no participants fell while they were on the force platform.

4.4 Lower extremity motor coordination test

Following the balance tests, lower extremity motor coordination was assessed using the OptojumpNext® (Microgate, Italy), an infra-red light system 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. 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.

4.5 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 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.

4.6 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 (PLA); 2). Placebo visual and Human Charger® transcranial (AURAL); 3). Luminette® visual and placebo transcranial (VISUAL); and 4). Luminette® visual and Human Charger® transcranial (COMBO). For the visual light intervention, commercially available headsets [Luminette®; 2000 lx; 400-750 nm 'blue-enriched' light or 560-650 nm 'orange' light placebo; Figure 2A] were worn [31]. The visual light exposure lasted 12 min to correspond with one cycle of the recommended transcranial 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 intervention, the Human Charger® earpieces (Valkee Ltd., Oulunsalo Finland; Figure 2B) delivering 9100 lx with white light-emitting diodes producing light with a peak in the short-wavelength blue region (448 nm) were inserted into the ear canal. Again, the participants were informed that the aural light intervention was effective in improving psychomotor tasks. For the transcranial placebo, unbeknownst to the participant, the earpieces were not switched on.

4.7 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. A one-way RM ANOVA was performed on the pre-intervention task data to compare the effect of TASK and CLOSED on postural control (AoS). To examine the efficacy of the intervention conditions on performance measures, a one-way RM ANOVA (condition: PLA, AURAL, VISUAL, COMBO) on pre- to post-intervention change (Δ) 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. 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. 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.

Declarations

Funding: This work was supported by funding from the University of Waikato Research Trust Contestable Fund.

Ethical Approval: The protocol was approved by the Human Research Ethics Committee of the University of Waikato [HREC(Health)2019#07] and complied with the Declaration of Helsinki. All participants signed informed consent, including consent to publish, prior to commencing the experimental protocol.

Conflicts of Interest/Competing interests: The authorship team affirm that no financial, non-financial, or personal conflicts, perceived or otherwise, exist relevant to the submission.

Availability of data and material: All raw data and associated variability is included in Tables 1 – 3.

Code availability: Not applicable.

Author Contributions: All authors contributed to the concept and design, and approved the interpretation of data and final manuscript. Acquisition of participants and data, and preparation of the manuscript draft was the responsibility of CMB.

CRediT roles: **Martyn Beaven:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing - original draft. **Liis Uiga**: Conceptualization; Investigation; Methodology; review & editing. **Kim Hébert-Losier:** Conceptualization; Investigation; Methodology; review & editing

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Figures

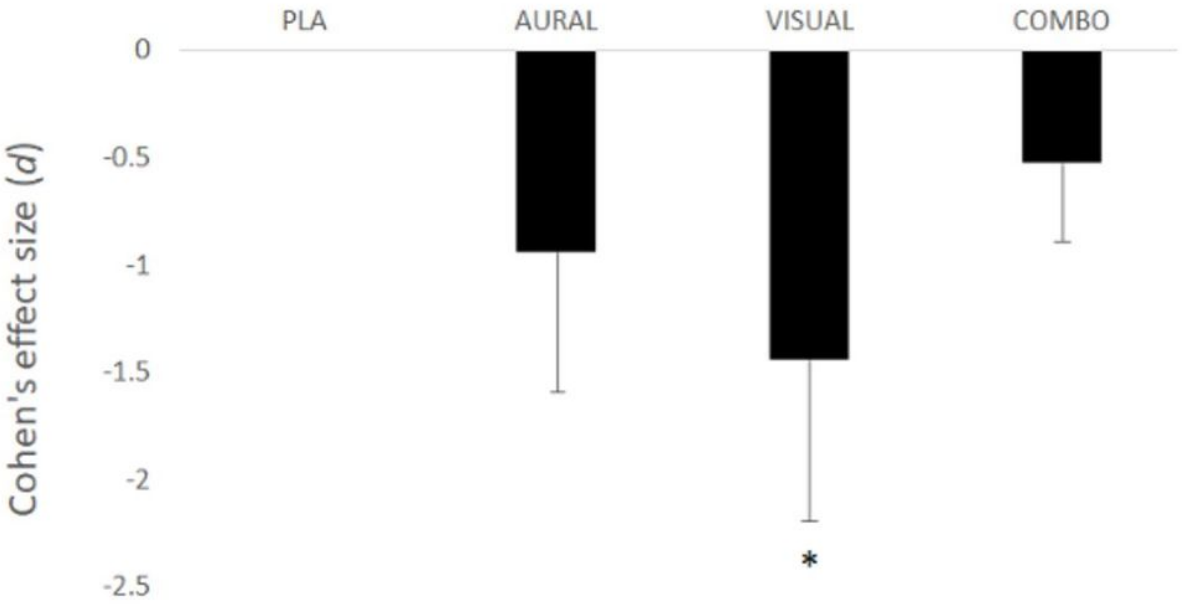

Figure 1

Standardized pre-post change in motor coordination relative to Placebo * Significantly different to Placebo, $p < 0.05$. PLACEBO Placebo visual and Placebo transcranial; AURAL Placebo visual and Human Charger® transcranial; VISUAL Luminette® visual and placebo transcranial; and COMBO Luminette® visual and Human Charger® transcranial.

Figure 2

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