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Effects of lighting illuminance levels on stair negotiation performance in individuals with visual impairment

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ABSTRACT

Background: Stair-related falls of older people cause a substantial financial and social burden. Deterioration of the visual system amongst other factors put older people at a high risk of falling. Improved lighting is often recommended. The aim of this study was to investigate the effect of lighting illuminance on stair negotiation performance in older individuals with visual impairment.
Methods: Eleven participants aged 60 or over with a vision of 6/18 or worse ascended and descended a staircase under: 50 lx, 100 lx, 200 lx, 300 lx and distributed 200 lx lighting. A motion capture system was used to measure movements of the lower limb. Clearance, clearance variability, temporal and spatial parameters and joint/segment kinematics were computed.
Findings: There was no effect on clearance or clearance variability. Participants had lower speed, cadence, increased cycle time and stance time in the 50 lx compared to 300 lx and distributed 200 lx lighting in descent. The minimum hip angle in ascent was increased in the 200 lx lighting. Clearance was found to be moderately correlated with balance scores.
Interpretation: Individuals with visual impairment adopt precautionary gait in dim lighting conditions. This does not always result in improvements in the parameters associated with risk of falling (e.g. clearance).

1. Introduction

Falls are a common cause of morbidity, mortality and loss of function in older people (NICE, 2013). Stair-related falls account for approximately one fifth to one third of accidental falls of older people at home (Sheldon, 1960; Lord et al., 2007). Falls on stairs is a leading cause of accidental death, accounting for 10% of fall-related mortality, approximately 80% of which are of individuals aged 65 or over (Startzell et al., 2000).

The presence of age-related diseases and disabilities, as well as the physiological changes caused by ageing that affect sensory and motor functions, put older people at a higher risk of falling than their adolescent counterparts. The deterioration of the visual system is one such change that has been related to an increased risk of falls in this population. Poor vision was found to be an independent risk factor (Lord, 2006; Rubenstein, 2006), approximately doubling the risk of falling of older persons (Rubenstein, 2006; Harwood, 2001; Koski et al., 1998).

In addition to intrinsic risk factors, environmental hazards are another leading cause of falls in older people, accounting for approximately one-third of reported falls (Rubenstein and Josephson, 2002). Studies assessing hazards that lead to falling in the homes of older people have identified inadequate lighting to be one of the main factors leading to a fall incidence (Carter et al., 1997; Northridge et al., 1995; Stevens et al., 2001). Few studies have attempted to quantify the link between the deterioration of vision in older people, poor lighting and the risk of falling.

Previous studies investigating the effects of lighting luminance levels on stair negotiation have looked at effects on ground reaction forces (Christina and Cavanagh, 2002), minimum foot clearance and clearance variability (Hamel et al., 2005; Zietz et al., 2011), temporal spatial parameters (Thies et al., 2005) and centre-of-mass progression (Zietz et al., 2011). In low lighting conditions, older participants were found to have a reduced step length (Zietz et al., 2011) and a decreased first peak of the vertical ground reaction force in stair descent

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(Christina and Cavanagh, 2002), thus suggesting an adoption of safer stepping strategies in poor lighting conditions. However, other studies have not found changes in other movement parameters when lighting conditions were altered (Thies et al., 2005).

None of the previous studies included participants with known visual impairments. This is particularly important as the association of poor vision and measures of static (Lord et al., 1991; Turano et al., 1994) and dynamic stability (Heasley et al., 2004) is well-documented in the literature. The presence of this risk factor as well as inadequate lighting may result in significant changes in the biomechanical characteristics of stair negotiation, which may help explain any relationship between visual impairment, poor lighting and the increased risk of falls in this population.

The aim of this study was to investigate the effect of lighting illuminance levels on stair negotiation performance in a group of older participants with visual impairments. The study assesses biomechanical parameters associated with risk of falling during stair ascent and descent; clearance and movement variability, as well as parameters related to changes in stepping strategies; joint kinematics, temporal and spatial parameters.

2. Methods

2.1. Participants

The study was reviewed and granted ethical approval by Surrey Research Ethics Committee. A power analysis for a repeated-measures ANOVA design revealed that a minimum of 9 participants are needed to achieve a statistical power of 0.8 with a significance level of 0.05. The effect size was estimated to be 0.25 and the correlation amongst repeated measures was estimated to be 0.80 based on the results obtained from a pilot study.

Eleven participants (seven males) with a mean age of 78 (6) years consented to taking part in the study and signed a consent form. Participants were included in the study if they were: (1) aged 60 or over, (2) partially sighted due to macular degeneration or advanced cataract caused by old-age, all patients with macular degeneration had a vision of 6/18 or worse and (3) able to negotiate stairs using a step-over-step strategy. Participants were excluded if they: (1) had a muscular or neurological condition or impairment that affected or limited their gait or (2) had a diagnosed vestibular disorder. In addition, a clinician assessed the participants' lower-limb joints (hip, knee and ankle) range of motion, lower-limb muscle power and mobility and used Berg Balance Score (BBS) (Berg et al., 1991), participants were excluded if they displayed reduced balance caused by dizziness. The activities-specific balance confidence scale (ABC) (Powell and Myers, 1995) and the stair self-efficacy questionnaire (SSE) (Hamel and Cavanagh, 2004) were also completed by the participants. Participants also completed questionnaires on the use of the laboratory stairs and the lighting conditions. Participants were asked if they thought the stairs were poorly lit and if the stairs were safe to use (see Table S1).

2.2. Laboratory setup and lighting configurations

A seven-step staircase (tread 300 mm, rise 180 mm, width 1000 mm, pitch 31°) was constructed from medium density fibre board (MDF). The staircase had a top landing area of 1500 × 1000 mm, handrails on one side and a wall on the other, thus simulating a domestic staircase. The walls were painted with neutral colour paint to simulate a domestic colour scheme.

An array of 4 × 100 W incandescent lamps were used on the top landing of the staircase, a 200 W lamp was used at the bottom landing of the stairs in addition to laboratory lights and diffusers (Fig. 1A). A dimmer switch control was used to allow adjustment of lighting conditions and a light meter (ISOTECH, England) was used to measure illuminance levels from the top landing. This configuration was used to achieve five lighting conditions; low illuminance 50 lx, sub-optimal lighting 100 lx, optimal lighting 200 lx, increased illuminance 300 lx and distributed 200 lx lighting. The poorest lighting condition used in this study (50 lx) was based on the findings of the study by Hill et al., (2000), which surveyed 150 older people's households and found that more than 60% of these had lighting of 50 lx or less during the day (Hill et al., 2000). Optimal lighting was defined as an illuminance of 200 lx based on the recommendations of Thomas Pocklington Housing Guide (Fisk and Raynham, 2010).

The distributed 200 lx lighting condition was achieved with the laboratory lights fully on, the top landing light off and the bottom landing of the stairs dimmed, this arrangement achieved illuminance level of 200 lx on the top landing. Other lighting conditions were achieved using 4 × 100 W incandescent lamps above the top landing and the dimmer switch. Lighting illuminance was measured at the top landing, the illuminance levels – with the exception of the distributed lighting condition-typically fell with the lower steps. This was believed to reflect lighting distribution on staircases in domestic environments.

2.3. Data collection

An 8-camera motion capture system (Qualysis, Gothenburg, Sweden) running at 100 Hz was used for data capture and the 6 degree-of-freedom marker model was used (Collins et al., 2009), the model makes use of 25 retroreflective markers to track the movement of the lower-limb segments in dynamic trials. These are divided into 3 markers on the pelvis, 4 marker-clusters on the two thigh and two shank segments and 3 marker-clusters on the two foot segments. Prior to dynamic trials, a pointer was used to digitise relevant anatomical landmarks to allow definitions of segmental coordinate frames (femoral and tibial epicondyles and the 2nd metatarsal head). In addition, three points at the area of the heel and three points at the area of the toes were digitised to cover the areas of the foot likely to be closest to the stair edge (see Fig. S1). The biomechanical model was used to redefine the positions of these points virtually using their relative distances to the markers on the foot segment. The minimum straight-line distance between the stair edge and any one of these points was used for foot clearance measurements (Hamel et al., 2005).

Participants were allowed to ascend and descend the staircase before data collection to familiarise themselves with the laboratory set up. Following familiarisation, participants were asked to ascend and descend the staircase using a self-selected speed without the use of handrails. Participants were also instructed to initiate gait using their right foot, this was to ensure that they were clearing and landing on the same steps with their right, consequently the gait cycles of the right (and left) limbs of all trials and all participants were comparable. Three sets of ascent/descent trials were collected, each set included ascending and descending the staircase under the five lighting conditions. The order of the lighting conditions in each set was randomised using a 1–5 random order generator in Microsoft Excel. This gave a total of 30 motion trials to be used for analysis: 3 trials of ascent and 3 trials of descent under each lighting condition.

2.4. Data analysis

Analysis was completed using Visual3D (C-Motion, Germantown, MD) software. The hip joint centre-of-rotation was computed using regression equations (Davis et al., 1991), the mid-points of the epicondyles and the malleoli markers were used to define the knee and ankle joints centres-of-rotation respectively. Coordinate frames for the pelvis, femurs, tibias and feet were defined and joint rotations were computed using a Cardan sequence of flexion-extension, abduction-adduction and internal-external rotation for the hip, knee and ankle joints (Collins et al., 2009). Gait events were identified using an algorithm (Zeni et al., 2008) implemented in Visual3D that makes use of kinematic data. The gait events were adjusted manually when they