A Practical Indoor Mobility Course to Assess the Functional Effect of Tunnel Vision

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Abstract

The purpose of this study was to design and validate an indoor mobility course that is sensitive and easy to assemble in a variety of settings. This course is proposed to be used in assessing functional performance in mobility for patients with tunnel vision.

Seventy participants were asked to walk twice along a 14 metre indoor corridor containing 16 obstacles, once in each direction. The participants were 20 patients with varying degrees of tunnel vision (TV) due to retinitis pigmentosa (TVPs) and 50 normally-sighted subjects with tunnel vision simulated by the use of different goggles (SIPs). Visual acuity (VA), contrast sensitivity (CS) and visual field (VF) were measured. The binocular field of view (FoV) of the TVPs varied from 4° to 21° and for the SIPs FoV ranged from 4° to 22°. The time taken to complete the test was expressed as the percentage preferred walking speed (PPWS) and the number of collisions was recorded.

For the SIPs, the PPWS and the collision scores both showed a significant relationship with the FoV. For the TVPs the FoV was also significantly related to their PPWS scores, but no relationship was found between FoV and collision scores. There was a significant relationship between the TVPs' VA and collision scores, and a moderate but not significant relationship between the TVPs' CS and collisions.

This mobility course is relatively short and does not require a dedicated space, so could be easily replicated in other studies. The results indicate that this design is valid and that the course could be a useful tool for assessing functional performance in tunnel vision patients.

Sammendrag

Hensikten med studien var å designe og validere en innendørs mobilitetsløype som skulle være sensitiv og enkel å sette opp i ulike utgaver. Mobilitetsløypen er foreslått brukt ved vurdering av mobilitet for personer med tunnelsyn.

Sytti deltakere ble bedt om å gå to ganger langs en 14 meter innendørs korridor med 16 hindringer, en gang i hver retning. Deltakerne besto av 20 pasienter med varierende grad av tunnelsyn (TV) som følge av retinitis pigmentosa (TVPs) og 50 normale kontroller hvor tunnelsyn simulert ved hjelp av ulike briller (SIPs). Visus (VA), kontrastsensitivitet (CS) og synsfelt (VF) ble målt. Binokulært synsfelt (FoV) hos de i TVPs gruppen varierte fra 4° til 21° og for SIPs gruppen varierte FoV fra 4° til 22°. I hvert tilfelle ble tiden det tok å fullføre mobilitetsløypen uttrykt som prosentvise foretrukne ganghastighet (PPWS) og antall kollisjoner ble registrert.

For SIP gruppen, viste både PPWS og antall kollisjoner en signifikant sammenheng med FoV. For TVP gruppen fantes også en signifikant korrelasjon mellom FoV og PPWS score, men det ble ikke funnet noen sammenheng mellom FoV og antall kollisjoner for denne gruppen. For TVP gruppen var det forøvrig en signifikant sammenheng mellom VA og antall kollisjoner, og en moderat, men ikke signifikant sammenheng mellom CS og antall kollisjoner.

Den utprøvde mobilitetsløypen er relativt kort og krever ikke å bli plassert et spesifikt sted. Den bør derfor være enkel å replisere i andre studier. Resultatene tyder på at denne designen er god og at mobilitetsløypen kan være et nyttig verktøy for å vurdere funksjonelle prestasjoner hos personer med tunnelsyn.

Introduction

The term "mobility" refers in this study to the ability to travel from one place to another safely and independently. However, the term mobility might not be, in some context, differentiated from the term "orientation" which could be defined as the situation where a person identifies his exact location from the information provided in the surrounding environment (Dickinson, 1998). Patients who have tunnel vision (TVPs) face difficulties with navigation and avoiding obstacles (Black et al., 1997; Geruschat, Turano, & Stahl, 1998; Haymes, Guest, Heyes, & Johnston, 1996; Turano, Rubin, & Quigley, 1999). The decline of mobility performance (i.e. the ability to travel in daily life situations) can markedly affect the individual's independence and quality of life (Sugawara et al., 2010).

Quantifying mobility performance in these individuals is a challenging area (Marron & Bailey, 1982), and there is no standard method of measurement. Suggested methods include assessing the mobility performance in a qualitative (Szlyk, Seiple, et al., 1998; Szlyk, Seiple, Stelmack, & McMahon, 2005) or quantitative approach by using indoor (Black et al., 1997; Leat & Lovie-Kitchin, 2006; Lovie-Kitchin, Soong, Hassan, & Woods, 2010; Soong, Lovie-Kitchin, & Brown, 2001; Turano, Geruschat, Stahl, & Massof, n.d.) and outdoor mobility courses (Haymes et al., 1996; Kuyk, Elliott, & Fuhr, 1998; Szlyk, Fishman, Grover, Revelins, & Derlacki, 1998) with a variety of obstacles, around which the participants must walk quickly (a measure of efficiency) and without errors (a measure of safety). It is usual to specify speed in terms of the percentage preferred walking speed (PPWS), as used in many previous studies (Black et al., 1997; Leat & Lovie-Kitchin, 2008; Lovie-Kitchin, Woods, & Black, 1996; Soong, Lovie-Kitchin, & Brown, 2004). The preferred walking speed (PWS) is generally considered to be the speed that the visually impaired patient would walk at, if his/her vision was restored (Soong et al., 2004). The percentage preferred walking speed (PPWS) is calculated by dividing the walking speed of the seeded route by the walking speed of the un-seeded route (i.e. the PWS).

An outdoor course would provide the actual environment in which the participants move, but has some important drawbacks such as the lack of control over the obstacles in the surrounding environment (e.g. pedestrians), illumination, weather and the potential danger to participants.

Several studies have designed and used indoor mobility courses to evaluate the mobility performance in a safe and controlled environment, although these have varied considerably in terms of length (from 4 meters to 440 meters), obstacle density (from none to 100 obstacles) and complexity (none to approximately 2 obstacles per meter). Some studies (Brown, Brabyn, Welch, Haegerstrom-portnoy, & Colenbrander, 1986; D. Wilcox & Burdett, 1989) (and Haymes et al. (1996) on their easiest route) have not been able to differentiate between control subjects with normal vision, and real patients with visual defects. This could be because these indoor courses were short (4 to 6 meters) and

the number of obstacles was low (0 to 4 obstacles). It appears that using short courses would not be useful in assessing the participants' functional performance (i.e. the ability to perform the activities of everyday living which are varied depending on the individual needs). The mobility scores in most studies have however been shown to be correlated with the visual function measures including visual field (VF) (Black et al., 1997; Lovie-Kitchin, Mainstone, Robinson, & Brian, 1990; Lovie-Kitchin et al., 2010; Turano et al., n.d., 1999), visual acuity (VA) (Long, Rieser, & Hill, 1990; Marron & Bailey, 1982; Turano et al., n.d.) and contrast sensitivity (CS) (Geruschat & Turano, 2002; Hassan, Lovie-Kitchin, & Woods, 2002; Haymes et al., 1996; Kuyk & Elliott, 1999; Turano et al., n.d.). This relationship was also found in the studies that investigated patients with TV (Black et al., 1997; Geruschat et al., 1998; Haymes et al., 1996). The strength of the relationships has varied between studies; however, 20% to 45% of the variation in the mobility scores has been explained by the VF (Black et al., 1997; Geruschat et al., 1998; Haymes et al., 1996). In terms of the VA and the CS: Black et al. (1997) did not find any relationship with mobility performance, while Haymes et al. (1996) and Geruschat et al. (1998) found a relationship which explained 30% to 40% of the variation in walking speed. In general, these courses were lengthy and took a lot of dedicated space, or would be time-consuming and difficult to set up repeatedly for each participant. Additionally, the reported contact scores in these studies were not high even though a large number of obstacles were used (up to 100). In this study a new design for an indoor mobility course is evaluated. The aim is to validate this new portable mobility course to assess functional performance in mobility for persons with tunnel vision. The new course is proposed to be used either in a research lab or in a practice. Two main changes were introduced in this design: 1) the length of the course and 2) the method used to arrange the obstacles. The length of the course was much shorter than previous designs. However, it was not too short in order to increase the chances that the patients would make some contact with obstacles. Frequent obstacles were arranged to test the participants repeatedly: if they did not make a change of direction each time, they were likely to collide with the obstacle. Some of these obstacles have been used previously, however, we have changed the arrangement in order to challenge the patients and differentiate between good and poor performers. These parameters were used to differentiate between the participants based on their field of view (FoV) and their adaptation to the situation, where the participants who travel confidently and who can adopt some useful strategies are expected to be more efficient performers. Our hypothesis is that both the PPWS and collision scores would have a significant relationship with the FoV: participants would be gradually walking faster and have fewer collisions as the FoV becomes larger. This expected outcome would provide evidence for the sensitivity of this new mobility course. This new course could be used as a standardised outcome measure of rehabilitational success, e.g. the use of optical aids or scanning training; or the current treatment interventions such as retinal prosthetics. The aim is for the new course to be easy to set up and be replicated in different research and/or clinical settings.

The sensitivity of this mobility course will be investigated by recruiting real patients with tunnel vision (TV), caused by retinitis pigmentosa, and in simulated impairment participants. The recruited patients had a FoV of 20° (diameter) or less (ranged from 5° to 20°). The FoV of approximately 20° was our cut off point to make sure that the mobility would be impacted (Faye, 1976; Hassan, Hicks, Lei, & Turano, 2007; Lovie-Kitchin et al., 2010). Further, this is the stage at which patients with this condition usually seek visual rehabilitation (Cohen, 1993; Dickinson, 1998). Using the SI group had the advantage that this group's scores would not be affected by variations in VA, CS, and adaptation to the impairment (as would be seen in real TV participants).

Material and Methods

Participants in the SI group attended for two visits, with a time between visits of one to two weeks: TV participants attended for one visit and one more visit as a part of a study of optical aids for TV (not reported here). The SI participants were tested in their monocular state (always the right eye) and the TV were in their habitual state (i.e. binocular vision) and, for both groups, their habitual correction (if any) was used while doing the test. The SI was systematically changed from 20° diameter to 5° diameter, in 5° steps, so every participant in the SI group navigated the mobility course four times, with progressively decreasing FoV. A random order protocol was not used here, to give participants the chance to get used to the field restriction progressively so as to avoid excessive disorientation or discomfort.

Vision assessment

The visual acuity was measured with logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US). The CS was measured with a Pelli-Robson contrast sensitivity chart at one meter with overhead illumination (approximately 85 cd/m^2) (Metropia Ltd in UK; Distributed by Clement Clarke Intl) Pelli, Robson, and Wilkins (1988). No change in refractive correction was made when measuring CS. For the SI Group, these measurements were taken without the simulation in place.

Participants

A total of 50 healthy volunteers (28 male and 22 female) whose mean age was 24.5 ± 6.50 years (ranging from 18 to 51 years) and 20 TV patients (9 males and 11 females) whose mean age was 24.50 ± 11.00 years were recruited. The SI participants satisfied the inclusion criteria: no history of ocular disease; the central visual acuity better than 6/9 (corrected with ordinary spectacles or contact lenses); and general physical ability to carry out the proposed tests. The TV participants were recruited through the University of Manchester eye clinic, and the retinitis pigmentosa (RP) Facebook support groups. The TV participants inclusion criteria were: the participant should be formally diagnosed with RP, Usher syndrome or choroideraemia; a remaining binocular VF of 20° or less; the VA should be better than 0.40 logMAR in at least one eye with best-correction, either with ordinary spectacles or contact lenses; and adequate physical ability to perform the mobility course (which was decided based on history taken from the patient). A favourable ethical opinion was given by the University of Manchester Research Ethics Committee. The tenets of the Declaration of Helsinki were followed, and all participants gave informed written consent.

Simulating tunnel vision

Four simulated impairment (SI) conditions were systematically replicated in each participant using four different simulators. The targeted FoV diameters were: SI 20°, SI 15°, SI 10° and SI 5°. The simulators were opaque circular discs with a central hole. They were painted black to reduce any light reflection, and placed in a trial frame which also held any refractive correction. A side shield was used to prevent the participant from having peripheral vision outside the simulator, and the nature of the simulation was such that viewing was monocular with the right eye.

The Bjerrum visual field screen was used to measure the binocular VF in TV participants and the simulated FoV in SI participants wearing each of the four simulators. The screen was viewed from 1 meter and the target used was white, 5 mm in size and was moved at 2 deg s^{-1}. A chin and head rest were

used.

Generally, the simulators showed that they are effective and produced approximately the intended restriction to the FoV. In detail, there was between-participants variation in the back-vertex distance of the simulator, therefore, the targeted FoV size varied slightly. The sizes of FoV for the four SI conditions were: $20° \pm 1°$ (mean $\pm$ SD), ranging from $18°$ to $22°$, $15° \pm 0.75°$, ranging from $14°$ to $16.50°$, $10.50° \pm 0.75°$, ranging from $9.50°$ to $12°$, and $5° \pm 0.50°$, ranging from $4°$ to $6°$.

The new course design

The PWS was assessed at the beginning of the experiment on each visit in both participant groups. Each participant (either the TV or the SI participant) was asked to walk for 11 m from one point to another in a straight-line at his/her normal pace. The participants were informed that there would not be any obstacles obstructing their path. This part was repeated and the travel time was averaged and recorded as the PWS.

The mobility course was an indoor corridor with no pedestrians. The course was 14 m long × 1.45 m wide, with mean illuminance of 430 lux (as measured at 1 m from the ground), and containing 16 cardboard obstacles (Figure 1). The arrangement of obstacles was the same for each participant in both groups in order to standardise the difficulty level. The obstacle heights were designed to cover (1) head and shoulder-height objects (4 cylindrical obstacles 14 cm to 18 cm in width hanging from the ceiling at 145 cm to 160 cm from the ground), (2) waist-height objects (3 objects, 102 cm in height and 22 cm in width), (3) knee-height objects (4 objects, 50 cm in height and 20 cm in width) and (4) low-lying objects (5 objects, 8 cm to 27 cm in height and 21 cm in width). Subjects with TV due to RP had reported in a difficulty rating study (Turano et al., n.d.) that these obstacle heights were of medium to high difficulty to avoid. The obstacle contrast ranged from low to high against the background (6 black, 6 white, and 4 grey). The Weber contrast values for the three obstacle colours were: black = 0.60, white = 1.90 and grey = 1.20. To perform a complete run of the course each participant had to walk the course once in one direction and once in the opposite direction. This means that the SI group walked the complete course four times, once with each of the four different SI goggles. The travel time taken to navigate each direction was recorded and then the scores for both directions were averaged in order to minimise "the within-subject" variation. The travel time was converted to a walking speed and then used to calculate the PPWS (the walking speed in the obstacle course / PWS × 100). The number of collisions in each direction were recorded and then averaged. A collision was any contact with an obstacle with any part of the body, stumbles, unintentional bump into the wall or examiner intervention.
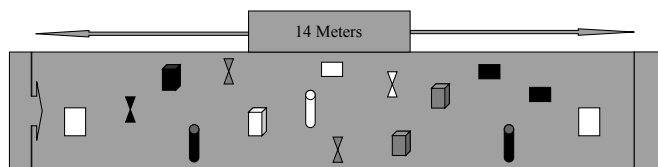

Figure 1: Mobility course layout, showing that obstacle separation varied, but was generally less than 1 meter. The collate shape refer to obstacles hung from the ceiling, cylindrical shape refer to waist-height obstacles, cube refer to the knee-height obstacles and rectangle shape refer to the low-lying obstacles.

The participants were informed that there would be obstacles of various sizes and colours randomly distributed in their path and that some of them were hanging from the ceiling. They were asked to negotiate the obstacle course while trying to not collide with any obstacle. The participants were not allowed to have a look at the course before doing the test, to avoid any potential planning of a route in advance. As the SI participant walked the course four times with various simulated FoV ($5°$, $10°$, $15°$ and $20°$) a training effect could be encountered, therefore, the Bootstrap statistic resampling method (explained in the results section) was used to counteract this possibility.

Results

The characteristics of the SI and TV groups are summarized in Table 1. The TV participants had been diagnosed with retinitis pigmentosa for at least 15 years and were in the advanced stages. The FoV size in the TV group ranged from $4°$ to $21°$: 5 participants had FoV of $4°$ to $6°$, 8 participants had FoV of $10°$ to $12°$, and 7 participants had FoV of $18°$ to $21°$. None of the TV participants had any functioning peripheral island of vision. Some of the collected data from the mobility course were not normally distributed (Kolmogorov-Smirnov, < 0.05), so non-parametric tests were used throughout.

Table 1: TV and SI participants' age and visual functions.

	TVPs (Binocular) Mean $\pm$ SD (Range)	SI (RE) Mean $\pm$ SD (Range)
Age (Years)	42.50 ± 11.00 (28 to 67)	24.50 ± 6.50 (18 to 51)
VA (logMAR)	0.20 ± 0.20 (-0.14 to 0.40)	-0.10 ± 0.11 (-0.30 to 0.10)
Log CS	1.50 ± 0.30 (0.60 to 1.85)	1.70 ± 0.08 (1.60 to 1.95)

SI Performance on the mobility course

Sensitivity

The mobility scores were responsive to the change in the FoV size. The PPWS scores gradually decreased as the FoV became more constricted (Figure 2). The number of collisions also increased as the FoV got smaller (Figure 3). The relationship between the FoV and the mobility scores was explored; however, as the SI participants had walked the same course with the four simulators, the relationship between the FoV and mobility measures might be influenced by the within-participants effect (i.e. the training factor). Therefore, a Bootstrap statistic resembling method was used (Efron & Tibshirani, 1993; R. Wilcox, 2011). Basically, this test randomly assigned each one of the 50 participants to one of four groups, which was determined by the four FoV sizes ($5°$, $10°$, $15°$ and $20°$). Every group had 12 participants and most importantly none of the participants fell into two groups at the same time. Then the relationship between the FoV and the mobility scores was determined using the Spearman Rank-Order correlation test. This test was conducted 1000 times using the R project for statistical computing (http://www.r-project.org), using a different assignment of participants on each occasion. The reported correlation coefficient value and the significant value are the median of the 1000 values. The Spearman test showed a highly significant positive relationship between the PPWS and FoV on both visits, $r = 0.58$, $p < 0.0001$ and $r = 0.56$, $p < 0.0001$, respectively (Figure 2): a higher PPWS was associated with a bigger FoV. The collisions were also found to have a statistically significant negative relationship with the FoV at both visits, $r = -0.50$, $p < 0.0001$ and $r = -0.55$, $p < 0.0001$, respectively (Figure 3). This suggests that a larger number of collisions occur with a smaller FoV.

A Wilcoxon Rank-Test was performed to test the repeatability of the mobility course. The PPWS scores were not found to be significantly different $p > 0.05$) between the two visits for any FoV in the four SI groups. Collision incidences were found to be significantly lower at the second visit for SI $20°$, $Z = -2.52$, $p = 0.012$.
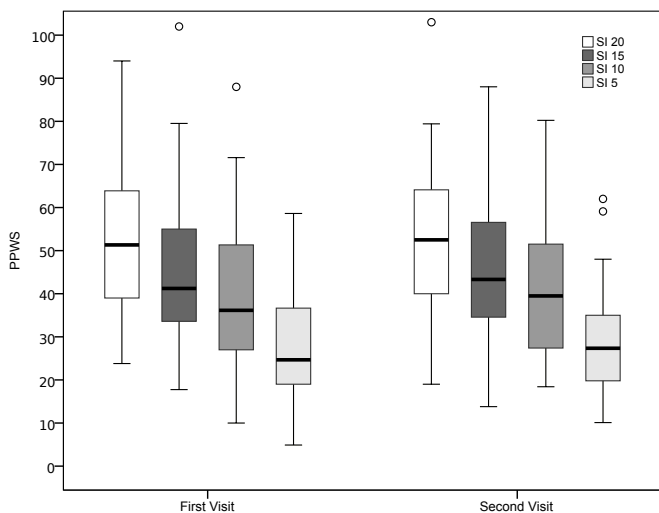
Figure 2: Relationship between SI FoV and PPWS on both visits. A positive relationship was found between both scores (Spearman's correlation, $r = 0.58$, $r = 0.56$, $p < 0.0001$).
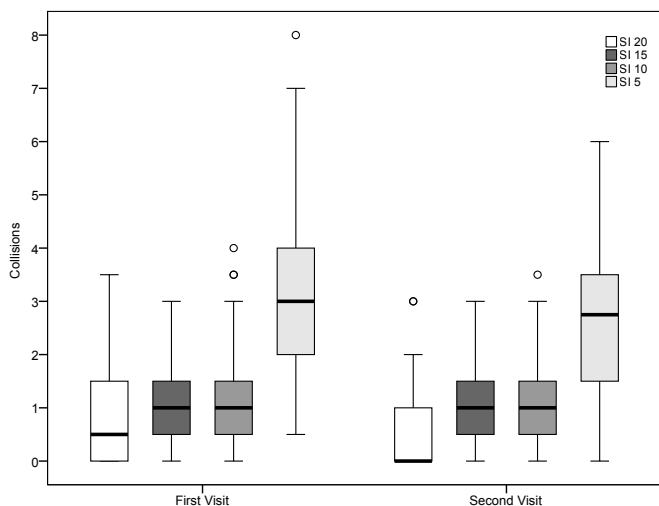

Figure 3: Relationship between SI FoV and collisions on both visits. A negative relationship was found between these variables (Spearman's correlation, $r = 0.50$, $r = 0.55$, $p < 0.0001$).

Repeatability

A Bland-Altman plot was used to explore the agreement between the mobility scores on both visits (Figure 4). The mean differences for the four SI conditions (SI 20° to SI 5°) were -0.50, -0.10, -1.78, and -0.90, respectively. These mean differences show that the slight increase in median speed on the second visit is minimal and the PPWS scores are scattered symmetrically around the zero difference, giving no evidence for a systematic change. The limit of agreement (LoA) slightly varied between the four conditions: for SI 20° it ranged from -24.34% to 23.31%; for SI 15° from -16.62% to 16.42%; for SI 10° from -18.48% to 14.92%; and for SI 5° from -13.50% to 11.70%.

The Bland-Altman test also shows an agreement of the collision incidences between the two visits (Figure 5). The mean differences for the four conditions (SI 20° to SI 5°) were 0.47, 0.24, 0.28, and 0.50, respectively. The slight decrease in collisions on the second visit is minimal, and the data points are scattered symmetrically above and below the zero difference, which suggests there was no learning effect. The LoA for collisions varied to some extent between the four SI conditions: SI 20° ranged from -1.24 to 2.20 collisions, SI 15° ranged from -1.64 to 2.12 collisions, SI 10° ranged from -2.1 to 2.65 collisions; and SI 5° ranged from -2.81 to 3.81 collisions.
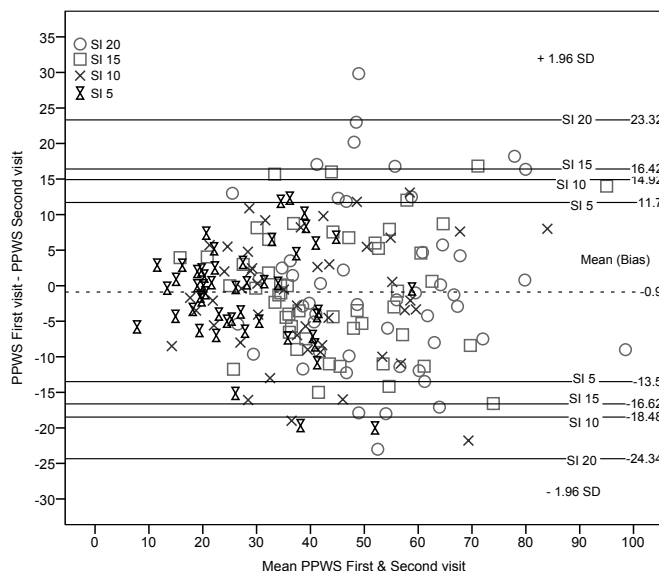

Figure 4: Bland-Altman test for the four SI groups, the bias value is the mean of difference of the pooled SI PPWS.
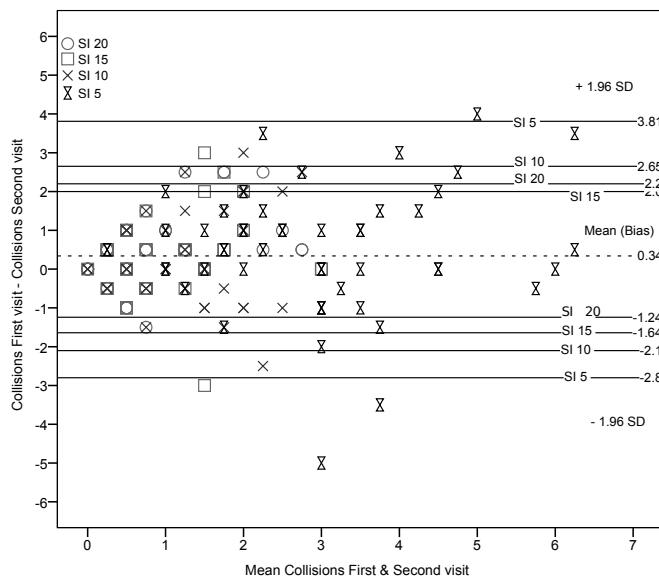

Figure 5: Bland-Altman test between the collisions on both occasions in the four SI groups. The mean value (dashed line) is the mean of difference of the pooled SI collisions.

TV Performance on the mobility course

The data collected were investigated for normality. Kolmogorov-Smirnov showed that the mobility scores were normally distributed ($p > 0.05$). Since the TV performance will be compared to the SI performance, the central tendency of the TV mobility scores is presented as median $\pm$ IQR. However, parametric testing was used when the relationship with the visual function was investigated as this does not involve comparison with the SI group.

The difference in PPWS between the largest and smallest FoV was about 1.50 times (Table 2). The median of the collision scores did not change markedly as the FoV decreased (Table 2). A significant positive relationship was found between the PPWS and FoV, Spearman $r = 0.40$, $p = 0.04$. The number of collisions did not have a significant relationship with the FoV, $r = -0.20$, $p = 0.28$.

Mobility scores relationship with visual function

Pearson correlation coefficient showed a significant relationship between the VA and collision incidences ($r = 0.40$, $p = 0.03$). The relationship between CS and the mobility scores was not significant, (r ranged from 0.20 to 0.30, $p > 0.05$).

Table 2: Median ± IQR of the PPWS and collisions for both groups.

	TV PPWS	TV collisions	SI PPWS	SI collisions
FoV 20°	54.00 ± 18.25	0.50 ± 1.00	51.25 ± 23.00	0.50 ± 1.50
FoV 10°	60.50 ± 27.25	1.00 ± 1.25	36.00 ± 23.25	1.00 ± 1.25
FoV 5°	32.50 ± 30.00	0.50 ± 1.25	24.50 ± 17.25	3.00 ± 2.25

The difference in performance between SI and TV groups

When comparing the TV and SI performances, it can be seen that the TV walked faster (higher PPWS) than the SI regardless of the FoV size (Table 2), but a statistically significant difference ($p > 0.05$) was only found in PPWS between the TV 10° and the SI 10° (Mann-Whitney U test). The individual scores in Figures 6 and 7 show considerable overlap between the TV and SI groups, even for the 10° field. The Mann-Whitney test showed a statistically significant difference ($p > 0.05$) between TV 5° and SI 5° in collision scores, otherwise, no significant difference ($p > 0.05$) was found in the other groups.
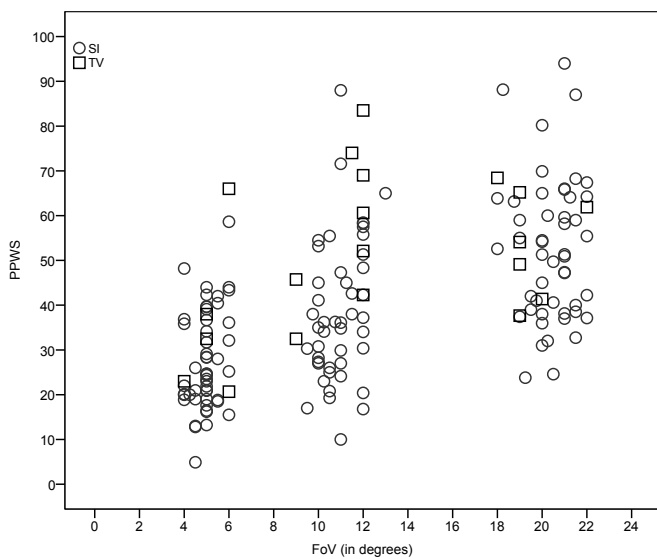

Figure 6: The scatter-plot of the PPWS in the three FoV sizes in both TV and SI groups.
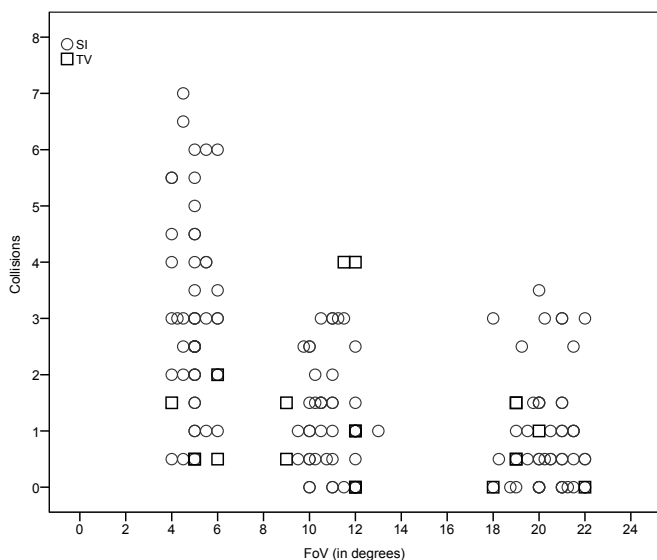

Figure 7: The scatter-plot of the collision scores for each participant in the three SI and TV groups.

Discussion

The mobility course developed in this study is an indoor course, because it gives good control over pedestrians, lighting and weather; and it allows the complexity of the course to be pre-determined. It was different from previous studies, being char-acterised by a high obstacle density, being walked twice in opposite directions, and it can be replicated in different studies and settings.

There were some limitations in using the simulated impairment group which include: the viewing had to be monocular, the possibility to perform scanning eye movements was very limited, which means scanning head movements were needed. In comparison, the TV patients were able to use a much wider range of head and eye movements in their navigation. Finally, even though the obstacles were in standstill position, the echolocation factor might have played a role. We did not explore this issue, but it could be included in future work.

In the SI group, the mobility scores have a highly significant relationship with the FoV. The relationship between the FoV and both mobility measures could provide evidence that the proposed mobility course is a sensitive measure.

The SI performance in the obstacle course did not change significantly between the two visits, except for collision incidence in SI 20°. The SI 20° condition was always tested first, so this outcome may suggest that there was a learning effect. However, this was not universal, since about 50% of the participants experienced no change in collisions or scored more collisions on the second visit. This is apparent in the Bland-Altman plots (Figures 4 and 5). This change in performance could be accounted for by the fact that the mobility course is a physical and be-havioural task, so it could be influenced by other factors such as the psychological status (people may walk quicker or slower based on their comfort or mood status), and the amount of attention they paid while doing the task. In general, the characteristics of the change in mobility scores across the SI conditions did not indicate that there was a learning effect.

The SI participants had performed the mobility course four times on each visit, which means that they had a much greater opportunity for learning than the TV participants had. However, it could be also true that every FoV restriction in our range of field display is a new situation, i.e. different from the earlier ones. This could mean that the training effect may then be limited. In addition, the SI participants were slower than the TV participants, which may indicate the importance of adaptation to the impairment in the individuals with TV. This methodology may lead to a further opportunity to improve performance with each SI participant as they gained additional experience in navigating the course. As the field was progressively reducing, this effect would have improved the performance for the smaller FoV and would therefore tend to reduce any correlation between mobility performance and FoV. There is no evidence of such an effect, and this may be because the course was relatively short which may indicate that participants did not have sufficient time to gain any relevant experience.

In the TV group, there was a positive significant relationship between the PPWS and FoV. Finding a less marked relationship in the TV group between PPWS and FoV, and not finding a relationship with collisions, could be accounted for by the existence of an "adaptation factor" in this group of participants. The TV participants are real patients who live their whole life with the RP condition while gradually losing their peripheral field. They will presumably have gained relevant experience and have adopted compensatory strategies, to varying degrees, to help them navigate their way safely and efficiently. Our observations supported this assumption as, for example, the TV participant number 9 with FoV 10° scored 60% PPWS and 0 collision, whereas, participant 14 with the same FoV walked at slower rate (PPWS = 40%), yet scored more collisions (4 collisions). Generally, the finding of a significant relationship between the PPWS and the FoV in the current study is similar to that in three previous studies (investigating glaucoma and RP) (Black et al., 1997; Geruschat et al., 1998; Haymes et al.,

1996).This outcome provides further evidence of the sensitivity of this mobility course.

The VA was found to have a significant relationship with collision incidences, but no significant relationship was found between the CS and the mobility scores. The three earlier studies have varied in their findings in terms of the relationship between the visual functions and the mobility scores. Black et al. (1997) found no significant relationship between the visual functions (VA was 0.68 ± 0.88 logMAR and the log CS was 1.05 ± 0.70) and the mobility scores. However, Haymes et al. (1996), and Geruschat et al. (1998) found a significant link between the mobility scores and the visual function measure. In Haymes et al. (1996)'s study, the VA ranged from 0.00 to 1.70 logMAR and the log CS ranged from 0.00 to 1.85. In Geruschat et al. (1998), the VA ranged from -0.16 to 1.66 and the log CS from 0.00 to 1.95. In our study, finding a moderate relationship, or one which did not reach the statistically significant level, could be accounted for by the restricted range of the CS and VA scores due to our inclusion criteria. All participants had VA better than 0.40 logMAR and the FoV was 20° or less which meant that our sample was a homogenous group that would need a much larger number of participants to reach the statistically significant level. These inclusion criteria were chosen because performing the mobility course was part of a bigger project which included using optical aids, and a reasonable VA level was required as these optical aids would impact negatively on the VA (e.g. reverse telescope).

The TV PPWS was generally faster than that of the SI at each FoV (Table 2), however, this difference was not statistically significant except for the PPWS scores at FoV of 10°. SI 5° participants scored more collisions than the TV, and this difference was statistically significant. Even though the SI walked slower in comparisons to TV, they had more collision incidences. Further, the difference in performance between both TV and SI group was also obvious in Figure 6 and 7, where some of the TV participants fell into the upper part of Figure 6 which means they were amongst the top performers and some also fell into the lower part of Figure 7 which means they were efficient and travelled more safely than the SI groups. This overall difference in performance across the range of FoV, may show the difference in experience between both groups.

This proposed mobility course was required to be sensitive to the change in FoV, sufficiently challenging to differentiate between good and poor performers in both groups, and easy to set up. This was achieved by using an obstacle-rich design, which might not be representative of the natural environment, yet would differentiate between various performance levels in a relatively short time and space, and would avoid the low / negligible number of obstacle contacts that have been reported in previous studies (Black et al., 1997; Geruschat et al., 1998; Kuyk & Elliott, 1999; Leat & Lovie-Kitchin, 2008; Lovie-Kitchin et al., 1996). The obstacle-rich design has been used previously, such as by Soong et al. (2001) and Lovie-Kitchin et al. (2010). Each obstacle in this proposed course was a potential collision and the separation between the obstacles was varied. Participants had to take repeated decisions to move either right or left, otherwise a collision would be highly probable. If collisions were to be frequent, it meant that all obstacles must be lightweight in order to avoid injuries. The course was designed to be short, to take only a few minutes to be arranged for every participant, and it should be easily replicated in other studies in different settings. This meant that it would require little space, and that space could be used for other purposes between experimental sessions.

In conclusion, the aim of this study was to validate a portable mobility course that could be used in assessing the mobility performance in persons with tunnel vision. The results found suggested that there is a potential use for this design in the as-

sessment of participants' performance, adaptation and rehabilitation success (e.g. retinal prosthesis and O&M training) or it could be used in validating other outcome measures.

Disclosures

The authors report no conflicts of interest.

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