ABSTRACT

The current study determined whether manipulations to walking path configuration influenced six-minute walk test (6MWT) outcomes and assessed how gait variability changes over the duration of the 6MWT in different walking path configurations. Healthy older (ODR) and younger (YNG) (n=24) adults completed familiarisation trials and five randomly ordered experimental trials of the 6MWT with walking configurations of; 5M, 10M and 15M straight lines, a 6m by 3m rectangle (RECT), and a figure of eight (FIG8). Six-minute walk distance (6MWD) and walking speed ($m.s^{-1}$) were recorded for all trials and the stride count recorded for experimental trials. Reflective markers were attached to the sacrum and feet with kinematic data recorded at 100Hz by a nine-camera motion capture system for 5M, 15M and FIG8 trials, in order to calculate variability in stride and step length, stride width, stride and step time and double limb support time. Walking speeds and 6MWD were greatest in the 15M and FIG8 experimental trials in both groups ($p<0.01$). Step length and stride width variability were consistent over the 6MWT duration but greater in the 5M trial vs. the 15M and FIG8 trials ($p<0.05$). Stride and step time and double limb support time variability all reduced between 10 and 30 strides ($p<0.01$). Stride and step time variability were greater in the 5M vs. 15M and FIG8 trials ($p<0.01$). Increasing uninterrupted gait and walking path length results in improved 6MWT outcomes and decreased gait variability in older and younger adults.

Keywords: Gait, variability, ageing, six-minute walk test, older adults

INTRODUCTION

The six-minute walk test (6MWT) measures the distance achieved in a continuous six-minute walking bout and is a global indicator of functional capacity [1]. Due to its simplicity and close relation to activities of daily living, the 6MWT has been used to represent functional capacity in chronic obstructive pulmonary disease and total knee arthroplasty patients and older individuals [1-3]. Conversely, measures of gait variability are more specific indicators of the neural control of gait [4] and have been used to discriminate between older fallers and non-fallers and to predict older adults at risk of falling, a major health hazard in this population [5,6].

Although the 6MWT distance achieved (6MWD) and gait variability have clear utility in characterising function and predicting falls risk respectively, non-adherence to the American Thoracic Society (ATS) 6MWT guidelines, result in adaptations to the walking path set-up or configuration, rest periods, turning strategy, familiarisation, and encouragement provided [1,7,8]. Adaptation to walking path configuration has been suggested to impact upon 6MWD due to the effects of turning and gait speed strategy adopted [9-11]. Adaptation to walking path configuration has also been shown to influence gait variability, with repeated single walking path trials displaying increased variability vs. continuous walking trials [12], perhaps due to the variability in the acceleration vs. steady-state phase of walking gait [13]. In order to ameliorate these issues, continuous overground walking path protocols, such as the ‘figure of eight’, have been proposed [14]. Currently, there is no agreement on the minimum number of gait cycles to recommend for reliable gait variability assessment, indicating that gait variability is also affected by the stride count and/or duration of a walking trial [13-15].

Both the functional capacity and gait variability of older adults have been assessed using continuous walking protocols [6,12,16]. However, results need to be interpreted with caution, considering the walking path configuration and trial duration employed.

Given that information regarding gait variability and 6MWD may inform clinical diagnostic processes, understanding the influence of differing 6MWT walking path configurations and trial duration on these measures is vital to enhance the homogeneity and interpretation of information from local testing protocols. Therefore, the aim of the current study was two-fold: firstly, (i) to determine if manipulations to walking path configuration influences 6MWT outcomes in older and younger individuals and secondly; (ii) to assess how gait variability changes over the duration of an extended period of walking (6MWT in this instance) in different walking path configuration manipulations in older and younger individuals. It was hypothesised that (1) 6MWT outcomes would be improved in walking path configurations with increased straight line walking distance and reduced turning requirements in both older and younger individuals. It was also hypothesised that (2) gait variability would exhibit an interaction effect, where walking path configurations with increased straight line walking distance and reduced turning requirements would have decreased variability in conjunction with reductions in variability across the 6MWT duration and that this effect would be present in both older and younger individuals.

METHODS

Participants

A consecutive sample of both older (ODR) and younger (YNG) individuals were recruited to form two groups of n=12. All participants in the ODR (3♂9♀, aged 70.2 ± 3.4 years, height 1.62 ± 0.07 metres and mass 77.4 ± 10.5 kilograms) and YNG groups (12♂, aged 21.9 ± 1.3 years, height 1.79 ± 0.07 metres and mass 76.1 ± 6.5 kilograms) provided written informed consent to participate in the study, which was approved by the XXXXXXXXXX XXXXX University Human Research Ethics Committee.

In order to recruit healthy older participants whose physical function would not be adversely affected by their health or lifestyle, prospective participants for the ODR group were included if they: 1) were community living adults aged between 60-75 years of age; 2) displayed a good health status as established by a health screen; 3) were able to walk, pain free, for period of six minutes without the use of a walking aid; 4) had good (corrected) vision and 5) partook in physical activity at least once a week for 30 minutes. These individuals were excluded if they: 1) had experienced an unintentional fall in the previous 12 months; 2) were current smokers; 3) were currently taking ≥5 prescribed medications.

For the YNG group, prospective participants were included if they: 1) were adults aged between 18-30 years of age and 2) displayed good health status as established by a health screen and were excluded if they: 1) had a current neuromuscular and/or musculoskeletal injury; 2) had a current medical condition that may affect gait and/or balance and 3) were current smokers.

Experimental Design

Participants completed two trials of the standard 6MWT along a 30m straight walking path according to the standardised ATS guidelines, which also acted as familiarisation trials [1], followed by five experimental trials of the 6MWT, where the walking path configuration was manipulated (Figure 1A). The five experimental walking path configurations were; five (5M); ten (10M); and fifteen metre (15M) straight lines with 180 degree turns; a six metre by three metre rectangle (RECT) with 90 degree turns; and a continuous figure of eight walking path (FIG8) with two intersecting straight line sections of 10 metres (Figure 1B). The ordering of experimental trials was randomised using a random number generator.

Insert Figure 1 here

Experimental Protocol

Participants attended data collection sessions wearing comfortable clothing and flat, everyday walking shoes. As foot kinematic measures offer a viable assessment of gait variability [17], participants were fitted with 14mm reflective markers bilaterally at 1st and 5th distal metatarsal heads, 2nd proximal metatarsal head, calcaneus, distal aspect of the foot, as well as a single marker on the sacrum during the 5M, 15M and FIG8 experimental trials. These experimental trials were selected in order to assess the effects of straight line walking path distance and continuous vs. repeated straight gait with turns, on gait variability. Participants started each trial by standing at the start of each walking path and were free to self-select a turning direction. Standardised instruction and demonstration at the start of the 6MWT, as well as verbal encouragement at one minute intervals, were provided according to the ATS guidelines [1].

A nine-camera motion capture system (Oqus 400, Qualisys AB, Gothenburg, SE) recorded the three-dimensional position of the reflective markers as they moved through a calibrated laboratory volume (ca. 10m x 4m) for the duration of the 6MWT trial. Thus, kinematic data were captured for central straight line walking and turning sections of the 5M trial and for the central straight line walking sections only for the 15M and FIG8 trials. As per standardised instructions, participants were informed when to stop walking, at which point 6MWT distance was recorded and the number of strides counted by an investigator using a hand tally counter, was confirmed and recorded.

Data Analysis

For all trials 6MWD (m) and walking speed (m.s^{-1}) were calculated with the total number of strides completed (stride count) being recorded for all experimental trials. For 5M, 15M and FIG8 trials, raw three-dimensional marker position data for sections of straight line walking, excluding turning strides, were extracted from the central area of the calibrated laboratory volume and were interpolated using a cubic spline algorithm and smoothed using a low-pass Butterworth filter with a cut-off frequency of 6Hz (Visual 3D v.5 Professional, C-Motion, Germantown, US). Gait events of heel strike and toe off were identified using a position-based algorithm, previously described [18]. Temporal-spatial data were calculated in 10 stride sections from the start for 0-10, 20-30 and 40-50 strides and then 10 stride sections counting back from the three and six minute intervals of the 6MWT. Spatial gait characteristics of stride length (m), step length (m) and stride width (m) and temporal characteristics of stride time (s), step time (s) double limb support time (s) were calculated. Many measures quantifying gait variability are based upon the standard deviation, which is also widely reported in gait studies not specifically concerned with gait variability [19]. Therefore, to widen the applicability of results from the current study, the standard deviation of temporal-spatial variables was selected to represent gait variability. Standard deviations of right and left limb temporal-spatial measures were calculated independently prior to the creation of a pooled standard deviation, which was used for analysis.

Statistical Analysis

An intra-class correlation coefficient (ICC) for the 6MWD from familiarisation trials was used to indicate familiarisation to the standard 6MWT. A group by walking path configuration two-way repeated measures ANOVA was used to assess how walking path configuration influenced 6MWD, walking speed and stride count in older and younger individuals. A group by walking path configuration by 6MWT duration, three-way repeated measures ANOVA was used to assess how gait variability changed over the duration of the 6MWT in different walking path configuration manipulations in older and younger individuals. Where the assumption of sphericity was violated, a Greenhouse-Geisser correction factor was applied. Effect sizes (partial eta squared) were calculated for each statistical comparison and post-hoc comparisons of significant effects were conducted using a Sidak adjustment. The alpha level of statistical significance was set at $p<0.05$. All statistical analysis was conducted in IBM SPSS v.22 (IBM, Portsmouth, UK).

RESULTS

Participants showed excellent reliability between the two standard familiarisation trials, achieving an ICC of 0.976 (95% CI = 0.944-0.999) in 6MWD.

Outcomes from the 6MWT

Group mean and standard deviation 6MWD, walking speed and stride count data, along with full statistical analyses are reported in Table 1. The manipulation of walking path configuration affected 6MWD, walking speed and stride count of both the ODR and YNG groups similarly, which was reflected by statistically non-significant interaction effects ($p>0.05$) (Table 1). Post-hoc tests revealed that the 6MWD and walking speed in each walking path configuration were different from one another ($p<0.01$), with the following exceptions: the two familiarisation trials, produced the greatest 6MWD and walking speeds, but were similar ($p=0.63$ and $p=0.62$ respectively); the 15M and FIG8 trials produced the next greatest 6MWD and walking speeds but were also not statistically different from each other ($p=0.68$ and $p=0.73$ respectively); followed by the 10M and RECT trials which were also similar ($p=0.34$ and $p=0.39$ respectively). The 5M trial produced the lowest 6MWD and walking speeds. The range of stride counts in both the ODR (17) and YNG (11) groups was affected less by the manipulation of walking path configuration however, post-hoc tests revealed that the 10M, 15M and FIG8 trials resulted in greater strides counts vs. the 5M and RECT trials ($p<0.01$). Finally, the 6MWD and walking speed of the YNG group was greater than that of the ODR group, ($p<0.01$) although the stride counts were similar between groups ($p>0.05$) (Table 1).

Insert Table 1 here

Spatial Variability

Group mean temporal-spatial variability plots are presented in Figure 2. The YNG groups stride length variability tended to reduce over the 6MWT period, whereas the ODR groups was more constant, which resulted in a significant interaction effect, $F(3.42,218.88) = 2.89$, $p=0.03$, $\eta p^2 = 0.04$. The YNG and ODR groups’ stride length variability responded differently to differing walking path configurations, particularly with the 5M trial being associated with greater variability in the YNG group, resulting in a significant interaction effect, F(2,64) = 8.22, $p<0.01$, $\eta p^2 = 0.20$. Step length variability was not affected by the 6MWT duration however, as step length variability in the 5M trial was greater vs. the 15M and FIG8 trials, particularly in the YNG group, a significant interaction effect was reported, F(2,63) = 14.97, p<0.0,1, $\eta p^2 = 0.26$. A similar interaction effect was noted in stride width variability, where the 5M trials resulted in the greatest variability, F(2,63) = 5.23, p=0.01, $\eta p^2 = 0.14$.

Insert Figure 2 here

Temporal Variability

As can be seen in Figure 2, both stride time (F(2.25,143.79) = 13.16, $p<0.01$, $\eta p^2 = 0.17$) and step time (F(2.27,145.53) = 8.19, $p<0.01$, $\eta p^2 = 0.11$) variability reduced between 10 and 30 strides. Similarly, both stride time (F(2,64) = 9.95, $p<0.01$, $\eta p^2 = 0.24$) and step time (F(2,64) = 12.67, $p<0.01$, $\eta p^2 = 0.28$) variability were greater in the 5M trial, compared to the 15M and FIG8 trials, with stride and step time variability being similar between groups. Variability in double limb support time reduced in both groups between 10 and 30 strides, although this reduction was greater in the YNG group vs. the ODR group, resulting in a significant interaction effect, F(3.29,184.02) = 7.65, p=0.04, $\eta p^2 = 0.05$. The ODR group had reduced double limb support time variability vs. the YNG group, F(1,56) = 15.67, $p<0.01$, $\eta p^2 = 0.22$ with the 15M trial being associated with the least variability, F(2,56) = 4.21, p=0.02, $\eta p^2 = 0.13$.

DISCUSSION

The aims of the current study were: (i) to determine if manipulations to walking path configuration influenced 6MWT outcomes in older and younger individuals and; (ii) to assess how gait variability changes over the duration of an extended period of walking in different walking path configuration manipulations in older and younger individuals.

Walking Path Configuration Effects on 6MWT Outcomes

In the current study, the general observation of greater 6MWD and faster walking speed with increasing length of straight line walking was consistent with previous research [8-10]. The greatest 6MWD and walking speeds from the experimental trials were associated with the 15M and FIG8 trials and this effect was independent of age. This suggested that the increased time and control required to perform turns in shorter walking paths and the higher gait speed strategies purported to be utilised in longer walking paths, affect both older and younger individuals similarly [9,11]. This implies that, in locations where the 6MWT is used to assess functional capacity in a range of populations, the subsequent effects on 6MWT outcomes can be expected to be similar. Thus, it can be stated that increasing uninterrupted gait i.e. reduced turning and increased walking path length, results in increased 6MWD and walking speeds in both older and younger individuals, confirming the first hypothesis.

Whilst the 5M trial resulted in a reduced 6MWD (155.6m) and walking speed ($0.43 m.s^{-1}$) compared to the second familiarisation trial, a 5M walking path is unlikely to be employed clinically. However, gait studies reporting or interpreting walking speed data from very short walking paths should note the large reductions in mean 6MWD and walking speed observed.

Results from the current study also corroborated the ATS guidelines and previous research assessing walking path configurations, as the greatest 6MWD and walking speeds were achieved during the 30m straight walking path familiarisation trials [1,8,9]. This re-iterates that where possible, a 30m walking path should be utilised to obtain an individual’s maximum 6MWD. However, constraints on space limit strict adherence to the ATS guidelines [8,20]. Therefore, results from the current study suggest that where space is limited, the use of 15M and FIG8 walking paths would, independent of age, better reflect an individual’s ‘standard’ 30M 6MWT performance when compared to a 10M walking path, reported to be used frequently [8].

Finally, the stride count data were similar between younger and older individuals and although they were also influenced by walking path configuration, the effect was not as great as observed for 6MWT outcomes. Although not assessed quantitatively, this suggested that stride frequency, was less sensitive to walking path manipulations when compared to stride length.

Walking Path Configuration and Duration Effects on Gait Variability

Results from the current study corroborated previous reports of repeated single walking path trials being associated with increased gait variability when compared to continuous walking path trials in older and younger adults, as an increased variability was associated with the 5M configuration, where the turning requirements were greatest [12]. The increased variability may be attributed to repeated stoppages or interruptions in steady state gait in the repeated-single protocols or walking protocols requiring frequent turning, as stride-to-stride fluctuations may be of greater magnitude and frequency in these cases [12,21]. Therefore, it can be stated that increasing uninterrupted gait through a longer walking length and/or a reduced requirement to turn, results in reduced spatial gait variability, confirming the second hypothesis. This implies future investigations aiming to assess gait variability should employ continuous walking path configurations, such as those stated in literature and employed in the current study (15M and FIG8), in order to obtain more reliable and valid estimates of gait variability [14].

Interestingly, the manipulation of walking path configuration had a different effect on temporal and spatial aspects of gait variability. As stated above, it appeared that individuals attempted to maintain a stride frequency throughout all experimental trials. However, stride and step length and stride width variability were greater during the 5M, compared to both the 15M and FIG8 configurations. This suggested spatial gait variability is increased when individuals are forced to modulate spatial aspects of gait at their preferred temporal frequency when dealing with increasing gait interruptions. This has significant implications, particularly for older individuals, for whom increased gait variability has been linked to increased falls risk [5,6].

No agreement exists on the recommendation for the minimum number of gait cycles required for reliable gait variability assessment, suggesting that gait variability is influenced by the duration of a walking trial and/or number of strides recorded [13-15]. Although spatial measures of gait variability seemed to be consistent across the 6MWT duration, temporal measures were clearly influenced in the early stages of the 6MWT. Temporal measures of gait variability, such as stride and step time and double limb support time, decreased between 10 and 30 strides of straight line walking, supporting the second hypothesis. This may be linked to the notion that participants seemed to have a temporal frequency to which they preferred to walk, thus the reduction in variability noted between 10 and 30 strides reflected the period required to adjust into this preferred frequency for each walking path configuration. Although not quantitatively assessed in the current study, further investigation of the effects of perturbations to individuals' preferred temporal frequency in performing activities of daily living such as level walking is warranted.

As with spatial gait variability, increased temporal variability was associated with the 5M configuration, further supporting the second hypothesis and the suggestion for the use of continuous walking path configurations to obtain valid and reliable estimates of gait variability.

Limitations

Participants in the ODR group were aged between 65-75 years of age and had relatively good levels of health and physical activity. However, this may limit external validity as the ODR group in the current study may not have been representative of a wider population of older individuals or other patient groups with additional health complications. This is significant, as the current study did not investigate how the experimental manipulations may have influenced gait variability and 6MWT outcomes in these patients groups, therefore future research in this area is warranted. Future research should also attempt to assess whether imposing slower walking speeds, independent of changes to walking path configuration, affect gait variability.

Thus understanding whether increased gait variability in non-continuous walking configurations is due to the interruptions to continuous walking or the subsequent reductions in walking speed observed.

CONCLUSION

Increasing uninterrupted gait and walking path length results in improved 6MWT outcomes and decreased gait variability in both older and younger individuals. Increasing the number of continuous strides between turning events reduces gait variability in both older and younger individuals. These results have implications for clinicians and researchers interested in functional capacity and gait variability as they show how walking path configuration, alongside the condition and/or intervention being investigated, may influence 6MWT outcomes and gait variability. Clinicians and researchers are advised to use a continuous walking path protocol with the maximum straight line walking distance possible.

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