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Full Length Article

# Head flexion and different walking speeds do not affect gait stability in older females

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## ABSTRACT

Head flexion is destabilizing in older individuals during quiet stance, yet the effect head flexion has on gait is not known. The study examined whether head flexion and gait parameters were altered when walking freely and fixed to a visual target, at different walking speeds. 15 young (23 ± 4 years) and 16 older (76 ± 6 years) healthy females walked at three different walking speeds (slow, comfortable, and fast) under two visual conditions (natural and fixed [focusing on a visual target set at eye level]). Head flexion was assessed using 2D video analysis, whilst gait parameters (step length, double support time, step time, and gait stability ratio) were recorded during a 9 m flat walkway. A mixed design ANOVA was performed for each variable, with age as the between-subject factor and, visual condition and walking speed as within-subject factors. When walking freely, older displayed a greater need for head flexion between walking speeds ($P < 0.05$) when compared to young. Walking under fixed condition reduced head flexion at all walking speeds in the older ($P < 0.05$), but had no effect on the young ($P > 0.05$). Walking at different speeds showed no difference in head flexion when walking under either visual condition and had no effect on gait stability for both groups. Despite older displaying differences in head flexion between visual conditions, there was no effect on gait parameters. Walking speed presented trivial difference in head flexion in older females, whilst overall gait stability was unaffected by different walking speeds.

## 1. Introduction

Walking is a habitual activity, requiring transition from a stable to an unstable position, i.e. from double to single leg support. Such movement results in a continuous perturbation in the balance equilibrium, as the centre of mass (COM) alters in relation to the also changing base of support (BOS) (Woollacott & Tang, 1997). This can prove challenging for older individuals (Ihlen et al., 2012; Prince, Corriveau, Hébert, & Winter, 1997), reflected by the fact that the majority of falls occur during walking in older individuals (Rubenstein, 2006).

Given the challenge gait poses to older individuals, head flexion is typically implemented to identify lower limb trajectory and enable better footfall vision (Marigold & Patla, 2008) and to gather more information when walking towards an obstacle (Muir, Haddad, Heijnen, & Rietdyk, 2015). This increased head flexion, whilst enabling better lower visual vision, may however have a negative impact on postural control, and subsequently, on fall risk (De Groot et al., 2014). During walking, at heel strike, the pelvis moves posteriorly due to ground reaction forces, which consequently causes the upper body to rotate forward over the feet, altering the COM towards the limits of the BOS, thus challenging balance (Winter, 1995). A flexed head, weighing ~7% of overall body mass

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(de Leva, 1996), may exacerbate this forward shifting of the COM, further threatening stability or making recovering from an unexpected perturbation difficult (De Groot et al., 2014). During quiet standing in older individuals Buckley, Anand, Scally, and Elliott (2005) reported a destabilising effect of head flexion. Although this destabilising effect has been seen in static conditions, it has not been examined in dynamic conditions and given the previously mentioned problems with falls during walking, it is important to examine the effect head flexion could have to either consider it in future studies and interventions or reject it as a contributor to gait instability.

Head flexion has also been shown to be influenced by gait speed in young individuals. Hirasaki, Moore, Raphan, and Cohen (1999) reported that at speeds $> 1.2\ m{\cdot}s^{-1}$, there was an increased magnitude of head pitch displacement, such that a greater amount of head flexion was observed. Although gait speed is commonly assessed as an outcome measure of functional capacity and gait ability in the older population (Bongers et al., 2015; Montero-Odasso et al., 2004; Toots et al., 2013; Verghese, Holtzer, Lipton, & Wang, 2009), it has rarely been considered the subject of investigation. In other words the effect of different walking speeds on head flexion has rarely been examined in older adults. During day to day life, however, walking at different speeds is required, for example, when walking faster due to being late for an appointment, or in contrast, walking slower to negotiate a busy shopping centre. If the findings by Hirasaki et al. (1999) in young also hold true for older adults, it is feasible that as walking speed increases, concurrently increasing head flexion, postural control may also be increasingly challenged.

In addition to the postural control issue that head flexion could cause during heel strike, it also raises an important methodological question. Gait studies typically instruct participants to focus on a visual target fixed at eye level to standardise head position during walking (Cromwell, Newton, & Forrest, 2002; Hirasaki et al., 1999). Such instructions, which constrain head movement, may mask a true effect, as they would reduce the naturally occurring head flexion. In turn, this could impact on gait stability and postural control, most likely underestimating the true challenge walking poses on older individuals and potentially reaching to erroneous results and less specific intervention advice. Therefore, understanding differences between a natural head position and a typical standardised head position, at different walking speeds, is warranted.

The aim of the study was twofold; to examine A) if head flexion and gait parameters were altered when walking without and with a visual target, and B) how the effect of using a visual target may change at different walking speeds. It was hypothesised that the implementation of a visual target would restrict head flexion, which in turn, would alter gait pattern. Females were the focus of the study as it has been reported that females dynamic stability declines to a greater extent than males (Wolfson, Whipple, Derby, Amerman, & Nashner, 1994) and tend to fall more often (Schultz, Ashton-Miller, & Alexander, 1997).

## 2. Methods

### 2.1. Participants

Sixteen healthy older females (age 75.5 ± 6.2 years, height 1.62 ± 0.04 m, body mass 74 ± 6.8 kg) and 15 healthy young females (age 23 ± 3.5 years, height 1.67 ± 0.04 m, body mass 63.3 ± 6.0 kg) participated in the study. Older females were recruited from local community groups while young were students at the Institution. All participants had no known neuromuscular disorders, impaired postural alignment such as kyphosis, osteoarthritis or neck related pain, while older participants were community residing, functionally independent, considered medically stable (Greig et al., 1994). All participants were able to perform all conditions without the use of bifocal or multifocal spectacles and had an uncorrected visual acuity ≥20/100 measured on the day of testing. Ethical approval was obtained from the Institutional Ethics Committee and written informed consent was obtained prior to testing.

### 2.2. Protocol

Walking trials were performed on an unobstructed 9 m flat walkway under two visual conditions; walking with no visual target and walking with a visual target. In the no visual target condition, no instructions were given to participants as to where to orient their gaze whereas in the visual target condition, participants were instructed to focus on a stationary target located at eye level, 3 m directly ahead of the end of the walkway. The visual target consisted of a black circle (15 cm diameter) on a white background. The position, size and distance of the visual target were decided following pilot testing, which allowed us to design a target which could be comfortably seen by the participants without excessive eye focusing effort. All participants underwent familiarisation with each visual condition and speed, and confirmed they were able to clearly see the target from the beginning of the walkway without the use of glasses.

Three trials were completed at three walking speeds (slow, comfortable, and fast). Instructions for walking speeds were given by associating the walking speeds to everyday activities (Thomas, De Vito, & Macaluso, 2007). Slow walking speed was described as 'the way you would walk during relaxed window shopping'; comfortable as 'how you would normally walk in a relaxed mood' and fast walking as 'how you would walk when late for an appointment'. Participants completed 18 trials in total (three trials per walking speed in both no visual target and visual target condition). The order of visual condition and walking speed was randomised and the mean of three trials was used for analysis.

### 2.3. Head flexion

To measure head flexion, a marker was placed on the apex of the skull (attached to a headband secured around the participant's

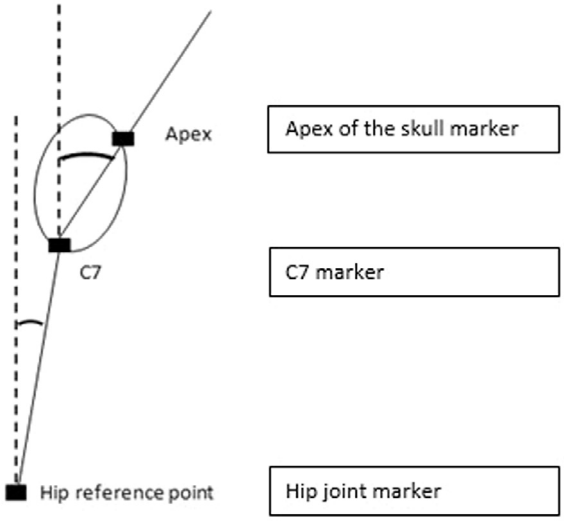


**Fig. 1.** Sagittal plane angles of the head and trunk. Black filled squares indicate markers placed on body landmarks.

head, horizontal to the ground, during standing in the reference body position) and a marker placed on the seventh cervical vertebrae (C7). The angle formed by the vertical axis (passing through the C7 marker) and the straight line between the C7 and the apex of the skull markers, was measured as head flexion angle.

To account for any trunk flexion and ensure any differences seen were the result of head flexion alone, trunk angle was also measured. A third marker was placed at the hip joint (firmly attached to a belt securely fastened around the participants' hips, horizontal to the ground, with the participant standing in the reference body position). The angle formed by the vertical axis (passing through the C7 marker) and the straight line between the hip joint and the C7 markers, was measured as trunk flexion. Both segments can be seen in the schematic diagram (Fig. 1).

Head and trunk flexion angles were measured in the sagittal plane using 2D video analysis (Kinovea for Windows, Version 0.8.15, www.kinovea.org) with a sampling frequency of 100 Hz, at the first heel strike of the left foot (first frame the heel made contact with the ground) as soon as the participant crossed the 6 m marker. To obtain a realistic understanding of changes in head and trunk flexion angles by avoiding 'postural adjustments' during standing measurements (Thomas, Bampouras, Donovan, & Dewhurst, 2016) the difference in angle from comfortable to slow walking speed and comfortable to fast walking speed (Δ values) were calculated for both age groups and both visual target conditions. Positive angle values indicated greater head and trunk flexion of the given walking speed in comparison to comfortable walking speed.

### 2.4. Walking velocity

The 6 m walk test was used to measure walking velocity at each walking speed as it has been shown to have high reliability for comfortable and fast walking (ICC = 0.97 and 0.96, respectively) (Steffen, Hacker, & Mollinger, 2002). Walking velocity was calculated from the time taken to walk between 3 m and 9 m (6 m) of the walkway using wireless timing gates (Brower timing gates, Draper, UT, USA) set at hip height.

### 2.5. Gait parameters

Gait parameters were recorded using the Optojump Next Jump System® (Microgate SRL, Bolzano, Italy) and included step length, double support time, and step time from the middle 3 m of the walkway. These gait variables were selected as they are frequently reported in the literature and been shown to be sensitive measures of changes in gait (Callisaya, Blizzard, Schmidt, McGinley, & Srikanth, 2010). The Optojump Next Jump System® (Microgate SRL, Bolzano, Italy) is an optical measurement system consisting of two infrared photocell bars that can derive contact time of each foot from the breaking of the transmitted beam. Gait stability ratio (GSR, calculated as cadence/velocity) has been developed from 2D gait analysis of flat walking and was used as a measure of walking stability. A higher GSR indicates a greater proportion of the gait cycle is spent in contact with the floor, thus avoiding the dynamic components of walking (Cromwell & Newton, 2004), as one would do when a greater need for stability is required.

### 2.6. Statistical analysis

To assess intrarater reliability of angle and gait measurements, sensitivity (typical error (TE), calculated as standard deviation of the change scores between measurement/√2) and intraclass correlation coefficient (ICC, calculated as $1 - TE^2$/mean between-

**Table 1**
Gait parameters during both visual conditions for each walking speed for young and older. Data is presented as mean ± SD.

| Variable | Speed | Young | | Older | |
|---|---|---|---|---|---|
| | | No visual target | Visual target | No visual target | Visual target |
| Gait Speed[a,c] ($m \cdot s^{-1}$) | Slow | 1.05 ± 0.15 | 1.10 ± 0.20 | 0.94 ± 0.21 | 1.01 ± 0.26 |
| | Comf | 1.58 ± 0.20 | 1.51 ± 0.10 | 1.32 ± 0.28 | 1.42 ± 0.29 |
| | Fast | 2.37 ± 0.30 | 2.23 ± 0.20 | 1.81 ± 0.20 | 1.81 ± 0.32 |
| Step Length [a,c] (cm) | Slow | 64.1 ± 3.94 | 65.16 ± 4.77 | 59.3 ± 5.20[b] | 65.4 ± 5.90 |
| | Comf | 73.8 ± 5.03 | 74.40 ± 4.38 | 68.9 ± 4.90 | 70.6 ± 4.20 |
| | Fast | 86.9 ± 4.96 | 86.18 ± 5.48 | 76.0 ± 5.10 | 76.6 ± 5.40 |
| DST [a,c] (s) | Slow | 0.39 ± 0.05 | 0.38 ± 0.07 | 0.45 ± 0.13 | 0.43 ± 0.11 |
| | Comf | 0.27 ± 0.04 | 0.27 ± 0.03 | 0.35 ± 0.21 | 0.31 ± 0.06 |
| | Fast | 0.15 ± 0.04 | 0.16 ± 0.03 | 0.20 ± 0.03 | 0.22 ± 0.04 |
| Step Time [a,c] (s) | Slow | 0.61 ± 0.04 | 0.57 ± 0.04 | 0.42 ± 0.07 | 0.41 ± 0.07 |
| | Comf | 0.49 ± 0.03 | 0.49 ± 0.03 | 0.29 ± 0.04 | 0.29 ± 0.02 |
| | Fast | 0.38 ± 0.05 | 0.42 ± 0.05 | 0.21 ± 0.03 | 0.22 ± 0.030 |
| GSR [a] ($Step \cdot m^{-1}$) | Slow | 1.62 ± 0.18 | 1.61 ± 0.16 | 2.48 ± 0.16 | 2.41 ± 0.22 |
| | Comf | 1.41 ± 0.12 | 1.39 ± 0.14 | 2.45 ± 0.70 | 2.53 ± 0.12 |
| | Fast | 1.16 ± 0.07 | 1.17 ± 0.12 | 2.92 ± 0.23 | 2.62 ± 0.26 |

Significant effects on the variables as follows.
DST, double support time; GSR, gait stability ratio.
[a] $p < 0.05$ for significant effects of age.
[b] $p < 0.05$ for significant effect of visual condition.
[c] $p < 0.05$ for significant effect of walking speed.

subject standard deviation between measurements) between the three trials were obtained from a customised spreadsheet (Hopkins, 2000).

Statistical analyses were carried out using IBM SPSS v19 (SPSS, Chicago, ILL). Normality of data was examined using the Shapiro-Wilk test and confirmed for all variables. A mixed design ANOVA was performed for each variable, with age group as a between-subject factor and visual condition and walking speed as within-subject factors. When a main effect existed, between group differences were examined using independent samples t-tests, while within group comparisons were conducted using a repeated measures ANOVA followed by dependent-samples t-tests, if a difference was found, with Bonferroni correction. For comparisons which showed significant differences, effect size (ES) was calculated to provide indication of the magnitude of difference, with 0.2, 0.5, and 0.8 representing a small, medium, and large effect respectively (Fritz, Morris, & Richler, 2012). An alpha level was set at $P < 0.05$. Data are presented as mean ± standard deviation (SD).

## 3. Results

Data for gait parameters are presented in Table 1. For clarity, effect sizes for significant differences are reported only if they were below moderate (0.05).

### 3.1. Reliability

Head and trunk flexion ICCs for both age groups in all measurements ranged from 0.89 to 0.90, indicating high reliability, whilst only a small TE (< 1.12°) was present. Similarly, ICC for step length ranged from 0.83 to 0.95, with only fast walking with visual target for the young exhibiting a lower ICC (0.77).

### 3.2. Head flexion

There was a significant main effect of age [P = 0.001], walking speed [P = 0.021] and visual condition [P = 0.001] for head flexion angle. There were significant interactions for age × visual condition [P = 0.001] and walking speed × visual condition [P = 0.011]. Delta values showed head flexion was significantly greater between slow-comfortable walking and comfortable-fast walking during the no visual target condition in older ([P = 0.01], ES = 0.06). Delta values showed head flexion was significantly lower at slow-comfortable walking compared to comfortable-fast walking during visual target condition in young ([P = 0.032], ES = 0.09). Changes in head flexion between walking speeds for young and older in each visual condition are depicted in Fig. 2.

### 3.3. Trunk flexion

There was a significant main effect of age [P = 0.013] and visual condition [P = 0.02] on trunk angle. There were significant interactions for age × visual condition [P = 0.026]. There was no difference in trunk flexion at any walking speed or visual

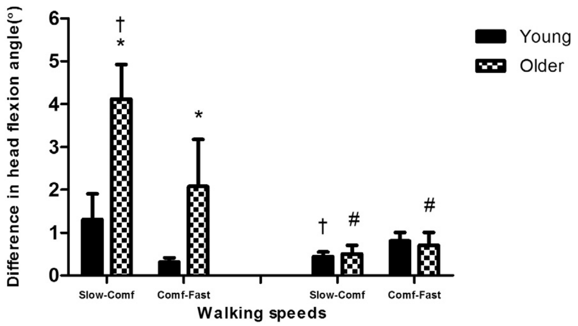


**Fig. 2.** Δ values in head flexion angle between walking speeds for young and older in each visual condition. Data is presented as mean ± SD. *indicates significant differences between age group, #indicates significant difference between no visual target and visual target conditions and † indicates significance between slow-comfortable and comfortable-fast walking speed. Slow-comf = slow to comfortable walking speed. Comf-fast = comfortable to fast walking speed.

condition between young and older [P > 0.05]. Delta values showed older displayed a greater increase in trunk flexion angle from the fast walking to comfortable walking ([P = 0.001], ES = 0.08) in the no visual target compared to the visual target condition, while there were no differences between visual conditions in young.

### 3.4. Walking velocity

There was no difference in gait velocity between visual conditions for either group. Predictably, walking velocity significantly increased with walking speed in both age groups ([P = 0.019], ES = 0.24–0.49 and [P = 0.038], ES = 0.28–0.39 for young and older respectively), indicating participants successfully followed walking speed instructions. Young were significantly faster at comfortable and fast walking compared to older [P = 0.008], however there was no difference in gait velocity at slow walking speed between groups.

### 3.5. Gait parameters

Gait parameters for both age groups for all conditions are shown in Table 1. There was a significant main effect of age and walking speed for all gait parameters [P = 0.001] with the exception of GSR. There was a significant interaction for age × walking speed [P = 0.002]. When comparing visual conditions, there were no differences in any gait parameters with the exception of older demonstrating a significantly longer step length in the visual target condition compared to the no visual target condition in slow walking speed only (6.1 ± 1.1 cm, [P = 0.018], ES = 0.14). When comparing between group differences, older had a significantly shorter step length and step time compared to young at all walking speeds [P = 0.032], whilst double support time was significantly greater in older adults at all walking speeds [P = 0.01]. Older displayed higher GSR than young at all walking speeds [P = 0.028]. With respect to within group differences in walking speeds, step length significantly increased from slow to comfortable to fast walking speeds whereas double support time and step time significantly decreased in duration across the same conditions in both age groups [P = 0.026]. There was no difference in GSR between walking speeds for either age group.

## 4. Discussion

The purpose of the present study was to examine if head flexion and gait parameters were altered when walking without and with a visual target, and how the effect of using a visual target may change at different walking speeds. Findings showed that older individuals adopted greater head flexion at all walking speeds in the no visual target condition compared to young, with no changes in gait parameters There were trivial differences in head flexion was observed between walking speeds for both groups, leaving gait stability unaffected.

It has been suggested that older individuals implement head flexion to enable better vision to identify potential hazards located at ground level (Marigold & Patla, 2008; Menant, George, Fitzpatrick, & Lord, 2010). Gait in the present study was over a known flat walkway free of obstacles; yet older still implemented a greater need for head flexion compared to young during the no visual target trials between speeds. Consequently, this raises the question of why older demonstrated greater difference in flexion than young, despite not being exposed to external threats. It could be suggested that head flexion is adopted by older individuals regardless of environment or threat perception. Alternatively, head flexion may be an adaptation which older individuals have become accustomed to due to having to negotiate obstacles on an everyday basis (Keller Chandra et al., 2011). The combination of older individuals, typically having an impaired lower visual field (Freeman, Muñoz, Rubin, & West, 2007) and the need to look two steps (of shorter step length) ahead (Patla & Vickers, 2003) to ensure a clear path, may have caused older to implement greater head flexion. Walking in the way they were used to, possibly increases the subjective feeling of stability regardless of walking environment, contributing to the lack of difference in GSR between visual conditions. Similar to findings by (Hirasaki, Kubo, Nozawa, Matano, & Matsunaga, 1993), we found there to be greater head movement during double stance. Hirasaki et al. (1993), however, reported increased head extension whilst we found increased head flexion. The reasons for this can possibly be attributed to a difference in population characteristics between studies. Interestingly, DST was not significantly different between young and older in Hirasaki et al., while our results showed that older did have significantly longer DST. Thus, results show that differences were not only seen for head position but actually for gait variables, lending to the speculation that differences may be due to differences in population characteristics. Hirasaki et al., proposed that older may have reduced flexibility of the vertebral column preventing flexion of the head, however very little information is given about the older participants in the study. Older participants in our study were healthy and physically active, therefore flexibility of the vertebral common may not have been a problem, allowing a more unrestricted head movement.

The hypothesis of focusing on a visual target (to reduce head flexion) altering gait parameters, can be rejected as gait parameters remained similar in both visual conditions. Sway has been seen to be affected by head flexion during static conditions (Buckley et al., 2005). Despite differences in head flexion between visual conditions for the older, there was no difference in GSR values, suggesting head flexion whilst walking did not pose any additional fall risk. In the present study, head flexion was measured independent of the trunk. Previous studies have shown that the trunk flexion can influence gait results (Saha, Gard, & Fatone), which is in agreement with the present study as we found no trunk flexion, demonstrating that it is possibly trunk flexion rather than head flexion responsible for altering gait.

Our original hypothesis raised an important methodological question. Gait studies typically instruct participants to focus on a visual target fixed at eye level to standardise head position during walking (e.g. Cromwell et al., 2002; Hirasaki et al., 1999). Such instructions, which constrain head movement, may have masked a true effect, as they would reduce the naturally occurring head flexion, supported by the findings in the present study. We hypothesised that this in turn, this would impact on gait stability and postural control, most likely underestimating the true balance challenge walking poses on older individuals and potentially reaching to erroneous results and specific intervention advice. From the findings of the present study, however, this does not appear to be so for the population studied.

Hirasaki et al. (1999) reported that at speeds > 1·2 m·s$^{-1}$ there was an increased magnitude of head pitch displacement and a further increase when walking at speeds of 2 m·s$^{-1}$ in young individuals. These results are reflected in the present study as young had greater head flexion between comfortable – fast (2.53 m·s$^{-1}$ compared to slow-comfortable (1.51 m·s$^{-1}$). Our results support Hirasaki et al. previous reports that head displacement changes with walking speed for young adults, however we found the opposite effect in older as older produced greater head flexion at slow – comfortable walking speed compared to comfortable – fast walking speed (with low effect sizes, however). Despite trivial differences in head flexion at different speeds, overall gait stability was unaffected in both age groups.

GSR values did not change despite the decrease in double support time with the associated increase in walking speed, suggesting the different walking speeds did not pose a perceived increased threat to overall gait stability. Kang and Dingwell (2008) suggested that factors such as loss of strength and flexibility must be taken into account rather than simply walking speed when identifying gait variability and instability in the older population. Our data supports the notion that other measures are contributing to gait instability and that ageing effects on speed are not straight forward, thus a more holistic assessment is warranted.

Older individuals can have a kyphotic posture, an exaggerated anterior curvature which tends to increase with age (Ailon, Shaffrey, Lenke, Harrop, & Smith, 2015; Katzman, Wanek, Shepherd, & Sellmeyer, 2010). This impaired postural alignment affects physical functioning and can have implications on fall risk for the elderly (Ailon et al., 2015; Katzman et al., 2010). The subjects in the present study were free from such condition and it would be expected that kyphotic individuals would present different findings to the current participants. Further, to ensure that changes in head flexion angle could be attributed to head movement rather than trunk flexion, the two segments were examined separately. The results showed that trunk flexion did not change in any substantial way (as indicated by the very small effects sizes), suggesting that trunk flexion remained relatively stable when changing between visual target conditions and walking speeds.

A limitation to the study was that although a visual target approach was used, it was not quantified using an eye tracking device to examine whether participants was fixating on the target. However, the use of the target was not aimed to fixate gaze, but rather to adjust the head position by fixing the gaze. This was achieved, even if eyes were not always on the target, as the instruction of keeping the head up was followed.

## 5. Conclusion

Older females displayed greater head flexion compared to young when walking without a visual target; however, head flexion was constrained to that similar of young when walking with a visual target. Despite the difference in head flexion between visual conditions in older, there was no effect, either beneficial or detrimental to gait parameters and stability. Walking speed presented trivial difference in head flexion, whilst overall gait stability was unaffected by different walking speeds.

## Conflict of interest

No conflict of interest to declare.

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