Temporo-spatial gait parameters during street crossing conditions: A comparison between younger and older adults

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ABSTRACT

Most traffic accidents involving pedestrians happen during street crossing. Safe street crossing by older adults requires complex planning and imposes high cognitive demands. Understanding how street crossing situations affect younger and older adults’ gait is important to create evidence-based policies, education and training. The objective of this study was to develop and test a method to evaluate temporo-spatial gait parameters of younger and older adults during simulated street crossing situations. Twenty-two younger (25 ± 2 years old) and 22 older adults (73 ± 6 years old) who lived independently in the community completed 3 walking trials at preferred gait speed and during simulated street crossing with regular and with reduced time. There were significant differences between groups (p < 0.001) and conditions (p < 0.001). Older adults’ street crossing walking speed was higher than their preferred speed (p < 0.001). Gait during simulated street crossing resulted in significant and progressive gait changes. The methods developed and tested can be used to (1) evaluate if people are at risk of falls and accidents during street crossing situations, (2) to compare among different groups, and (3) to help establish appropriate times for older pedestrians to cross streets safely. The current time to cross streets is too short even for healthy older adults.

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1. Introduction

Accidents involving pedestrians are responsible for serious injuries and deaths. Nearly 5000 US pedestrians are killed and 68,000 are injured yearly; 63% of accidents involving pedestrians happen during street crossing [1,2]. Collisions of cars with pedestrians represent 27% of all traffic accidents and are responsible for 47% of all motor vehicle accident-related deaths [3]. Thirty percent of people who suffer traffic accidents are 65 and older; aging-related physiological changes make older adults more susceptible to injury and death [4,5].

Safe street crossing requires complex planning and impose high cognitive demands on older adults because it is necessary to perform multiple tasks simultaneously (i.e. paying attention to traffic signals, turning cars and walking with increased speed) [6]. Gait and balance declines when completing simultaneous tasks; older adults have greater performance decline and falls risk during dual-tasks than younger adults [7–10]. Balance assessment during dual tasking is more sensitive for predicting falls and for detecting changes than during single tasking [11]. There is a significant relationship between the occurrence of falls and changes in gait and performance during dual-tasks [12]. Therefore, dual-task gait scenarios, such as street crossing, can be useful for assessing the risk for falls in older adults.

Increased risk of falls is associated with aging-related gait changes [13]. The consequences of falls can be serious, especially when they occur in situations of risk such as street crossing. Gait impairments in older adults are related to declines in balance, muscle strength, and range of motion [14]. Aging-related gait changes include decreased speed, step and stride length, increased double support time, shorter swing phase and increased variability [15,16]. Older adults’ gait speed decreases up to 20% under dual-task conditions; gait changes vary according to the demands of the cognitive task, the difficulty of the motor task, age and balance [16]. Having a decreased gait speed is a risk for older adult falls [17], and for accidents during street crossing [2]. In addition to gait speed, the inclusion of other temporo-spatial parameters may increase the sensitivity of falls and accident risk assessments.
Understanding how street crossing situations affect younger and older adults’ gait patterns is relevant for public policies and regulations, education, and training. We did not find studies evaluating tempo-spatial gait parameters during road crossing situations. Previous studies evaluating dual-task gait (e.g. walking and counting backwards) found changes to be related to falls risk [17,18]. However, it is also important to improve the ecological validity of the dual-task methodology to further understand changes in dual-task gait [12], simulated street crossing conditions is a novel functional dual-task condition. The purpose of this study was to develop and test a method to evaluate tempo-spatial gait parameters of younger and older adults during a dual-task: simulated street crossing. The research hypothesis was that gait during simulated street crossing with regular and reduced time would result in significant and progressive changes in tempo-spatial gait parameters for both young and older adults.

2. Methods

2.1. Participants

Forty-four subjects participated in the study (Table 1). The sample size was determined using the program G* Power for a power of 95% with an α error of 5%, assuming an effect size of 73% based on data collected in an initial pilot study. The inclusion criteria were absence of pain, fractures or severe soft tissue injury in the previous 6 months. The Florida International University Institutional Review Board approved the study protocol (IRB-13-0136) and all participants signed an informed consent form.

2.2. Equipment

Gait parameters were assessed using the GAITRite® system (SN: Q209, CIR Systems Inc). The GAITRite® system measures of speed, cadence, and step length were found to have high concurrent validity (ICC = 0.91–0.99) when compared to Vicon-512® system measures [19]. A standard-size sidewalk ramp was used at the beginning of the walkway during the simulated street crossings. To simulate street crossing situations, a projector (BenQ MS504 SVGA DLP) displayed a video of an intersection into a screen placed 2 m after the end of the walkway (Fig. 1). The video included traffic noise and displayed an intersection situation with cars crossing; the subject was positioned on the sidewalk at the intersection looking at incoming traffic from both directions; a pedestrian light was also displayed on the screen.

2.3. Procedures

All tests were completed in one 1-h session. Participants’ weight (kg), height (cm), and leg length (cm) from the greater trochanter to the lateral malleolus were measured. The subjects completed tests under three conditions: gait at preferred speed, gait during simulated street crossing with regular time (7 s), and gait during simulated street crossing with reduced time (3 s). Street crossing with regular time was determined based on the pre-programmed pedestrian street signals (20 s to cross a four-lane street). Three familiarization trials were completed for each of the conditions, followed by another three recording trials under each gait condition. The order of gait condition testing was randomized. During the preferred gait speed condition, the participants were instructed to walk on the GAITRite® as they usually do during their daily activities [20]. During the simulated street crossing conditions, the participants were instructed to cross the walkway when the pedestrian light on the video indicated that it was safe to initiate crossing and to complete crossing before the countdown ended. We used a functional dual-task (a dual-task that commonly performed during the activities of daily living) including visual cues and the participants had to interpret those cues and adjust their gait accordingly.

2.4. Data analysis

The gait data was processed using the GAITRite® Software (Version 4.7.4, CIR Systems Inc). Ten steps were used in each gait condition in order to determine the gait parameters and to calculate their variability. We analyzed the following tempo-spatial gait parameters:

- Velocity (gait speed in cm/s calculated as distance covered divided by the ambulation time),
- Cadence (steps/min),
- Normalized step length (distance in cm between the heel center of one foot to the heel center of other foot during heel strike, divided by leg length and multiplied by 100),
- Base of support (the distances in cm between a line linking the center of one foot during two subsequent steps and the center of the opposite foot during mid stance),
- Step time (time from first contact of one foot to first contact of the opposite foot),
- Swing time (time from toe off to heel strike),
- Stance time (time from heel strike to toe off), and
- Double support time (time that both feet are on the floor simultaneously).

2.5. Statistical analysis

PASW 18.0 (SPSS Inc.) was used for all statistical analyses. Descriptive statistics were calculated and presented to describe the participants’ characteristics. The Shapiro–Wilk test results showed that the data were normally distributed. Therefore, two-way mixed measures ANOVA were used to compare the gait parameters between younger and older adults, and Bonferroni post hoc tests were used to compare among the conditions. The significance level for all statistical tests was set at p < 0.05.

3. Results

In general, there were significant differences between groups on all variables other than base of support, stance and double support time. There were significant differences among conditions on all variables except for base of support. Fig. 2 presents the gait velocity, step length, and cadence for the groups and conditions, and Fig. 3 presents step, stance, swing and double support times for the groups and conditions.

3.1. Comparison between groups

During gait at preferred speed, younger adults walked on average 24 cm/s faster (F = 21.5, p < 0.001), with 12% longer steps (F = 17.3, p < 0.001), 20% longer swing times (F = 6.4, p = 0.015) and 50 ms shorter double support times (F = 13.3, p < 0.001) than older adults. However, there were no significant differences between the groups in cadence, base of support, step or stance time.

During street crossing with regular time, older adults had higher cadence (mean difference = 11 steps, F = 15.4, p < 0.001) and shorter step time (mean difference = 50 ms faster, F = 17.9, p < 0.001), with 40 ms shorter swing time (F = 19.8, p < 0.001), and 60 ms shorter stance time (F = 12.3, p = 0.001) than...
young adults, but there were no significant differences between the groups in gait speed, double support time, step length or base of support.

During street crossing with reduced time, younger adults walked on average 11 cm/s faster ($F = 3.8$, $p = 0.048$) even though they had lower cadence (mean difference $= 9$ steps/minute, $F = 7.9$, $p = 0.007$) because they took 7% longer steps ($F = 4.3$, $p = 0.033$) with 40 ms longer swing periods ($F = 19.2$, $p = 0.001$) than older adults. However, there were no significant differences between the groups in base of support, stance or double support times.

3.2. Comparison between conditions

In general, there were no significant differences between walking at preferred speed and during regular time street crossing for the younger adults, while there were significant differences between walking at preferred speed and during street crossing with regular time for the older adults (Figs. 2 and 3).

For the younger adults, there were significant differences among the conditions in velocity ($F = 13.9$, $p < 0.001$), cadence ($F = 4.5$, $p = 0.014$), step length ($F = 10.1$, $p < 0.001$), step time ($F = 4.2$, $p = 0.019$), stance time ($F = 5.5$, $p = 0.006$), and double support time ($F = 8.9$, $p < 0.001$), but there were no significant differences in base of support or swing time. The post hoc analysis revealed that gait speed was on average more than 20 cm/s higher during street crossing with reduced time than during the other conditions ($p < 0.002$). There were no significant differences between preferred gait speed and speed during street crossing with regular time. The younger adults took eight more steps/min during street crossing with reduced time than when walking at preferred speed ($p = 0.012$). However, there were no significant differences in cadence when walking at preferred speed compared to street crossing with regular time. The younger adults’ step length was more than 9% longer during street crossing with reduced time than during the other conditions ($p < 0.003$). There were no significant differences in step length during preferred gait speed and during street crossing with regular time. Step and stance time were 30 ms and 60 ms shorter during street crossing with reduced time compared to when walking at preferred speed ($p = 0.018$ and 0.006), while double support time was more than 30 ms shorter during street crossing with reduced time than during the other two conditions ($p < 0.08$).

For the older adults, there were significant differences among the walking conditions in all variables other than base of support: velocity ($F = 28.9$, $p < 0.001$), cadence ($F = 15.4$, $p < 0.001$), step length ($F = 14$, $p < 0.001$), step time ($F = 21.3$, $p < 0.001$), swing time ($F = 4.6$, $p = 0.014$), stance time ($F = 29.8$, $p = 0.001$), and double support time ($F = 34.5$, $p < 0.001$). Gait speed was more than 34 cm/s higher during both street crossing conditions than when walking at preferred speed ($p < 0.001$). Older adults took at least 13 more and 13% longer steps during both street crossing conditions than when walking at preferred speed ($p < 0.001$). Step and stance time were 60 ms and 100 ms shorter and double support time was 70 ms longer during the street crossing conditions than when walking at preferred speed ($p < 0.001$), while swing time was 30 ms shorter during street crossing with reduced time compared to when walking at preferred speed ($p = 0.016$).

4. Discussion

Gait during simulated street crossing with regular and reduced time resulted in significant and progressive changes in temporospatial gait parameters. Younger adults’ cadence during preferred gait speed ($112 \pm 7$ steps/min) was similar to the findings of previous studies involving subjects 23–58 years old ($112 \pm 9$ steps/min) [21]. There were significant differences in step length between the groups and conditions. Step length and gait velocity were highest during street crossing with reduced time. To increase speed subjects increased step length and/or cadence.

There were no differences in gait speed between the groups during the regular time street crossing, but the older adults decreased step and swing time and increased cadence. Step length and width increased as step and swing time decreased for both groups, but in particular for the older adults. Other studies also found that older adults take smaller steps than younger adults [22]. The spatial gait compensations of healthy young and older adults for a faster gait were similar. However, older adults had shorter and more variable steps which indicate inconsistent stepping patterns, reduced postural control, and increased risk of falls [23].

During the street crossing conditions, there were age-related differences in speed, cadence, step length, step, swing and stance time. Street crossing is a dual-task because it results in motor–cognitive interference. Street crossing requires motor and cognitive skills; these skills decline with age [24]. The mechanisms that may lead to the observed differences include sarcopenia-related strength decline/reduced muscle mass, reduced balance, cognition, reduced nerve conduction velocity, agility and range of motion, changes on the visco-elasticity of connective tissues and on collagenous tissues [13–15,24]. Older adults may be at higher risk for falls during street crossing and in particular during street crossing with reduced time because they have to adopt walking speeds that are significantly higher than their preferred speeds by increased cadence. These characteristics may predispose older adults to tripping and falls, because they have less floor clearance than younger adults [25].

Simulated street crossing resulted in gait changes for both younger and older adults. This new method of gait testing was capable of inducing gait adaptations to accomplish the tasks. Our results demonstrate the feasibility and usefulness of the methods used. Some of the interesting findings with important implications include:

- Older adults walking speed during street crossing with regular time was higher than their preferred walking speed. Therefore, the time currently allowed to cross streets is too short even for healthy older adults.
- To match younger adults speed to cross streets, healthy older adults had to increase the number of steps they took. This can possibly expose them to greater risk for tripping and falls during street crossing.
- Older adults were not able to walk as fast as younger adults during the street crossing with reduced time. This may
predispose them to falls and/or accidents. Therefore, when countdown begins, older adults should wait for the next cycle before crossing.

Future studies may compare different populations using the methods and gait conditions presented. Such evaluations may help identify risks during road crossing situations, evaluate the effects of different interventions, and help reduce accidents. We evaluated simulated street crossing as opposed to actual street crossing situations. Field-testing could represent high risks to the participants, especially for the simulation of street crossing with reduced time. However, future studies using virtual-reality or other methods that could increase the realism of the situation could be beneficial.

In our study, the measures were derived from ten steps; increasing the number of steps could provide better estimates for the variability measures. Lindemann et al. recommended more than 40 steps to evaluate gait variability [26]. However, both groups followed the same procedures, so the comparisons between groups and among the conditions were not compromised by the small number of steps. Including additional steps would have required additional trials under each of the conditions and could result in participant fatigue. That been said, future studies with less conditions and different goals could include more steps in the analysis, especially if they use instrumented treadmills. When using instrumented treadmills, Owen and Grabiner recommended that at least 400 steps are needed for accurate estimation of the variability of gait temporo-spatial parameters [27].

![Fig. 2. Comparison of means (standard deviations) of gait velocity, step length, and cadence among gait conditions and between younger (n = 22) and older adults (n = 22).](image)

{ curly brackets indicates significant difference between younger and older adults within gait condition:  
  *p<0.05, **p<0.001.  
  ># indicates that for this group the mean for this condition is significantly higher than the mean for the condition numbered: *p<0.05, **p<0.001.  
}

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In conclusion, gait during simulated street crossing with regular and with reduced time resulted in significant and progressive changes in tempo-spatial gait parameters, especially for older adults. The methods developed and tested can be used to evaluate if people are at risk of falls and accidents during street crossing situations and the results may be used to establish appropriate times for pedestrians to cross streets more safely.

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Conflict of interest statement

None of the authors has financial or personal relationships with other people or organizations that could inappropriately influence (bias) the work presented in this article.

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