Physical Therapy and Rehabilitation
ISSN 2055-2386 | Volume 5 | Article 13

HOAJ
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Original Research Open Access

Effect of age on dynamic walking balance in a healthy population between the ages of 20 and 80 years

Marc Robertson[1*] and Robert Gregory[1†]

*Correspondence: robertsonm1@southernct.edu

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[†]This author Contributed equally to this work.
[1]Southern Connecticut State University, New Haven, Connecticut, USA.

Abstract

Background: Falls have been attributed to deterioration of dynamic walking balance. Accurate age-range determination of dynamic walking balance deterioration has yet to be elucidated. The purpose of this quasi-experimental study was to determine, by age/decade range, dynamic walking balance deterioration to provide a more accurate age range for interventional dynamic walking balance assessment and treatment.

Methods: Participant demographic data were collected [age (years), gender, height (cm), body mass (kg), and body mass index (BMI) ($kg \cdot m^{-2}$)] on one hundred fifteen individuals between the ages of 20 and 80 years. Participants then completed a modified version of Rubenstein and colleagues' Fall Risk Questionnaire (mFRQ) and performed two trials of the ten step tandem walk test eyes open (TSTWT EO). Participant TSTWT EO scores were averaged and recorded as number of tandem walking steps, maximum of ten, prior to loss of balance.

Results: A single factor ANOVA compared the effects of age, distributed per decade of life, on human dynamic walking balance. A statistically significant effect of age on TSTWT EO was found [$F(1, 228) = 509.5053$, $p=4.8E-60$]. Post hoc comparisons using two-sample t-tests indicated that the mean TSTWT EO score for the fourth decade of life group (30-39 years) ($M=9.15$, $SD \pm 0.65$) was significantly different from the fifth decade of life group (40-49 years) ($M=6.00$, $SD \pm 1.61$) ($p=1.65E-10$, $d=2.57$), after Bonferroni correction. No statistically significant difference between participants' capacity to successfully perform the TSTWT EO was found between the third and fourth life decades (20-29 and 30-39 years), fifth and sixth life decades (40-49 and 50-59 years), sixth and seventh life decades (50-59 and 60-69 years), nor seventh and eighth life decades (60-69 and 70-79).

Conclusion: A statistically significant difference was found in the dynamic walking capacity of participants ranging in age from 20 to 80 years. Statistically significant dynamic walking balance deterioration was shown to occur during the fifth decade of life compared to the fourth decade of life, which indicated that balance assessment and mediation be considered during an individual's fifth decade of life, between the ages of 40 to 49 years.

Keywords: Postural balance, dynamic balance, walking balance, falls, gait, tandem walk, tandem walk test, aging

Introduction

A common supposition has existed regarding dynamic walking balance deterioration and its association with falls which has inferred that these conditions inherently and exclusively reside within the elderly population, individuals 65 years and older [1]. Falls represent a significant personal and financial burden to the population of the United States (US) and throughout the world [1,2]. Individuals between the ages of 45-64 years in the US experienced 26.56 million falls compared with 17.05 million falls reported in individuals 65 years and older in 2013 [1]. However, elderly individuals sustained a greater number of falls and fall-related injuries predicated on a ratio of individuals with a history of falls and fall related injury to the total number of individuals in the 65 years and older age cohort compared with the 45-64 years age cohort [1]. An estimated 1 in 4 [2,3] to 1 in 3 [1] people over the age of 65 years fall each year in the US and those who fall are two to three times more likely to fall again within that same year [1]. Individuals 65 years and older experienced between 2.8 million [3] and 3.2 million [1] fall-related injuries in 2013. Despite medical advances and improved communicable and non-communicable disease outcomes in the US, an annual increase (4% in women and 5% in men) in the number of falls and fall-related injuries in the elderly population was reported between the years 2004 and 2013 [1]. Most falls in the elderly population occurred during locomotion in which extrinsic and/or intrinsic factors played a primary etiological role [4-7]. Extrinsic factors have been associated with environmental hazards such as slippery surfaces, unstable throw rugs, obstructions, sudden impact, or unexpected movement of the supporting surface [8]. Intrinsic factors have been associated with individual qualities such as dynamic balance, strength, flexibility, and medication usage [4]. Intrinsic factors have been identified as the primary etiological fall predictors in the elderly population [4]. Chu, Chi, & Chiu [9] reported the most prevalent age-associated intrinsic fall risk factors in the elderly population were; previous history of falls, very old age, arthritis of the knees, stroke, Parkinson's disease, postural hypotension, limitations in physical function, weak hand grip strength, motor weakness as per difficulty standing up from a chair, poor balance while standing, limited turning capacity, unstable change of position with walking, poor tandem gait capacity, gait impairment, cognitive impairment, depressive symptoms, poor vision, and the use of 4 or more prescription medications. There appeared to be little consensus in the available research identifying a primary etiological intrinsic factor regarding falls in the elderly population. Much of the available research focused on a single impairment or disability as the origin of falls related to intrinsic fall factors in the elderly population. The primary intrinsic impairments researched have been strength [10-16], gait anomalies [17-33], functional flexibility [4,5,34], neurologic/cognitive decline [35-38], proprioception [39], general balance [40-47], and individuals with a combination of the above impairments [48-51].

The majority of falls in the elderly occurred due to impairment of intrinsic factors, such as, loss of balance, strength, and flexibility [4], all encompassed under the term dynamic balance. Fall prevention programs have targeted restoration of dynamic balance in people 65 years old and older, with the majority of fall prevention programs aimed at elderly who had already experienced considerable balance deterioration and/or a previous fall [16]. Individualized rehabilitative interventions appeared to improve dynamic balance and functional walking capacity in fall prone elderly individuals, but detraining to pre-interventional levels was typical within three months post-treatment termination, attributed to low independent program compliance [16].

Deterioration of both static and dynamic balance occurred in both healthy young and elderly individuals [10,20,25,52-58] and between healthy young and middle-aged individuals [45,47,59] Fall incidence rates typically refer to individuals 65 years and older considering this segment of the population has experienced the greatest number of injurious and fatal falls, per capita [2]. When considering age-related fall statistics, one may assume that intrinsic impairments begin at, or after, the age of 65 years [6,7,42,60,61], although, static and dynamic balance deterioration has been shown in healthy individuals in their middle-age years, fourth through sixth life decades, when compared with young individuals [14,21,30,45,46,62-65].

An age-related decline in dynamic balance has been reported, with deterioration onset as late as the seventh [42] and as early as the fourth [45] decade of life. Fall prevention interventions have been efficacious but the benefits appeared fleeting. The literature suggested no consensus regarding the approximate age range when healthy individuals' dynamic walking balance initially demonstrated functional deterioration; the appropriate time for impairment mediation through skilled intervention. Accurate data regarding the age range, per decade, of dynamic walking balance deterioration could significantly help reduce the number of falls and fall related disability as individuals progress in age and enter into the elderly age cohort. Age-range identification of the initial deterioration in dynamic walking balance could lead the way for enhanced preventative balance screening, examination, and evaluation. The hypothesis that directed this study stated that the onset of age-related dynamic walking balance deterioration in healthy individuals occurred in decades prior to the seventh life decade, more specifically, prior to age 65. Therefore, the purpose of this study was to determine the age range of dynamic walking balance deterioration using the ten step tandem walk test eyes open (TSTWT EO) [66] to provide an appropriate age range for skilled, interventional dynamic walking balance assessment and treatment.

Methods

Participants

This cross-sectional study was conducted at Southern Connecticut State University (SCSU) in the greater New Haven County of Connecticut, USA and was approved by the Southern Connecticut State University Institutional Review Board (IRB #15-139). One hundred fifteen (115) healthy participants from New Haven County, Connecticut between the ages of 20 and 80 years were recruited for voluntary test participation. All participants were informed of the study procedure, purpose, known risks, and provided written informed consent prior to study participation.

Study participant inclusion criteria were: Participants had to be between the ages of 20–80 years, walk without an as-

doi: 10.7243/2055-2386-5-13

sistive device (cane, walker, crutches), no lower extremity or trunk surgeries within the past year, no acute illness or current traumatic injuries, no neurological conditions that could impact dynamic walking balance, no unstable health conditions, and each participant had to be able to independently walk for greater than or equal to four minutes continuously without help/assistance.

Procedures

1. Participants were explained the test purpose, methodology, and asked to sign the informed consent document.

Upon voluntary acceptance of study participation:

2. Participants completed a modified version of Rubenstein and colleagues' Fall Risk Questionnaire (mFRQ) prior to test protocol initiation [67].
3. Each participant wore a standard rehabilitative gait belt (Briggs Healthcare, Waukegan, IL) for the duration of the test session.
4. Participant demographic data were collected [age (years), gender, height (cm), body mass (kg), and body mass index (BMI) (kg•m^{-2})]. Height and weight (mass) were assessed using a medical scale (Detecto, Webb City, MO-USA).

Tandem walk test

A fifteen foot long, one inch wide piece of white training tape was placed along a level concrete floor approximately two feet away from and parallel with a structural wall. The participant was asked to walk forward along the taped line, placing one foot directly in front of the other, as per the heel of one foot directly in front and in contact with the toes of the contralateral foot. Each participant attempted two trials which included two sets each for TSTWT EO then TSTWT eyes closed (EC) per trial. Each participant was asked to tandem walk a maximum of ten steps at a comfortable pace with his/her arms folded across his/her chest without performing a test error which included forward progression stoppage, sidestepping, opening the eyes (if applicable), unfolding arms, not maintaining a parallel foot position with the taped line (when applicable), and/or requiring gait belt assistance to maintain an upright position. Test protocol was demonstrated by the tester prior to the participant's attempts. Maximum number of steps achieved before error was recorded. For example, a score of ten steps was recorded for participants who completed ten consecutive steps without loss of balance. A score of two would have been recorded for a participant who completed two consecutive tandem steps before loss of balance.

Statistical analysis

A single-factor analysis of variance (ANOVA) was calculated using IBM SPSS Statistics (version 21, IBM Corp. Armonk, New York, USA) to determine if a statistically significant difference existed between mean performance, distributed per participant age categorized by decade of life, on the TSTWT EO, denoting the third, fourth, fifth, sixth, seventh, and eighth life decades. Post-hoc comparisons were performed using two-sample t-tests with Bonferroni correction (Excel, Microsoft Office, 2016) to identify between decade statistically significant differences regarding TSTWT EO capacity.

Results

One hundred fifteen volunteers successfully completed the current test protocol. See Table 1 for participant characteristics.

A single-factor ANOVA compared the effects of age, distributed per decade, on participants' capacity to perform the TSTWT EO. Alpha was set at $p<0.05$, <0.003 with Bonferroni correction upon post hoc analysis. A statistically significant effect of mean per decade age in years on TSTWT EO balance loss was determined [$F(1,228)=509.5053$, $p=4.8E-60$] (see Figure 1). Post hoc comparisons using two-sample t-tests indicated that the mean TSTWT EO score for the fourth decade of life group (30-39 years) ($M=9.15$, $SD\pm0.65$) was significantly different from the fifth decade of life group (40-49 years) ($M=6.00$, $SD\pm1.61$) ($p=1.65E-10$, *d=2.57*), after Bonferroni correction, in the number of steps successfully completed regarding the TSTWT EO. No statistically significant difference between participants' capacity to successfully perform the TSTWT EO was found between the third and fourth life decades (20-29 and 30-39 years), fifth and sixth life decades (40-49 and 50-59

Table 1. Participant Characteristics.

Participant Characteristics						
	Male		Female		Male/Female Combined	
Decade (years)	Age	BMI	Age	BMI	Age	BMI
20-29	23 ± 2.9	25 ± 1.7	23 ± 2.9	23 ± 4.2	23 ± 2.4	24 ± 3.4
30-39	35 ± 2.0	28 ± 4.3	35 ± 3.1	22 ± 3.7	35 ± 2.4	25 ± 4.7
40-49	45 ± 2.3	25 ± 2.4	44 ± 2.1	24 ± 3.5	45 ± 2.1	25 ± 3.0
50-59	54 ± 1.9	27 ± 4.5	54 ± 3.3	26 ± 4.7	54 ± 2.7	26 ± 4.6
60-69	64 ± 3.2	26 ± 6.5	65 ± 3.7	26 ± 4.0	65 ± 3.3	26 ± 5.1
70-79	72 ± 2.8	25 ± 1.7	74 ± 3.0	23 ± 2.5	73 ± 2.9	24 ± 2.1
Age (years) BMI (kg•m^{-2}) presented as mean ± standard deviation						

years), sixth and seventh life decades (50-59 and 60-69 years), nor seventh and eighth life decades (60-69 and 70-79) (See **Figure 1**). Statistically significant mean TSTWT EO differences were noted between participants in their; third life decade (20-29 years) , (p=2.29E-10, p=6.08E-11, p=5.81E-12, p=4.20E-12) and the fifth, sixth, seventh, and eighth life decades respectively, between participants in their fourth life decade (30-39 years) (p=1.65E-10, p=8.39E-11, p=7.84E-13, and p=1.34E-13) and participants in their fifth, sixth, seventh, and eighth life decades, respectively, between participants in their fifth life decade (40-49 years) (p=2.29E-10, p=1.65E-10, p=0.001, and p=0.0003) and their third, fourth, seventh, and eighth life decades, respectively, between participants in their sixth life decade (50-59 years) (p=6.06E-11 and p=8.39E-11) and their third and fourth life decades, respectively, between participants in their seventh life decade (60-69 years) (p=5.81E12, p=7.84E-13, and p=0.001) and their third, fourth, and fifth life decades, respectively, and between participants in their eighth life decade (70-79 years) (p=4.20E-12, p=1.34E-13, and p=0.0003) and their third, fourth, and fifth life decades, respectively. See **Table 2** for the statistically significant per decade differences in mean TSTWT EO capacity.

Discussion

Falls represent a significant personal and financial burden across the US and throughout the world. Approximately 1 in 3 [1] people over the age of 65 years will experience a fall each year in the US. Individuals 65 years and older experienced between 2.8 million [3] and 3.2 million [1] fall-related injuries in 2013, primarily derived from impairment of intrinsic factors, such as impaired dynamic walking balance. Reported fall incidence rates increased annually by 4% in women and 5% in men [1] between the years 2004 and 2013 despite technological developments in balance assessment and treatment. The purpose of this study was to ascertain if a statistically significant per decade difference existed in dynamic walking balance in individuals between the ages of 20 and 80 years, and if so, in what decade of life did dynamic walking balance deterioration initially manifest. The results from the current study supported the hypothesis that age-related dynamic walking balance deterioration onset in healthy individuals occurred in decades prior to the seventh life decade, more

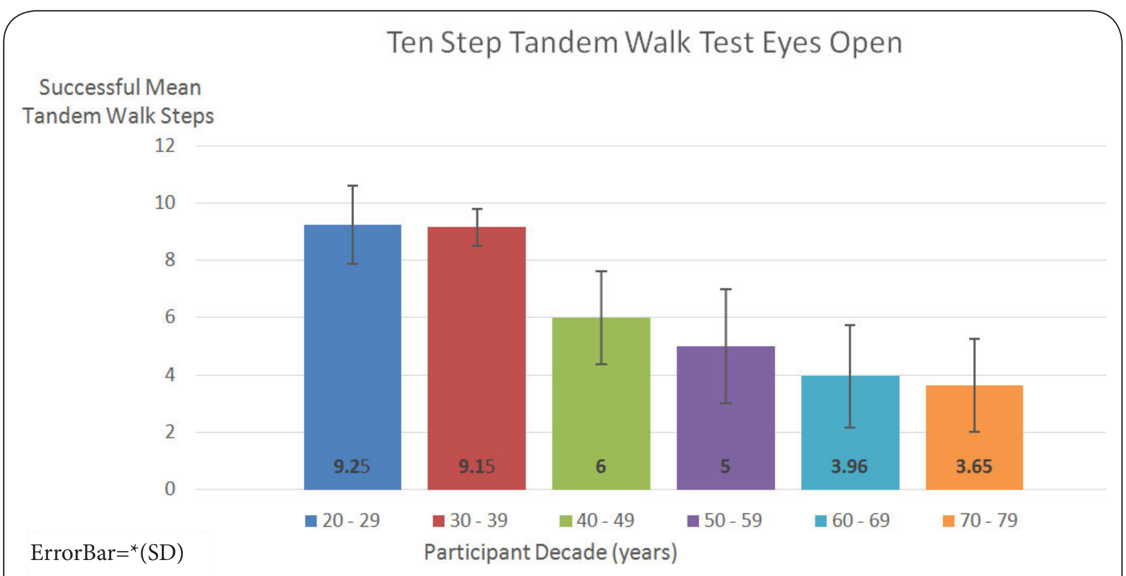

Figure 1. Participant TSTWT EO Successful Steps by Decade (Mean±SD*).

Table 2. Difference between Participants' TSTWT EO Mean Score.

Difference Between Per Decade TSTWT EO Mean Score						
Decade (years)	20-29	30-39	40-49	50-59	60-69	70-79
20-29		p=0.7654	p=2.29E-10	p=6.08E-11	p=5.81E-12	p=4.20E-12
30-39	p=0.7654		p=1.65E-10	p=8.39E-11	p=7.84E-13	p=1.34E-13
40-49	p=2.29E-10	p=1.65E-10		p=0.062	p=0.001	p=0.0003
50-59	p=6.08E-11	p=8.39E-11	p=0.062		p=0.147	p=0.074
60-69	p=5.81E-12	p=7.84E-13	p=0.001	p=0.147		p=0.680
70-79	p=4.20E-12	p=1.34E-13	p=0.0003	p=0.074	p=0.680	

Data presented as p-values   Level of significance p < .003

specifically, prior to age 65. Age-related dynamic walking balance, determined from performance on the TSTWT EO, was found to initially deteriorate most significantly (p=1.65E-10) between the fourth (30-39 years) and fifth (40-49 years) life decades. Several studies have investigated and reported on dynamic walking balance differences between young and elderly healthy individuals using the TWT [53,54,62]. Fregly et al. [53] found an age effect in the capacity of normal male participants between the ages of 16 and 60 years to successfully complete a version of the TWT, Walk Eyes Open, which consisted of three trials of tandem walking five steps, each trial on a ¾ inch wide rail, eight feet in length. Positional test criteria and evaluative assessment regarding test success was similar to the current study's test criteria. Fregly et al. [53] reported significant reduction in Tandem Walk Eyes Open capacity in participants between the age range of 30-40 years. Fregly et al. [53] assessed dynamic walking balance deterioration approximately a decade earlier than the results from the current study. Participants' base of support was narrowed to the width of their foot in the current study, where-as, Fregly et al's. Tandem Walk Eyes Open test protocol [53] narrowed the participants' base of support to less than the width of their foot, resulting in a greater challenge to dynamic walking balance. The reduced support surface may have explained the difference between study results, yet both studies were suggestive of dynamic walking balance deterioration well before the historical norm set during the seventh life decade. Gill et al. [62] assessed measures of sway with angular velocity transducers affixed to young (15-25 years), middle-aged (45-55 years), and elderly (65-75 years) participants' lumbar spines upon an 8-step tandem walk test. Variables assessed included roll (side to side) and pitch (anterior–posterior) angle and velocity [62]. A significant difference (p<0.05) was reported for both roll and pitch angle and velocity between elderly participants and both middle-aged and young participants [62]. Only pitch angle was reported to be statistically different (p<0.05) between young and middle-aged participants which indicated no significant reduction in medial-lateral stability between young and middle-aged participants [62]. Gill et al. [62] did not directly account for upper extremity posture or proximal trunk sway upon tandem walk testing. Conversely, Nitz et al. [45] reported a significant decline (p< 0.02) in medial-lateral stability in female participants in their fifth life decade upon clinical measures of postural stability. Choy et al. [65] reported a decline in postural stability initiated in the fifth life decade with progressive deterioration found in each consecutive decade.

Vereeck et al. [42] utilized a 20-step TWT with participants between the ages of 20.7 and 83.2 years to determine cross-sectional normative balance values. Vereeck et al. [42] observed participant failure at performance of the 20 step TWT beginning within the seventh life decade (60-69 years). All participants in the third through sixth life decade successfully completed all 20 TWT steps, which inferred a TWT ceiling effect up to age 60 years [42]. Dynamic walking balance assessment includes functional assessment parameters inclusive of lower extremities, pelvis, head, arms, and trunk (HAT) [42]. Vereeck et al. [42] assessed lower extremity, primarily foot placement, parameters as determinants of successful test criteria, with no account for HAT. The current study utilized trunk and upper extremity parameters as determinants of successful/unsuccessful test criteria which were more representative of dynamic walking balance capacity.

Relevant cross-sectional studies utilizing functional tests of dynamic balance, TWT not included, have yielded a conglomeration of results. Isles et al. [64] performed a cross-sectional study in women between the ages of 20-80 years which included Timed Up and Go (TUG), Step Test, and Functional/Lateral Reach Tests and reported a significant period of balance decline in women between the ages of 40-60 years with linear TUG and Step Test performance decline initiated in the fifth life decade. El Haber et al. [63] performed static and dynamic assessments of postural stability in 212 female participants between the ages of 21-82 years and suggested initiation of fall prevention programs between the ages of 40-55 years; both studies support the results of the current study. Era et al. [46] reported center of pressure stabilization differences between participants in their fourth, fifth, and sixth life decades, yet primarily noted after 60 years. Bohannon et al. [47] tested static balance using the timed single leg stance test in 184 male and female participants between the ages of 20 and 79 years. Maximal test duration was set at 30 seconds [47]. All participants in their third and fourth life decades successfully completed the test procedure with test failure onset demonstrated in participants in their fifth life decade [47], which corresponded with the results from the current study regarding initiation of balance deterioration.

Several factors may have limited the generalizability of the current study's results including urban/sub-urban participant population and a limited number of participants. Linear statistical analyses were performed to analyze data which could misrepresent trends in age-related cross-sectional studies [63]. Despite methodological controls built into this research design, a degree of subjectivity in regards to TSTWT LOB assignment may have influenced test results. Notwithstanding the reported clinical efficacy of the TSTWT EO as reported by Robertson & Gregory [66], careful consideration regarding clinical application of this study's findings should be applied to dynamic walking balance test selection and assessment as the participant population was limited to a healthy population and did not include a clinical population.

Future studies should investigate specific etiological kinematic/kinetic variables involved in age-related deterioration in dynamic walking balance as shown between individuals in their fourth and fifth life decades.

Conclusion

A statistically significant difference was found in the dynamic walking capacity of participants ranging in age from 20 to 80 years, assessed using the TSTWT EO. Statistically significant dynamic walking balance deterioration was shown to occur during the fifth decade of life compared to the fourth decade of life, indicating that balance assessment and intervention be considered during an individual's fifth decade of life, between the ages of 40 to 49 years.

List of Abbreviations

ANOVA: Analysis of Variance
BMI: Body mass index
cm: centimeters
COM: Center of mass
d: Cohen's d
HAT: Head, arms, and trunk
IRB: Institutional Review Board
Kg: Kilogram
M: Mean
mFRQ: Modified Fall Risk Questionnaire
SCSU: Southern Connecticut State University
SD: Standard deviation
TUG: Timed-up-and-go
TWT: Tandem walk test
TSTWT EC: Ten step tandem walk test eyes closed
TSTWT EO: Ten step tandem walk test eyes open
US: United States
USA: United States of America

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Authors' contributions	MR	RG
Research concept and design	✓	✓
Collection and/or assembly of data	✓	--
Data analysis and interpretation	✓	✓
Writing the article	✓	--
Critical revision of the article	✓	--
Final approval of article	✓	✓
Statistical analysis	✓	--

Acknowledgements

The authors would like to thank Dr. Robert Axtell for his advisory and editorial contribution to this project.

Publication history

Editor: Gordon John Alderink, Grand Valley State University, USA.
Received: 20-Jun-2018 Final Revised: 03-Aug-2018
Accepted: 09-Aug-2018 Published: 28-Aug-2018

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Citation:
Robertson M and Gregory R. **Effect of age on dynamic walking balance in a healthy population between the ages of 20 and 80 years**. *Phys Ther Rehabil*. 2018; **5**:13.
http://dx.doi.org/10.7243/2055-2386-5-13