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Original Research Article

The Relationship between Gait Kinetics and Normalized Gait Kinematics

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Abstract

Purpose: Falls in the elderly are a significant problem threatening the emotional, financial and physical well-being of older adults. As intrinsic risk factors have gained traction as significant contributors to increased falls risk, one problem with parameters such as biomechanical variables is that they are difficult to compare across individuals in raw form. To combat this issue, it may benefit researchers to focus on how scaled biomechanical variables in an effort to increase comparison capabilities. The purpose of this study was to correlate selected gait kinetics with the normalized gait kinematic measure of stride length to leg length ratio. **Methods:** Data collection sessions were conducted separately across 36 areas in the United States, producing an initial pool of 850 subjects. Subjects first completed a non-extensive medical history form that included a history of past falls then lengths of the right and left legs of each subject were measured to the nearest 0.01cm and recorded. Lastly, gait data were collected by The Electronic Caregiver Co. (ECG), Mobile Fall-Risk Assessment Unit from a pressure sensitive walkway (Tekscan, Boston, MA.) where each subject walked across at their own pace. After trials, all data was converted to digital format in a deidentification process by the Electronic Caregiver® Mobile Falls Risk Assessment Laboratory team then sent to New Mexico State University Laboratorio de Biomechanica (NMSU-LdB) for subsequent analysis. **Results:** Impulse, maximum force, and peak pressure with regards to standard deviation showed to be only slightly varied (≤1 difference) while the other variables had a greater difference in standard deviation when comparing the right and left leg. There was greater overall deviation in the right leg than left excluding max peak pressure which shows a minimal of 3.2% greater in the left leg than the right leg. All variables were correlated to stride length to leg length ratio, but the normalized variables had a stronger correlation ($p < 0.01$) than the non-normalized variables on both the right and left sides. **Conclusion:** These data indicate there are significant correlations between right and left leg maximum resultant ground force reaction, maximum peak pressure and impulse and stride length to leg length ratio. These relationships may provide a possible normalization factor allowing gait characteristics to be compared across individuals of different builds.

Key Words: walking, fall-risk, biomechanics, correlation

Introduction

Falls in the elderly are a significant problem that threatens the emotional, financial and physical well-being of older adults. The emotional impact of falling has been shown to include feelings of fragility, loss of control and helplessness and approximately 25% of older adults have been shown to express a fear of falling related primarily to their emotional status[1-2]. With regard to financial implications the CDC reports that the average hospitalization costs per fall in 2002 was $34,294[3]. Although Medicare covers approximately 78% of the cost of falls this potentially leaves individuals who have been hospitalized due to falls with a related cost in excess of $7500[3]. It should also be noted that as age increases, the cost associated with the treatment falls increases potentially leaving aged individuals at an increased financial risk as they become less financially stable in the latter portion of their lives[3]. In regards to physical impact, over 700,000 patients a year are hospitalized because of a fall injury[4]. Additionally, reports indicate 68.1% of fallers experience physical injuries with 5.9% being major injuries[5] such as traumatic brain injuries, hip fractures and broken bones[3,6].

The prevalence and consequences of falls has led to research identifying numerous risk factors associated with falling[7-19]. These risk factors are typically classified as extrinsic or intrinsic. Extrinsic factors often include environmental and polypharmaceutical variables. These variables contribute to increased fall risk due to factors such as walking on uneven surfaces or tripping[20] and actions occurring within the household during activities of daily living[21]. Additionally, falls risk increases significantly with the number of drugs used per day[23]. Although extrinsic factors play a significant role in increased falls risk, they are many times difficult to address. However, intrinsic factors, which include biomechanical and/or physiological variables, are sometimes alterable through the use of training and intervention strategies. The study of these intrinsic variables has also shown their impact on fall risk. A recent meta-analytic study of 16 studies investigating risk factors associated with falling identified biomechanical variables as three of the top four risk factors having the greatest influence on falls risk ratio[23] with the majority of falls occurred during whole body movements[8, 24-25]. Although there has been significant research on those factors associated with falling in the elderly, there appears to be little to no decline in the rate of falls. Thus it is imperative that research into this problem continue.

To date, there have been few studies that have attempted to examine kinematic gait variables nomralized to specific individuals. Although gait analyses have increased our understanding of the problem, the applicability of these findings across large sections of the population continues to evade researchers in this field. While we ubderstand the relationship between what has been measured and overall functionality, without scaled gait kinematics comparison across individuals remains difficult. Because of these factors, we feel it may benefit to focus on how biomechanical variables correlate to normalized gait kinematics. Thus, the purpose of this study was to correlate selected gait kinetics with the normalized gait kinematic measure of stride length to leg length ratio. It was hypothesized that peak pressure, impulse and ground reaction will be positively correlated to stride length to leg length ratio.

Methods

Participants

Data collection sessions were conducted separately across 36 areas in the United States, producing an initial pool of 850 subjects. Subjects that had blindness, displayed inability to walk for 30 seconds, or could not complete the participation waiver were excluded from participation. Prior to the test trials for data collection, all subjects were informed of the potential risks and benefits of their participation in the study and were allowed to ask any questions. Following the question and answer period, all subjects consenting to participate in the study provided written consent. These processes resulted in a loss of 12.5% of the initial subject pool with a total of 742 subjects (age: 71.4±8.2yrs, height: 158.9±21.6cm, mass: 59.1±8.7kg) ultimately participating in the study.

Procedures

The Electronic Caregiver® Mobile Falls Risk Assessment Laboratory team collected all consent forms voluntarily signed by all subjects to participate in test trials. Subject testing consisted of three stages. First, subjects completed a non-extensive medical history form that included a history of past falls. Second, the lengths of the right and left legs of each subject were measured to the nearest 0.01cm and recorded. Lastly, gait data were collected by The Electronic Caregiver Co. (ECG), Mobile Fall-Risk Assessment Unit from a pressure sensitive walkway (Tekscan, Boston, MA.). For this last stage, the data collection procedures were demonstrated for each participant before they walked down the walkway. For the data collection pass, all walking pace characteristics were self-selected by the participant and data describing gait biomechanics were collected at 100Hz. Following the completion of testing trials, all data converted to digital format in a process where subject identification was extracted and replaced with a unique identifier in order to maintain confidentiality on all subject data (i.e. medical history, gait trial data, and leg lengths).

Following the de-identification of the data by the Electronic Caregiver® Mobile Falls Risk Assessment Laboratory team and the provision of a unique identifier, the de-identified data were digitally transmitted to the New Mexico State University Laboratorio de Biomechanica (NMSU-LdB) for subsequent analysis. Prior to any analysis by the NMSU-LdB, a request for secondary data analysis was submitted to and approved by the NMSU Institutional Review Board.

Statistical analyses

All gait kinetics and kinematics were initially analyzed to assess measures of stability (central tendency) and instability (variability) within the distribution. Once it was observed that the distributional characteristics were such that the model assumptions associated with subsequent analyses would be met, bivariate correlation analyses were carried out to determine the strength of the relationship between the scaled stride length to leg length variable and standard kinetic variables (i.e. impulse, ground reaction force and peak pressure). For all correlation analyses, the scaled stride length variable was the dependent variable and the gait kinetic parameters were the dependent variables. Due to the fact that multiple correlation analyses were run with sets of three independent kinetic parameters, the initial alpha level was set at $\alpha = 0.05$ and then corrected using the Bonferroni correction technique. This resulted in the final alpha level associated with the correlation analyses being set at $\alpha = 0.016$ for the determination of significance. With regard to statistical power, a prior estimation of sample size indicted that with alpha set at $\alpha = 0.016$ due to the Bonferroni correction, $1\text{-}\beta$ set at 0.80 as is deemed the standard in inferential analyses and $r = 0.113$ for the observation of a weak relationship between variables, the necessary sample size for returning a significant result was estimated to be $n = 695$.

Results

The results of distributional assessments indicated that the scaled gait kinematic of stride length to leg length ratio was fairly stable, exhibited symmetry and were approximately normally distributed across both the right and left sides of the body. With regard to kinetic variables assessed, the non-normalized version of the variables returned similar results to those observed for stride length to leg length ratio. However, the normalized versions of these kinetic variables demonstrated a distinct lack of symmetry and were observed to be significantly leptokurtic (peaked). These results are displayed in Table 1. Additionally due to the symmetrical nature of gait, it was necessary to examine the symmetry of the data collected for the right and left sides. Examination of the central tendency measures for each side of the body indicated each variable was similar for the right and left bodily sides with differences in mean values ranging between less than 1% and 4%, indicating fairly symmetrical gait across the sample.

Results of the correlation analyses are displayed in Table 2. These analyses indicated that all kinetic variables were significantly correlated to the scaled stride length to leg length variable for both the right and left sides. The direction of the relationship between the variables was the same for both sides of the body with impulse (both raw and scaled form) being inversely related to stride length to leg length ratio and both maximum force and maximum peak pressure (in raw and scaled form) being directly related to stride length to leg length ratio.

Table 1. Normalized version of kinetic variables.

Variable	Mean (±SD)	Min	Max	Skew	Kurtosis
Right					
Maximum Force (%BW)	118.84±41.55	53.70	634.20	8.01	83.10
Maximum Force (KG*sec)	86.76±23.51	30.04	209.04	.90	2.37
Impulse (%BW*sec)	72.21±28.95	34.80	402.10	6.28	56.78
Impulse (KG*sec)	53.14±19.19	20.26	143.95	1.48	3.67
Maximum Peak Pressure (KPA)	422.90±96.87	129	657	-0.31	-0.04
Left					
Maximum Force (%BW)	115.86±40.59	42.80	627.30	7.880	84.51
Maximum Force (KG*sec)	84.39±22.47	20.68	187.80	0.66	1.48
Impulse (%BW*sec)	69.68±25.67	24	338.30	5.13	40.69
Impulse (KG*sec)	51.22±17.83	13.57	136.62	1.33	3.36
Maximum Peak Pressure (KPA)	421.05±99.98	127	648	-0.22	-0.14

Table 2. Correlation data of the subjects.

Conditions	**Maximum Force (BW*sec)**	**Maximum Force (KG)**	**Impulse (%BW*sec)**	**Impulse (KG*sec)**	**Maximum Peak Pressure (KPA)**
SLLL Ratio R	.133	.126	-.163	-.176	.337
	.000	.001	.000	.000	.000
	699	700	699	700	700
SLLL Ratio L	.153	.184	-.129	-.130	.353
	.000	.000	.001	.001	.000
	673	675	673	675	675

Discussion

Descriptive and distributional assessments throughout this study demonstrated that both the gait kinematics and gait kinetics of those subjects included in the sample were symmetrical. These findings indicate that the sample included in this analysis is representative of the typical sample presented in gait analysis research. However, it should be discussed that the distributional characteristics of the kinetic variables analyzed in this study were observed to be dramatically different based on the application of normalization techniques. Although the normalized kinetic data demonstrated high magnitudes of skewness and kurtosis with regard to the distribution of data, the Pearson Product Moment Correlation coefficient has been shown to be remarkably robust and retain power even when model assumption violations with regard to distributional assessments are violated[26]. Thus the potential violations associated with the distributional characteristics of the normalized gait kinetic variables should not be interpreted as having a significant impact on the findings. This is further supported by the fact that the direction of the relationship was not altered with normalization and the magnitude of the relationship was not altered significantly (normalization explained only 0.18% more variability in the normalized gait kinematic for maximum force and only 0.44% less variability in the normalized gait kinematic for impulse).

With regard to maximum force all descriptive data were slightly greater in the right leg than the left leg and a greater correlation was observed for the right side of the body. The positive correlation between maximum force and stride length to leg length ratio on both sides of the body is an indicator that increased maximum force may correspond to an increase in stride length to leg length ratio. This finding is not surprising because anterior/posterior ground reaction forces regulate linear gait velocities[27]. Because gait velocity is a function of stride and/or step length and cadence, increases in force in the anterior direction should result in increased stride length to leg length ratio if cadence remains consistent. Additionally, because linear gait velocity is so strongly related to fall risk in the elderly, this finding may provide clinical applications for decreasing fall risk in those individuals over the age of 65 years. Many times those patients presenting with decreased gait velocity, cadence and step or stride length also present with an increased fear of falling[28]. This fear of falling may result in clinicians working with aged individuals experiencing difficulty in their attempts to alter gait parameters associated with risk of falls. However, the finding this work may provide clinicians the ability to focus on working with patients to increase maximum force in the anterior direction in an effort to increase stride length to leg length ratio. This may remove the focus from those gait variables shown to be associated with fear in aged individuals (cadence and stride or step length) while still eliciting positive changes in gait that reduce the risk associated with falling.

With regard to impulse all descriptive data was slightly greater in the right leg than the left leg along with a greater correlation in the right leg. The negative correlation between impulse and stride length to leg length ratio indicates that decreased impulse corresponds to an increase in stride length to leg length ratio. This finding is not surprising if impulse is examined from a momentum perspective; it seems that decreases in the change in momentum of the system (change in impulse) correspond to increases in stride length to leg length ratio. As with maximum force, it is understood that linear gait speed is regulated by anterior/posterior impulses[27]. Additionally from walking speeds between 1.0m/s and 2.0m/s increased impulse is observed while walking speeds between 2.0m/s and 3.0m/s decreased impulse is observed. Again, as cadence remains constant, increased linear gait velocity may be a function of increased stride/step length. For those individuals over the age of 65 years, decelerating and accelerating when walking is seen frequently from constantly trying to maintain their stability throughout gait. An individual who has a constant mass and cadence (velocity) could potentially alter their momentum to a point where constant speed throughout the gait cycle is exhibited, resulting in a greater stride length to leg length ratio. As a clinician, working on achieving a constant speed in gait, assuming cadence is constant, could result in the individual feeling a greater stability throughout rather than their previously feeling of constant instability. Once an elderly individual no longer focuses on the accelerating or decelerating of their gait, but rather focus on constant momentum then their risk for falling decreases.

With regard to maximum peak pressure all descriptive data was slightly greater in the right leg than the left leg and a larger correlation coefficient was also observed for the right leg. The positive correlation between maximum peak pressure and stride length to leg length ratio is an indicator that increased maximum peak pressure could potentially correspond to an increased stride length to leg length ratio. Again, this finding is not surprising, particularly given the relationship between maximum force and pressure (force per unit area). As force increases as it did in the current study, the overall area of the foot remains constant. Although it must be assumed that the contact area associated with foot strike in gait remain constant, if this occurs any increase in maximum force would result in an increase in peak pressure. Thus, it may be that the increased peak pressure observed in this study is more a function of the observed increase in maximum force that was also observed. Therefore, it may benefit clinicians to focus more on maximum force generation than peak pressure when working with aged individuals in an effort to alter stride length to leg length ratio.

Conclusion

Due to the incidence of falls in older individuals and the negative effects of these adverse events, the need for additional information describing gait characteristics of aged individuals is massive. The results of this study indicated that kinetic variables (in both scaled and raw form) were correlated to the scaled gait kinematic parameter of stride length to leg length ratio. This finding is important in that the scaling of stride length to leg length may potentially allow for intra-subject comparisons of gait kinematics in a manner that has yet to be accomplished.

Although the findings of this study may be applicable to many individuals, the next step would be to determine whether causal relationships exist. These future investigations would provide a starting point for impacting an extremely negative, yet common occurrence in aged individuals. These investigations should use an approach that allows for inter-subject comparison rather than an approach making attempts to only generalize to an aged population.

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