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**CHANGES IN SPATIOTEMPORAL DIFFERENCES BETWEEN THE SEXES DUE TO
PAIRED WALKING**

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14. ABSTRACT As social beings, much of our everyday lives are spent in interaction with others, yet the vast majority of gait studies examine solo walking without any distraction. It is largely unknown how walking in a dyad, both with and without talking, affects gait speed, cadence, and step length of adults; however, these same metrics dictate design parameters for widely varying fields from rehabilitation goals and ergonomic environments to animation models and surveillance objectives. This study examined the differences in spatiotemporal metrics between solo and paired walking for same- and opposite-sex pairs while using talking as a method of distraction. Results from 12 female-female (F-F), 10 female-male (F-M), and 12 male-male (M-M) pairs were analyzed. Significant changes from solo walking were only found with opposite-sex pairs ($p < 0.05$), with women (F-M/female) increasing speed and men (F-M/male) decreasing speed. Unlike solo walking, changes in speed during paired walking were driven by alterations to step length with very minimal change in cadence. When subjects were directed to talk while walking, both solo and as a pair, gait speed decreased significantly by 4-5%. Because significant changes were observed in paired versus solo walking, both with and without distraction, there may be reason to reevaluate and develop environment-specific rehabilitation goals and normative metrics					
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1.0 INTRODUCTION

Female and male gait appear different even to the untrained eye. Many studies in psychology, sociology, and biomechanics have shown that, with limited information, observers are able to accurately differentiate between and identify the sexes during gait [1-5]. These studies have shown that sex is perceived not only through contextual clues such as clothing, hairstyle, or accompanying accessories, but substantially through spatiotemporal and kinematic differences. Today there are numerous applications where understanding sex differences during motion is important. For example, differences in joint ranges of motion between sexes have long been implicated in the etiology of many impairments and pathologies [6, 7]. Rehabilitation, ergonomic environments, clothing design, and shoe construction have all been tailored based on known differences in the way that men and women move [8-11]. Other fields, such as animation and surveillance [12-15], also have a vested interest in this topic.

One limitation in applying many of the above cited studies to their associated applications is that these studies primarily examined walking in solo conditions under laboratory constraints. Arguably, a large part of each day is spent in interaction with others and with myriad distractions, rather than individually in an isolated environment. In a laboratory setting subjects are generally instructed to walk "naturally," yet awareness of observation by itself may actually create unnatural movements. Field studies have been done to observe people unaware [16, 17], but studying particular aspects of gait are difficult without controls. In pediatric populations, distraction techniques are often used to shift focus away from observation and achieve a more natural walking pattern. The same techniques may also be useful in adult populations.

The purpose of this study was to examine how walking as a pair and with distraction affect spatiotemporal gait parameters. We also sought to determine whether men and women responded differently to these influences. To accomplish this, subjects walked both alone and in a pair with another subject of either the same or opposite sex. Talking was used as a distraction in both conditions. We hypothesized that the same-sex pairs would see an increase in speed over solo conditions, with talking further increasing speed.

2.0 METHODS

2.1 Subjects and Protocol

Subjects between 18 and 59 years old were recruited in pairs in order to ensure consistency and establish that dyads were not composed of strangers. Relationship of subjects within a pair was recorded. All subjects signed informed consent forms approved by the Institutional Review Board at the Air Force Research Labs at Wright-Patterson Air Force Base.

A set of 80 retro-reflective markers were placed on the body as part of a larger study, but only heel and toe (hallux) markers were used to calculate the spatiotemporal results examined herein. Throughout the collection, subjects wore their own shoes. Shoes were required to be low-heeled and allow for free, comfortable movement. During the motion trials, marker positions were captured at 120 Hz using 16 Motion Analysis Raptor 12 cameras (Motion Analysis Corp, Santa Rosa, CA).

Subjects were first asked to walk in the solo condition at a comfortable (i.e. self-selected) speed across a 15 m walkway. Four continuous trials were recorded, with the turn-arounds at the end of the walkway edited out in post-processing. The order of distraction trials (no talking or talking) were randomized. During the solo, talking trials, subjects either talked aloud about a pre-determined topic, or were prompted during the trial by the study leaders.

After both subjects had completed solo trials, the pair walked together. Four continuous trials were recorded both not talking and talking, with the pair instructed to carry on a balanced 2-way conversation for the latter. Talk/no talk trial order was again randomized.

2.2 Data Processing

Marker trajectories were processed using Visual3D software (C-Motion Inc., Germantown, MD). All files were filtered with a low pass Butterworth Filter at a 6 Hz cutoff frequency. Heel strikes were calculated using a variation of the method presented by Ghousayni et al. [18], and toe-off events were calculated according to Zeni et al. [19]. Spatiotemporal metrics were assessed based upon these gait events.

Solo data were examined through mixed-model analyses of variance performed using level of distraction (no talk/talk) as a within factor and sex as a between factor. This analysis was completed for gait speed, cadence, and step length on both raw and dimensionless values. Data were made dimensionless using the method described by Hof [20] with height used as the measure of length.

Paired conditions were initially examined through analysis of paired gait speed. Again, a mixed-model analysis of variance was performed with speed the dependent variable using level of distraction as a within factor and pair type as a between factor. Post-hoc paired comparisons of pair type were completed using two-tailed t-tests with pooled error.

A final analysis examined the changes from solo to paired walking. Because mean patterns and paired comparisons were very similar for raw and dimensionless measures, only raw values are presented. The data were treated as from four pair types: female-female pairs (F-F), female-male pairs with a female subject (F-M/female), female-male pairs with a male subject (F-M/male), and male-male pairs (M-M). For each pair type, level of distraction was tested using a two-tailed, paired t-test. No significant differences were observed, so all remaining comparisons of pair type were completed using an average across level of distraction (no talk/talk) for each subject. Two-tailed t-tests were used to determine whether there was significant change from solo walking for each of the four pair types. The differences between pair types were then

evaluated using two-tailed, two-sample t-tests. All comparisons were deemed significant at the $p < 0.05$ level.

3.0 RESULTS

Seventy-eight subjects were recruited. These subjects comprised 13 female-female (F-F) pairs, 13 female-male (F-M) pairs, and 13 male-male (M-M) pairs. The subject pool comprised both military and civilian personnel.

Subjects were excluded due to high BMI (4 subjects, 2 pairs), excessively high or low speeds (4 subjects, 2 pairs), and situational concerns (2 subjects, 1 pair). Sixty-eight subjects which comprised 12 F-F pairs, 10 F-M pairs, and 12 M-M pairs were evaluated in all subsequent analyses. Female ages ranged from 18 to 50 years old. Male ages ranged from 19 to 52 years old.

3.1 Solo Walking

All F-tests had (1, 66) degrees of freedom. Distraction and sex did not significantly interact for any analysis ($p > 0.4398$) (Figure 1).

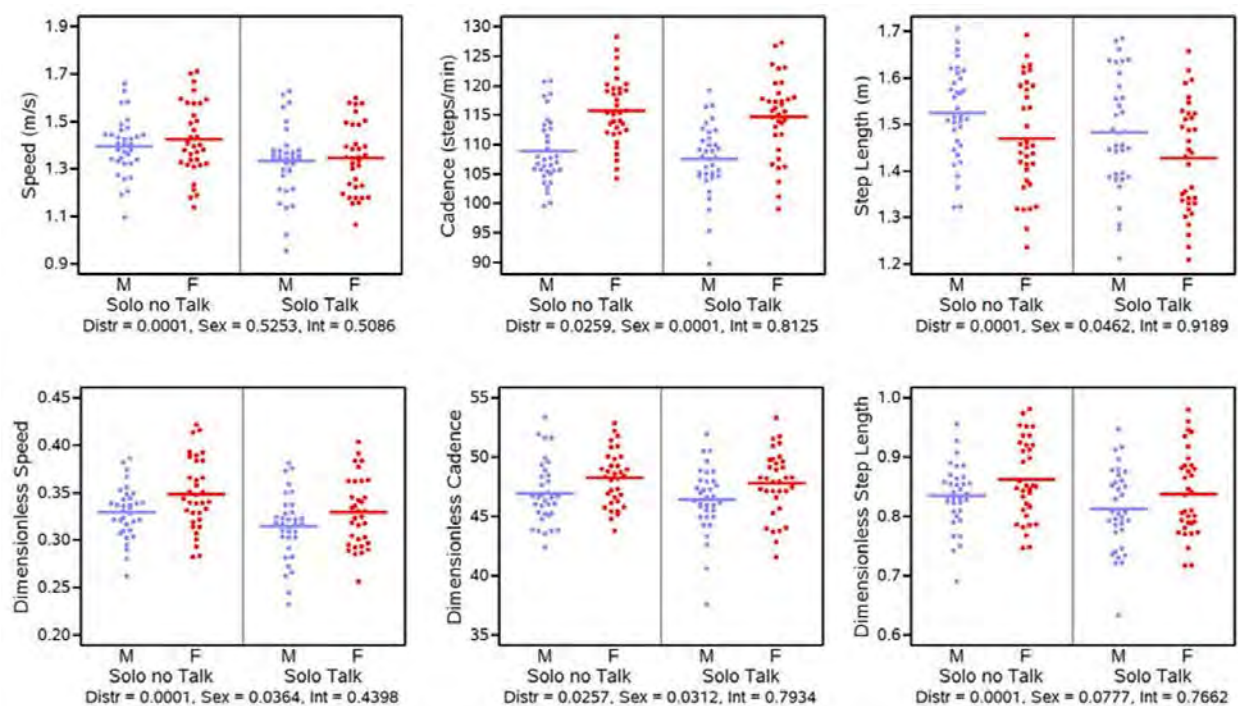


Figure 1: Raw and dimensionless data for solo walking trials at both levels of distraction (Distr) Each dot represents one subject. Horizontal lines indicate means by sex and level of distraction. Red marks (dark if viewing in grayscale) represent female subjects, and blue marks (light if viewing in grayscale) represent male subjects).

The talking trials decreased all metrics. Compared to no talking, means when talking were 5.1% less for raw speed ($p = 0.0001$) and 5.0% less for dimensionless speed ($p = 0.0001$), 1.0% less for raw cadence ($p = 0.0259$) and 1.0% less for dimensionless cadence ($p = 0.0257$),

and 2.8% less for raw step length ($p = 0.0001$) and 2.8% less for dimensionless step length ($p = 0.0001$) (**Error! Reference source not found.**).

Table 1: Results of mixed-model analysis of variance for solo walking

Distraction, no talk/talk, (Distr) was a within factor and sex was a between factor.

							Main Effect Means						
Dependent Variable	Distraction		Sex		Distr*Sex		Females		Males		Cohen's d	NT Mean	T Mean
	F	p	F	Mean	SEM	p	Mean	SEM	Mean	SEM			
Raw Speed (m/s)	41.35	0.0001	0.41	1.385	0.025	0.5086	1.385	0.025	1.364	0.022	0.16	1.411	1.339
Dimensionless Speed	42.18	0.0001	4.56	0.339	0.006	0.4398	0.339	0.006	0.322	0.005	0.53	0.339	0.322
Raw Cadence (steps/min)	5.19	0.0259	26.42	115.28	1.01	0.8125	115.28	1.01	108.22	0.93	1.27	112.34	111.17
Dimensionless Cadence	5.21	0.0257	4.85	48.02	0.41	0.7934	48.02	0.41	46.70	0.44	0.54	47.61	47.11
Raw Step Length (m)	33.27	0.0001	4.13	1.449	0.020	0.9189	1.449	0.020	1.503	0.018	0.50	1.497	1.455
Dimensionless Step Length	34.22	0.0001	3.21	0.851	0.012	0.7662	0.851	0.012	0.823	0.010	0.44	0.849	0.825

When compared to male results, means for females were 1.5% greater for raw speed ($p = 0.5253$) and 5.3% greater for dimensionless speed ($p = 0.0364$), 6.5% greater for raw cadence ($p = 0.0001$) and 2.8% greater for dimensionless cadence ($p = 0.0312$), and 3.6% less for raw step length ($p = 0.0462$) and 3.4% greater for dimensionless step length (0.0777).

3.2 Paired Walking – Gait speed

Mean speed for the F-F pair type was 7.5% greater than the M-M pair type ($p = 0.0322$) and 10.9% greater than the F-M pair type ($p = 0.0055$) (Figure 2). The gait speed of the F-M and M-M pair types were similar ($p = 0.4043$). Mean gait speed when talking was 4.0% less than during no talking trials ($p = 0.0001$). There was not a significant distraction level * pair type interaction ($p = 0.0610$) (**Error! Reference source not found.**). However, the near significance is likely due in part to an increase in speed difference between F-F and the other two pair types during the no talking trials.

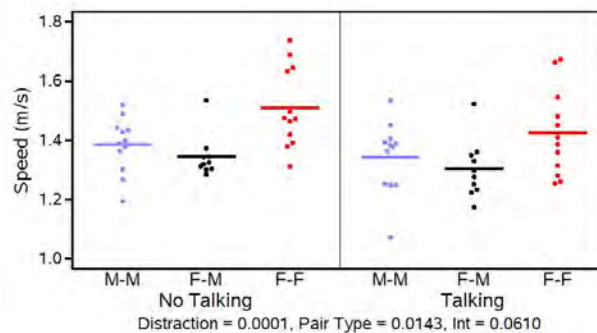


Figure 2: Gait speed for paired walking by pair type and distraction level

Each dot represents one pair. Horizontal lines indicate means by sex and level of distraction. Red marks (dark if viewing in grayscale) represent female subjects, and blue marks (light if viewing in grayscale) represent male subjects).

Table 2: Gait speed comparisons by pair type

P-value for pooled t-test. Main effect means for distraction: no talk = 1.414, talk = 1.357

		Level 1		Level 2		Pooled t-test p	Cohen's d
Level 1	Level 2	Mean	SEM	Mean	SEM		
M-M	F-M	1.365	0.030	1.324	0.026	0.4043	0.45
M-M	F-F	1.365	0.030	1.468	0.040	0.0322	0.88
F-M	F-F	1.324	0.026	1.468	0.040	0.0055	1.29

3.3 Paired Walking - Comparison to solo walking

The same-sex pair types (F-F and M-M) show no significant changes from solo to paired walking during analysis of speed, cadence, or step length. Likewise, cadence in the opposite sex pair types (F-M/female and F-M/male) showed almost no mean change from solo to paired (Figure 3). However, females in opposite sex pairs (F-M/female) increased their step length by 3.2% ($p = 0.0123$) and their speed by 5.0% ($p = 0.0246$) while males in opposite sex pairs (F-M/male) decreased their step length 4.6% ($p = 0.0201$) and their speed by 7.3% ($p = 0.0172$). The differences between F-M/female and F-M/male were significant for both speed ($p = 0.0010$) and step length ($p = 0.0009$). No other significant differences were found between pair types.

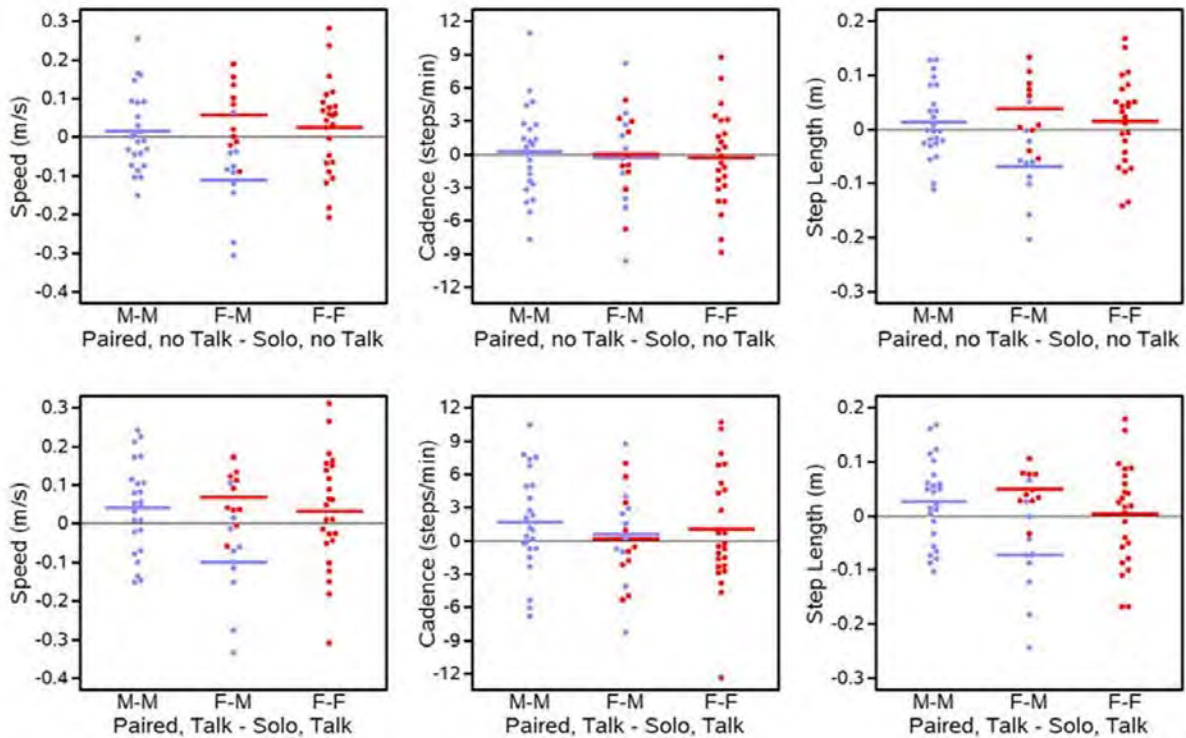


Figure 3: Paired walking as compared to solo walking for gait speed, cadence, and step length for both levels of distraction

Each dot represents one pair. Horizontal lines indicate means by sex and level of distraction. Red marks (dark if viewing in grayscale) represent female subjects, and blue marks (light if viewing in grayscale) represent male subjects).

4.0 DISCUSSION

This study examined the gendered differences in the ways that spatiotemporal metrics were altered by a distraction (talking) and a social interaction (paired walking). By studying both solo and paired trials of the same subject, this study was able to describe how pair type - same or opposite sex pairing - as well as distraction level - no talking or talking - affect gait speed, cadence, and step length. In opposition to our hypothesis, significant changes in gait speed from solo walking were only found with opposite sex pairs. Against our hypothesis once again, levels of distraction were not shown to cause significant changes from solo to paired walking within a pair type; however, the talking condition slowed both solo and paired walking by 4-5%. Thus this study was the first to explore whether gendered strategies for solo walking remain when walking in a dyad.

The consistency of the distraction effect on both solo and paired walking may influence the way in which researchers approach controlled laboratory studies, particularly when using self-selected speeds. Changes in walking speed have been shown to have a large effect on gait (e.g. [21-23]). When gait comparisons are made before and after various interventions, changes in gait speed can be a confounding factor if not properly accounted for. In our study, subjects consistently exhibited slower gait speeds during the talking trials, as compared to the no talking trials. In applications where self-selected speeds must closely reflect the social and cognitive effects that are present in everyday activities of living, a distraction technique may be beneficial for simulating realistic conditions.

Perhaps the most dramatic result of this study was the way in which women adjusted their speed when walking as a dyad as opposed to walking alone. Previous research has shown that, in general, subjects modulate speed by adjusting both cadence and step length in roughly equal amounts [24, 25]. Additionally, studies on sex differences in walking show that, even when normalized, women walk with a higher preferred cadence, while men prefer a higher step length [26]. Our analysis of raw values from solo walking match this observation, with women using higher cadences and men using greater step lengths to achieve similar preferred speeds. Similarly, when dimensionless values were examined, it was again shown that women have higher cadences than men. However, during paired walking, alterations in step length accounted for nearly all changes in speed. Interestingly, the subjects that participated as opposite sex pairs were clustered on one end of the walking speed distribution, with men tending to walk faster and women tending to walk slower than average. Thus, opposite sex participants needed to adjust gait speed when paired, even though there was no significant difference between female and male gait speed overall. When they did so, women increased speed and men decreased speed, both by adjusting step length only. While this clustering should be examined in future studies, this study does suggest that the number of persons composing a walking environment (i.e. dyads vs. solo) may alter the way in which subjects achieve a desired gait speed.

The average age difference between partners in this study was 3.8 years. Of the four partners who had an age difference of greater than 10 years, three (one F-F pair, 14 years difference; one F-M pair, 16 years difference; and one M-M pair, 20 years difference) were located some distance away from the main cluster of their pair type. Though not considered outliers, it is interesting to note the separation of these pairs from the larger groups. Furthermore, the only pair with an age difference greater than 10 years that also did not show distance from the main cluster of data was a M-M pair with a 12-year age gap. It has been observed that, while men and women experience decreases in gait speed and cadence during ageing at approximately the same rate, women show a greater decrease in step length with

increasing age than men [26]. Because changes in step length account for a greater amount of compensation during paired walking than cadence, large differences in age between partners may disproportionately affect dyads with female partners more than all-male pairs.

Group walking has been previously studied under the context of urban planning. To this end, Costa found that dyad walking speed was highest for male-male pairs and lowest for female-female pairs, with opposite-sex pairs falling in between [16]. These authors also found an insignificant difference in speed between female-female and female-male pairs. Furthermore, in a different study, Boles found that individuals walked faster than same-sex dyads [27]. The results from this study did not reach similar conclusions to either of these citations. One difference between these cited studies and the results presented herein is the location of data collection. Both of the cited studies were conducted in outdoor, pedestrian environments. As a result, situational factors such as level of activity/stress, coming to/from appointments, and gender makeup at each location may have skewed results from what was found in the presented laboratory environment. For example, if more women were recorded in leisure-type settings (e.g. shopping malls, parks, etc.) while more men were recorded in business parks or outside places of offices, this locational prompt might manifest as an artificial gender difference. The combined results of the cited studies with the results presented here suggest that location, type of social interaction, and situation factors may affect spatiotemporal metrics.

Wagnild and Wall-Scheffler also examined changes in speed due to dyad walking [17]. These authors standardized walking conditions by recording their subjects on an outdoor athletic track. Along with evaluating the effect of pair type on gait speed, these authors also examined the effect of romantic relationships on the difference in gait speed from solo to paired walking. Of the 10 female-male pairs studied here, three were composed of married couples, three were composed of boyfriend/girlfriends, and four were of no romantic relationship. These sample groups were too small to adequately evaluate the effects of romantic relationship on spatiotemporal metrics; however, through visual inspection, it was determined that the results for each relationship type were intermixed throughout the opposite sex data. Though it could not be determined, it is anticipated the results presented herein would not be affected by presence or absence of romantic relationship and would more closely match the non-romantic, opposite-sex pairing found in Wagnild and Wall-Scheffler.

In conclusion, this study demonstrated that talking as a distraction had the effect of slowing walking speed, and walking as a pair altered walking strategies, as step length was the primary means of adjusting for speed rather than shared adjustments in step length and cadence. These results may be useful in a variety of situations. Normative gait values are often used as a comparison to diagnose, evaluate, or treat pathologies that affect walking. Our results, combined with other studies, suggest that there may be instances when these normative values, such as spatiotemporal metrics used to evaluate balance and rehabilitation after a stroke or injury from falls [28, 29] may be enhanced by accounting for subject sex, situational factors, and environment specific goals.

REFERENCES

1. Barclay, C. D., J. E. Cutting and L. T. Kozlowski, Temporal and spatial factors in gait perception that influence gender recognition. *Percept Psychophys*, 1978. 23(2): 145-152.
2. Cutting, J., A program to generate synthetic walkers as dynamic point-light displays. *Behavior Research Methods & Instrumentation*, 1978. 10(1): 91-94.
3. Kozlowski, L. and J. Cutting, Recognizing the sex of a walker from a dynamic point-light display. *Perception & Psychophysics*, 1977. 21(6): 575-580.
4. Mather, G. and L. Murdoch, Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 1994. 258(1353): 273-279.
5. Murray, M. P., et al., Comparison of free and fast speed walking patterns of normal men. *Am J Phys Med*, 1966. 45(1): 8-23.
6. Arendt, E. and R. Dick, Knee Injury Patterns Among Men and Women in Collegiate Basketball and Soccer: NCAA Data and Review of Literature. *The American Journal of Sports Medicine*, 1995. 23(6): 694-701.
7. Ferretti, A., et al., Knee ligament injuries in volleyball players. *The American Journal of Sports Medicine*, 1992. 20(2): 203-207.
8. Bohannon, R. W., Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. *Age Ageing*, 1997. 26(1): 15-19.
9. Bohannon, R. W., A. W. Andrews and M. W. Thomas, Walking speed: reference values and correlates for older adults. *J Orthop Sports Phys Ther*, 1996. 24(2): 86-90.
10. Nigg, B. M. B., Jennifer; Maurer Christian; Federolf, Peter, Shoe midsole hardness, sex and age effects on lower extremity kinematics during running. *Journal of biomechanics*, 2012. 45(9): 1692-1697.
11. Pheasant, S. H., Christine M., *Bodyspace: Anthropometry, Ergonomics and the Design of Work*. ed., ed. Vol. 2005. CRC Press.
12. Lee, L. and W. E. L. Grimson, Gait analysis for recognition and classification, in *Automatic Face and Gesture Recognition*, 2002. *Proceedings. Fifth IEEE International Conference on, 'Editor'^'Editors'*, 2002, IEEE. 148-155.
13. Li, X., et al., Gait components and their application to gender recognition. *Systems, Man, and Cybernetics, Part C: Applications and Reviews*, IEEE Transactions on, 2008. 38(2): 145-155.
14. McDonnell, R., et al., Virtual shapers & movers: form and motion affect sex perception, in *Proceedings of the 4th symposium on Applied perception in graphics and visualization, 'Editor'^'Editors'*, 2007, ACM. 7-10.
15. Moghaddam, B. and M.-H. Yang, Gender classification with support vector machines, in *Automatic Face and Gesture Recognition*, 2000. *Proceedings. Fourth IEEE International Conference on, 'Editor'^'Editors'*, 2000, IEEE. 306-311.
16. Costa, M., Interpersonal distances in group walking. *journal of nonverbal behavior*, 2010. 34: 15-26.
17. Wagnild, J., Wall-Scheffler, Cara M., Energetic consequences of human sociality: walking speed choices among friendly dyads. *PLoS ONE*, 2013. 8(10).
18. Ghoussayni, S. S., Christopher; Durham, Sally; Ewins, David, Assessment and validation of a simple automated method for the detection of gait events and intervals. *Gait & Posture*, 2004. 20: 266-272.
19. Zeni, J. A. J. R., J.G.; Higginson, J.S., Two simple methods for determining gait events during treadmill and overground walking using kinematic data. *Gait & Posture*, 2008. 27: 710-714.
20. Hof, A. L., Scaling gait data to body size. *Gait & Posture*, 1996. 4(3): 222-223.
21. Van Hedel, H., L. Tomatis and R. Müller, Modulation of leg muscle activity and gait kinematics by walking speed and bodyweight unloading. *Gait & posture*, 2006. 24(1): 35-45.

22. Kirtley, C., M. W. Whittle and R. Jefferson, Influence of walking speed on gait parameters. *Journal of biomedical engineering*, 1985. 7(4): 282-288.
23. Hanlon, M. and R. Anderson, Prediction methods to account for the effect of gait speed on lower limb angular kinematics. *Gait & posture*, 2006. 24(3): 280-287.
24. Tanawongsuwan, R. and A. Bobick, A study of human gaits across different speeds, in, 'Editor'^'Editors', 2003, Georgia Tech, Tech. Rep.
25. Hirokawa, S., Normal gait characteristics under temporal and distance constraints. *J Biomed Eng*, 1989. 11(6): 449-456.
26. Frimenko, R. G., Charles; Bruening, Dustin, Interactions of sex and aging on spatiotemporal metrics in non-pathological gait: a descriptive meta-analysis. *Physiotherapy*, 2015. 101(3): 266-272.
27. Boles, W., The effect of density, sex, and group size upon pedestrian walking velocity. *Man-Environment Systems*, 1981. 11(1-2): 37-40.
28. Purser, J. L., et al., Walking speed predicts health status and hospital costs for frail elderly male veterans. *Journal of rehabilitation research and development*, 2005. 42(4): 535.
29. Van Kan, G. A., et al., Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *The journal of nutrition, health & aging*, 2009. 13(10): 881-889.