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Abstract:	Background and purpose: Low and slowing gait speeds among nursing home residents are linked to a higher risk of disability, cognitive impairment, falls, and mortality. A better understanding of the spatio-temporal parameters of gait that influence declining mobility could lead to effective rehabilitation and preventative intervention. This study aims were to objectively quantify the spatio-temporal characteristics of gait in the nursing home setting and define the relationship between these parameters and gait speed. Methods: One hundred nursing home residents were enrolled into the study and completed three habitual gait speed trials over a distance of 3.66 m. Trials were performed using an instrumented gait analysis. The manner in which the spatiotemporal parameters predicted gait speed was examined by univariate and multivariable regression modelling. Results: The nursing home residents had a habitual gait speed of 0.63 ± 0.19 m/s, a stride length of 0.83 ± 0.15 m, a support base of 0.15 ± 0.06 m and step time of 0.66 ± 0.12 s. Multivariable linear regression revealed stride length, support base and step time predicted gait speed ($R2= 0.89$, $p<0.05$). Step time had the greatest influence on gait speed with each 0.1 s decrease in step time resulting in a 0.09 m/s (95% CI 0.08 - 0.10) increase in habitual gait speed. Conclusion: This study revealed step time, stride length and support base are the strongest predictors of gait speed among nursing home residents. Given the impact of low and slowing gait speed in this population, future research should concentrate on developing and evaluating intervention programs that were specifically designed to focus on improving step time, stride length and support base in nursing home residents. As gait speed has been shown to be predictive of many adverse events in older adults, we would also suggest that routine assessments of gait speed, and if

	possible their spatiotemporal characteristics be done on all nursing home residents in an attempt to identify residents with low or slowing gait speed.
Response to Reviewers:	Response to the editor and reviewer's comments can be found in the cover letter in a table that includes point-by-point response to each comment.

Gait Speed Characteristics and Its Spatio-Temporal Determinants in Nursing Home Residents: A Cross-Sectional Study

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Gait Speed Characteristics and Its Spatio-Temporal Determinants in Nursing Home Residents: A Cross-Sectional Study

ABSTRACT

Background and purpose: Low and slowing gait speeds among nursing home residents are linked to a higher risk of disability, cognitive impairment, falls, and mortality. A better understanding of the spatio-temporal parameters of gait that influence declining mobility could lead to effective rehabilitation and preventative intervention. This study aims were to objectively quantify the spatio-temporal characteristics of gait in the nursing home setting and define the relationship between these parameters and gait speed.

Methods: One hundred nursing home residents were enrolled into the study and completed three habitual gait speed trials over a distance of 3.66 m. Trials were performed using an instrumented gait analysis. The manner in which the spatiotemporal parameters predicted gait speed was examined by univariate and multivariable regression modelling.

Results: The nursing home residents had a habitual gait speed of 0.63 ± 0.19 m/s, a stride length of 0.83 ± 0.15 m, a support base of 0.15 ± 0.06 m and step time of 0.66 ± 0.12 s. Multivariable linear regression revealed stride length, support base and step time predicted gait speed (R^2= 0.89, p<0.05). Step time had the greatest influence on gait speed with each 0.1 s decrease in step time

resulting in a 0.09 m/s (95% CI 0.08 - 0.10) increase in habitual gait speed.

Conclusion: This study revealed step time, stride length and support base are the strongest predictors of gait speed among nursing home residents. Given the impact of low and slowing gait speed in this population, future research should concentrate on developing and evaluating intervention programs that were specifically designed to focus on improving step time, stride length and support base in nursing home residents. As gait speed has been shown to be predictive of many adverse events in older adults, we would also suggest that routine assessments of gait speed, and if possible their spatiotemporal characteristics be done on all nursing home residents in an attempt to identify residents with low or slowing gait speed.

Keywords: health professionals; gait speed; nursing home; spatio-temporal determinants

INTRODUCTION

Walking is a key physical performance task for people of all ages, including older adults. The majority of older adults, especially those living in nursing home (residential aged care) settings have decreased physical activity[1] and poor physical function as indicated by their reduced gait speed, muscle strength and balance.[2] Older adults with slower gait speeds are at higher risk of disability, cognitive impairment, institutionalization, falls, and mortality.[3] While a variety of gait speed thresholds exist, healthy community dwelling older adults tend to experience poorer health when their habitual gait speed is < 0.8 m/s,[3,4] whereas for nursing home residents > 80 years of age, a threshold of < 0.5 m/s has been proposed.[4,5] A recent systematic review which included 34 studies quantifying the gait speed of residents living in nursing homes reported a mean habitual pace gait speed of 0.48 m/s (95% confidence interval (CI) 0.40-0.55).[6] Gait speeds this low suggest that most nursing home residents are limited in mobility and independence, have decreased stability and are at increased risk for many other age-related conditions.[6]

Currently, little is known in relation to the physical determinants or risk factors for low gait speed in low-functioning older adults and those living in nursing home facilities. While McGough et al.[7] and Keogh et al.[8] have reported that measures of physical function, balance, lifetime physical activity levels and sitting time correlate with gait speed in these less functioning older cohorts, no studies have quantified the spatio-temporal determinants (e.g. step length, step rate) that determine gait speed in a nursing home population.[9] Figure 1 presents a pictorial representation of the relationship between selected spatio-

temporal parameters and gait speed. When compared to younger adults, older adults walk more slowly; have a shorter step length and a broader support base than their younger counterparts, with these differences more pronounced in older adults living in nursing home and/or with a high risk of falls.[10-13]

Insert Figure 1 here.

A greater understanding of nursing home residents' gait speed and spatio-temporal determinants may assist health professionals to identify nursing home residents at high risk of adverse events and allow for a more specific-tailored physical therapy and rehabilitation program for each individual.[11] We would argue this is very important as indicated by a systematic review that found exercise-related improvements in older adults' gait speed are typically smaller in magnitude and more variable than the improvements in muscular strength.[14] Specifically, semi-regular monitoring of gait speed and spatiotemporal parameters could assist appropriate health professionals to prescribe resistance, balance and gait exercises that target their clients' major spatiotemporal limitations. The collection of this gait spatiotemporal data may also allow the exercise therapist to provide their client task-relevant augmented feedback (e.g. visual cues, instant or delayed feedback) during these exercises to improve the transfer of training to their habitual walking performance[15,16].

This study aims were to objectively quantify the spatio-temporal determinants and gait speed of nursing home residents and to gain some insight into whether these spatiotemporal parameters may predict their gait speed.

METHODS

Recruitment and Study Design

The study employed a cross-sectional design, with data collected over an eight-month period across three nursing home facilities in South East Queensland, Australia. The facilities were from different providers that were either part of a small chain of nursing homes or a not for profit organisation. The flow of recruitment to assessment is represented in Figure 2. Facilities were approached via email and telephone follow-up seeking an expression of interest for participation. Following an expression of interest, nursing homes were visited and the study explained to the Service Manager. Once the service manager approved the participation of their nursing home in the project, eligible participants were identified at a meeting between the project lead researcher and the Service Manager, head Registered Nurse and head Diversional Therapist. Ethical approval for this study was attained from the University Human Ethics Research Committee (RO 1823) and gatekeeper's approval obtained through the nursing homes.

Insert Figure 2 here.

Based on study's eligibility, participants were eligible for inclusion if they were: a) aged 65 years and over, b) residing in a nursing home facility, c) ambulate independently or without a walking aid and d) could provide informed consent. The exclusion criteria included: a) end-stage terminal and/or life expectancy <6-months (ethical reasons), b) two person transfer or increased falls risk during ambulation (as assessed by the nursing home staff), c) unable to communicate or follow instructions (personal needs beyond the scope of this project) and d) behaviors that would endanger the participant or research staff.

All participants were approached personally about participation and given the opportunity to ask questions or raise concerns about the study. Following this discussion and reading of the participant information sheet, participants provided their informed consent if they wished to participate. A total of 100 participants took part in the study, with the primary investigator responsible for observing and administering all of the assessments.

Primary Outcome Measures: Gait Speed

Gait speed was assessed using a computer interfaced electronic system (model GaitMat II, EQInc, USA) which required participants to walk across a level pressure mat system that was 3.66 m (11.91 ft.) long.[17] The concurrent validity of the spatio-temporal determinants of gait recorded with the GaitMat II is extremely high when compared to the criterion method of 3-D motion capture (*R* =.99).[18,19] The Gait Mat II was chosen due to it being much more feasible to use in nursing homes and 3-D motion capture. The GaitMat II system automatically measured gait speed and spatio-temporal determinants, with this data automatically stored in a Microsoft Excel spreadsheet.

Participants completed the trials at their habitual gait speed in their regular footwear. The following instructions were provided, “Walk towards the end of the room in the centre of the mat at a pace that is comfortable for you”. All measures were initiated from a standing start 2 m (6.56 ft.) from the GaitMat II platform in order to reduce the effect that acceleration or deceleration may have on the outcomes.[20,21] The average gait speed (m/s) from three attempts was used for data analysis. Participants were allowed as much rest as required between attempts, with rest periods typically being up to one minute.

Secondary Outcome Measures

A full spectrum of spatio-temporal gait determinants outputted was recorded. These spatio-temporal gait determinants included step length, stride length, support base, step time, swing time, stance time, single support time and double support time and are defined by the GaitMat II manual found in Table 1.

Insert Table 1 here.

In addition handgrip strength, the Mini-Cog test[22] and a simple five-item questionnaire (SARC-F) [23,24] were collected for the purpose of cohort characteristics description. Nursing home facility records provided other relevant descriptors including the number of medical conditions and medications.

Data Management and Statistical Analysis

All data were initially checked for normality prior to analysis. As data were normally distributed, descriptive statistics are presented as mean and standard deviations for continuous variables. A one-way ANOVA and post-hoc Tukey and Scheffe tests were performed to investigate between nursing home differences. Linear regression analyses were performed to gain insight into the potential determinants of gait speed (i.e. gait spatio-temporal determinants) in residents. Univariate analyses of all gait spatio-temporal determinants were employed to identify possible determinants of gait speed (two-tailed). Factors with a significance $p \leq 0.10$ determined from simple linear regression analyses were included in the multiple linear regression model. This multivariable model determined which combination of variables best-predicted gait speed in

residents. The 95% confidence interval (95% CI) was included for the coefficients in the multivariable model. All data were analysed using SPSS statistic software (version 22) with statistical significance set at $p<0.05$ a priori.

RESULTS

Participants

One hundred of 166 (60.24%) invited, eligible residents were recruited to the study. There were no significant differences between all variables for nursing home cohorts in this study ($p>0.05$), thus data combined into one group for analysis. Cohort data are present in Table 2. The average age of the 100 residents was 85.7 (7.1) years with a mean gait speed of 0.63 (0.19) m/s, an average of 11.0 (4.9) medical conditions and 14.0 (5.8) prescribed medications. There were no significant differences with gait speed and spatio-temporal parameters, handgrips strength, sarcopenia status and medications and chronic diseases across males and females. However, males were significantly younger ($p = 0.038$) and had a lower Mini-Cog assessment ($p = 0.002$) in comparison to females.

Insert Table 2 here.

The majority of participants (79%, n = 79/100) presented with below normal habitual gait speeds (< 0.80 m/s), whilst 26% (n = 26/100) ambulated at below the mean reported for nursing facilities residents (< 0.48 m/s, 95% CI 0.396-0.554).[6]

Results of the univariable linear regression analyses identified three spatio-temporal factors as being predictive of gait speed: stride length ($p<0.001$), support base ($p<0.001$) and step time ($p=0.002$) (see Table 3). Of

these factors, stride length contributed to the largest change in gait speed, with each 0.1 m increase in stride length resulting in an average 0.09 m/s (95% CI 0.06 – 0.13) faster habitual gait speed.

Insert Table 3 here.

The multivariable linear regression model that included stride length, support base and step time predicted 89% (R^2 = 0.89) of the variation in gait speed (see Table 3). Specifically, step time contributed to the largest change in gait speed with every 0.1 s decrease in step time resulting in a mean increase in gait speed of 0.09 m/s (95% CI 0.08 – 0.10). A 0.1 m increase in stride length was also associated with a mean increase of 0.08 m/s (95% CI 0.07 – 0.09) in gait speed. The third determinant identified in the multivariable regression, support base appeared to have a smaller effect on gait speed, with a 0.1 m decrease in support base resulting in a mean gait speed increase of 0.04 m/s (95% CI 0.02 – 0.07).

DISCUSSION

This study demonstrated that nursing home residents who can self-ambulate with or without a walking aid still walk at a gait speed (0.63 ± 0.19 m/s) and possess spatiotemporal parameters that place them at high risk of falls and other adverse age-related events.[3,11,12] A total of 79 participants presented with below normal habitual gait speeds (< 0.80 m/s), which is a threshold defined to screen for sarcopenia in older adults aged 80 years and older.[25] A total of 27 participants also walked at a threshold below 0.48 m/s which a meta-analysis of 48 studies found to be the mean gait speed for older adults in nursing homes.[6]

Results of the regression analyses also indicated that nursing home residents who ambulated at a slower habitual gait speed were more likely to have an increased step time, shorter stride length and a wider support base than their more ambulatory counterparts. While the finding that some spatio-temporal parameters do predict gait speed is not overly surprising, to our knowledge this is the first study to investigate the potential for spatio-temporal determinants to determine gait speed in the nursing home setting. The importance of the spatio-temporal parameters in determining gait speed also appear consistent with Sterke et al.[11] and Taylor et al.[12] who demonstrated that slower older walkers with increased falls risk had shorter stride lengths, longer double support times and a wider support base when compared to aged matched individuals with no falls history.

The significant ability of spatio-temporal determinants such as step time, stride length and support base to determine gait speed in the current study (R^2 = 0.89) and falls in previous studies[11,12] would appear to reflect a variety of biomechanical concepts. For example, the ability of step time and stride length to determine gait speed may be explained by the impulse-momentum relationship and/or the nursing home residents' reduced ability to maintain balance during the gait cycle. It is fair to conclude that reduced lower-body muscle strength and power may mean that the nursing home residents require greater single/double support times to produce the necessary impulse (force multiplied by time) to propel their body forward during the gait cycle.[26] Their reduced force production ability and greater stance time would then contribute to a reduced stride length, increased step time and ultimately a reduced

habitual gait speed. Poor stride length may also be suggestive of shuffling gait and low plantar flexor and hip flexor strength.[26] Therefore, certain exercises such as calf raises and leg raises coupled with gait training may need to be incorporated in resistance training programs to improve gait speed in nursing home residents.[21]

The clinical significance of this study is that gait speed characteristics and spatio-temporal determinants are becoming more easily measured and analysed in nursing home settings. Health professionals can then use this individualized gait data to identify residents at risk of adverse events and intervene where appropriate by providing an individualized exercise intervention for each resident. In doing so, residents are likely to benefit more from these exercise programs as they are better tailored to the specific spatio-temporal parameters underlying the participants' poor gait speed and/or falls risk. Such an approach may also improve exercise adherence as these programs can better concentrate on improving gait performance in activities of daily living (ADL).[27]

Collectively, the manner in which the nursing home residents walk (as described by their spatio-temporal determinants) have major implications to exercise therapy and rehabilitative approaches to improving gait speed in this cohort. With the clinical implications being that if health professionals can continually monitor and assess gait speed and spatio-temporal determinants, we may be able to decrease or prolong the amount of residents who are induced into the vicious cycle of reduced physical activity and decreased

mobility and physical performance that have a direct effect on their health and survival.

However, it is also possible that the tendency for the slower nursing home residents to have shorter stride lengths, increased step times and wider support bases may be indicative of a compensation for their reduced strength and dynamic stability. Longer strides and a narrower support base increase the distance that the centre of mass travels outside the anterior-posterior and medial-lateral bases of support, respectively.[26] As Sherrington et al.[28] has reported that exercise programs that do not sufficiently challenge balance may actually increase rather than decrease the risk of falling of nursing home residents, we would recommend that nursing home residents with short strides and wide support bases focus initially on improving their static and dynamic balance. Once balance has been improved in the anterior-posterior and medial lateral directions, these residents may further prioritize resistance and gait retraining to safely improve their gait speed and overall mobility.

Given the interplay between decreasing mobility and increasing disability, the monitoring of gait speed by health professionals (and if possible the primary spatio-temporal determinants) on at least an annual basis in the nursing home setting has been recommended.[8,29] For those nursing home residents identified with poor and slowing mobility, systematic review evidence suggests that regular progressive resistance and balance training can improve their habitual gait speed by 0.07 m/s (95% CI 0.02-0.11) when compared to non-exercising controls.[30] While these reported improvements in gait speed are positive, there may be two potential criticisms of the studies reviewed in this meta-analysis

(and the wider literature). The first is that the studies have typically used quite generic exercise prescriptions that focus on improving muscular hypertrophy and strength in a variety of muscle groups. Based on emerging evidence that reduced gait speed in older adults is primarily a result of reduced ankle plantarflexor rather than hip or knee extensor moment and muscle power,[26] a greater focus on increasing the muscle strength and power of the plantarflexors compared to the traditional focus on the knee and hip extensors may be warranted. In addition, the majority of studies in this area that have included balance training primarily used static balance tasks that require the older adults to hold a position for a period of 10-20 s e.g. two feet stands on unstable surface or with eyes closed or semi-tandem/tandem stance. Based on our results, we suggest that dynamic balance ability, which would appear more closely related to the balance requirements of human gait, be taught by health professionals on a weekly basis. Therefore, nursing home residents may obtain greater gait speed benefit from performing dynamic balance tasks (e.g. stepping and perturbation response) than static balance tasks.[31-33]

The Gait Mat II provided a feasible, reliable and valid tool to measure gait speed and spatio-temporal determinants in nursing home adults.[2,18,19] New equipment has been developed since the data collection of this study. One suggestion for future studies would be to use inertial sensors[34] which may be a more portable and affordable gait assessment. Such advancements in inertial sensor technology would more easily allow health professionals to routinely monitor gait speed and spatiotemporal parameters in the nursing home setting,

which may further increase allow the development of targeted exercise programs for each nursing home resident.

Participation selection bias is a limitation that may have influenced our findings as the inclusion criteria deemed that a participant should have the ability to walk with or without an aid. A total of 55% of residents in the nursing home facilities were ineligible because of the inability to mobilize or because they were deemed too high a risk to participate. Because of this bias in selecting individuals who were ambulant (with or without assistive devices), the gait speed and spatiotemporal parameters obtained in this study may not be generalized to all nursing home residents. Nevertheless, the participants in the current study were still below the cut off for physical performance and at risk of further decreased disability, cognitive decline and mortality,[35] with every 0.1 m/s reduction in gait speed equating to a 10% decrease in older adult's ability to perform ADLs.[36] It must also be acknowledged that static or dynamic balance ability were not directly assessed in this study. Therefore, while our proposition of poor dynamic balance contributing to the reduced gait speed of nursing home participants has some experimental support,[37,38] we cannot explicitly state that is the case with our participants.

CONCLUSIONS

This is the first study to investigate gait speed characteristics and spatio-temporal determinants in the nursing home setting. While our cross-sectional study suggests that step time, stride length and support base are highly predictive of gait speed in nursing home residents, longitudinal research is

required to determine if changes in these three spatio-temporal determinants may be predictive of changes in gait speed. If these longitudinal relationships between gait speed and spatio-temporal determinants can be found, health professionals may be better able to alter aspects of their exercise prescription and augmented feedback approach to improve outcomes for nursing home residents.

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Disclosure statement

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Figure Legends

Figure 1. Deterministic model of gait speed outlining the direct relationships between the spatio-temporal determinants and gait speed.

Figure 2. Consort flow diagram of the recruitment process within the nursing home facilities.

Figure 1

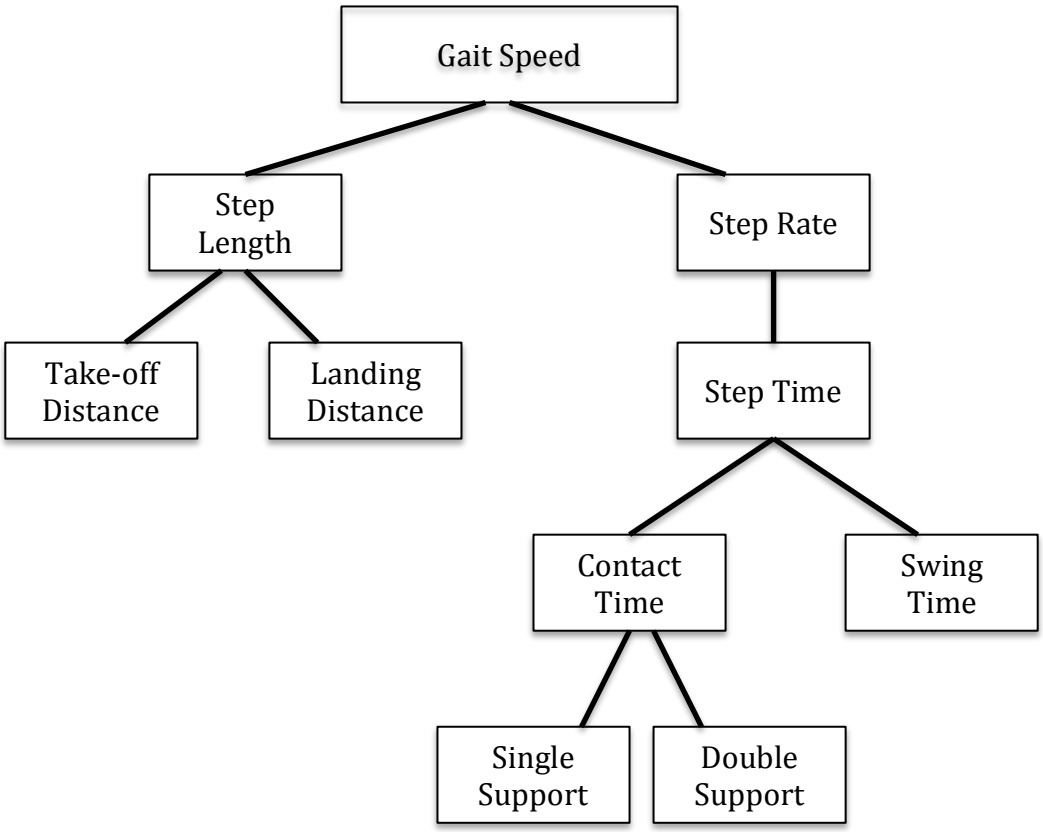

Figure 1. Deterministic Model of Gait Speed Outlining the Direct Relationships Between the Spatio-Temporal Determinants and Gait Speed.

Figure 2

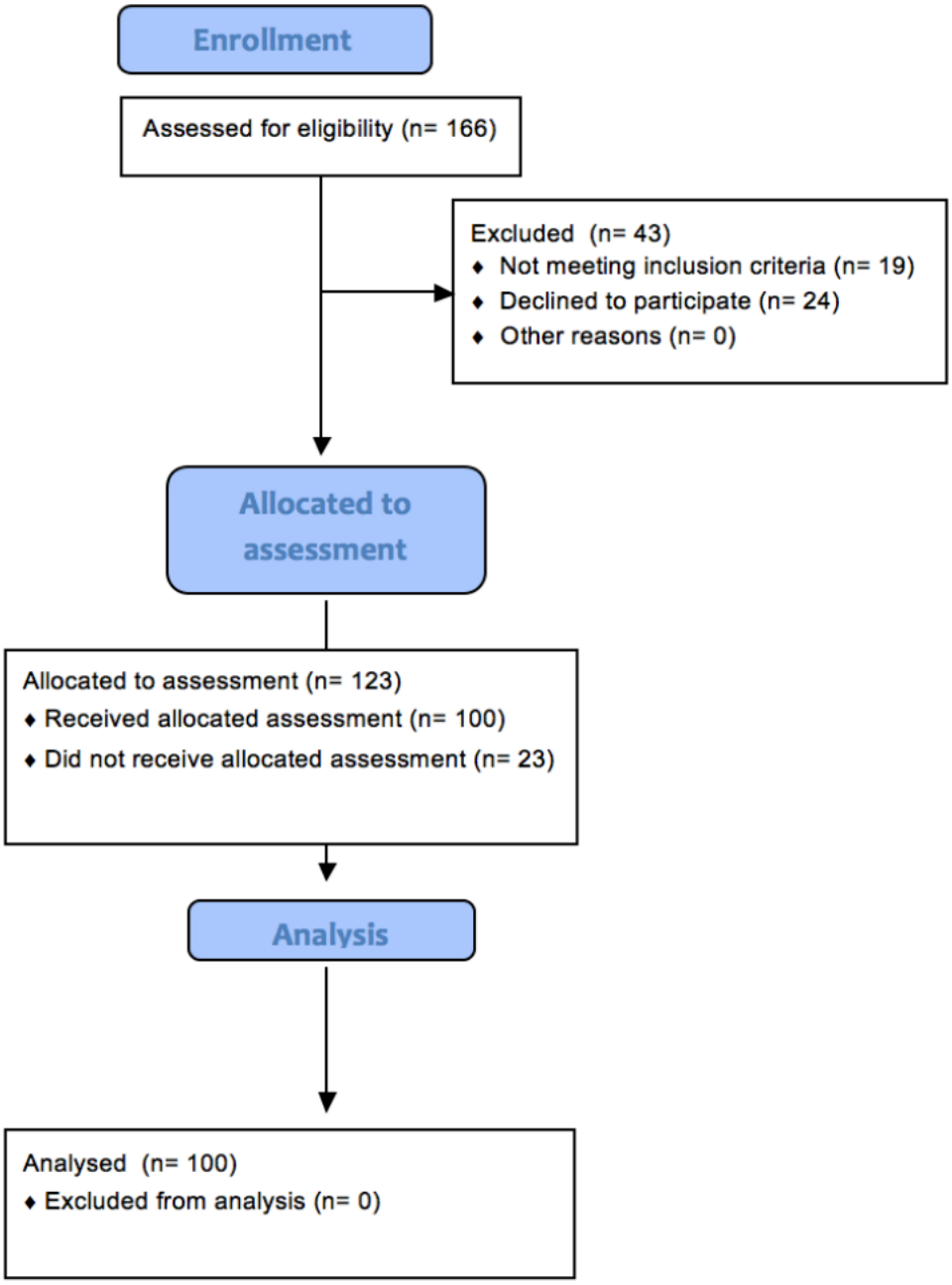

Figure 2. Consort Flow Diagram of the Recruitment Process Within the Nursing Home Settings.

Table 1: Spatio-temportal gait determinants and definitions as defined by the GaitMat II manual.

Spatio-temporal gait determinants	Definitions
Step length	The distance from the first switch closure of one footprint to that of the footprint on the contralateral side.[39]
Stride length	The distance from the first switch closure of one footprint to the next footprint on the ipsilateral side.[39]
Support base	The medial lateral distance across the mat to the innermost switch closure for one footprint from the innermost switch closure of the previous footprint on the contralateral side.[39]
Step time	The time to the earliest switch closure of a footfall from the earliest switch closure of the previous footfall on the contralateral side.[39]
Swing time	The time to the earliest switch closure of a footfall from the latest switch opening of the previous footfall on the ipsilateral side.[39]
Stance time	The time to the latest switch opening of a footfall from the earliest switch closure of the same footfall.[39]
Single support time	The time to the earliest switch closure of the next footfall on the contralateral side from the latest switch opening of the previous footfall on the contralateral side.[39]
Double support time	The time to the latest switch opening of the previous footfall on the contralateral side from the earliest switch closure of a footfall.[39]

Table 2: Characteristics of the Cohort of 100 Nursing Home Residents.

Parameter	Group Mean (SD)	Females (n=67) Mean (SD)	Males (n=33) Mean (SD)
Age, y	85.7 (7.1)	86.1 (6.6)*	85.0 (8.1)
Handgrip Strength, kg	11.1 (4.9)	10.7 (4.2)	11.7 (6.2)
Mini COG, #	1.2 (0.4)	1.8 (0.4)*	1.3 (0.5)
SARC-F, #	5.5 (3.3)	4.9 (3.3)	6.6 (3.1)
Medical Conditions, #	11.0 (4.9)	11.4 (4.9)	10.2 (4.9)
Medications, #	14.0 (5.8)	13.8 (6.1)	14.4 (5.3)
Gait speed, m/s	0.63 (0.19)	0.65 (0.20)	0.58 (0.16)
Step length, m	0.41 (0.08)	0.42 (0.07)	0.41 (0.07)
Stride length, m	0.83 (0.15)	0.84 (0.16)	0.81 (0.14)
Support base, m	0.15 (0.06)	0.16 (0.06)	0.15 (0.07)
Step time, s	0.66 (0.12)	0.64 (0.12)	0.70 (0.12)
Swing time, s	0.42 (0.07)	0.41 (0.07)	0.44 (0.08)
Stance time, s	0.91 (0.20)	0.88 (0.19)	0.98 (0.20)
Single support Time, s	0.42 (0.07)	0.41 (0.06)	0.43 (0.08)
Double support Time, s	0.24 (0.07)	0.23 (0.06)	0.27 (0.08)

= number; Mini COG = Mini Cognitive test; SARC-F = Sarcopenia Five-Item Questionnaire

* = Statistical significance $p<0.05$.

Table 3: Univariable and Multivariable Linear Regression Model of the Spatio-Temporal Predictors for Habitual Gait Speed in 100 Residents Living in Nursing Homes.

Factor	Univariable		Multivariable	
	Coefficient (95% CI)	***p*-value**	**Coefficient (95% CI)**	***p*-value**
Stride length, m	0.93 (0.55 – 1.31)	< 0.001	0.83 (0.74 – 0.92)	< 0.001
Support base, m	-0.51 (-0.77 to -0.26)	< 0.001	-0.44 (-0.68 to -0.21)	< 0.001
Step time, s	-0.70 (-1.13 to -0.27)	0.002	-0.92 (-1.03 to -0.81)	< 0.001

CI = Confidence Interval.

R2 of multiple regression equals 0.892.

Note: All results significant $p<0.05$.