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Association Between Daily Life Walking Speed and Frailty Measured by a Smartphone Application: A Cross-Sectional Study

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ABSTRACT

Objectives: To assess whether frailty can be assessed using a smartphone and whether daily walking speed (DWS) is associated with frailty.

Design: Cross-sectional study

Setting: Three prefectures（Kanagawa, Saitama, and Tokyo) in Japan

Participants: The study enrolled 163 participants (134 in the robust group and 29 in the frailty group) by sending letters to house owners aged ≥55 years.

Primary and Secondary outcome measures: The participants downloaded the DWS measurement application on their smartphones, which measured the daily walking (DW) parameters (DWS, step length, and cadence) and the Kihon checklist for frailty assessment. The differences in the DW parameters between the robust and frailty groups were examined using a *t*-test. We conducted logistic regression analysis for the Crude model (each DW parameter), Model 1 (adjusted for the number of steps), and Model 2 (Model 1 + age, sex, and the number of chronic diseases). The discriminability of frailty based on DWS was examined using receiver operating characteristic analysis.

Results: DWS was marginally significantly slower in the frailty group than that in the robust group (robust 1.26 m/s vs frailty 1.19 m/s, P=0.091). The step length was significantly smaller in the frailty group than that in the robust group (robust 66.1 cm vs frailty 62.3 cm, P<0.05). Logistic regression analysis for the three models revealed that DWS was significantly associated with frailty. The area under the curve of frailty discrimination by DWS was 0.644 (95% confidence interval: 0.514–0.774) in the Crude model and 0.697 (0.584–0.810) in the fully adjusted model.

Conclusions: DWS measured by the smartphone application were associated with frailty. Additional items may increase the discriminability of DWS for frailty.

Keywords: cross-sectional study; daily life walking speed; frailty; Kihon checklist; smartphone

Strengths and limitations of this study

- The participants accessed the website for the smartphone application using the QR code printed on the invitation letter and downloaded the daily walking speed (DWS) measurement application on their smartphones.
- Unlike previous studies, frailty in this study was assessed using a web-based smartphone application, and frail participants were included.
- The participants did not have to go to a designated place and could answer the Kihon checklist through the application.
- However, the participants were not randomly selected but were those with access to a smartphone and those interested in frailty prevention and health promotion.
- In addition, DWS was limited to outdoor measurements as the application was based on GPS.

INTRODUCTION

Walking speed is closely associated with many health outcomes and predicts dependency and death in older individuals.[1,2] A meta-analysis showed that decreased walking speed is associated with the incidence of cardiovascular diseases and associated mortality.[3] Based on these studies, walking speed is recognized as the sixth vital sign, following blood pressure, pulse, respiration, temperature, and pain.[4] Conventional walking speed is often measured by recording the time required to walk a certain distance, such as 5 m, using a stopwatch. This method can measure the walking speed easily and accurately and has been used in several studies; however, concerns have been raised since the participants are required to come to a specific measurement site, and they can intentionally change their walking speed.

Recent studies have measured daily walking speed (DWS) using wearable accelerometers and smartphone applications.[5-9] If DWS can be used for health assessment in a manner similar to the conventional 'laboratory walking speed (LWS)', such daily measurements can be used for the early detection of health risks, continuous health assessment, and health promotion. However, the measurement of DWS is not well-established, and its definition differs depending on the study. In addition, previous studies on DWS have only shown the difference between DWS and LWS [6,9,10] and their values,[8,11] and only a few studies have investigated the association between DWS and health outcomes.

Recent studies have reported an association between DWS and pre-frailty.[12,13] Frailty is a state in which vulnerability increases owing to ageing, and the risk of dependency and death increases.[14] The prevention of frailty is extremely important for maintaining the health of older individuals. However, few studies on DWS have examined the association between DWS and frailty. Kawai et al.[12] used the Japanese version of the Cardiovascular Health Study (CHS) criteria, which comprises five domains (weight loss, weakness, slowness, exhaustion, and low activity) to assess frailty;[15] however, participants corresponding to

frailty were not included in the study. Takayanagi et al.[13] used the Kihon checklist (KCL),[16] which comprises 25 questions to assess frailty; however, participants with frailty were excluded from the study. These studies, which recruited participants from a cohort study involving community-dwelling older adults and measured DWS using a smartphone application or an accelerometer, could not include frail participants because the participants were required to go to the survey venue or designated location for collecting and uploading the data, which may be difficult for frail participants. Solftani et al.[17] recently reported the discriminability of DWS for frailty; however, the frailty definition included only the body mass index (BMI) and handgrip strength and was limited to weight loss and weakness.

We customized the DWS application for examining certain health indicators by using a chatbot to measure frailty without going to a designated location. This study aimed to examine whether frailty can be assessed using this application and elucidate the association between DWS and frailty.

METHODS

Participants

This cross-sectional study was conducted in three prefectures, Kanagawa, Saitama, and Tokyo, in Japan. The participants were recruited by sending letters to house owners aged 55 years or older who lived in a house provided by a housemaker. The housemakers solicited their participation in the research, which aimed at promoting frailty prevention using the smartphone application. The letters were sent twice to recruit as many participants as possible. The participants accessed the download site using the QR code printed on the invitation letter and downloaded the DWS measurement application on their smartphones after reading the study documentation displayed on the site and consenting to participate in the study. The

application was limited to Android smartphones. The sample size was planned to be n = 34 for frailty group and n = 100 for robust group, assuming that the ratio of frailty to robust is 1: 3 with effect size d = 0.5 and a power of 0.8.

Between August 2020 and January 2021, 416 participants downloaded the application. Among them, 163 participants who could measure DWS and frailty were included in the analysis (Figure 1).

Patient and Public Involvement

No patient involved.

Measurement of Daily Walking Parameters

Daily walking (DW) parameters, such as walking speed, step length, and cadence during daily life, were measured using a smartphone application (Chami, InfoDeliver Co. Ltd., Tokyo, Japan). The application automatically measured DWS in a manner imperceptible to the participants. The walking start time was determined by the pedometer application programming interface (API) response in the smartphone operating system and geomagnetic sensors installed in the smartphone. When the pedometer API and GPS detected a stable walking trajectory ≥20 m, the walking speed was measured until interrupted. The use of GPS implied that measurements were limited to outdoor walking.

Since the walking speeds measured in this manner were approximately normally distributed,[11] we defined the average of the walking speed measured in daily life as DWS and reported on the excellent test-retest reliability of DWS.[7] This application was used in a study on the changes in walking behaviour due to the coronavirus disease pandemic [18] and a study on seasonal changes in DWS.[19]

The application can measure the DW step length and cadence from the number of steps on the step counter in addition to walking speed. We defined the average values during the

measurement period as DWS, DW step length, and DW cadence. The DW step length modified by body height was also calculated.

Frailty Assessment

Frailty was assessed using KCL, which consists of 25 questions and has been validated using the Japanese version of the CHS criteria for frailty assessment.[16] According to the study, scores of ≥8, 4–7, and 0–3 were evaluated as frail, pre-frailty, and robust, respectively.

In this study, the text of each question in KCL was displayed in the chatbot program of the application, and the participants responded by pressing the 'Yes' or 'No' buttons.

Other Measurements

The participants self-reported their height, weight, history of chronic disease (high blood pressure, diabetes, stroke, cancer, and heart disease), hip and knee pain complaints, self-rated health (very healthy, healthy enough, not very healthy, and not healthy), psychological well-being (WHO-5 Well-Being Index [WHO-5]),[20] dietary variety score (DVS),[21] and Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC).[22] These questions were also displayed in the chatbot program, and the participants answered them through the program.

WHO-5 is a five-question psychological well-being index; the participants selected one of the five options: 0, no time; 1, some of the time; 2, less than half the time; 3, more than half the time; 4, most of the time; and 5, all of the time (total score range: 0–25 points). A higher score reflected higher psychological well-being. DVS covers ten food groups (fish and shellfish, meat, eggs, milk, soybean/soybean products, green and yellow vegetables, potatoes, seaweeds, fruits, and fats and oils). One point was added for consuming items from the food groups almost every day (total score range: 0–10 points). A higher score reflected a more diverse food intake. TMIG-IC is an index of higher functional capacity, consisting of 13 items (0–13 points). A higher score reflected higher functional capacity.

Statistical Analysis

The frailty group comprised participants with eight or more KCL items, while the robust group comprised those with seven or fewer items. The differences between the robust and frailty groups for all variables were examined using the *t*-test for continuous variables and the chi-square test for categorical variables. We conducted logistic regression analysis for the Crude model (each DW parameter), Model 1 (adjusted for the number of steps), and Model 2 (Model 1 + age, sex, and the number of chronic diseases) to examine the associations between each DW parameter and frailty. The frailty discrimination ability of DWS was assessed by the area under the curve (AUC) of the receiver operating characteristic (ROC) curve analysis. In addition, the cut-off value, sensitivity, and specificity were calculated based on the Youden index. SPSS 27.0 J (IBM Japan, Ltd., Tokyo, Japan) was used for all statistical analyses, and the significance level was set at 5%.

RESULTS

The mean age [standard deviation (SD), range] of the participants was 72.1 [6.85, 57–93] years. There were 163 participants in the study, with 134 participants in the robust group and 29 in the frailty group (Table 1). Height, weight, history of stroke, knee pain complaints, self-rated health, KCL, WHO-5, and DW step length were statistically significant between the robust and frailty groups.

Table 1. Characteristics of the participants

	(A) Robust (n=134)			(B) Frailty (n=29)			*P**
	n	(%)		n	(%)		
	n	Mean	SD	n	Mean	SD	
Sex (female)	45	(33.6)		14	(48.3)		0.135
Age (years)	134	71.9	6.44	29	72.6	8.62	0.641

Height (cm)	126	163.1	7.10	27	158.3	8.72	**0.003**
Weight (kg)	126	59.8	8.48	26	54.8	10.13	**0.008**
Chronic disease							
Hypertension	46	(34.6)		13	(44.8)		0.229
Diabetes	19	(14.3)		3	(10.3)		0.575
Stroke	0	0.0		2	(6.9)		**0.002**
Cancer	12	(9.0)		3	(10.3)		0.824
Heart disease	13	(9.8)		2	(6.9)		0.628
Hip pain	45	(33.8)		10	(34.5)		0.947
Knee pain	25	(18.8)		11	(37.9)		**0.025**
Self-rated health							**<0.001**
Very healthy	15	(11.3)		1	(3.4)		
Healthy enough	105	(78.9)		16	(55.2)		
Not very healthy	11	(8.3)		8	(27.6)		
Not healthy	2	(1.5)		4	(13.8)		
Health assessment							
KCL	134	3.6	1.97	29	10.6	2.40	**<0.001**
WHO-5	110	16.9	4.43	20	11.7	4.01	**<0.001**
DVS	55	5.3	1.95	11	4.8	1.72	0.475
TMIG-IC	64	12.1	0.98	11	11.7	1.01	0.324
Daily walking parameters							
DWS (m/s)	134	1.26	0.13	29	1.19	0.21	0.091
DW step length (cm)	134	66.1	5.50	29	62.3	8.35	**0.024**
DW step length/Height (%)	126	40.6	3.05	27	39.8	4.13	0.346
DW cadence (step/min)	134	114.8	7.46	29	114.6	8.69	0.919
Number of steps (steps/day)	134	2567.4	2368.72	29	2810.5	2416.51	0.618
Number of measurements	134	1473.9	1530.15	29	1290.7	1170.59	0.545

KCL: Kihon checklist; DVS: Dietary Variety Score; TMIG-IC: Tokyo Metropolitan Institute of Gerontology Index of Competence; DW: Daily life Walking; DWS: Daily life Walking Speed

[a] *t*-test or Chi-square test.

* Numbers in bold font are statistically significant ($P<0.05$).

The participants in the frailty group were significantly shorter in height and lighter in weight than those in the robust group ($P<0.01$). Further, the participants in the frailty group had a significantly higher frequency of stroke history ($P<0.01$) and knee pain complaints ($P<0.05$) than those in the robust group. Compared with the robust group, the proportion of those who were not very healthy and not healthy per the self-rated health was significantly higher in the frailty group ($P<0.001$). The KCL score was significantly higher in the frailty group than that in the robust group ($P<0.001$). WHO-5 was significantly lower in the frailty group than that in the robust group ($P<0.001$). The DW step length was significantly smaller in the frailty group than that in the robust group ($P<0.05$). DWS tended to be slower in the frailty group than that in the robust group; however, the difference was not statistically significant ($P=0.091$). No significant differences in DW step length modified by body height were observed between the frailty and robust groups. Logistic regression analysis for all three models (Crude model, Model 1, and Model 2) revealed the same tendencies: DWS and DW step length were significantly associated with frailty (Table 2).

Table 2. Logistic regression analysis with frailty as the dependent variable and each DW parameter as independent variables

	Crude model		Model 1		Model 2	
	OR	95% CI	OR	95% CI		95% CI
DWS (m/s)	**0.024**	0.001 - 0.571	**0.012**	0.000 - 0.368	**0.022**	0.001 - 0.784

DW step length (cm)	**0.902**	0.842	-	0.967	**0.895**	0.832	-	0.962	**0.907**	0.841	-	0.978
DW cadence (step/min)	0.997	0.946	-	1.051	0.994	0.941	-	1.050	0.999	0.941	-	1.061

OR: odds ratio; CI: confidence interval; DW: daily life walking; Model 1: Adjusted for the number of steps; Model 2: Model l + adjusted for age, sex, and the number of chronic diseases

* Numbers in bold font are statistically significant (P<0.05).

ROC analysis for the discriminability of frailty by DWS showed that the AUC (95% confidence interval) was 0.644 (0.514–0.774) (Figure 2). The cut-off value was 1.11 m/s, with a sensitivity of 41.4% and a specificity of 92.5%. The fully adjusted Model 2 showed an increased AUC of 0.697 (0.584–0.810) (Figure 2).

DISCUSSION

This study examined whether DWS is associated with frailty using a smartphone application. Since some previous studies on DWS could not include a sufficient number of participants with frailty, only the association with pre-frailty was reported. However, in this study, frailty was assessed using a web-based smartphone application, and frail participants were included. The results showed that the DW step length was smaller, and DWS tended to be lesser in the frailty group compared with the robust group.

The study participants were house owners residing in houses provided by a private housemaker. This housing service provides an urban detached house, suggesting that the residents may be those whose socioeconomic statuses were higher than those of community-dwelling older adults. Additionally, the participants were those who could use a smartphone since they could access the QR code. In our previous study, we found that smartphone-based

study participants were younger, had a higher physical function, and were healthier than non-participants.[10] Only 0.9% of the 45,000 participants who downloaded the application received an invitation letter. The number of individuals who read the study document in the letter may have been even fewer. The participants should be interested in health information. Although the participation rate may have been low since the application was limited to Android smartphones, participation in this study might have been biased toward healthy individuals rather than being representative of community-dwelling older adults.

However, the mean age of the participants in this study, which included 29 (17.8%) frail participants, was not significantly different from that of the participants in the community cohort. A previous study in which frailty was assessed using KCL, similar to that in this study, from a large cohort of more than 5,000 community-dwelling older individuals, reported that the prevalence of frailty was 17.2%, which was also similar to that in this study.[16] In addition, the DWS (1.25 m/s) in this study was not significantly different from that reported in the previous study (1.28 m/s), measured using a smartphone application in the community cohort.[10] Therefore, the participants of this study probably had good socioeconomic status and could use a smartphone; however, these participants were considered similar to those recruited from the community from the frailty and DWS perspectives. Therefore, we believe that the results of this study are reflective of the community.

KCL is usually examined using a self-administered questionnaire. In this study, the participants entered KCL using a smartphone application, and frailty was assessed from the recorded data. As described above, since the prevalence of frailty in this study was similar to that of a previous study in which frailty was assessed using a self-administered questionnaire in the community cohort, we believe that frailty can be assessed using a smartphone application.

Additionally, there was a significant difference between the robust and frailty groups in height, weight, history of stroke, knee pain complaint, self-rated health, KCL, and WHO-5, indicating a reasonable result that reflects frailty. However, statistical differences in DVS and TMIG-IC reported to be associated with frailty [21] and decline with age [23] were not found between the groups. KCL consists of 25 items. Although there were more items compared to other questionnaires, KCL items were asked in the first half of the conversation with the chatbot, and priority was given to assessing frailty. However, there were many questions, such as the 10 items for DVS and 13 items for TMIG-IC, which were asked in the latter half of the conversation. Consequently, the number of participants who responded to the questionnaire was lower than those who provided KCL information. This lack of statistical power might explain why no statistical differences were observed in DVS and TMIG-IC between the robust and frailty groups. Thus, future research with a larger number of participants is required. Overall, we believe that the frailty assessment in this study using the application would be appropriate.

DWS tended to be slower in the frailty group than that in the robust group; however, the difference was not statistically significant. In contrast, the DW step length was significantly smaller in the frailty group than that in the robust group. The significantly smaller DW step length in the frailty group could decrease the DWS in the frailty group; however, the difference in DWS between the robust and frailty groups was small (0.07 m/s). Assuming a statistical power of 0.8, a sample size of 187 would be required to detect this difference; therefore, the power in this study may be slightly insufficient. Additionally, since the DW step length modified by body height was similar between the groups, the difference in the DW step length between the groups must be caused by the difference in body height. However, body size is one of the unmodifiable features of frailty in older adults. Thus, we did not adjust for body height in the logistic regression analysis. The logistic regression analysis

of the three models revealed that DWS was significantly associated with frailty. Therefore, we believe that DWS is an important factor associated with frailty.

From examining the discriminability of DWS for frailty by ROC analysis, the 95% confidence interval of the AUC exceeded 0.5, and the association between DWS and frailty was statistically significant. Although the AUC of 0.664 in this study was not very high, previous studies reported an AUC of 0.567,[13] where the association between DWS measured by the accelerometer and pre-frailty was examined, and 0.643 [10] and 0.516,[24] where the discriminability of LWS to pre-frailty was examined, suggesting that the AUC in this study was similar to or better than that in those studies. LWS is used to measure the frailty in the CHS criteria.[15] Our results suggest that DWS can be used as a criterion for frailty. Following a method of combining DWS and the number of steps to improve the detection accuracy of pre-frailty proposed in a previous study,[13] we also adjusted the number of steps and other covariates and found that the AUC increased slightly to approximately 0.7. The sensitivity and specificity of DWS for detecting frailty were 55.2% and 83.5%, respectively. Although the sensitivity of frailty detection was not very high, such additional items increased the discriminability of DWS for frailty.

Limitations

This study has some limitations. The participants were not randomly selected but were those who could use a smartphone and were interested in frailty prevention and health promotion. However, since the participants did not have to go to the designated place and could answer the KCL through the application, this study included participants with frailty with a prevalence similar to that in the community.

DWS varies according to sex and age.[11] However, subgroup analysis could not be conducted in this study because of the small number of participants with frailty. An analysis stratified for sex and age will be necessary in the future. Since DWS was measured using an

application based on GPS, it was limited to outdoor measurements. Further studies are needed on the association between DWS measured indoors and frailty. It may be necessary to maintain cognitive function to measure DWS and assess frailty using a smartphone application; however, cognitive function was not measured in this study. Since this study had a cross-sectional design, the predictability of DWS for future frailty occurrence is unclear. Future studies, including more representative large samples, are needed.

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Competing Interest Statement

This study was funded by Asahi Kasei Homes Corporation. There are no other conflicts of interest to declare.

Author Contribution

Hisashi Kawai: Conceptualization, Methodology, Visualization, Investigation, Writing-Original draft

Shuichi Obuchi: Conceptualization, Writing - Review & Editing, Supervision, Project administration.

Manami Ejiri: Data Curation, Writing - Review & Editing

Kumiko Ito: Visualization, Investigation, Writing - Review & Editing

Data sharing statement

The datasets analysed in this study are not publicly available due to intellectual property rights, but are available upon reasonable request.

Ethics Approval

This study was approved by the ethics committee of the Tokyo Metropolitan Institute of Gerontology (approval number: 2020-5). The study was conducted in accordance with the tenets of the Declaration of Helsinki.

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FIGURE LEGENDS

Figure 1. Flowchart of the study participation

Figure 2. Receiver operating characteristic curve of DWS for frailty

DWS: daily living walking speed; AUC: area under the curve; Model 2: Adjusted for the number of steps, age, sex, and the number of chronic diseases

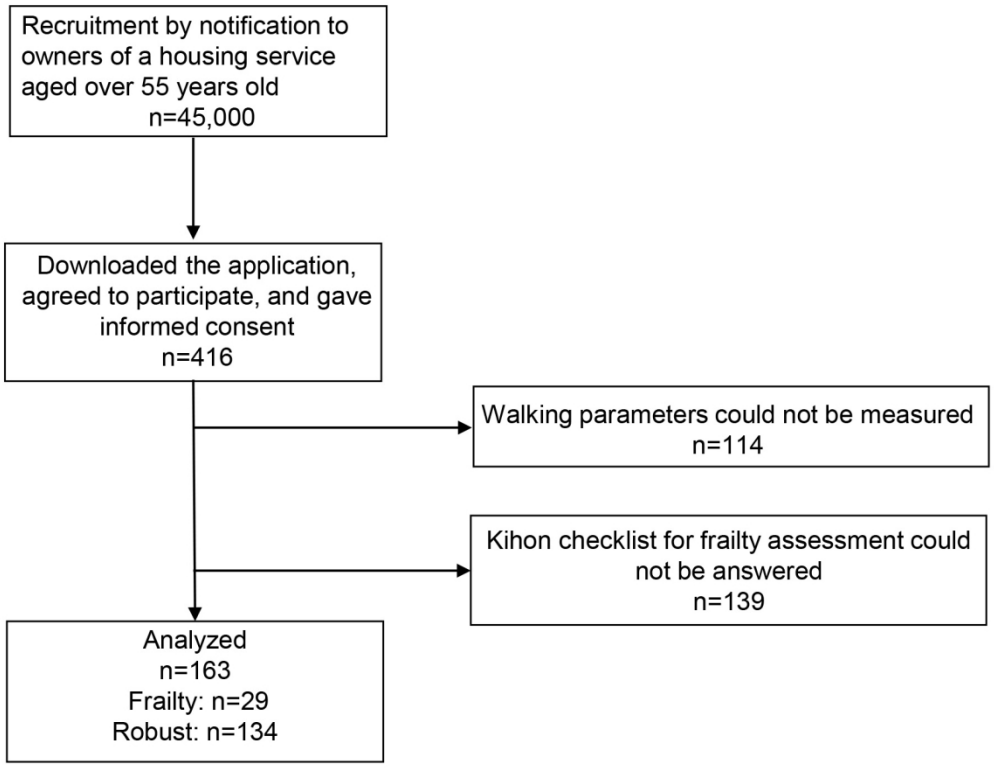
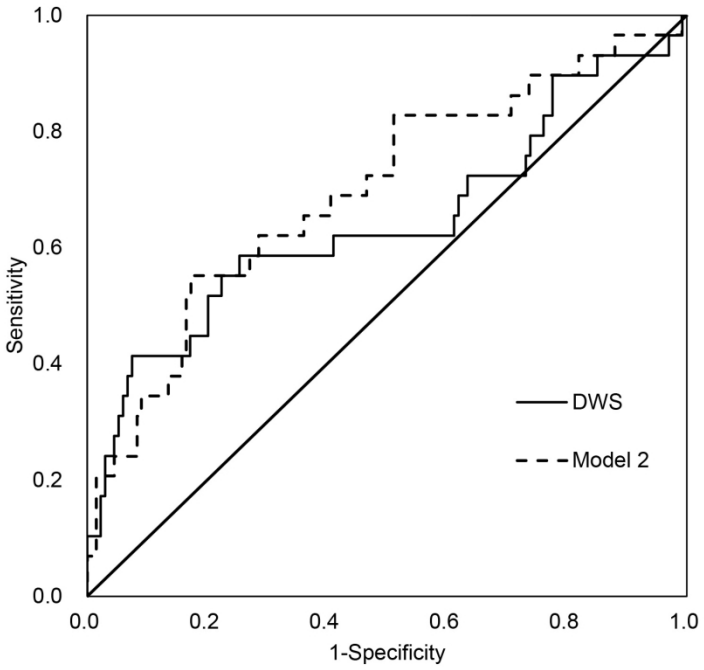


Figure 1

152x117mm (300 x 300 DPI)



	Cut-off (m/s)	Sensitivity	Specificity	AUC	95% confidence interval	
DWS	< 1.11	41.4%	92.5%	0.644	0.514	0.774
Model 2	-	55.2%	83.5%	0.697	0.584	0.810

Figure 2

179x157mm (300 x 300 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	NA
		(*c*) Explain how missing data were addressed	NA
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	NA

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	Figure 1
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	NA
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	Table 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 2
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14-15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	11-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Association Between Daily Life Walking Speed and Frailty Measured by a Smartphone Application: A Cross-Sectional Study

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ABSTRACT

Objectives: To assess whether frailty can be assessed using a smartphone and whether daily walking speed (DWS) is associated with frailty.

Design: Cross-sectional study

Setting: Three prefectures (Kanagawa, Saitama, and Tokyo) in Japan

Participants: The study enrolled 163 participants (65 in the robust group, 69 in the pre-frailty group, and 29 in the frailty group) by sending letters to house owners aged ≥55 years.

Primary and Secondary outcome measures: The participants downloaded the DWS measurement application on their smartphones, which measured the daily walking (DW) parameters (DWS, step length, and cadence) and the Kihon checklist for frailty assessment. The differences in the DW parameters between the robust, pre-frailty, and frailty groups were examined using one-way analysis of variance. We conducted logistic regression analysis for the Crude model (each DW parameter), Model 1 (adjusted for the number of steps), and Model 2 (Model 1 + age, sex, and the number of chronic diseases).

Results: DWS was marginally significantly slower in the frailty group than in the pre-frailty and robust group (robust 1.26 m/s vs pre-frailty 1.25 m/s vs frailty 1.19 m/s, P=0.060). Step length was significantly smaller in the frailty group than in the robust group (robust 66.1 cm vs pre-frailty 65.9 vs frailty 62.3 cm, P<0.01). Logistic regression analysis for the three models revealed that DWS was significantly associated with frailty.

Conclusions: DWS measured using the smartphone application was associated with frailty. This was probably due to the shorter step length and body height seen in frail individuals.

Keywords: cross-sectional study; daily life walking speed; frailty; Kihon checklist; smartphone

Strengths and limitations of this study

- The participants accessed the website for the smartphone application using the QR code printed on the invitation letter and downloaded the daily walking speed (DWS) measurement application on their smartphones.
- Unlike previous studies, frailty in this study was assessed using a web-based smartphone application, and frail participants were included.
- The participants did not have to go to a designated place and could answer the Kihon checklist through the application.
- However, the participants were not randomly selected but were those with access to a smartphone and those interested in frailty prevention and health promotion.
- In addition, DWS was limited to outdoor measurements as the application was based on GPS.

INTRODUCTION

Walking speed is closely associated with many health outcomes and predicts dependency and death in older individuals.[1,2] A meta-analysis showed that decreased walking speed is associated with the incidence of cardiovascular diseases and associated mortality.[3] Based on these studies, walking speed is recognised as the sixth vital sign, following blood pressure, pulse, respiration, temperature, and pain.[4] Usual walking speed has been often measured by recording the time required to walk a certain distance using a stopwatch in the previous studies. This method can measure the walking speed easily and accurately and has been used in several studies; however, concerns have been raised since the participants are required to come to a specific measurement site, and they can intentionally change their walking speed.

Recent studies have measured daily walking speed (DWS) using wearable accelerometers and smartphone applications.[5-9] If DWS can be used for health assessment in a manner similar to the conventional 'laboratory walking speed (LWS)', such daily measurements can be used for the early detection of health risks, continuous health assessment, and health promotion. However, the measurement of DWS is not well-established, and its definition differs depending on the study, with variations in factors such as differences in sensor type used for measurement (accelerometer vs GPS), range of days for measurement (14 days vs 1 week), and representative value (average vs percentile). In addition, previous studies on DWS have only shown the relationship between average[6,10] or percentile values of DWS[8,9] and LWS, minimal detectable change in 95% (MDC95) of average of DWS[7], and age-sex reference values for average DWS,[11] and only a few studies have investigated the association between DWS and health outcomes.

Recent studies have reported an association between DWS and pre-frailty.[12,13] Frailty is a state in which vulnerability increases owing to ageing, and the risk of dependency and death increases.[14] The prevention of frailty is extremely important for maintaining the

health of older individuals. However, few studies on DWS have examined the association between DWS and frailty. Kawai et al.[12] used the Japanese version of the Cardiovascular Health Study (CHS) criteria, which comprises five domains (weight loss, weakness, slowness, exhaustion, and low activity) to assess frailty;[15] however, participants corresponding to frailty were not included in the study. Takayanagi et al.[13] used the Kihon checklist (KCL),[16] which comprises 25 questions to assess frailty; however, participants with frailty were excluded from the study. These studies, which recruited participants from a cohort study involving community-dwelling older adults and measured DWS using a smartphone application or an accelerometer, could not include frail participants because the participants were required to go to the survey venue or designated location for collecting and uploading the data, which may be difficult for frail participants. Solftani et al.[17] recently reported the discriminability of DWS for frailty; however, the frailty definition included only the body mass index and handgrip strength and was limited to weight loss and weakness.

We customised the DWS application for examining certain health indicators by using a chatbot to measure frailty without going to a designated location. This study aimed to examine whether frailty can be assessed using this application and elucidate the association between DWS and frailty.

METHODS

Participants

This cross-sectional study was conducted in three prefectures, Kanagawa, Saitama, and Tokyo, in Japan. These are neighbouring prefectures, and the environmental characteristics of the regions are similar. The participants were recruited by sending letters to house owners aged 55 years or older who lived in a house provided by a housemaker. The housemakers

solicited their participation in the research, which aimed at promoting frailty prevention using the smartphone application. The letters were sent twice to recruit as many participants as possible. The participants accessed the download site using the QR code printed on the invitation letter and downloaded the DWS measurement application on their smartphones after reading the study documentation displayed on the site and consenting to participate in the study. The application was limited to Android smartphones. Individuals were included in this study if they habitually used a smartphone, could walk independently, and were not recommended restricted physical exercises by a doctor. We did not examine whether participants received help downloading or operating the application. The sample size was planned to be n = 34 for frailty group and n = 100 for pre-frailty and robust group, assuming that the ratio of frailty to pre-frailty and robust is 1: 3 with effect size d = 0.5 and a power of 0.8.

Between August 2020 and January 2021, 416 participants downloaded the application. Among them, 163 participants who could measure DWS and frailty were included in the analysis (Figure 1).

Patient and Public Involvement

No patient involved.

Measurement of Daily Walking Parameters

Daily walking (DW) parameters, such as walking speed, step length, and cadence during daily life, were measured using a smartphone application (Chami, InfoDeliver Co. Ltd., Tokyo, Japan). The application automatically measured DWS in a manner imperceptible to the participants. The walking start time was determined by the pedometer application programming interface (API) response in the smartphone operating system and geomagnetic sensors installed in the smartphone. A stable walking trajectory was detected from position information acquired by the smartphone GPS during walking using the linear least squares

method (patent number: WO2016043081).[7] When the pedometer API and GPS detected a stable walking trajectory ≥20 m, the walking speed was measured until interrupted. The use of GPS implied that measurements were limited to outdoor walking. GPS measurements may be difficult to obtain because of buildings and terrain types, including outdoors. However, this problem was overcome using all positions measured by the GPS during walking and using the average value of walking speed measured multiple times a day, rather than using only the beginning and ending positions.

Although walking speed in daily life can change depending on the environment and situation of walking; however, in our previous study,[11] we showed that walking speed measured using this application multiple times in daily life has a single-peaked normal distribution. Therefore, we defined the average of the walking speed measured in daily life as DWS and reported on the excellent test-retest reliability of DWS.[7] This application was used in a study on the changes in walking behaviour due to the coronavirus disease pandemic [18] and a study on seasonal changes in DWS.[19]

The application can measure the DW step length and cadence from the number of steps on the step counter in addition to walking speed. We defined the average values during the measurement period as DWS, DW step length, and DW cadence. The DW step length modified by body height was also calculated. The MDC95 for DWS, DW step length, and DW cadence in our previous study[7] was 0.101 m/s, 5.662 step/min, and 3.498 cm, respectively.

Frailty Assessment

Frailty was assessed using KCL, which consists of 25 questions and has been validated using the Japanese version of the CHS criteria for frailty assessment.[16] The KCL is a simple yes/no questionnaire that assesses multiple aspects of physical, oral, cognitive, and psychosocial functions. Total KCL score was significantly associated with pre-frailty and

frailty based on the CHS criteria in the previous study. Further, this study showed that pre-frailty and frailty by KCL can predict the incidence of 3-year dependency and mortality in older adults.[16] According to the study, scores of ≥8, 4–7, and 0–3 were evaluated as frail, pre-frailty, and robust, respectively.

In this study, the text of each question in KCL was displayed in the chatbot programme of the application, and the participants responded by pressing the 'Yes' or 'No' buttons.

Other Measurements

The participants self-reported their height, weight, history of chronic disease (high blood pressure, diabetes, stroke, cancer, and heart disease), hip and knee pain complaints, self-rated health (very healthy, healthy enough, not very healthy, and not healthy), psychological well-being (WHO-5 Well-Being Index [WHO-5]),[20] dietary variety score (DVS),[21] and Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC).[22] These questions were also displayed in the chatbot programme, and the participants answered them through the programme.

The WHO-5 is a five-question psychological well-being index; the participants selected one of the five options: 0, no time; 1, some of the time; 2, less than half the time; 3, more than half the time; 4, most of the time; and 5, all of the time (total score range: 0–25 points). A higher score reflected better psychological well-being. DVS covers 10 food groups (fish and shellfish, meat, eggs, milk, soybean/soybean products, green and yellow vegetables, potatoes, seaweeds, fruits, and fats and oils). One point was added for consuming items from the food groups almost every day (total score range: 0–10 points). A higher score reflected a more diverse food intake. TMIG-IC is an index of higher functional capacity, consisting of 13 items (0–13 points). A higher score reflected higher functional capacity.

Statistical Analysis

The differences between the robust, pre-frailty, and frailty groups for all variables were examined using one-way analysis of variance for continuous variables and the chi-square test for categorical variables. We conducted logistic regression analysis using the pre-frailty and robust vs frailty as the dependent variable. We examined the Crude model (each DW parameter), Model 1 (adjusted for the number of steps), and Model 2 (Model 1 + age, sex, and the number of chronic diseases) to assess the associations between each DW parameter and frailty. SPSS 27.0 J (IBM Japan, Ltd., Tokyo, Japan) was used for all statistical analyses, and the significance level was set at 5%.

RESULTS

The mean age [standard deviation (SD), range] of the participants was 72.1 [6.85, 57–93] years. There were 163 participants in the study, with 65 participants in the robust group, 69 in the pre-frailty group, and 29 in the frailty group (Table 1). Height, weight, history of stroke, knee pain complaints, self-rated health, KCL, WHO-5, and DW step length had a significant main effect between the robust, pre-frailty, and frailty groups.

Table 1. Characteristics of the participants

	(A) Robust (n=65)			(B) Pre-frailty (n=69)			(C) Frailty (n=29)			
	n	(%)		n	(%)		n	(%)		P^a
	n	Mean	SD	n	Mean	SD	n	Mean	SD	
Sex (female)	24	(36.9)		21	(30.4)		14	(48.3)		0
Age (years)	65	70.5	5.67	69	73.2	6.87	29	72.6	8.62	0.242
Height (cm)	59	162.7	6.93	67	163.5	7.28	27	158.3	8.72	**0.009**
Weight (kg)	58	59.8	8.96	68	59.8	8.11	26	54.8	10.13	**0.031**
Chronic disease										
Hypertension	23	(35.9)		23	(33.3)		13	(44.8)		0.556
Diabetes	11	(17.2)		8	(11.6)		3	(10.3)		0.549
Stroke	0	0.0		0	0.0		2	(6.9)		**0.010**
Cancer	7	(10.9)		5	(7.2)		3	(10.3)		0.745
Heart disease	7	(10.9)		6	(8.7)		2	(6.9)		0.805
Hip pain	23	(35.9)		22	(31.9)		10	(34.5)		0.883
Knee pain	9	(14.1)		16	(23.2)		11	(37.9)		**0.036**
Self-rated health										**0.001**
Very healthy	8	(12.5)		7	(10.1)		1	(3.4)		
Healthy enough	52	(81.3)		53	(76.8)		16	(55.2)		
Not very healthy	3	(4.7)		8	(11.6)		8	(27.6)		
Not healthy	1	(1.6)		1	(1.4)		4	(13.8)		
Health assessment										
KCL	65	1.9	1.01	69	5.3	1.04	29	10.6	2.40	**<0.001**
WHO-5	54	18.2	3.65	56	15.6	4.73	20	11.7	4.01	**<0.001**
DVS	32	5.5	1.95	23	4.9	1.93	11	4.8	1.72	0.388

TMIG-IC	35	12.3	1.05	29	11.8	0.83	11	11.7	1.01	0.062
Daily walking parameters										
DWS (m/s)	65	1.27	0.12	69	1.25	0.14	29	1.19	0.21	0.060
DW step length (cm)	65	66.4	5.26	69	65.9	5.74	29	62.3	8.35	**0.009**
DW step length / Height (%)	59	40.8	2.58	67	40.4	3.42	27	39.8	4.13	0.397
DW cadence (step/min)	65	115.1	7.34	69	114.5	7.61	29	114.6	8.69	0.913
Number of steps (steps/day)	65	2427.1	1815.08	69	2699.5	2799.45	29	2810.6	2416.51	0.710
Number of measurements	65	1468.7	1361.74	69	1478.8	1683.49	29	1290.7	1170.59	0.832

KCL: Kihon Checklist; DVS: Dietary Variety Score; TMIG-IC: Tokyo Metropolitan Institute of Gerontology Index of Competence; DW: Daily life Walking, DWS: Daily life Walking Speed

[a] One-way analysis of variance or Chi-square test. Number in bold indicate statistically significance ($P<0.05$).

The participants in the frailty group were significantly shorter in height and lighter in weight than those in the pre-frailty and robust groups (P<0.01). Further, the participants in the frailty group had a significantly higher frequency of stroke history (P<0.01) and knee pain complaints (P<0.05) than those in the pre-frailty and robust groups. Compared with the pre-frailty and robust groups, the proportion of those who were not very healthy and not healthy per the self-rated health was significantly higher in the frailty group (P<0.001). WHO-5 score was significantly lower in the frailty group than in the pre-frailty and robust groups (P<0.001). The DW step length was significantly smaller in the frailty group than in the robust group (P<0.01). DWS tended to be slower in the frailty group than in the pre-frailty and robust groups (P=0.060). No significant differences in DW step length modified by body height were observed between the frailty and robust groups. Logistic regression analysis for all three models (Crude model, Model 1, and Model 2) revealed the same tendencies: DWS and DW step length were significantly associated with frailty (Table 2).

Table 2. Logistic regression analysis with frailty as the dependent variable and each DW parameter as independent variables

	Crude model		Model 1		Model 2	
	OR	95% CI	OR	95% CI	OR	95% CI
DWS (m/s)	**0.024**	0.001 - 0.571	**0.012**	0.000 - 0.368	**0.022**	0.001 - 0.784
DW step length (cm)	**0.902**	0.842 - 0.967	**0.895**	0.832 - 0.962	**0.907**	0.841 - 0.978
DW cadence (step/min)	0.997	0.946 - 1.051	0.994	0.941 - 1.050	0.999	0.941 - 1.061

OR: odds ratio; CI: confidence interval; DW: daily life walking; Model 1: Adjusted for the number of steps; Model 2: Model l + adjusted for age, sex, and the number of chronic diseases

* Numbers in bold font are statistically significant (P<0.05).

DISCUSSION

This study examined whether DWS is associated with frailty using a smartphone application. Since some previous studies on DWS could not include a sufficient number of participants with frailty, only the association with pre-frailty was reported. However, in this study, frailty was assessed using a web-based smartphone application, and frail participants were included. The results showed that the DW step length was smaller, and DWS tended to be lesser in the frailty group compared with the robust group.

The study participants were house owners residing in houses provided by a private housemaker. This housing service provides an urban detached house, suggesting that the residents may be those whose socioeconomic statuses were higher than those of community-dwelling older adults. Additionally, the participants were those who could use a smartphone since they could access the QR code. In our previous study, we found that smartphone-based study participants were younger, had a higher physical function, and were healthier than non-participants.[10] Only 0.9% of the 45,000 participants who downloaded the application received an invitation letter. The number of individuals who read the study document in the letter may have been even fewer. The participants should be interested in health information.

However, the mean age of the participants in this study, which included 29 (17.8%) frail participants, was not significantly different from that of the participants in the community cohort. To recruit more participants, this study invited people aged ≥55 years. Although participants under 60 years were included in the analysis, there were only two participants aged 57 and 59. Therefore, almost all participants were older individuals. A previous study in which frailty was assessed using KCL, similar to that in this study, from a

large cohort of more than 5,000 community-dwelling older individuals, reported that the prevalence of frailty was 17.2%, which was also similar to that in this study.[16] In addition, the DWS (1.25 m/s) in this study was not significantly different from that reported in the previous study (1.28 m/s), measured using a smartphone application in the community cohort.[10] Therefore, the participants of this study probably had good socioeconomic status and could use a smartphone; however, these participants were considered similar to those recruited from the community from the frailty and DWS perspectives.

KCL is usually examined using a self-administered questionnaire. In this study, the participants entered KCL using a smartphone application, and frailty was assessed from the recorded data. As described above, since the prevalence of frailty in this study was similar to that of a previous study in which frailty was assessed using a self-administered questionnaire in the community cohort, we believe that frailty can be assessed using a smartphone application.

Additionally, there was a significant difference between the robust, pre-frailty, and frailty groups in height, weight, history of stroke, knee pain complaint, self-rated health, KCL, and WHO-5, indicating a reasonable result that reflects frailty. However, statistical differences in DVS and TMIG-IC reported to be associated with frailty [21] and decline with age [23] were not found between the groups. KCL consists of 25 items. Although there were more items than in other questionnaires, KCL items were asked in the first half of the conversation with the chatbot, and priority was given to assessing frailty. However, there were many questions, such as the 10 items for DVS and 13 items for TMIG-IC, which were asked in the latter half of the conversation. Consequently, the number of participants who responded to the questionnaire was lower than those who provided KCL information. This lack of statistical power might explain why no statistical differences were observed in DVS and TMIG-IC between the robust and frailty groups. Thus, future research with a larger

number of participants is required. Overall, we believe that the frailty assessment in this study using the application would be appropriate.

DWS tended to be slower in the frailty group than those in the pre-frailty and robust groups; however, the difference was not statistically significant. In contrast, the DW step length was significantly smaller in the frailty group than those in the pre-frailty and robust groups. The significantly smaller DW step length in the frailty group could decrease the DWS in the frailty group; however, the difference in DWS between the robust and frailty groups was 0.08 m/s, which was smaller than 0.101 m/s for MDC95 of DWS.[7] Therefore, the statistical power in this study may be slightly insufficient to detect this difference. Additionally, since the DW step length modified by body height was similar between the groups, the difference in the DW step length between the groups must be caused by the difference in body height. However, body size is one of the unmodifiable features of frailty in older adults. Thus, we did not adjust for body height in the logistic regression analysis. The logistic regression analysis of the three models revealed that DWS was significantly associated with frailty. Therefore, we believe that DWS is an important factor associated with frailty.

Limitations

This study has some limitations. The participants were not randomly selected but were those who could use a smartphone and were interested in frailty prevention and health promotion. The participation rate has been low since the application was limited to Android smartphones. Participation in this study might have been biased toward healthy individuals rather than being representative of community-dwelling older adults. However, since the participants did not have to go to the designated place and could answer the KCL through the application, this study included participants with frailty with a prevalence similar to that in the community.

DWS varies according to sex and age.[11] However, subgroup analysis could not be conducted in this study because of the small number of participants with frailty. An analysis stratified for sex and age will be necessary in the future. Since DWS was measured using an application based on GPS, it was limited to outdoor measurements. Further studies are needed on the association between DWS measured indoors and frailty. It may be necessary to maintain cognitive function to measure DWS and assess frailty using a smartphone application; however, cognitive function was not measured in this study. We also did not examine other possible covariates that may affect DWS, such as visual impairment, fear of falling, and walking aids. Since this study had a cross-sectional design, the predictability of DWS for future frailty occurrence is unclear. Future studies, including more representative large samples, are needed.

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Competing Interest Statement

This study was funded by Asahi Kasei Homes Corporation. There are no other conflicts of interest to declare.

Contributors

HK contributed to the Conceptualization, Methodology, Visualization, Investigation, Writing-Original draft. SO contributed to the Conceptualization, Writing - Review & Editing, Supervision, Project administration. ME contributed to the Data Curation, Writing - Review & Editing. KI contributed to the Visualization, Investigation, Writing - Review & Editing.

Data sharing statement

The datasets analysed in this study are not publicly available due to intellectual property rights, but are available upon reasonable request.

Ethics Approval

This study was approved by the ethics committee of the Tokyo Metropolitan Institute of Gerontology (approval number: 2020-5). The study was conducted in accordance with the tenets of the Declaration of Helsinki.

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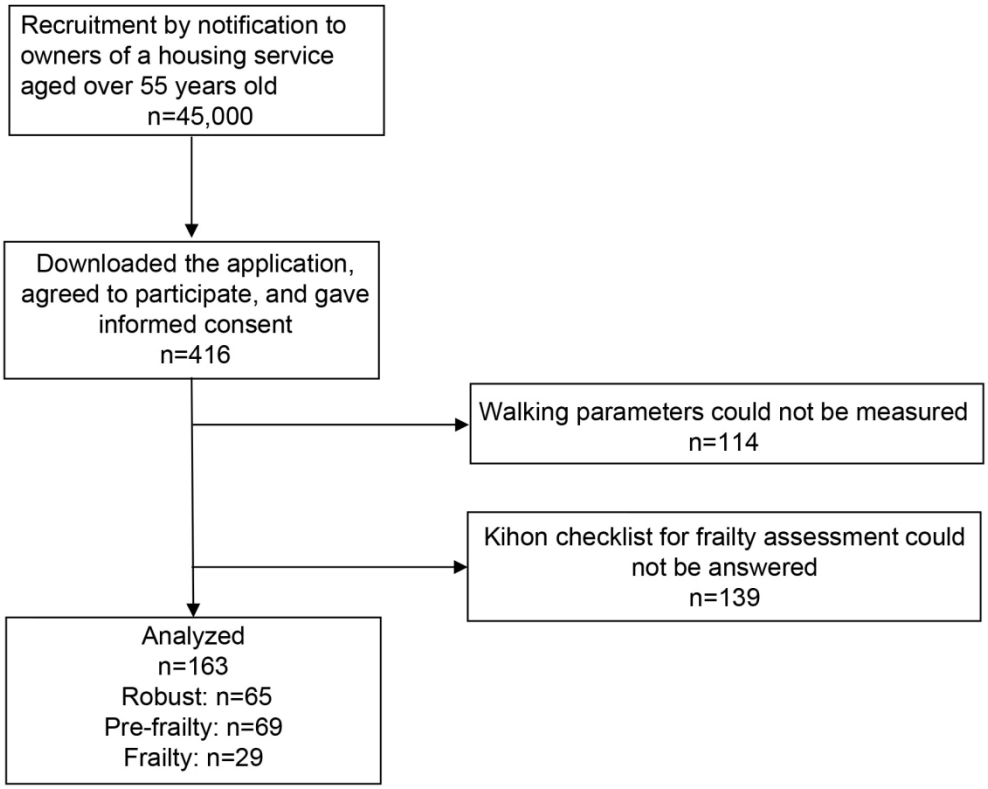
FIGURE LEGENDS

Figure 1. Flowchart of the study participation



153x123mm (300 x 300 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	NA
		(*c*) Explain how missing data were addressed	NA
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	NA

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	Figure 1
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	NA
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	Table 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 2
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14-15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	11-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.