Medical Engineering and Physics 68 (2019) 116–121

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Communication

Unintentional body movement parameters and pulse rate variability parameters are associated with the desire to void

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ARTICLE INFO

Article history:
Received 25 April 2018
Revised 22 March 2019
Accepted 31 March 2019

Keywords:
Gerontechnology
Load cells
Patient monitoring
Unconstrained measurement

ABSTRACT

Urinary incontinence is highly prevalent in elderly populations with physical and cognitive impairment. For the assessment and care of urinary incontinence, the desire to void is important. We have developed a bed sensor system that non-invasively and unconstrainedly measures the parameter changes of unintentional body movements. This study is aimed to evaluate the validity of measurement by the sensor system and parameters in healthy adults. We conducted experiments on 29 healthy adult volunteers. The parameters were unintentional body movement derived from changes in center of gravity and pulse rate variability (PRV) based on pulse wave measurements using a finger probe; further the relationship between the desire to void and measured parameters were examined. The body movement parameters at the buttock and thigh were associated with the desire to void ($p < 0.050$). All the PRV parameters trended significantly with desire to void as well ($p < 0.050$). The parameters achieved sensitivities of 0.18–0.88 in estimating strong desire to void, and 7 among 14 sensitivity measurements included in the receiver operating characteristic analysis exceeded 0.70. The body movement parameters and PRV parameters were useful in the estimation of the desire to void in healthy adults. To achieve accurate estimation, a combination of the PRV parameters and body movement parameters is required.

1. Introduction

Urinary incontinence is prevalent in elderly populations, with 25% of community dwelling elderly and 59% of nursing home residents reportedly exhibiting symptoms of urinary incontinence [1,2]. Urinary incontinence is a risk factor of adverse events such as falls among people with dementia [3]. Urinary incontinence is also related to decreased quality of life [4–6]. Further, severe urinary incontinence is related to increased dementia symptoms [7]. Thus, the continence care of elderly persons with cognitive impairment is important. When providing care, not only the cognitive condition but the physical condition, such as mobility should be considered [8]. Prompted voiding is effective in such people [9,10].

Moreover, ultrasound-assisted prompted voiding, in which the bladder volume of a person is regularly monitored using an ultrasound device, and the person is prompted to void based on bladder volume, is shown to be effective in decreasing diaper use in nursing home residents [11]. Therefore, prompted voiding combined with bladder volume measurement is a promising strategy for decreasing urinary incontinence. Moreover, wearable ultrasonic bladder volume measurement devices are now commercially available [12–14]. These devices will enable precise measurements and promote personalized continence care in elderly persons.

The desire to void is more important than bladder volume in the assessment and care of elderly persons with urinary incontinence [8]. Sensor systems for bladder volume measurement can be used for the estimation of the desire to void. However, the applications of those systems to date have involved wearable-type sensors. Considering the clinical applications in the care of elderly persons, wearable-type sensors are not suitable because sensors in

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https://doi.org/10.1016/j.medengphy.2019.03.019
1350-4533/

continuous contact with the skin around the lower abdomen can be uncomfortable. Moreover, they can cause skin disorders for elderly people having fragile skin.

Thus, we focused on the measurement of the desire to void, using a mattress and bed as the measurement device, as that is where elderly people with physical and cognitive impairments tend to spend most of their time. For estimating the desire to void, we focused on unintentional body movements and pulse rate variability (PRV).

In previous studies, body movements were employed for predicting bed leaving [15], the moment when participants can no longer endure the desire to void. The body movements that they focused on were intentional and large; therefore, they could only find the changes in body movement immediately before leaving the bed. The relationship between the desire to void and unintentional changes in movements has been suggested [16]; therefore, we hypothesized that unintentional body movements would reflect the desire to void.

Generally, heart rate variability (HRV) is a parameter that reflects the activity of the autonomic nervous systems (ANS). The relationship between the desire to void and activities of the ANS evaluated by HRV has been suggested, and HRV is used for assessing the ANS activity in healthy adults and people with overactive bladder syndrome or stress urinary incontinence [17–19]. Thus, HRV parameters can be suitable for the estimation of a desire to void. However, a precise HRV analysis requires electrocardiogram (ECG) recordings using electrodes attached to a person's body. Considering the future application as a bed sensor system, a precise ECG recording is difficult [20,21]; however, a heartbeat can be detected as a slight force or pressure changes. Unfortunately, no mattress-embedded systems can accurately detect heartbeat signals; therefore, in this study, the PRV parameters computed from photo plethysmography (PPG) signals, which have been shown to be highly correlated with HRV parameters in healthy adults and moderately correlated in cardiovascular disease patients [22], were employed to estimate ANS activity instead of HRV.

The ultimate goals of this research are to develop a bed sensor system that non-invasively and unconstrainedly estimates the desire to void of bedridden elderly patients, and to provide a continence care strategy based on information from the sensor system. In this study, the first step of the project is reported. This study aims to explore and validate body movements and PRV parameters for the estimation of the desire to void among healthy people who can express their desire to void.

2. Methods

2.1. Bed sensor system

The bed sensor system consists of five force sensor units (Fig. 1) [23]. Two types of sensor units were employed, one was the Wii Balance Board™ (Nintendo, Kyoto, Japan), and the other was a new custom-built sensor unit. The Wii Balance Board™ can be used for the continuous force and location measurements of the center of gravity. Three Wii Balance Boards™ and two new sensor units were used.

The new sensor unit consists of a rectangle aluminum frame and four load cells (LMB-A-1KN, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan), one under each corner of the frame. The load cell measures the vertical force, and the capacity is 1 kN. The force data acquired by Wii Balance Board™ and the new sensor units were recorded at sampling rates of 100 and 5 Hz, respectively. The two types of sensors were employed to precisely measure force changes around the torso and buttocks (custom-built load cell unit) and body movements at a high sampling rate (Wii Balance Board™).

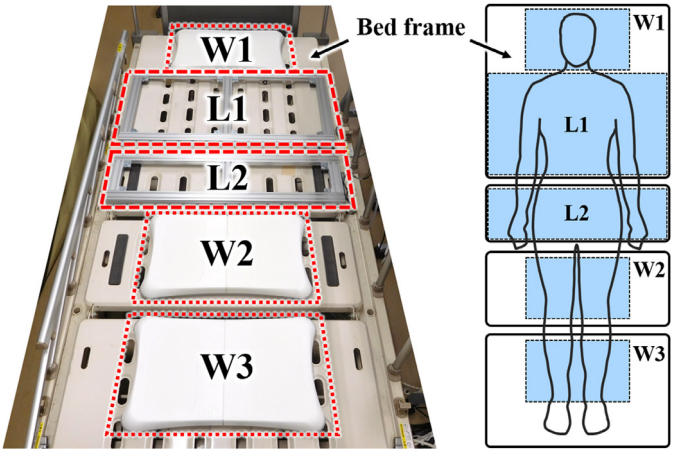

Fig. 1. The newly developed bed sensor system. The sensor system consists of three Wii Balance BoardsTM (W1/W2/W3) and two newly developed load cell units (L1/L2), which correspond to five body parts. The sensor system was placed on the bed frame, and a mattress was placed on the sensor system.

2.2. Protocols

Twenty-nine volunteers aged 20 to 65 years with no urologic diseases were recruited. Before the experiments, the presence of overactive bladder syndrome, which affects the sensation of the desire to void, was assessed with an overactive bladder symptom score (OABSS) [24]. The OABSS assesses four domains (daily micturition, nocturia, urinary urgency, and urge urinary incontinence) and consists of four questions corresponding to the domains whose maximum scores are 2, 3, 5, and 5, respectively. The diagnostic criteria for an overactive bladder are more than two points for urinary urgency and a total score of more than three points.

Participants were instructed to not eat for 2 h before an experiment, and not drink or use the bathroom for 1 h before the experiment, to prevent them from having the desire to defecate and eliminate the effect of digestive tract movement, although water intake 1–2 h before the experiment was recommended to generate sufficient urine during the measurements.

Measurements were conducted twice; with/without feeling the desire to void (measurements 1 and 2). In both measurements, participants were instructed to lie on a bed in the supine position with sensors attached. During the measurements, the participants were instructed not to change their posture. In measurement 1, participants were instructed to endure their desire to void until they felt the maximum desire to void (a score of 10 on the scale described below). Measurement 1 was completed in 2 h even if a participant did not feel the maximum desire to void. After measurement 1, participants emptied their bladders and the volume of voided urine was measured.

Subsequently, the participants were again instructed to lie on the bed, and sensor data was recorded for 30 min (measurement 2). They were asked to again empty their bladders and the voided volume was measured.

2.3. Data acquisition

During the measurements, the participants' physiology data were continuously recorded. The desire to void was measured with a 0.0 (no desire to void) to 10.0 (maximum desire to void) scale, similar to a visual analogue scale (VAS). Each participant held a slider potentiometer in his/her right hand and was instructed to use the sensor to report his/her desire to void (Fig. 2). They were instructed to freely change the slider position higher or lower whenever they felt a stronger or weaker desire to void. The sensor

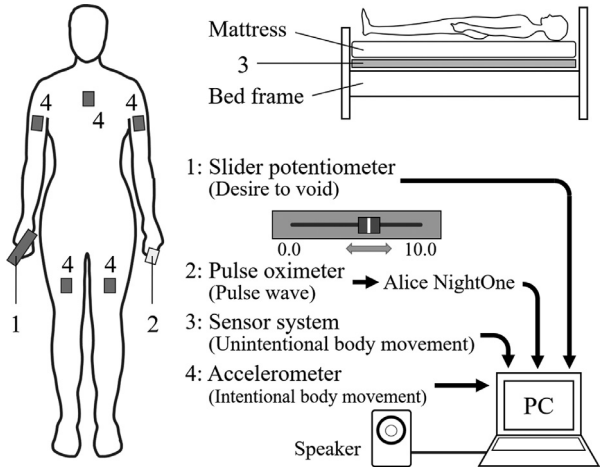

Fig. 2. Experimental settings. Participants' physiological data were acquired by multiple sensors. A slider potentiometer was used for participants to report their desire to void. When a participant changed the slider position, the newly changed value was automatically reported from a speaker for the participant to hear.

used in the experiments automatically reported the current value from a speaker when a participant changed the slider position, to enable the participant to report the level of their desire to void without moving their body. The level of the desire to void was recorded at a sampling rate of 3.95 Hz. VAS was used in cystometry for the participants to report their bladder sensations, and demonstrated a good correlation with a few standard bladder sensation parameters [25]. Moreover, VAS-like sensor systems have demonstrated their usefulness in assessing the desire to void [26].

Unintentional body movements were measured using the new bed sensor system to provide force data, which were used in body movement analysis.

Pulse waves were acquired using a medical device, Alice NightOne (Philips Respironics Inc., Murrysville, PA), which was designed for home sleep testing. The SpO_2 probe (PureLight® Soft Sensor, Nonin Medical Inc., Plymouth, MN) of the device was attached to the participant's left forefinger, and the pulse wave was recorded at a sampling rate of 100 Hz. The pulse wave data were used in the PRV analysis.

Intentional body movements such as turn-over and limb movements were also measured as orientation changes of each body part, to verify that the participants followed the protocol and avoided gross changes to their posture. The orientation changes were measured using five accelerometers (ADXL345, Analog Devices, Inc., Norwood, MA) attached on the chest and both the upper arms and thighs. The sampling rate of the accelerometers was 16.3 Hz.

2.4. Parameters

2.4.1. Unintentional body movement

The changes in center of gravity on the five force sensor units were used as unintentional body movement parameters, which were calculated as follows: Compute the center of gravity of each force sensor unit, X axis in the left-to-right direction ($g_x(t)$), and Y axis in the head-to-foot direction ($g_y(t)$) at time point t:

$$\boldsymbol{g}(t) = (g_x(t), g_y(t)). \tag{1}$$

Calculate the time differentials of $\boldsymbol{g}(t)$:

$$\frac{d}{dt}\boldsymbol{g}(t) = \left(\frac{d}{dt}g_x(t), \frac{d}{dt}g_y(t)\right) \tag{2}$$

For successive 10 s windows, the mean and standard deviation (SD) of the differential coefficients of the x and y coordinates were calculated. Values between mean–2SD and mean+2SD were considered as noise, and they were excluded from further calculations. For each 10 s window, the differential coefficients of the x and y coordinates of $\boldsymbol{g}(t)$ were each squared, and the sum of the squares were calculated to provide the following three body movement parameters:

$$x : \sum\left(\frac{d}{dt}g_x(t)\right)^2, y : \sum\left(\frac{d}{dt}g_y(t)\right)^2,$$
$$\text{total} : \sum\left(\frac{d}{dt}g_x(t)\right)^2 + \sum\left(\frac{d}{dt}g_y(t)\right)^2. \tag{3}$$

The body movement parameters were normalized by the following calculation, because they varied among the participants, where the mean and SD are across all participants:

$$normalized\ param = \frac{param - mean}{SD}. \tag{4}$$

2.4.2. Pulse rate variability

Frequency domain analyses of peak-to-peak intervals were performed on the pulse wave recorded by the SpO_2 probe at the fingertip, in addition to determining the pulse rate. In the HRV analysis, calculating frequency indices on sequences of 256 consecutive RR intervals is recommended in short-term recordings [27]; therefore, frequency indices on sequences of 256 consecutive peak-to-peak intervals of pulse wave were calculated. PRV indices were calculated every 10 s.

The frequency indices employed were very low frequency (VLF, 0–0.04 Hz), low frequency (LF, 0.04–0.15 Hz), and high frequency (HF, 0.15–0.40 Hz) components, total power (P_{total}, 0–0.40 Hz); normalized LF and HF (nLF and nHF, $100 \times LF/(P_{total}\text{-}VLF)$ and $100 \times HF/(P_{total}\text{-}VLF)$), and LF-to-HF ratio (LF/HF).

2.5. Statistical analysis

Results were summarized as means and standard deviations (SD), or proportions (%). Three analyses were performed on the body movement and PRV parameters, and the desire to void. The data from the first 10 min of each experiment were excluded from the analysis, being considered as acclimating time.

To confirm the difference in the body movement and PRV parameters between strong and weak desire to void, the parameters were compared between the desire-to-void level of 9 or more (i.e., strong desire to void) in measurement 1 and the level of 1 or less in measurement 2 (i.e., weak or no desire to void). The time from the start of measurements was matched. Because the samples were relatively small owing to the cropping by the desire to void and time, the median value was calculated in each measurement to exclude outliers. The median values from two measurements were compared by a paired t-test.

To test the relationship between the body movement and PRV parameters, and the desire to void, linear mixed-effects model analysis was performed on the pooled samples of measurements 1 and 2. Considering each body movement and PRV parameter as a response variable, the desire to void and measurement (1 or 2) were used as fixed effects, and participants were employed as a random effect.

The parameters that are significantly related to the desire to void in the regression analysis were employed for receiver operating characteristic (ROC) analysis. The sensitivity and specificity in predicting the desire-to-void level of 7 or more was examined. This is because previous research reported that the strong desire to void was consistently measured as 6–8 in VAS [25]. Cutoff values for each parameter were determined based on Youden's index [28].

Table 1
Participants' characteristics ($N = 25$).

Characteristic	Value	
Age (year)	30	(7)
Male	14	(56)
BMI (kg/m^2)	22.8	(3.3)
OABSS		
0	20	(80)
1	3	(12)
2	2	(8)
Voided volume (mL)		
After measurement 1	587	(247)
After measurement 2	160	(98)

Data is shown as mean(SD) or N(%). BMI, body mass index; OABSS, overactive bladder symptom score.

Table 2
Time until feeling the maximum desire to void.

Desire to void	Time	
0	94:47	(29:45)
1	85:25	(25:55)
2	63:04	(29:25)
3	57:07	(25:05)
4	50:03	(21:33)
5	47:29	(29:30)
6	39:29	(25:29)
7	36:33	(27:24)
8	27:55	(22:39)
9	17:38	(14:31)
10	07:03	(09:03)

Data is shown as mean(SD). Unit: MM:SS.

A p-value < 0.050 was considered statistically significant. The linear mixed-effects model analysis was conducted using R 2.3.1. Other statistical analyses were performed using the SciPy 0.19.0 library in Python 2.7.13.

3. Results

Twenty-nine healthy volunteers participated in the experiments. Of the 29 participants, four cases were excluded from the analysis owing to missing data from some sensors or insufficient measuring time of measurement 1 (i.e., < 10 min.). The characteristics of the 25 analyzed cases are shown in Table 1. None had exhibited obvious overactive bladder syndrome.

During measurement, intentional body movements (i.e. changing lying posture or moving limbs) were not observed based on the accelerometer data.

The elapsed time until the participants reported feeling the maximum desire to void is summarized in Table 2. The time corresponding to the desire-to-void level of X indicated the duration until the end of measurement 1 after a participant reported X desire to void. The standard deviations were large compared to the means in most cases (in 6 of the 11 desire-to-void levels, the SD was $>$ 50% of the mean.), and the coefficient of variation ranged 30–129%. There were no significant differences between males and females.

As for the comparison between strong and weak desire to void, the body movement parameters of the W1 y-axis (head area) and L2 x-axis (buttock area), and the pulse rate were significantly higher when a strong desire to void was felt, i.e., 0.03 (0.21) vs −0.17 (0.13), $p = 0.043$; −0.06 (0.33) vs. −0.26 (0.17), $p = 0.048$; and 70.8 (9.60) vs. 65.3 (9.3), $p = 1.0 \times 10^{-5}$, respectively (measurement 1 vs. 2, mean (SD)).

The body movement parameters of the L2 x-axis, total; W2 y-axis were associated with the desire to void ($p = 0.031$, 0.036, and 0.007), and L2 y-axis, total; W2 y-axis were associated with the measurements ($p = 0.035$, 0.036, and 0.013). All of these body movement parameters were larger when the desire to void was stronger (Table 3). All the PRV parameters trended significantly with both the desire to void and measurements (Table 4).

Body movement parameters from L2 and W2 (buttock and thigh), and all the PRV parameters were analyzed for ROC. The results of ROC analysis are shown in Table 5. The largest area under curve was 0.608 achieved by nLF and LF/HF. Regarding the body movement parameters, the sensitivities of L2 and W2 were 0.770, 0.578, and 0.772, and 0.742, 0.505, and 0.750 (x-, y-axis, and total).

4. Discussion

This is the first study observing unintentional body movements using multiple force sensor units to obtain the correlation with the desire to void. Previous research attempted to monitor body movements by putting load cells under the bed legs [29], and the captured movements were intentional gross body movements such as limb movements and rolling over. We placed five force sensor units under the mattress corresponding to each of the five body parts (i.e., head, torso, buttock, thigh, and lower limb), and detected unintentional body movements at the buttock that are related to the desire to void.

The body movement parameters were computed with differentiations, using a 10-second window. This enabled the detection of

Table 3
Relationships between the body movement parameters and desire to void.

		Desire to void					Measurement				
		Beta	95%CI			p	Beta	95%CI			p
W1 (Head)	X axis	-2.0×10^{-3}	-1.0×10^{-2}	–	5.9×10^{-3}	0.61	-1.4×10^{-2}	-8.3×10^{-2}	–	5.4×10^{-2}	0.68
	Y axis	-2.6×10^{-3}	-1.1×10^{-2}	–	5.3×10^{-3}	0.52	-2.7×10^{-2}	-9.6×10^{-2}	–	4.2×10^{-2}	0.45
	Total	-2.4×10^{-3}	-1.0×10^{-2}	–	5.6×10^{-3}	0.55	-1.8×10^{-2}	-8.7×10^{-2}	–	5.1×10^{-2}	0.61
L1 (Torso)	X axis	6.4×10^{-3}	-1.8×10^{-3}	–	1.5×10^{-2}	0.13	5.0×10^{-2}	-2.0×10^{-2}	–	1.2×10^{-1}	0.16
	Y axis	4.1×10^{-3}	-4.2×10^{-3}	–	1.2×10^{-2}	0.33	2.8×10^{-2}	-4.3×10^{-2}	–	1.0×10^{-1}	0.44
	Total	4.4×10^{-3}	-3.9×10^{-3}	–	1.3×10^{-2}	0.30	3.2×10^{-2}	-3.9×10^{-2}	–	1.0×10^{-1}	0.38
L2 (Buttock)	X axis	9.0×10^{-3}	8.4×10^{-4}	–	1.7×10^{-2}	0.031*	7.0×10^{-2}	-8.9×10^{-4}	–	1.4×10^{-1}	0.053
	Y axis	6.0×10^{-3}	-2.7×10^{-3}	–	1.5×10^{-2}	0.18	8.0×10^{-2}	5.5×10^{-3}	–	1.5×10^{-1}	0.035*
	Total	8.8×10^{-3}	5.7×10^{-4}	–	1.7×10^{-2}	0.036*	7.6×10^{-2}	4.8×10^{-3}	–	1.5×10^{-1}	0.036*
W2 (Thigh)	X axis	7.5×10^{-3}	-1.2×10^{-3}	–	1.6×10^{-2}	0.092	5.4×10^{-2}	-2.0×10^{-2}	–	1.3×10^{-1}	0.16
	Y axis	1.2×10^{-2}	3.3×10^{-3}	–	2.1×10^{-2}	0.007*	9.5×10^{-2}	2.0×10^{-2}	–	1.7×10^{-1}	0.013*
	Total	8.2×10^{-3}	-9.5×10^{-4}	–	1.7×10^{-2}	0.079	5.7×10^{-2}	-2.0×10^{-2}	–	1.3×10^{-1}	0.15
W3 (Lower limb)	X axis	4.6×10^{-3}	-3.4×10^{-3}	–	1.3×10^{-2}	0.26	4.8×10^{-2}	-2.1×10^{-2}	–	1.2×10^{-1}	0.18
	Y axis	5.6×10^{-4}	-7.4×10^{-3}	–	8.5×10^{-3}	0.89	1.5×10^{-2}	-5.4×10^{-2}	–	8.4×10^{-2}	0.68
	Total	3.8×10^{-3}	-4.2×10^{-3}	–	1.2×10^{-2}	0.35	4.4×10^{-2}	-2.5×10^{-2}	–	1.1×10^{-1}	0.21

* : $p < 0.050$, Measurement is a dummy variable that assumes value 1 if the data is from Measurement 2.

Table 4
Relationships between the PRV parameters and desire to void.

	Desire to void					Measurement				
	Beta	95%CI			p	Beta	95%CI			P
Pulse rate	2.3×10^{-1}	2.0×10^{-1}	–	2.6×10^{-1}	0.000*	−1.7	−1.9	–	−1.6	0.000*
Total power	5.7×10^{-2}	4.8×10^{-2}	–	6.6×10^{-2}	0.000*	6.7×10^{-1}	5.9×10^{-1}	–	7.1×10^{-1}	0.000*
VLF	2.2×10^{-2}	1.8×10^{-2}	–	2.6×10^{-2}	0.000*	2.3×10^{-1}	2.0×10^{-1}	–	2.5×10^{-1}	0.000*
LF	1.2×10^{-2}	8.3×10^{-3}	–	1.5×10^{-2}	0.000*	1.6×10^{-1}	1.3×10^{-1}	–	1.7×10^{-1}	0.000*
Nlf	6.9×10^{-1}	5.8×10^{-1}	–	8.0×10^{-1}	0.000*	1.1	1.8×10^{-1}	–	1.6×10^{-1}	0.021*
HF	2.3×10^{-2}	1.9×10^{-2}	–	2.8×10^{-2}	0.000*	2.8×10^{-1}	2.4×10^{-1}	–	3.0×10^{-1}	0.000*
nHF	-6.8×10^{-1}	-8.0×10^{-1}	–	-5.7×10^{-1}	0.000*	−1.1	−2.0	–	-6.1×10^{-1}	0.028*
LF/HF	2.0×10^{-2}	6.5×10^{-3}	–	3.3×10^{-2}	0.004*	-2.7×10^{-1}	-3.8×10^{-1}	–	-2.1×10^{-1}	0.000*

* : $p < 0.050$, Measurement is a dummy variable that assumes value 1 if the data is from Measurement 2. VLF, Very low frequency; LF, Low frequency; nLF, normalized low frequency; HF, High frequency; nHF, normalized High frequency; LF/HF, ratio of LF to HF.

Table 5
ROC analysis on the body movement and PRV parameters.

Parameter		AUC	Largest Youden's index	Cutoff	Sensitivity	Specificity
L2	X axis	0.52	0.089	−0.34	0.77	0.32
	Y axis	0.51	0.060	−0.16	0.58	0.48
	Total	0.52	0.075	−0.33	0.77	0.30
W2	X axis	0.50	0.030	−0.40	0.74	0.29
	Y axis	0.50	0.021	−0.10	0.51	0.51
	Total	0.50	0.024	−0.42	0.75	0.27
Pulse Rate		0.56	0.15	69	0.31	0.84
Total Power		0.57	0.11	0.15	0.87	0.24
VLF		0.56	0.13	0.049	0.88	0.24
LF		0.58	0.15	0.038	0.88	0.27
nLF		0.61	0.20	45	0.68	0.51
HF		0.52	0.094	0.59	0.18	0.92
nHF		0.51	0.10	54	0.36	0.74
LF/HF		0.61	0.20	0.81	0.69	0.51

AUC, Area under curve.

small movements of the center of gravity, while eliminating noise. Changes in body movement parameters related to the desire to void were found in the "x-axis" and "total" parameters at the buttock. This suggests that the "x-axis" parameter reflects the slight left-to-right swing around the buttock. Although a discussion regarding the cause of this movement is beyond the scope of this study, it might reflect some movements of the pelvic floor muscles.

PRV was employed as an estimating parameter of the desire to void. Previous research demonstrated that the nLF and LF/HF became larger, and the nHF became smaller when a person felt a strong desire to void [18]. The present results support those of previous research.

The participants were instructed to not move their bodies such that only unintentional slight movements relating to a desire to void are monitored; the accelerometer confirmed the absence of intentional gross body movements.

The elapsed time until feeling the maximum desire to void decreased as the magnitude of the desire increased, although it varied between participants. Thus, the VAS-like scale was a valid method for measuring the desire to void. To eliminate intra-individual correlation and time-dependent changes in the parameters, the relationships between the PRV and body movement parameters, and the desire to void was tested in the linear mixed-effects model adjusted according to person, and the effect of measurements (1 and 2). Measurements on the "y-axis" and "total" parameters presented significant effects. This could be due to differences in the location of the participants on the mattress.

In the ROC analysis, four of six body movement parameters at the buttock and thigh achieved relatively high sensitivities (0.742–0.770), the specificities were low, and the PRV parameters achieved a high value in either the sensitivity or specificity. For future applications, the sensor system will be required to exhibit 90% sensitivity and specificity in estimating the strong desire to void. However, none of the parameters had achieved this level in this study. Generating another parameter calculated from the combination of body movement parameters and PRV parameters would be promising to achieve such a high sensitivity and specificity.

Considering the results of regression analysis and ROC analysis, the most useful body movement parameter would be the x-axis parameter at the buttock, with a sensitivity of 0.770 and specificity of 0.319. Meanwhile, the parameters at the head, torso, and lower limbs were not associated with the desire to void. Although the bed sensor system in this study consists of five units corresponding to five body parts, only one sensor unit at the buttock may be sufficient for future applications.

This study had some limitations. First, the participants were continuously monitored for their desire to void, body movements, and pulse wave. Additionally, the condition (being monitored) might affect the measured variables. However, we considered the effect of monitoring on the variables were minimized by comparing the two situations (with and without the desire to void). Next, the PRV parameters may be affected by other factors including gross body movements. In the experiments, we prohibited the participants from gross body movements and eliminated the effects on PRV parameters. Considering future applications, PRV analyzing method eliminating the effect of gross body movements must be developed.

The further development of a bed sensor system capable of measuring PRV will improve the estimation of the desire to void. The precise measurement of the PRV parameter using a bed sensor system is difficult; thus, PRV parameters were extracted from the PPG signal acquired at the finger sensor in this study. A previous study demonstrated that the force changes measured by load cells under the bed legs included signals that were highly correlated to HRV parameters from ECG recordings [30]. The development of an estimation method is left for further research.

5. Conclusion

Body movement parameters derived from changes in the center of gravity and PRV parameters were associated with the desire to void in healthy adults. To achieve an accurate estimation, combining the body movement parameters with the PRV parameter and bladder volume would be required. Future research will include estimating PRV parameters using a bed sensor system.

Conflicts of interest

None declared.

Funding

This work was supported in part by JSPS KAKENHI Grant Number 16H02694 and Japan Society of Geriatric Urology.

Ethical approval

The study protocol for the healthy volunteer experiment was approved by the ethics committee of the Graduate School of Medicine, The University of Tokyo (Approval No. 11674-(2)).

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