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**PART II. PHYSICAL ACTIVITY OF SOCIAL AND PROFESSIONAL GROUPS**
**DZIAŁ II. AKTYWNOŚĆ FIZYCZNA GRUP SPOŁECZNYCH I ZAWODOWYCH**

# VALIDITY OF THREE HIP-WORN PEDOMETERS FOR STEP COUNTS IN A LABORATORY SETTING

# ZASADNOŚĆ STOSOWANIA TRZECH KROKOMIERZY NOSZONYCH NA BIODRACH DO LICZENIA KROKÓW W WARUNKACH LABORATORYJNYCH

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C. Data analysis/statistics
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D. Data interpretation
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E. Preparation of manuscript
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G. Funds collection
zebranie funduszy

**Summary**

**Background.** Objectively measuring physical activity with a functional and inexpensive device is important in large-scale health research. Therefore, this study aimed to determine the validity of the Omron HJ-321 (HJ-321), Omron GoSmart HJ-112 (HJ-112), and Yamax SW200 Digiwalker (YX) for measuring step counts (SC) obtained from the sum of different speeds in a laboratory setting.
**Material and methods.** A total of 26 healthy males aged between 19 and 35 years (26.4±6.3 years) participated voluntarily. During the 10-minute treadmill protocol, the participants were asked to wear HJ-321 and HJ-112 pedometers on the right side and YX on both sides of their hips. The digital image processing code was written in MATLAB (R2013B) for calculating the actual step counts (ASC) with 100% accuracy. The SC for all the pedometers and ASC were recorded simultaneously.
**Results.** HJ-112 and YX have a small Mean Absolute Percentage Error (MAPE) of <10%, while the HJ-321 showed a high MAPE of >10%. There was a significant correlation between the ASC and the HJ-112, and the YX worn both on right and left sides (respectively, ICC and 95%CI: 0.583 (0.069, 0.813); 0.638 (0.193, 0.838); 0.516 (-0.079, 0.783)). However, a significant correlation was not found for the HJ-321 (0.025 (-1.212, 0.570)).
**Conclusions.** This study shows that the HJ-112 and YX on both sides are valid for measuring total step count during 10 minutes of walking and running in a laboratory setting.
**Keywords:** Omron HJ-321, Omron GoSmart HJ-112, Yamax SW200 Digiwalker, pedometer, validity, hip

**Streszczenie**

**Wprowadzenie.** Obiektywny pomiar aktywności fizycznej za pomocą funkcjonalnego i niedrogiego urządzenia jest ważny w badaniach zdrowia na dużą skalę. Dlatego też niniejsze badanie miało na celu określenie zasadności stosowania urządzeń Omron HJ-321 (HJ-321), Omron GoSmart HJ-112 (HJ-112) oraz Yamax SW200 Digiwalker (YX) do pomiaru liczby kroków (ang. *step count* – SC) uzyskanych z sumy różnych prędkości w warunkach laboratoryjnych.
**Materiał i metody.** W badaniu uczestniczyło dobrowolnie łącznie 26 zdrowych mężczyzn w wieku od 19 do 35 lat (26,4±6,3 lata). Podczas 10-minutowego protokołu na bieżni, uczestnicy zostali poproszeni o noszenie krokomierzy HJ-321 i HJ-112 po prawej stronie oraz YX po obu stronach bioder. Kod cyfrowego przetwarzania obrazu został napisany w programie MATLAB (R2013B) w celu obliczenia rzeczywistej liczby kroków (ang. *Actual Step Count* – ASC) ze 100% dokładnością. SC dla wszystkich krokomierzy oraz ASC były rejestrowane jednocześnie.
**Wyniki.** HJ-112 i YX mają mały średni bezwzględny błąd procentowy (ang. *Mean Absolute Percentage Error* – MAPE) wynoszący <10%, natomiast HJ-321 wykazał wysoki MAPE wynoszący >10%. Stwierdzono istotną korelację pomiędzy ASC a HJ-112 i YX noszonemu zarówno po stronie prawej, jak i lewej (odpowiednio ICC i 95% CI: 0,583 (0,069; 0,813); 0,638 (0,193; 0,838); 0,516 (-0,079; 0,783)). Nie stwierdzono natomiast istotnej korelacji dla HJ-321 (0,025 (-1,212; 0,570)).
**Wnioski.** Badanie to pokazuje, że stosowanie HJ-112 i YX po obu stronach ciała jest zasadne do pomiaru całkowitej liczby kroków podczas 10 minut chodu i biegu w warunkach laboratoryjnych.
**Słowa kluczowe:** Omron HJ-321, Omron GoSmart HJ-112, Yamax SW200 Digiwalker, krokomierz, zasadność, biodro

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## Introduction

Ambulatory activities such as walking and running are the most common form of physical activity recommended by health professionals [1]. The number of steps is often used in large-sample clinical and public health researches, because it can be more easily interpreted by participants [1], especially as an indicator of physical activity (PA) in intervention studies [2]. Activity trackers used to measure and track steps are commonly used, especially in physical activity-related interventions [3].

Because walking is the dominant form of PA for the general population, pedometers are often used to evaluate the number of steps taken daily as an objective measurement of PA [4]. Pedometers are also commonly used to measure PA [5] in clinical studies because they are relatively inexpensive, simple, convenient, and provide the user with quick feedback on the daily number of steps [6]. Pedometers which record the number of steps taken over a given period are reliable measurement tools used to measure ambulatory physical activities [7]. But, the accuracy of the pedometers is known to vary depending on their quality (e.g., string-leveraged vs. piezoelectric pedometers), environmental conditions [8], the speed of walking, the body fat distribution, the type of pedometer [9,10], wearing location [9], and the brand of the pedometer [8,11]. Lab-based studies, in particular, have shown that factors such as treadmill walking speed, device angle of tilt, and body size affect the accuracy of pedometers worn around the waist [12]. Pedometers may underestimate steps at slow walking speeds, whereas they may overestimate steps at fast walking speeds (16 km/h) [13,14]. Many studies reported that there were no valid or appropriate measurement devices for assessing PA at slow walking speeds (3.2 km/h) [14,15]. Some studies reported that many different brands and models of pedometers accurately measure speeds above 80 $m.min^{-1}$ [11,14,16]. Even if the brands and models of pedometers are the same, it has been shown that different results are obtained depending on the research method (for example: age, body composition, free-living or laboratory setting, and PA intensity). In this context, the research method must be considered when determining the brand and model of the pedometer.

Studies have revealed that the validity of the Yamax SW200 Digiwalker pedometer (YX) in healthy adults is acceptable [17]. There are also studies showing that its accuracy increases at higher treadmill speeds [15]. On the other hand, the YX underestimated the number of steps at slow walking speeds on the treadmill [15]. The accuracy of the Omron HJ-321 pedometer (HJ-321) did not change regarding walking speeds [18]. There was no notable bias with the Omron GoSmart HJ-112 pedometer (HJ-112) at any speed and placement positions [19].

Previous studies reported different findings regarding the validity and accuracy of the YX, HJ-321, and HJ-112. To the authors' knowledge, although the literature does contain validity and accuracy studies on HJ-321, HJ-112, and YX, no study has been found to evaluate the total number of steps obtained as a result of the combination of different speeds in a laboratory environment. Given that the accuracy of pedometers is likely to vary at different speeds, the accuracy of pedometers should be examined using a combination of different speeds. Accordingly, the aim of the study was to determine the validity of the HJ-321, HJ-112, and YX for step counts (SC) during a 10-minute treadmill protocol obtained from the sum of different speeds in a laboratory setting.

## Material and methods

### *Participants*

The minimum sample size required was calculated as 25 to estimate the sample size with α=0.05, 80% power, and moderate effect size (0.5) for paired t-tests. G-power analysis was used to determine the sample size. Twenty-six healthy men aged between 19 and 35 years participated voluntarily in this study ($Mean_{age}$= 26.4±6.3; $Mean_{height}$= 176.1±10.2; $Mean_{weight}$= 74.8±10.0; $Mean_{BMI}$= 24.1±2.3). The right side is the dominant side for all the participants. After being informed about the purpose of the study and the test protocol, the participants who agreed to take part in the study were asked to sign a consent form. Hitit University Non-interventional Researches Ethics Board approved this study (no. 2018-144).

*Instruments and procedures*

The HJ-321, HJ-112, and YX were tested against the actual step counts (ASC) in the laboratory setting in this study. The HJ-321 pedometer (Omron Corporation, Healthcare Division, Kyoto, Japan) is a three-axis piezoelectric pedometer [20]. It can be used in the pocket, bag or on the hip [21]. With dual-accelerometer technology, the HJ-112 Pocket Pedometer can be placed horizontally or vertically at the hip, in a pocket or in a bag [22]. The HJ-112 is a piezoelectric pedometer that records the number of steps while walking and jogging. The Yamax Digiwalker SW-200 (YX) is a spring-lever pedometer that evaluates the number of steps for ambulatory activities such as walking, hiking, jogging, or running [23].

Before the treadmill protocol, the height and weight of the participants were measured and pedometers were attached to the right hip (HJ-321, HJ-112, YX) and left hip (YX) with the aid of a clip. Height and weight were measured with an accuracy of 0.1 cm and 0.1 kg, respectively. A Holtain Harpenden stadiometer (Holtain Ltd, England) and Tanita TBF 401A (USA) were used to measure height and weight respectively. Body mass index (BMI) was calculated. Also, some preliminary preparations were completed before the test protocol to determine the ASC. A 16 mm diameter spherical marker was attached to the participants' right shoe, which was covered with reflective tape for optimum camera visibility. A thin black sock was worn over the shoe to make the marker more clearly visible and stable. In addition, two LED projectors and one tripod were used to make the marker appear clearer in the video image during recording. The participants were asked to stand on a Woodway PPS Med (USA) treadmill, and both the angle and image clarity of the camera and light sources were adjusted so that the marker would look best when standing still.

After attaching the pedometers, placing the marker and adjusting the camera setting, the participants were asked to take the first step on the Woodway PPS Med treadmill starting with their right foot and walk for two minutes at speeds of 2 km/h, 4 km/h, 6 km/h, and then run for two minutes at speeds of 8 km/h and 10 km/h. The total step count from the HJ-321, HJ-112, and YX occurred from the sum of the minutes of walking/running (10 min in total) at speeds of 2 km/h, 4 km/h, 6 km/h, 8 km/h, and 10 km/h. During the treadmill protocol, which lasted 10 minutes, the video was taken using a Canon (200d) camera focused on the marker placed on the participant's shoe and the walking area.

After the treadmill protocol, the ASC were calculated as a reference method. The calculations and data analysis were made with 100% accuracy by using specific codes written in MATLAB (R2013B) by following the marker attached to the shoe of the participant. In the first stage, the video image of the developed digital image processing code was converted into image data, and in the second stage, the ASC was obtained by comparing the position of the marker in each image with the previous image. The SC obtained from the HJ-321, HJ-112, and YX pedometers for 10 minutes were compared statistically with the ASC.

*Statistical analysis*

The Mean Absolute Percentage Error (MAPE) values for the SC were calculated for each pedometer by dividing the absolute bias (ASC – measured steps) with the reference method: [(ASC – steps measured)/ASC] × 100. Results with MAPE values below 10% were accepted as valid [24]. The intraclass correlation coefficients (ICC) with a 95% confidence interval (CI) were calculated to understand the correlation between the ASC and the SC obtained from three different pedometers. The categories for the ICC are as follows: ICC>0.5, 'poor'; ICC>0.5-0.75, 'moderate'; ICC>0.75-0.9, 'good'; and ICC>0.9, 'excellent' [25]. Statistical analyzes were performed using SPSS 21.0. Significance was accepted as $\alpha=0.05$.

## Results

In this study involving a treadmill exercise at increasing speeds, levels of agreement were calculated between the number of steps obtained from different pedometers and the number of steps obtained with the reference method. Furthermore, it was determined which of these value(s) is compatible with the values obtained from the reference method.

The mean values of the total step count obtained from the sum of 2 minutes of walking and running (10 minutes) at speeds of 2, 4, 6, 8 and 10 km/h were shown by the box plots in Figure 1. Accordingly, these values, obtained from both the ASC and the HJ-112, HJ-321, YX (right hip), and YX (left hip) were 1254.2±68.3; 1221.6±115.6; 1211.2±170.02; 1193.7±147.6 and 1197.3±183.1, respectively.

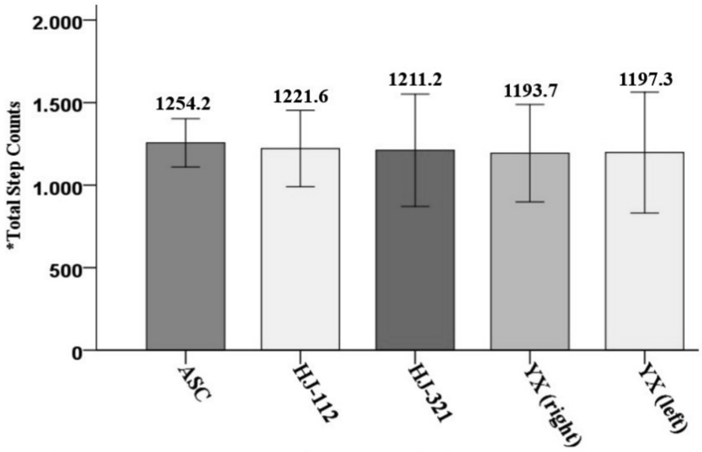


**Figure 1.** The mean values of the total step count for the ASC and pedometers

Notes: *Total step counts obtained from the sum of 2 min of walking/running (10 min) at speeds of 2, 4, 6, 8, 10 km/h.

Table 1 shows the MAPE values for the number of steps obtained from the treadmill protocol for 10 minutes for each pedometer. The HJ-112 had the lowest MAPE (6.9%), while the HJ-321 had the highest (11.1%), as shown in the table. The HJ-112, YX (right hip), and YX (right hip) were found valid because of low (<10%) MAPE values. However, the HJ-321 was invalid due to a high (>10%) MAPE value.

**Table 1.** MAPE (%) values, ICC and 95% CI for each pedometer and the ASC

| Devices | n | MAPE (%) | ASC | |
|---|---|---|---|---|
| | | | ICC (95% CI) | *p*-value |
| HJ-112 | 25 | 6.9 | 0.583 (0.069, 0.813) | 0.017* |
| HJ-321 | 26 | 11.1 | 0.025 (-1.212, 0.570) | 0.475 |
| YX (right hip) | 26 | 7.3 | 0.638 (0.193, 0.838) | 0.007* |
| YX (left hip) | 26 | 7.1 | 0.516 (-0.079, 0.783) | 0.038* |

Notes: *$p<0.05$.

The ICC was calculated to obtain the correlation between different pedometers and the ASC in the Table. The validity was moderate for the HJ-112, YX (right hip), and YX (right hip) (ICC=0.583; ICC=0.638, and ICC=0.516, respectively), and the ICC values of the pedometers were statistically significant ($p<0.05$). However, the HJ-321 ICC value was not statistically significant ($p>0.05$), and its validity was poor (ICC=0.025).

**Discussion**

This study checked the validity of the HJ-321, HJ-112, and YX for the SC during the 10 minutes treadmill protocol against the ASC in laboratory settings. It is important to investigate how accurately the activity monitors evaluate the number of steps because the accuracy of the step counts obtained from activity monitors may vary for a number of reasons [26].

In our study, the MAPE values of the YX worn on the left and right hip are valid (MAPE<10%). Also, the results of the ICC analysis revealed that the YX worn on the right and left hip was valid for evaluating step counts during the 10-minute treadmill protocol. In agreement with our findings, Kooiman et al. [17] found that the MAPE of the YX were -1.2 in laboratory setting and the validity of the YX was acceptable for healthy adults. Accordingly, Chia [15] revealed that the accuracy of the YX increases at higher treadmill speeds. Especially for three hip wear positions (mid-left hip, mid-right hip, mid-back) at 6.4 km/h, the accuracy of the YX was close to 100%. The findings suggest that the YX is valid in our study and this supports the findings of studies in the literature. However, the literature generally concludes that the YX underestimates steps at slower walking speeds. For example, several studies have revealed that the YX pedometer underestimated the number of steps taken at different low walking speeds (such as 54 $m \cdot min^{-1}$ and 53.3 $m \cdot min^{-1}$) [15,16]. The YX uses a spring-suspended horizontal lever arm, which moves up and down in response to the vertical accelerations of the hip. Spring-leveraged pedometers such as the YX can accurately evaluate walking at speeds greater than 3.0 mph, but they can significantly underestimate steps at slower walking speeds [11]. Therefore, we consider that the YX was found to be valid since it is a spring-leveraged pedometer and was used at treadmill speeds greater than 3.0 mph in our study. In addition, the step count difference for the same pedometer model on the right and left hip can be as much as 5%. This may be regarded as an acceptable difference [27]. We considered it insignificant because the difference between the right and left hip in our study was less than 5%.

The vertical acceleration threshold needed to calculate a step model may differ between pedometers. This feature is thought to be related to the internal mechanism of the devices [27]. It may be responsible for underestimating the number of steps taken from pedometers at the vertically accelerated threshold. From this point of view, the YX needs a momentum of over 0.35 g to record a step [16]. Tudor-Locke et al. [28] compared the YX to the Computer Science & Applications (CSA) model 7164 accelerometer and found that the YX counted an average of 1,845 fewer steps per day than the CSA model 7164. The reason for the finding is that the vertical acceleration threshold (0.35g) of the YX is higher than the CSA model 7164 (0.30). Having a lower vertical acceleration threshold increases the likelihood of registering steps at slower walking speeds [27]. When considered from this point of view, although not statistically significant, the "vertical acceleration threshold" may be the reason that the number of steps obtained from the YX was smaller than those obtained from ASC.

HJ-321 is invalid in evaluating the total number of steps obtained from the sum of different speeds (MAPE value: 11.1% (MAPE>10%); ICC=0.025, 95% CI=-1.21-0.57). Huang et al. [18] stated that some activity monitors, including the HJ-321, tend to underestimate the number of steps at slow walking speeds. Lower walking speeds cause smaller magnitude impact, which is insufficient to register walking movements on activity monitors as steps [18]. This effect can impair the accuracy of monitors, especially at low walking speeds. In this regard, the non-validity of the HJ-321 in our study (MAPE value>10%; ICC=0.025, $p<0.05$) can be explained by the acceleration of the small magnitude impact of ambulatory activities, including low walking speeds on the treadmill at different speeds. However, our finding is in disagreement with the findings of Giannakidou et al. [14] which were obtained with a high accuracy (r=0.80-0.99) at five different speeds for different models of Omron (54, 67, 80, 94, and 107 $m. min^{-1}$). Similarly, the study of Battenberg et al. [20] found that the HJ-321 has an accuracy of over 95% in walking and running. This disagreement is probably due to the methodological differences brought about by the laboratory environment in our study. In the literature, because of the scarcity of studies describing the validity of the HJ-321, little is known about it. Besides, to our knowledge, no previous study in the literature has investigated the validity of the HJ-321 in a laboratory environment.

We found that HJ-112 was a valid device in the laboratory, measuring the total number of steps at different speeds for 10 minutes (MAPE value: 6.9%; ICC=0.583, 95%CI=0.069, 0.813). Our findings are consistent with those of Hasson et al. [19], who reported that measuring the number of steps taken on the treadmill at different speeds (1.12, 1.34, and 1.56 $m.s^{-1}$) was valid. The pedometers, which have piezoelectric mechanisms for evaluating the number of steps, are more sensitive than the spring-leveraged pedometers, which record the number of steps depending on the adequate displacement of the pendulum. Thus, piezoelectric pedometers can more accurately evaluate the number of steps at slower walking speeds [19]. From this perspective, in our study, the more accurate evaluation of the HJ-112 is likely to result from having a piezoelectric mechanism because the accuracy of the pedometers involving the piezoelectric mechanism increase, particularly at slow walking speeds. Furthermore, it is known that the HJ-112 measures the number of steps at slow walking speeds with superior accuracy compared to spring-levered pedometers [29]. Identifying the HJ-112 as piezoelectric helps us understand what makes it the most accurate pedometer.

One of the limitations of this study is that the participants were all healthy male individuals, and another is that the number of steps at each individual speed was not obtained separately. The powerful aspect of the study is that ASC is calculated using MATLAB software with 100% accuracy, and the data from different pedometers is collected at five different speeds.

## Conclusions

In conclusion, this study shows that the pedometers Yamax Digiwalker SW-200 and Omron HJ-112 are valid for the total step counts for 10 minutes in the laboratory setting, but the Omron HJ-321 pedometer is not. In future studies, different target groups (such as obese people) should be examined in different field settings (free-living and laboratory). Additionally, the validity and comparison of more piezoelectric and spring-levered pedometers should be examined in both laboratory settings and free-living conditions.

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