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Validation protocol for walking speed as extracted from various sensor systems that measure human body motion for the healthcare sector

Protocole de validation de la vitesse de marche extraite de divers systèmes de capteurs mesurant les mouvements du corps humain pour le secteur des soins de santé

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Foreword

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 3, *Anthropometry and biomechanics*.

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Introduction

Walking speed is recognized as being a reliable predictor of healthy function for people of all ages, and in particular for the elderly, and has been referred to as one of the "vital signs" of physical health and as one of the predictive factors of future health and death[1]–[4]. Studies of community-dwelling older adults (65 years and older: mean ± standard deviations age 74,2 ± 2,9 years for one study[4] and 74,1 ± 5,7 years for another[5]) have shown that walking speeds faster than 1,0 m/s suggest healthier ageing, while walking speeds slower than 0,6 m/s suggest an increased likelihood of poor health and function[4],[5].

In the healthcare sector, measuring walking speed by using a stopwatch and a tape measure is the gold standard (hereafter, reference method)[6]–[8]. Recent new technologies enable walking speed to be measured using various sensor systems (e.g. wearable sensors, environment-embedded sensors)[9],[10]. These technologies offer possible improvements on the reference method in healthcare for measuring walking speed, such as being able to measure walking speed during daily living[10]. Measurements taken during daily living could produce a more accurate health index due to decreased examiner influence and the ability to measure walking speed for longer distances and more frequently than in a clinical setting. Further, sensor systems can be utilized to establish a fatigue index in the work environment.

There is, however, no fixed standard to validate walking speed measured by such new technologies against the reference method. Therefore, users of such systems (e.g. physicians, therapists, ergonomists) cannot compare the accuracy between different systems based on the same evaluation protocol.

The intent of this document is to provide manufacturers of sensor system technologies with a standard means of validating and reporting walking speed values against the values provided by the reference method for measuring walking speed in the healthcare sector.

There are several different fundamental technologies underlying commercially available sensor systems that measure walking speed. This document covers these technologies, including accelerometer-based systems, depth-sensor-based systems and global positioning system (GPS)-based systems.

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Validation protocol for walking speed as extracted from various sensor systems that measure human body motion for the healthcare sector

1 Scope

This document provides a procedure for the standard validation and reporting protocol of walking speed measurements by technological sensor systems compared with the values provided by the reference method, namely walking speed as measured by a tape measure and a stopwatch.

It does not address the detailed or specific uses of various technological sensor systems in healthcare.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
reference method
method to measure walking speed using a measuring tape and a stopwatch, often used in the healthcare sector

3.2
parallax error
error that occurs when the observer's eyes are positioned at an angle to the measurement markings

4 Validation protocol of walking speed as provided by various sensor systems

4.1 General

For a sensory system to be validated against the reference method for measuring walking speed, the validation study procedure shall be followed. A validation study shall be done by comparing walking speed as extracted by sensor systems and walking speed as measured by the reference method. Each participant shall be measured by the sensor systems and reference method simultaneously. The measurer shall use a stopwatch and a tape measure that is provided with an individually serial-numbered traceable certificate from a calibration laboratory meeting the requirements of ISO/IEC 17025[11].

4.2 Qualifications of the measurer

The measurer should have learned and practised the measurement method under the supervision of a person with clinical experience for the reference method and a representative from the manufacturer or distributor of the sensor system.

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It is preferable that the same measurer measures (or be present for measurements being taken) all participant(s) for all test protocols. When there are multiple measurers, inter-measurer differences in measurement accuracy can occur. Therefore, it is preferable to report inter-rater reliability, such as intraclass correlation coefficients (case 2), by measuring the same subjects with multiple measurers.

4.3 Sample size and participant selection for the validation study

Based on the sample size of the previous studies[12],[13], the sample size of the validation study shall be at least 50 data points, covering the entire walking speed range (i.e. mean ± 2 standard deviations) of the target population intended by the sensor system design. These data are preferably collected from multiple people walking several times each, because the walking speed extracted from the sensor system can be affected by the parameters that vary from participant to participant (e.g. body size, which can influence body-worn inertial sensors). In such cases, the test shall cover the entire range of these conditions in addition to the range of walking speeds.

On the other hand, these data can be collected from one person walking 50 times and covering the entire range of walking speeds of the target population if the measurement of a single person is not expected to affect the walking speed extraction of a sensor system (e.g. a sensor system that uses GPS to measure walking speed will possibly not be affected by the body size of the participants).

Sample ranges of walking speed of various age ranges for healthy males and females[14]–[16] and sample ranges of body size for healthy males and females[17],[18] are available for reference. If the range of walking speeds is not known in the intended target population, then at least 50 individuals representing the target population while walking their comfortable normal walking speed shall be tested.

4.4 Validation study procedure

4.4.1 Establishing walking distance

The measurer shall establish a walkway with a suitable distance (at least 10 m) for participants to walk on. The distance and the location (inside or outside) of the walkway should be decided by the measurer based on the characteristics of the sensor systems. For example, a GPS-based system requires participants to walk outside for a relatively long distance to validate its accuracy, whereas an accelerometer-based system and a depth-sensor-based system do not require participants to walk outside for such a long distance. Therefore, this document does not fix the distance and the location of the walkway.

The measurer shall set a sufficient distance (about 3 m) for the participant(s) to accelerate and decelerate at the beginning and end of the specified walkway, so that the sensor system can measure walking speed during a steady speed.

4.4.2 Measurement of walking speed

The measurer shall have participants walk on the walkway while measuring the time the participants take to walk the length of the walkway, using a stopwatch. The measurer shall start and stop the stopwatch when the same part of the participant's body passes across the starting line and the finish line. To reduce the parallax error, especially for longer walking distances, the measurer may walk along with the participant or arrange other methods. Because there are various ways to measure walking speed[19], this document does not establish the body part that passes across the starting and finish lines as the measurer starts and stops the stopwatch. Rather, this document establishes the rules for how the validation procedure (including information such as what body part was observed for crossing the finish line) are reported.

Simultaneously, the participants' body motion data shall be obtained using a sensor system which extracts the walking speed from the starting line to the finish line. The measurer shall place the sensor(s) on the intended location(s) of the participant's body and/or their accessories. A sensor system can, for example, require the sensor to be placed on the lower back of the participant to validate the accuracy. If there is an assumption that the sensor can be placed on various locations, including

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accessories (e.g. breast pocket, hip pocket, handbag or backpack), the measurer shall validate the accuracy with all major locations.

4.4.3 Comparison of measured walking speeds

The difference, *d*, between the walking speed extracted from the sensor system and the walking speed measured by the reference method protocol shall be calculated for each trial, and the root-mean-square error (RMSE) and 95 % confidence interval of mean shall be calculated. (Clause 5 provides reporting requirements.)

Sample ranges of 95 % confidence interval of the mean when comparing the walking speed extracted from the sensor system and the walking speed measured by the reference method protocol[12],[13] are available for reference.

5 Validation study reporting

A report of the validation study shall be published and/or included in the manual of the system. A sample template of the report is shown in Annex A. This report shall include the following information:

— The types of participants (e.g. healthy elderly, infants, young adults).

— The expected and tested range of walking speed.

— The number of participants, including the number of males and females.

— The average and standard deviations of participants' age (years), height (cm) and mass (kg). Gross mass (mass including sensor system) shall be reported here.

— The conditions of the walking speed measurement, including the participants' clothing, footwear, measured distance, measured environment (inside or outside) and the body part that was observed to cross the finish line for measuring walking speed in the reference method protocol, as well as the sensor type and sensor location.

— The name and pertinent details (or references) describing the sensor system being validated, including the hardware model number and the software version number.

— The means, standard deviations of the measurements taken by each method, and the root-mean-square error (RMSE) and 95 % confidence interval of mean and measurement bias of the difference of measurements taken by the two methods.

— Bland–Altman plots with 95 % confidence interval of mean, which can indicate the characteristics of measurement bias.

Annexes A and B provide a reporting template and a sample report.

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Annex A
(informative)

Template to report the results of a validation study

Demographic data of the participants	
Number of participants	Total (males, females)
Age (years)	Average (standard deviations)
Height (cm)	Average (standard deviations)
Mass (kg) Gross weight (including sensor system)	Average (standard deviations)
Settings of the measurement	
Participant's clothing	
Participant's footwear	
Measured distance (m)	
Measured environment	
The body part that was observed to cross the finish line for measuring walking speed in the reference method protocol	
Sensor type	
Sensor location (s)	
Details of sensor system	
Name of the sensor system	
Hardware model number	
Software version number	
Results of the measurement (walking speed extracted from sensor system)	
Mean (m/s)	
Standard deviations (m/s)	
Results of the measurement (walking speed extracted by the reference method)	
Mean (m/s)	
Standard deviations (m/s)	
Results of the measurement (walking speed extracted from sensor system – walking speed extracted by the reference method)	
Root-mean-square error (RMSE) (m/s)	
95 % confidence intervals of mean (m/s)	
Measurement bias (Bland–Altman plot)	

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Annex B
(informative)

Sample report of the results of a validation study

Demographic data of the participants	
Number of participants	50 (M: 25, F: 25)
Age (years)	54,2 (3,55)
Height (cm)	170,2 (5,8)
Mass (kg) Gross weight (includes sensor system)	60,1 (12,05)
Settings of the measurement	
Participant's clothing	Participant's own casual wear
Participant's footwear	Tennis shoes
Measured distance (m)	10 m
Measured environment	Indoor
The body part that was observed to cross the finish line for measuring walking speed in the reference method protocol	Pelvis: Centre of right and left PSIS (posterior superior iliac spine)
Sensor type	IMU sensor
Sensor location (s)	Lower back (pelvis)
Details of sensor system	
Name of the sensor system	XXX Coop.
Hardware model number	Model XXX
Software version number	Software version 1.XXX
Results of the measurement (walking speed extracted from sensor system)	
Mean (m/s)	1,24
Standard deviations (m/s)	0,32
Results of the measurement (walking speed extracted by the reference method)	
Mean (m/s)	1,27
Standard deviations (m/s)	0,15
Results of the measurement (walking speed extracted from sensor system – walking speed extracted by the reference method)	
Root-mean-square error (RMSE) (m/s)	0,10
95 % confidence intervals of mean (m/s)	$-0{,}13 \leq \mu \leq 0{,}07$

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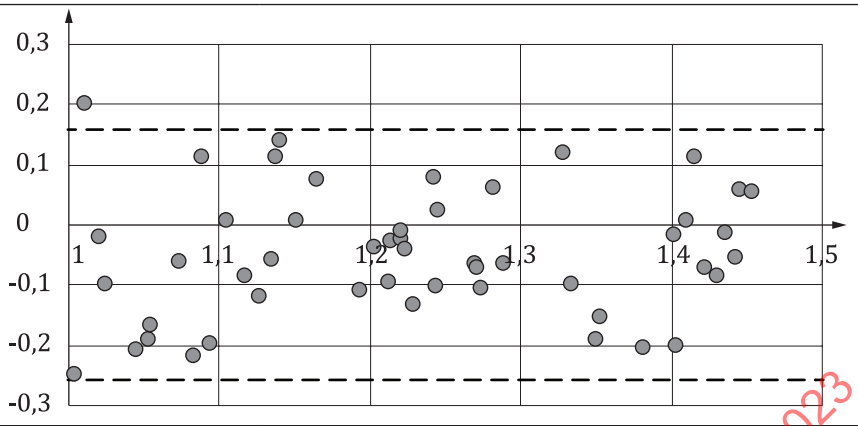
Measurement bias (Bland–Altman plot)	

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