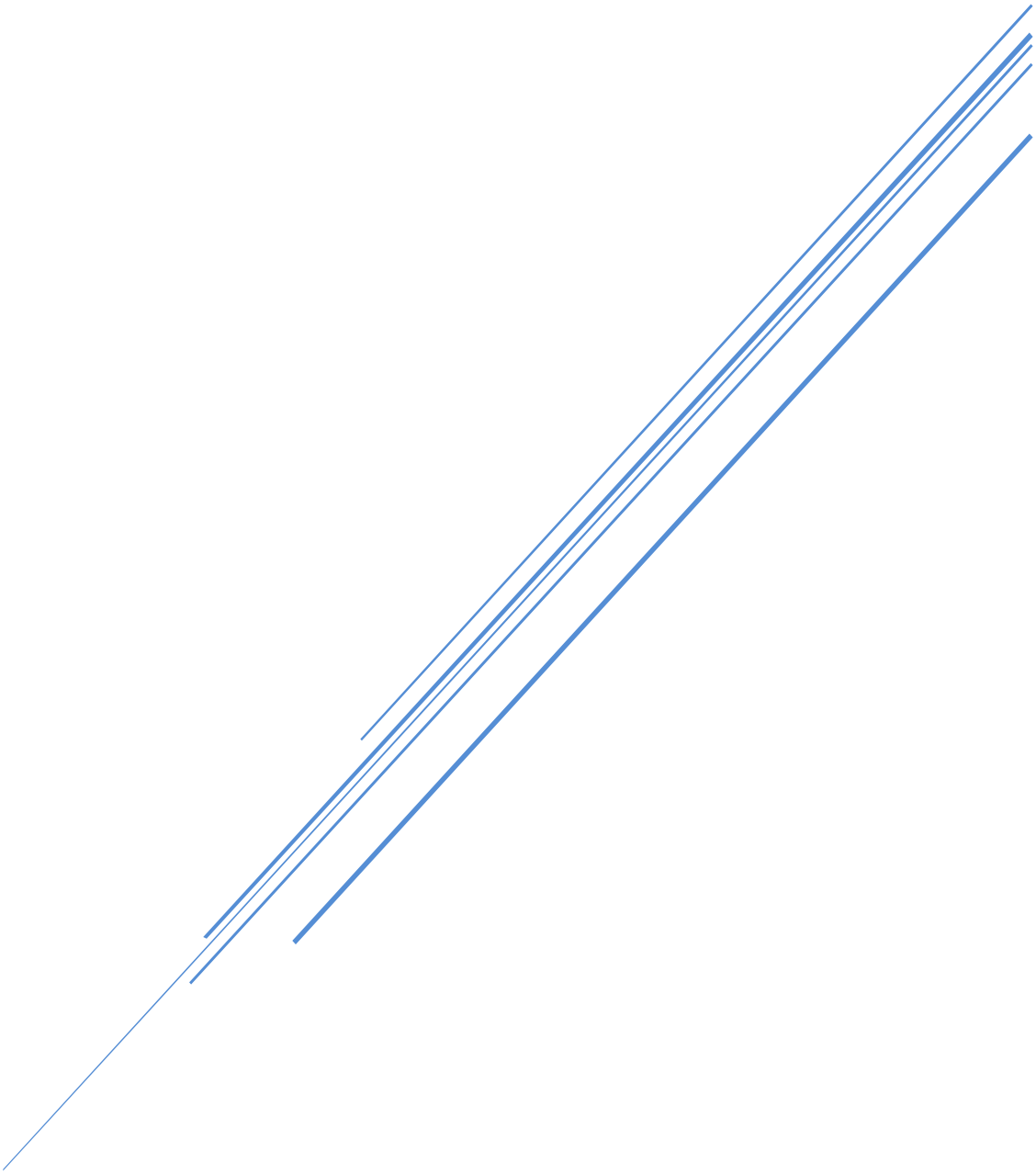
# Method validation of MOTI as a tool for estimating standing balance



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Method validation of MOTI as a tool for estimating balance

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**Background:**
Falls are a common and widespread problem among the elderly, and a third of people over the age of 65 and up to half of the people over 85 falls each year.
Many of the currently used assessment tools are subjective, qualitative, and use threshold assessment scores to either categorize people as fallers or non-fallers. Subjective tests rely on the knowledge and experience of the assessor, decreasing the accuracy of the balance assessment which calls for more objective assessment tools
Force-platforms are considered the gold-standard for the assessment of balance. However, the feasibility of routinely using them in clinical settings relates to their immobility and high cost. As a proxy to measure postural stability, accelerometry may be a convenient method for acquiring clinically-relevant measures for balance, comparable with those from force-platforms.
**Purpose:**
Investigate whether MOTI is a reliable tool for assessing standing balance that can give similar results as a force-platform (gold standard).
**Methods:**
A cross sectional study design with 30 subjects. Data was collected using a force-platform and an accelerometer (MOTI) in different standing balance positions.
Correlation and test-retest reliability was investigated with ICC $_{3.1.}$
**Results:**
Correlation between MOTI and the force-platform ranged from poor to good. The test-retest reliability of MOTI ranged from poor to moderate.
**Conclusion:**
MOTI has the highest correlation and test-retest reliability for double-leg stance with both eyes open and closed eyes. MOTI has the lowest correlation for single-leg stance with eyes open and lowest test-retest reliability in single-leg stance with closed eyes.

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# 1 Introduction

*This section will briefly explain the prevalence of falls in the elderly and the consequences of these.*

Falls are a common and widespread problem among the elderly, and a third of people over the age of 65 and up to half of the people over 85 falls each year (Gillespie et al., 2012; Park, 2018; Pfortmueller et al., 2014; Sun and Sosnoff, 2018; Villumsen et al., 2020). It is estimated that the number of injuries caused by falls will increase significantly in the coming years due to the aging population, the incidence of falls and the fact that related injuries increase with age (Florence et al., 2018; Freiberger et al., 2013; Gillespie et al., 2012; Park, 2018; Pfortmueller et al., 2014; Rubenstein, 2006). Serious injuries such as traumatic brain injury and fractures occur in approximately 10% of falls where the consequences can be a disability, reduced quality of life, and financial costs to society (Gates et al., 2008; Gillespie et al., 2012; Pfortmueller et al., 2014). Falls result in up to 95% of all hip fractures in the elderly and 20% of the elderly who suffer a hip fracture will die within a year (da Costa et al., 2012). In the United States alone the costs of fall-related injuries were approximately $50 billion in 2015 and are expected to increase in the years to come (Florence et al., 2018).

The risk factors for falls are numerous, including a history of falls, muscle weakness, multimorbidity, polypharmacy, and balance deficits (Deandrea et al., 2013; Gates et al., 2008; Lajoie and Gallagher, 2004; Lusardi et al., 2017; Pfortmueller et al., 2014; Rubenstein, 2006; Villumsen et al., 2020). These can be divided into two distinct categories “intrinsic” and “extrinsic” (Pfortmueller et al., 2014; Villumsen et al., 2020). The extrinsic risk factors can be e.g. improper footwear, a loose carpet or a slippery footpath whereas intrinsic are age-related physiological factors (Lajoie and Gallagher, 2004). Studies find that poor balance is one of the best predictors of falls in the elderly and is a better predictor than visual impairment, which to a large degree is part of balance or medication (Clark et al., 2010; Gates et al., 2008).

# 2 Background

*This section will briefly explain what balance is, information about prediction tools, objective tools, and lastly information about force platforms and accelerometers.*

## 2.1 Balance

Balance or postural stability is defined as the ability to integrate sensory information from the somatosensory, vestibular, and visual systems, which work together with the neuro-muscular system, and thereby control postural stability by stabilizing the body's center of mass (CoM) when exposed to a perturbation (Browne and O'Hare, 2001; Dunsky et al., 2017; Heebner et al., 2015; Karlsson and Frykberg, 2000; Pollock et al., 2000). Balance is usually divided into two different types: Static and dynamic balance where static balance is defined as the ability to maintain an upright posture and to keep the line of gravity within the base of support (BoS), whereas dynamic balance pertains to the ability to maintain stability during changing BoS (Dunsky et al., 2017; Pollock et al., 2000). Aging and other factors like stroke, head injuries, or chronic diseases can impair balance, and therefore increase the risk of falls (Florence et al., 2018; Karlsson and Frykberg, 2000; Pfortmueller et al., 2014; Rice et al., 2015). Identifying individuals at risk of falling may help to prevent falls by implementing a targeted fall prevention strategy in due time (da Costa et al., 2012; Gates et al., 2008; Gillespie et al., 2012; Rubenstein, 2006). It is therefore important to identify balance issues in the early phases, as the first fall can predispose the elderly to subsequent falls with possible injury and fears of falling, which may lead to further limited physical activity (Gillespie et al., 2012; Pajala et al., 2008). Therefore, it is necessary to have balance measurements sensitive enough to identify subtle underlying balance issues (Pajala et al., 2008).

## 2.2 Prediction tools

There is no consensus on which fall risk prediction tools are best for identifying the elderly at risk of falling (Morse, 2006; Oliver, 2006; Villumsen et al., 2020). Some studies find that common screening tools for fall prediction lack accuracy, sufficient sensitivity and specificity to be useful for such purposes (da Costa et al., 2012; Gates et al., 2008; Kozinc et al., 2020; Lee et al., 2013; Lusardi et al., 2017; Matarese et al., 2015; Park, 2018; Sun et al., 2018; Villumsen et al., 2020). Methodological limitations in studies evaluating the available screening protocols include a lack of blinding, definitions of what constitutes a fall, and large variations in follow-up after the intervention (da Costa et al., 2012; Gates et al., 2008; Lee et al., 2013; Lusardi et al., 2017; Matarese et al., 2015; Park, 2018). Moreover, a review found large inconsistencies in fall outcomes, e.g. how these are reported, which further increases the

diversity of how to assess the risk of falls and the effect of a targeted rehabilitation intervention (Gates et al., 2008).

The review found that fall outcomes were reported in several different ways (Gates et al., 2008). Most of the studies included all falls, while others reported recurrent falls, falls not due to an external hazard, falls not due to a medical event, indoor falls, or a combination of these (Gates et al., 2008). Eight out of 25 studies did not report results for all the performed screening tests which give the possibility of reporting bias (Gates et al., 2008).

Combining screening tools can increase the diagnostic accuracy of predicting the risk of fall, where a combination of two-three assessment tools seems to be optimal for predictive value (Lee et al., 2013; Park, 2018). It has been suggested that combining five subjective findings and two performance-based (objective) measures is a useful way to identify the elderly in need of a more in-depth balance assessment (Lusardi et al., 2017).

Other important aspects to consider are how and where the prediction tools are used (Matarese et al., 2015). Hospital chief administrators and risk managers often prefer adopting similar fall risk screening tools across hospital units (Matarese et al., 2015). Even though this policy aims to make clinical assessment easier, it fails to consider that risk factors may differ depending on the age of the hospital population or the setting (Matarese et al., 2015).

### 2.3 Objective assessment tools

Many of the currently used assessment tools are subjective, qualitative, and use binary threshold assessment scores to either categorize people as fallers or non-fallers (Howcroft et al., 2013; Mancini and Horak, 2010). This approach may oversimplify the fall risk amongst the elderly, which is more accurately represented by a continuum of fall risk, ranging between multiple risk categories, such as low, moderate, and high fall risk (Howcroft et al., 2013). Subjective tests rely on the knowledge and experience of the assessor, decreasing the accuracy of the balance assessment which calls for more objective assessment tools (Heebner et al., 2015; Howcroft et al., 2013; Kis, 2020; Mancini and Horak, 2010; Zakeri et al., 2017). Objective tools provide quantitative data that enable healthcare professionals to evaluate and assess progress without interpretation apart from being a necessary part of evidence-based practice (Howcroft et al., 2013; Kis, 2020; Tyson and Connell, 2009). Despite this, objective tools are not widely adopted for such purposes (Tyson and Connell, 2009). Healthcare workers report that a lack of resources e.g. time and money can make it difficult to identify and learn how to use appropriate assessment tools (Tyson and Connell, 2009). Therefore, the objective tools must be affordable and easy to use and implement.

### 2.4 Assessing balance - force platform

A laboratory-grade force platform is used in many studies focusing on static balance and has been shown to be an effective tool for assessing the movement of center-of-pressure (CoP) and thus balance performance (Clark et al., 2010; Haas and Burden, 2000; Lee and Sun, 2018; Zakeri et al., 2017). Force platforms are thus considered the gold-standard for the assessment of balance and postural stability (Clark et al., 2010; Haas and Burden, 2000; Zakeri et al., 2017). However, force platforms have multiple limitations such as immobility, high cost, and require longer setup times and are therefore often only feasible to use in a laboratory setting and not in clinical practice (Heebner et al., 2015; Zakeri et al., 2017).

### 2.5 MOTI - a novel device for evaluating balance

MOTI is a novel inertial sensor from MOTI ApS Aalborg Denmark that uses an accelerometer, gyroscope, and magnetometer and is an advanced motion analysis device. An accelerometer is a device that measures acceleration i.e., rate of change of velocity or G-forces. Accelerometry seems to be a convenient method of acquiring clinical measures for balance and can be comparable with measures from force platforms (Dewan et al., 2019; Hsieh et al., 2019; Hsieh and Sosnoff, 2021; Mancini et al., 2012; Ozinga et al., 2017; Seimetz et al., 2012; Sun et al., 2018; Sun and Sosnoff, 2018; Whitney et al., 2011). MOTI is connected to a mobile application where motion data are displayed. This may provide the healthcare professional with an easier, cheaper, and faster objective way to evaluate balance. Because of the novelty of MOTI, there are not yet any published studies about MOTI although similar technologies have been evaluated for such purposes (Dewan et al., 2019; Hsieh et al., 2019; Hsieh and Sosnoff, 2021; Mancini et al., 2012; Ozinga et al., 2017; Seimetz et al., 2012; Sun et al., 2018; Sun and Sosnoff, 2018; Whitney et al., 2011). A recent study demonstrated that the use of accelerometry with the technology called SWAY Balance is comparable with a force platform when the subjects were balancing using one leg, but were not sensitive enough when subjects were standing using both legs (Dewan et al., 2019). Furthermore, accelerometers seem to be able to effectively distinguish between static and dynamic tasks although not being able to demonstrate direct correlations between the force platform and the accelerometer (Heebner et al., 2015). However, this is not a universal finding as Lindemann et al., 2012 had less promising results, which were related to the suboptimal placement of the accelerometer, which regards the balance strategy employed in the study. Furthermore, a study by Moe-Nilssen and Helbostad, 2002 found unacceptably low sensitivity for the accelerometer used in the study. These findings indicate a need for further

investigation for the use of accelerometry as a method of evaluating balance compared to a force platform.

### 2.6 Summary

The present rate of falls in the elderly is problematic and is estimated to rise significantly in the coming years. The current fall prediction tools lack accuracy and an easily quantifiable way to evaluate results. Accelerometers show promising results as a convenient method of evaluating balance in clinical practice. Therefore, this project aims to investigate whether an accelerometer like MOTI is a viable alternative to the gold standard, force platform.

# 3 Aim and Hypotheses

*This section describes the aims and hypotheses of this project.*

## Aim and Hypotheses

This project aims to:

- Investigate the validity of using MOTI when assessing standing balance by comparing it to a gold standard.
- Investigate MOTI's test-retest reliability when assessing standing balance.

The hypotheses are:

H01: The two-way mixed single measures intraclass correlation coefficient with consistency is equal to or higher than 0.75 between MOTI and the force platform for each individual stance.

HA1: The two-way mixed single measures intraclass correlation coefficient with consistency is less than 0.75 between MOTI and the force platform for each individual stance.

For MOTI's test-retest reliability:

H02: The two-way mixed single measures intraclass correlation coefficient with consistency is equal to or higher than 0.75 between the second and third measurement for each individual stance for MOTI.

HA2: The two-way mixed single measures intraclass correlation coefficient with consistency is less than 0.75 between the second and third measurement for each individual stance for MOTI.

# 4 Method

*This section will describe the methods used in this project.*

## 4.1 Design

This study had a cross-sectional design including 30 healthy subjects to validate the use of MOTI for assessing standing balance.

## 4.2 Literature Search

The free-text search of the project was found among publicly available articles in Google scholar and peer-reviewed articles accessed with an Aalborg University account. The databases used for the systematic literature search were PubMed and Embase. The structured literature search in this project aimed to have balanced recall and precision rates that were in line with the scope of the project. The searches were made using relevant keywords from similar articles and chain searches on relevant articles. Two structured searches were performed with two and three blocks respectively. The first search was divided into two blocks. Block one: Elderly, Block two: Fall prediction. The two blocks were searched with related synonyms (Appendix A). This search had the following search limits: English, Danish, Humans, Systematic Review, and Meta-analysis. The Systematic Review and Meta-analysis search limits were chosen to get the strongest evidence in this field. A flowchart illustrating the selection process is presented in figure 1. The second search was divided into three blocks. Block one: Force platform, Block two: Accelerometer, Block three: Balance (Appendix B). All three blocks were also searched with related synonyms. This search had the following search limits: English, Danish, Humans. A flowchart illustrating the selection process is presented in appendix C.

In both structured searches, duplicates were removed when screening for the title. After title screening, the studies' abstracts were screened and in- or excluded. Lastly, full-text screening of the remaining studies was performed, and 27 studies from the two searches were included in this project.

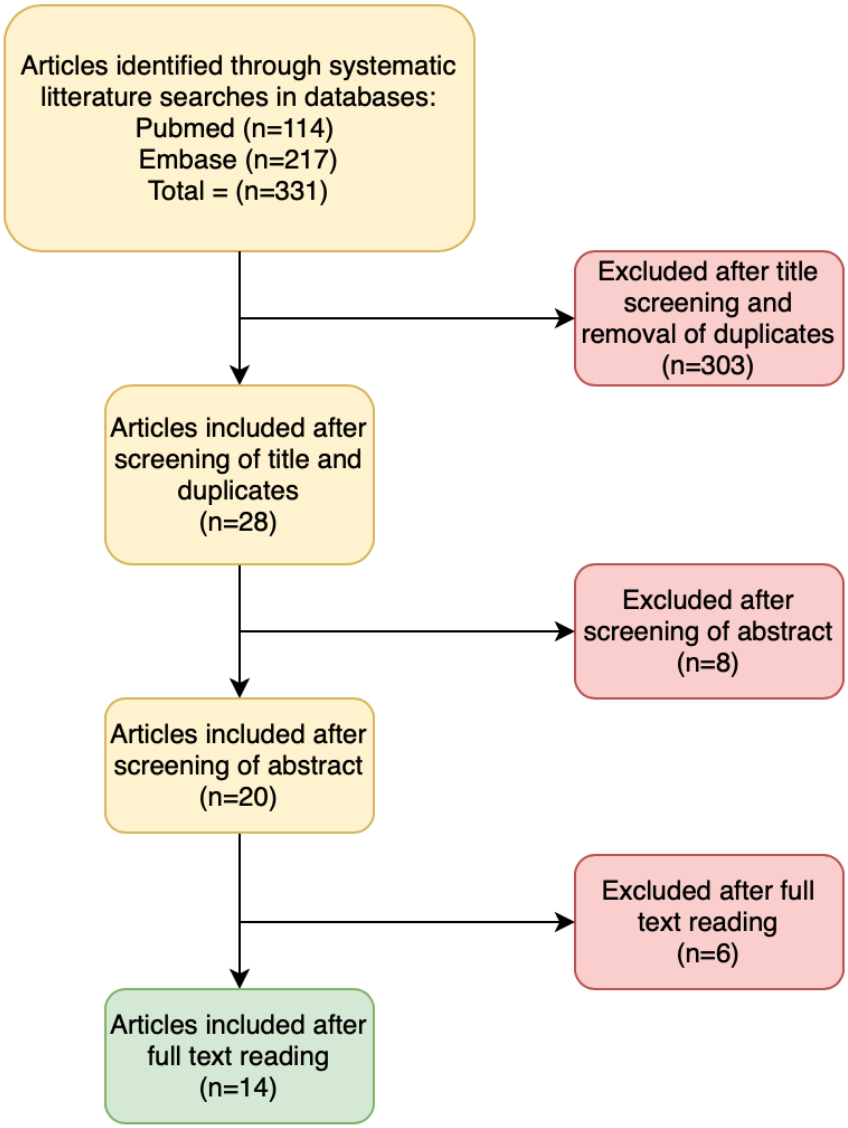


*Figure 1: Flowchart of the selection process for search 1*

## 4.3 Protocol

### 4.3.1 Recruitment

Sample size estimation was based on previous studies with similar methods (Dewan et al., 2019; Hsieh and Sosnoff, 2021; Mancini et al., 2012). Because of this, a sample of convenience consisting of 30 healthy subjects over the age of 18 was included in the project. The subjects took part in a single experimental session lasting approximately 30 mins. The session took place in a quiet setting with a stable room temperature.

### 4.3.2 Equipment

As gold-standard for measuring standing balance, a force platform (*Flintec Type: BK2-200 kg-™-GP, Hudson, MA*) with four channels was used to extract CoP from both medial-lateral (ML) and anterior-posterior (AP) direction. Data were collected via a Bluetooth connection and processed using OpenSignals software (*BioSignals Plux v. 2.1.1, Lisbon*).

MOTI Digital Goniometer (*MOTI ApS, Aalborg*) was used to collect accelerator data in the AP and ML directions from each participant. All data were collected via a Bluetooth connection on a smartphone (*P Smart 2019, Huawei, Shenzhen*).

### 4.3.3 Practical execution

Two trained physiotherapists conducted all tasks related to the data collection in this study. Pilot testing was performed on three subjects to familiarize the physiotherapists with the equipment, procedures, to evaluate the time required to complete each trial, and to refine the assessment methods.

**Oral instructions and informed consent:**

The subject was informed of the purpose of the project and allowed to ask questions regarding their participation. Subsequently, the subject was asked to sign the informed consent (Appendix E). After registering demographic information, the subject was instructed in the execution of the trial.

**Placement of the accelerometer:**

MOTI was placed at L5 on the lower back using a MOTI mounting sticker. MOTI was placed so that the logo was oriented horizontally on all subjects. The lower back was chosen based on previous recommendations for assessing changes in CoM (Ghislieri et al., 2019; Heebner et al., 2015; Howcroft et al., 2013; Hsieh et al., 2019; Mancini et al., 2012; Moe-Nilssen and Helbostad, 2002; Sun et al., 2018; Whitney et al., 2011). Prior to placing MOTI, the skin was prepared by removing all hair and dead skin with a disposable shaver followed by cleaning the skin with a single-use alcohol swab. This was to improve adherence of MOTI to the skin. After the placement of MOTI, the distance between MOTI and the floor was measured.

**Placement on the force platform:**

For all balance measurements, the subject stood in the middle of the force platform without shoes and faced the wall. The subject was instructed to stand in each position for approximately five seconds before data collection started where each position was then held

for 15 seconds. This was done with eyes both open and closed in a sequence from easiest (open eyes double-leg stance) to most difficult (closed eyes, single-leg stance). For each condition, three consecutive measures were performed with approximately 30-second intervals. The reason for the different stances with and without visual feedback is to confirm that this affects balance, as demonstrated in previous studies (Dewan et al., 2019; Heebner et al., 2015; Hsieh et al., 2019) and to confirm that the effect hereof is detected in a similar fashion by MOTI and the force platform.

Data collection from the force platform was performed by starting the recording without the subject standing on the force platform to ensure that the inbuilt offset was recorded. After a few seconds, the subject was instructed to take a position on the force platform. After 10 seconds of recording on the force platform, the recording started with MOTI which lasted an additional 15 seconds. Hereafter, data collection was stopped on both units.

***Double-leg stance***

The subject stood with legs together and arms down the side of the body while looking straight forward onto a fixed point at eye level. The subject stood in the middle of the force platform.

*Figure 2: The double-leg stance position*

***Single-leg stance***

The subject stood on one leg with the knee of the opposite leg bent at a 90-degree angle. The subject was allowed to use their arms for balance. Afterward, the subject switched to the other leg.

*Figure 3: The single-leg stance position*

### 4.3.4 Safety and ethical considerations

The protocol was exempt from requiring approval from the regional Ethical Committee as it falls under a category of methodological validation ("NVK," n.d.). The study was nevertheless conducted in accordance with the Helsinki Declaration where all participants provided their informed consent after receiving information about the study and their rights as participants in writing and orally. The study was reported under the University's collaborative agreement with the national data protection agency.

### 4.3.5 Data collection and processing

Data from the force platform were collected on a portable laptop (*HP ENVY Notebook*) via the OpenSignals software (sampling frequency: 1000 Hz, v. 2.1.1). Data from MOTI was collected on the Huawei P Smart 2019 via MOTI Research Application. These data were collected with a sampling frequency of 84 Hz. Data from the force platform and MOTI were saved as .txt files, and a custom script in MatLab_R2020B (*MathWorks Inc., Natick, MA*) was used to process the different data and convert data into Microsoft Excel (*v. 16.47, 2021*) files. In Excel, the standard deviation of the total CoP displacement (resultant of ML and AP-directions) and acceleration (resultant of ML and AP-directions) close to the CoM were calculated. Furthermore, the average of the three measurements from each stance was

calculated and used for the statistical analysis. For visual representation of the data a min-max normalization was performed with the following equation $x^i = \frac{x - min(x)}{max(x) - min(x)}$

### 4.3.6 Statistical analysis

Data were imported from Excel into IBM SPSS statistic version 27 (*IBM Corp. Armonk, NY*). Data for each stance were initially analyzed for normal distribution with the Shapiro-Wilk test. If data was not normally distributed, Log transformation was performed and then analyzed for normality again. If data were still not normally distributed, appropriate non-parametric tests were performed. The ICC values of MOTI compared to the force platform and the test-retest reliability were investigated by using a Two-way mixed single measures, consistency analysis ($ICC_{3,1}$) with associated confidence intervals (CI). The test-retest reliability was determined using trial 2 and 3 for both technologies.

ICC values lower than 0.5 are considered poor, between 0.5-0.75 are considered moderate, between 0.75-0.90 are considered good, and greater than 0.90 are considered excellent (Koo and Li, 2016). The Standard Error of Mean (SEM) was used to calculate the Minimal Detectable Change 95 (MDC95) for MOTI ($SEM\ x\ 1.96\ x\ \sqrt{2}$). MDC is a statistical estimate of the smallest amount of change that can be detected (Huang et al., 2011). The MDC was in this project calculated on the average of all measurements from each stance for MOTI.

Lastly, a mixed model repeated measures ANOVA was performed to investigate whether the force platform and MOTI could differentiate between the conditions with open and closed eyes and the different stances. As the dataset had an over representation of the single-leg stances (60 cases of single-leg measurements vs. 30 cases of double-leg measures), the right-leg stance was used to represent single-leg stance postural stability in the ANOVA for investigating the differences between double-leg stances and single-leg stances. If the assumption of sphericity was violated, the Greenhouse-Geisser correction was used. The Bonferroni post hoc test was used to control for multiple comparisons. A significance level of $P < 0.05$ was set to determine significant differences.

# 5 Results

*This section contains the results from the trial.*

### 5.1 Demographics

A sample of 30 healthy subjects (7 females) was included in this project. A full demographic overview is presented in table 1:

| | |
|---|---|
| Age (years) | 27.1 (± 3.6) |
| Weight (kg) | 82.8 (± 15.9) |
| Height (cm) | 177.3 (± 8.3) |

*Table 1: Demographic data of the 30 subjects*

### 5.2 Intraclass correlation and minimal detectable change

The ICC values ranged from poor to good where the best results were found in double-leg stance (eyes open and eyes closed) whereas the poorest were found for single-leg stance with eyes open (table 2). The MDC95 values for MOTI were 0.0049 to 0.1120 with the higher levels being found mainly in the single leg conditions with the eyes closed (table 2).

| Stance | ICC (95% CI) | MDC95 MOTI ($m/s^2$) |
|---|---|---|
| DLS EO | 0.788 (0.602-0.893) | 0.0049 |
| DLS EC | 0.857 (0.721-0.929) | 0.0070 |
| SLS R EO | 0.304 (-0.057-0.595) | 0.0130 |
| SLS L EO | 0.462 (0.128-0.702) | 0.0151 |
| SLS R EC | 0.674 (0.419-0.830) | 0.1120 |
| SLS L EC | 0.599 (0.304-0.790) | 0.0747 |

*Table 2: $ICC_{3.1}$ values (95% CI) for the different stances and MDC95 values for MOTI*

### 5.3 Test-retest reliability

The Intraclass Correlation coefficients ($ICC_{3.1}$) for consistency ranged between poor and moderate for both MOTI and the force platform (table 3).

| Stance | MOTI (95% CI) | Force Platform (95% CI) |
|---|---|---|
| DLS EO | 0.593 (0.301-0.783) | 0.575 (0.276-0.772) |
| DLS EC | 0.608 (0.317-0.795) | 0.499 (0.169-0.729) |
| SLS R EO | 0.463 (0.129-0.703) | 0.442 (0.103-0.689) |
| SLS L EO | 0.562 (0.252-0.767) | 0.465 (0.125-0.707) |
| SLS R EC | 0.121 (-0.251-0.462) | 0.462 (0.122-0.706) |
| SLS L EC | -0.054 (-0.413-0.319) | 0.180 (-0.200-0.514) |

*Table 3: Test-retest reliability for MOTI and the force platform using two-way mixed single measures, ICC*

### 5.4 Differences between conditions

The mixed model ANOVA indicated group x condition interaction (eyes open vs eyes closed) for all trials DLS EO vs DLS EC: ($F(1,58)=7.504$, $P=0.008$), SLS R EO vs SLSR EC: ($F(1,58)=10.685$, $P=0.002$), SLS L EO vs. SLS L EC:( $F(1,56)=13.769$, $P<0.001$). The results indicated a significant difference between the eyes open and eyes closed conditions for both modalities (Bonferroni: *$P<0.001$). The mixed model ANOVA also indicated group x condition x device interaction for DLS EO vs DLS EC vs SLSR EO vs SLSR EC: ($F(1,58)=22.842$, $P=<0.001$). The results indicated a significant difference between all stances and conditions (Bonferroni: *$P<0.001$).

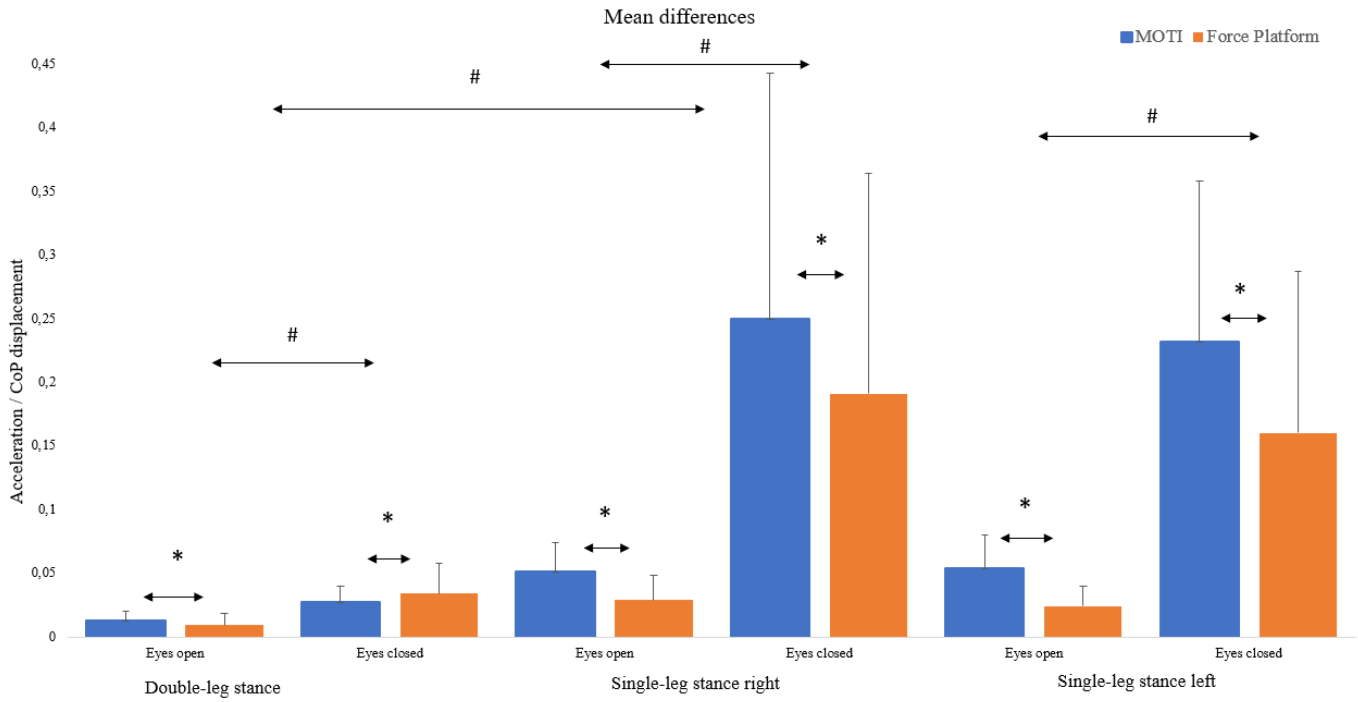


*Figure 4: Mean differences (95CI) using min-max normalized data. Significant differences (P < 0.05) between modalities are indicated with * whereas significant differences between conditions are indicated with #*

# 6 Discussion

*In this project, MOTI's ability to assess standing balance compared with a gold standard was investigated. The main findings were that MOTI were able to produce similar results compared to the gold standard for double-leg stance with both open and closed eyes. For single-leg stance the results were less similar compared to the gold standard. These findings and potential future perspectives will be discussed in the following.*

## 6.1 MOTI's applicability

The ICC values for the double-leg stance tasks were good (0.788-0.857) and in line with/slightly better as compared with previous findings (Mancini et al., 2012; Sun et al., 2018). The difference between the current findings and the two studies may relate to the difference in duration of data sampling (2 min and 30 sec. respectively) as compared with the 10 seconds used in this project. Although speculative, it is possible that a longer duration of data sampling may result in increased variability as fatigue may set in from standing still, especially in single leg standing. However, the clinical applicability will inevitably increase if the measurements can be done quicker. To evaluate whether the duration of performing the task and indeed whether fatigue affects the measurements, requires a study designed for such purposes.

MOTI's performance compared with the platform during the single leg stance tasks with closed eyes was slightly worse (ICC values 0.599-0.674) than the double-leg stance tasks. Interestingly, the ICC values during single leg stance with eyes open were poor (0.304 - 0.462). These findings are similar to previous reports (Dewan et al., 2019; Heebner et al., 2015) and may relate to a few factors. One is that the sensor placement may have affected the outcome as the distance from BoS can negatively affect the outcome (Dewan et al., 2019). It is therefore possible that the outcome reflects the differences in corrective actions measured by the platform and the sensor (Heebner et al., 2015). The force platform is designed to continuously measure the force exerted on it, and therefore it detects the resultant of all strategies used to maintain balance i.e. ankle, knee, hip and trunk strategies (Parker, 2001). With MOTI placed at the level of L5, it is possible that the increased trunk movement seen with reducing the BoS (visual inspection) affected MOTI's measurement to a greater extent than by the platform, potentially explaining the differences seen here.

Heebner et al. 2015 hypothesized that the reason for the poor correlation in their study was due to the fact that the two devices measured different aspects of postural stability, and because the force platform measures forces at the ground-foot level which may be more accurate of the corrective actions taken by the subjects e.g., using ankle strategy to maintain postural stability. In this project however, the usage of mainly the ankle strategy only appeared to be a factor in the single-leg stance with eyes open as seen in the poor correlation for SLS R EO and SLS L EO. However, this was only observed through visual inspection and not measured. The lower ICC values for SLS R EO and SLS L EO compared to the same stances with closed eyes could be explained by the fact that the hip is mainly used for more demanding postural tasks while the ankle is mainly used for less demanding tasks (Blenkinsop et al., 2017). This may relate to the fact that the ankle strategy mainly consists of a rotation of the body about the ankle joint with minimal movements about the superior joints (Blenkinsop et al., 2017). Another location of MOTI, closer to the ankle could potentially have resulted in higher ICC values.

A study by Abe et al., 2014 found that strategies can change with aging, and that the ankle strategy is more prominent in the adult population while the elderly population tends to use a hip dominant strategy. Therefore, placing MOTI at L5 could be optimal for estimating balance in an older population than measured here.

MOTI was secured with a custom-made mounting sticker directly on the skin which led to closer contact with the body, and thereby possibly reduced unwanted sway disturbance compared to using a belt or holding MOTI in the hand. This factor could be part of the reason for the higher ICC values found in this project.

For future reference, it could be interesting to use additional sensors with different placements e.g., shin, thigh, and lower back. This to get more information about which balance strategies are being used since the three sensors measure the same, and the differences in the measurements therefore reflect which strategies are being used at the joint below each sensor.

### 6.1.1 Minimal Detectable Change

In this project, MOTI's MDC95 values were low (Table 2), indicating its ability to detect very small changes. It can be argued that changes in postural stability in such low ranges can be of little clinical value. However, it is important to remember that training balance can take time, where the most effective improvements in overall balance performance are seen to occur after 11-12 weeks of training (Lesinski et al., 2015). To ensure compliance, it may therefore be beneficial to be able to monitor gradual improvements over time which cannot be captured with the naked eye. This can be used to assess modest improvements in postural stability during and after a rehabilitation process. Because of the low MDC, it may be possible to use MOTI to determine more subtle thresholds with e.g., very low risk, low risk, moderate risk, high and very high risk of falling.

### 6.1.2 MOTI can capture changes in postural stability

MOTI could detect increased postural sway between the eyes open and eyes closed conditions similar to the force platform (fig 4). The visual system is an important factor in postural stability where reduced visibility and visual impairments can increase the risk of falling significantly (Alshammari et al., 2018; Shumway-Cook and Woollacott, 2012). Likewise, postural sway is to a large degree dependent on the BoS where a smaller contact area results in greater postural sway (Shumway-Cook and Woollacott, 2012). It is important that clinical tools aimed at evaluating balance in clinical populations can detect differences in postural sway when these systems are affected.

Here, MOTI detected significant increases in postural sway, similar to the force platform (fig 4). Additional factors to consider for future reference are whether MOTI can detect changes in postural stability caused by changed sensory feedback from muscles and joints. Muscle fatigue is known to negatively affect postural stability which may be of relevance for older populations at risk of falling as well as younger populations e.g. athletes (Parreira et al., 2013; Shimpi et al., 2014). Likewise, the loss of sensory input caused by e.g., damage to ligaments (cruciate tear, ankle sprain) is known to affect balance where a significant part of the recovery relates to re-training postural control (Akbari et al., 2015, 2006).

Future studies need to confirm whether MOTI can be used for detecting sensory loss in clinical populations.

## 6.2 Limitations and future perspectives for methodologic refinement

### 6.2.1 Test-retest reliability and standardization

The test-retest reliability of MOTI was poor to moderate, but this was also seen for the force platform (Table 3). This is in contrast with previous findings which reported moderate (Mancini et al., 2012) to excellent (Heebner et al., 2015) test-retest reliability. These differences may relate to differences in standardization. By employing at a stricter level of standardization e.g., requiring participants to maintain exactly a 90-degree flexion of the knee in the single-leg stances could potentially have improved the test-retest reliability instead of the subject's subjective assessment. In some cases, participants would move slightly to maintain balance (observation) which may have contributed to the low test-retest ICC values. This could have been avoided by standardizing the foot position by marking the area for foot placement and repeating measurements where this was deviated from e.g., if the participant moved to maintain the balance. Using the arms for gaining or maintaining balance was not standardized in this study, but it was observed that the use of arms varied greatly (both within and between subjects). This could have been standardized by e.g., asking the subjects to stand with their shoulders abducted at a 90 degrees angle.

Although standardizing the standing position could have resulted in higher test-retest reliability, it is questionable how or whether this is of value when assessing postural stability which, by definition, is a dynamic and constantly changing activity (Shumway-Cook and Woollacott, 2012). This is reflected in the poor test-retest reliability demonstrated on the gold standard (force platform, table 3).

### 6.2.2 Average trial ICC vs. each trial ICC

The variance inevitably increased by using the average values from the three trials during each condition (see table 2). A secondary analysis was performed to investigate whether the ICC values improved by performing a head-to-head analysis for each trial in each condition (Appendix I). This did not reveal any differences in ICC values compared to the test performed on the average data.

### 6.2.3 Potential learning effect

It is possible that by completing the tasks on the left and right side three times, resulted in a learning effect, where the performance improved with time. Visual inspection of figure 4, indicates that subjects were consistently better (non-significant) standing on their left leg compared to their right leg both with open and closed eyes. This could be explained by the

fact that the single-leg stance always started with the subjects standing on their right leg. Another thing to consider is the potential role fatigue could have had on the performance. This could have been avoided by randomizing the order of the tasks.

### 6.2.4 Synchronized data collection

Data collection from the force platform and MOTI were recorded manually and therefore not perfectly synchronized. This was due to data being extracted using two different software programs and could have resulted in inaccuracies between the CoP displacement and CoM acceleration. However, as data were extracted from around the middle of the data collection sequence for both devices the postural movements captured on each respective device were the same. It is therefore not expected that this lack of synchronization should have had any noticeable effect on the results.

### 6.2.5 Literature search

The literature search in this project aimed to have balanced recall and precision rates. In practice, it is difficult to perform a search with a recall rate of 100, as it will result in a low precision and thus a high number of hits (Buus et al., 2008). It is therefore important to balance recall and precision of the search according to the framework of the given project (Buus et al., 2008). In this project search 1 had relatively low precision due to the number of studies excluded based on the title alone, whereas search 2 had relatively high precision. This could be due to more specialized keywords in search 2 compared to search 1, and the fact that search 2 is a more limited research field. For both search 1 and 2 chain searches were used to increase recall (Buus et al., 2008).

# 7 Conclusion

MOTI is a valid tool for assessing standing balance with open and closed eyes in the double-leg stance position with good correlation compared to the gold standard. For other tasks in single-leg stance, the correlation ranged from poor to moderate. MOTI could likewise detect differences in postural stability between open and closed eyes tasks. The findings in this project are the first steps in validating MOTI as a tool to assess balance.

The current findings are promising as they indicate a potential of using MOTI as a valid tool for estimating standing balance. Future research and methodologic refinement needs to investigate MOTI's ability to estimate balance in other positions (e.g. tandem position), conditions (e.g. fatigue) and populations (e.g. various age groups with compromised balance such as the elderly people at risk of falling and younger individuals with ligament injuries). Assessing balance in a larger cohort would allow for constructing a continuum with multiple threshold values which could potentially predict fall risk more precisely by dividing people into different fall risk groups. Furthermore, future studies need to determine the best methods to evaluate balance during single-leg stance.

In the current form, MOTI does not have a user-friendly interface and is therefore not feasible to use by healthcare professionals in clinical practice. This element would allow them and their patients to get objective information easily and objectively about the patient's balance and in the end, help predict the risk of falling.

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# Appendices

## A) Search 1

Pubmed:

| OR | AND | OR |
|---|---|---|
| Elderly | | Fall prediction |
| Geriatric | | Fall risk screening |
| Older adults | | Fall risk screening tool |
| Aging population | | Risk of fall |
| Aged (MeSH) | | Risk of falls |
| Aged | | Fall risk assessment |
| | | Fall risk assessment tool |
| Hits: 5.613.264 | | Hits: 4.058 |

Hits blokkene tilsammen: 3.294
Filtre:
Danish, English, Humans, Systematic Review, Meta-Analysis
Hits efter filtre: 114
Dato: 16/2-2021

Embase:

| OR | AND | OR |
|---|---|---|
| Aged | | Fall prediction |
| Geriatric | | Fall risk screening |
| Older adults | | Fall risk screening tool |
| Aging population | | Risk of fall |
| | | Risk of falls |
| | | Fall risk assessment |
| | | Fall risk assessment tool |
| Hits: 4.909.280 | | Hits: 7.534 |

Filtre:
Danish, English, Humans, Systematic Review, Meta-Analysis
Hits efter filtre: 217
Dato: 16/2-2021

## B) Search 2

Pubmed:

| OR | AND | OR | AND | OR |
|---|---|---|---|---|
| Force platform | | Accelerometer | | Balance |
| Force plate | | Accelerometry Mesh | | Static balance |
| | | Accelerometry | | Postural Stability |
| | | Inertial sensor | | Stability |
| | | | | Postural control |
| | | | | Center of pressure |
| | | | | Center of mass |
| | | | | Sway |
| | | | | Postural sway |
| Hits: 5.663 | | Hits: 20.091 | | Hits: 765.951 |

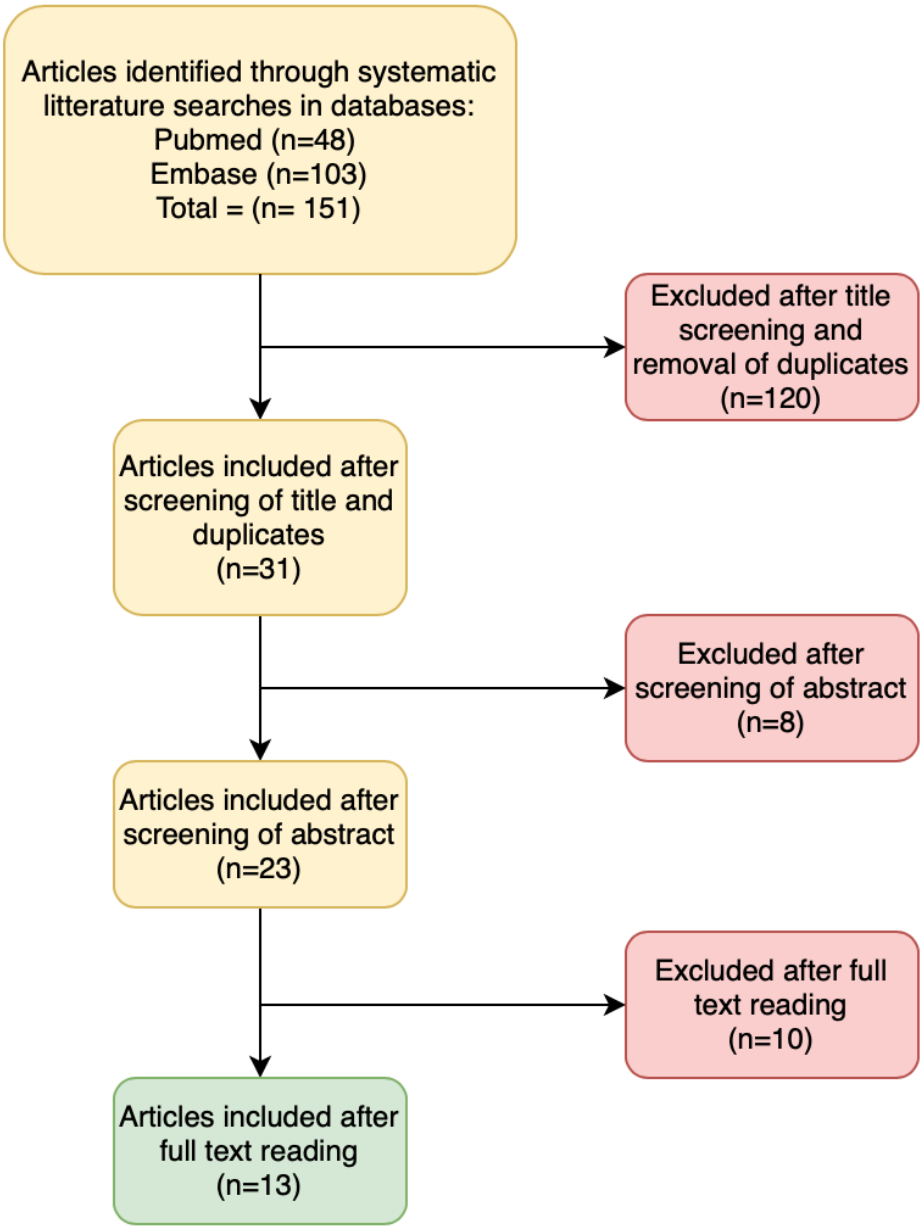
Hits: 58
Dato: 22/2-2021

Embase:

| OR | AND | OR | AND | OR |
|---|---|---|---|---|
| Force platform | | Accelerometer | | Balance |
| Force plate | | Accelerometry | | Static balance |
| | | Inertial sensor | | Postural Stability |
| | | | | Stability |
| | | | | Postural control |
| | | | | Center of pressure |
| | | | | Center of mass |
| | | | | Sway |
| | | | | Postural sway |
| Hits: 7.116 | | Hits: 25.203 | | Hits: 988.322 |

Hits: 103
Dato: 22/2-2021

C) Flowchart 2



# D) Deltagerinformation

*Metodevalidering af MOTI som et redskab til at estimere balance*

Vi vil spørge, om du vil deltage i et videnskabeligt forsøg, der udføres på Frederik Bajers Vej 300, 9220 ved GROW AAL.

Før du beslutter, om du vil deltage i forsøget, skal du fuldt ud forstå, hvad forsøget går ud på, og hvorfor vi gennemfører forsøget. Vi vil derfor bede dig om at læse denne deltagerinformation grundigt.

Du vil blive inviteret til en samtale om forsøget, hvor denne deltagerinformation vil blive uddybet, og hvor du kan stille de spørgsmål, du har om forsøget. Du er velkommen til at tage et familiemedlem, en ven eller en bekendt med til samtalen.

Hvis du beslutter dig for at deltage i forsøget, vil vi bede dig om at underskrive en samtykkeerklæring. Husk, at du har ret til betænkningstid, før du beslutter, om du vil underskrive samtykkeerklæringen.

Det er frivilligt at deltage i forsøget. Du kan når som helst og uden at give en grund trække dit samtykke tilbage.

**Formål med forsøget**
Formålet med dette forsøg er at validere MOTI, som er et digitalt goniometer og bevægelsessensor, og om hvorvidt denne teknologis målinger om balance korrelerer med målinger fra en kraftplatform, som anses for at være guld standard.

**Hvem kan deltage i forsøget?**
Du kan deltage i forsøget, hvis du er rask og over 18 år.

**Hvordan foregår forsøget?**
Forsøget vil være en enkelt session af en varighed på omtrent 30 min., og du vil skulle gennemføre fire forskellige statistiske balance stillinger på en kraftplatform. Disse er: Stående på begge ben og stående på et ben. Begge stillinger udføres med både åbne og lukkede øjne og stående på et ben gennemføres på højre og venstre ben. Hver stilling udføres tre gange. MOTI vil blive placeret på lænden, og forud for påsættelsen vil lænden blive præpareret med skraber, såfremt det er nødvendigt. Dataindsamling fra kraftplatformen og MOTI vil foregå samtidig.

**Risici, bivirkninger og ulemper**
Der er ingen kendte risici ved at deltage i forsøget.

**Nytte ved deltagelse**
Din deltagelse vil bidrage med data, som kan være med til at klarlægge, om MOTI er en valid metode til estimering af balance og vil på sigt kunne bruges som et screeningsværktøj til f.eks. at vurdere faldrisiko.

**Udelukkelse fra og afbrydelse af forsøg**
Reagerer du efter forsøgslederens vurdering uventet på forsøgets procedurer, eller viser du dig på anden vis ikke egnet til videre deltagelse i forsøget, kan din deltagelse i forsøget til ethvert tidspunkt afsluttes. Forsøget som helhed vil blive stoppet, hvis det skulle vise sig, at forsøgspersonerne ikke er i stand til at gennemføre forsøgsprotokollen.

**Oplysninger om økonomiske forhold**
Ingen i forsøgsgruppen har økonomiske interesser i dette forsøg, og der udbetales ikke kompensation i forbindelse med deltagelse i forsøget.

**Adgang til forsøgsresultater**
Forsøgets resultater offentliggøres uanset udfaldet.

Vi håber, at du med denne information har fået tilstrækkeligt indblik i, hvad det vil sige at deltage i forsøget, og at du føler dig rustet til at tage beslutningen om din eventuelle deltagelse. Vi beder dig også om at læse det vedlagte materiale "Forsøgspersonens rettigheder i et sundhedsvidenskabeligt forskningsprojekt".

Hvis du vil vide mere om forsøget, er du meget velkommen til at kontakte undertegnede.

Med venlig hilsen

Christian Mikkelsen - cmikke19@student.aau.dk

Malik Gaardbo - mgaard19@student.aau.dk

**Forsøgspersonens rettigheder i et sundhedsvidenskabeligt forsknings-projekt**

Som deltager i et sundhedsvidenskabeligt forskningsprojekt skal du vide at:

· Din deltagelse i forskningsprojektet er helt frivillig og kan kun ske efter, at du har fået både skriftlig og mundtlig information om forskningsprojektet og underskrevet samtykkeerklæringen

· Du til enhver tid mundtligt, skriftligt eller ved anden klar tilkendegivelse kan trække dit samtykke til deltagelse tilbage og udtræde af forskningsprojektet. Såfremt

du trækker dit samtykke tilbage påvirker dette ikke din ret til nuværende eller fremtidig behandling eller andre rettigheder, som du måtte have

· Du har ret til at tage et familiemedlem, en ven eller en bekendt med til informationssamtalen

· Du har ret til betænkningstid, før du underskriver samtykkeerklæringen

· Oplysninger om dine helbredsforhold, øvrige rent private forhold og andre fortrolige oplysninger om dig, som fremkommer i forbindelse med forskningsprojektet, er omfattet af tavshedspligt

· Behandling af oplysninger om dig, herunder oplysninger i dine blodprøver og væv, sker efter reglerne i databeskyttelsesforordningen, databeskyttelsesloven samt sundhedsloven. Den dataansvarlige i forsøget skal orientere dig nærmere om dine rettigheder efter databeskyttelsesreglerne.

· Der er mulighed for at få aktindsigt i forsøgsprotokoller efter offentlighedslovens bestemmelser. Det vil sige, at du kan få adgang til at se alle papirer vedrørende forsøgets tilrettelæggelse, bortset fra de dele, som indeholder forretningshemmeligheder eller fortrolige oplysninger om andre.

· Der er mulighed for at klage og få erstatning efter reglerne i lov om klage- og erstatningsadgang inden for sundhedsvæsenet. Hvis der under forsøget skulle opstå en skade, kan du henvende dig til Patienterstatningen, se nærmere på www.patienterstatningen.dk.

# E) Samtykkeerklæring

**Informeret samtykke til deltagelse i et sundhedsvidenskabeligt forskningsprojekt.**

Forskningsprojektets titel: *Metodevalidering af MOTI som et redskab til at estimere balance*

**Erklæring fra forsøgspersonen**:

Jeg har fået skriftlig og mundtlig information, og jeg ved nok om formål, metode, fordele og ulemper til at sige ja til at deltage.

Jeg ved, at det er frivilligt at deltage, og at jeg altid kan trække mit samtykke tilbage uden at miste mine nuværende eller fremtidige rettigheder til behandling.

Jeg giver samtykke til, at deltage i forskningsprojektet, og har fået en kopi af dette samtykkeark samt en kopi af den skriftlige information om projektet til eget brug.

Forsøgspersonens navn: _____

Dato: _____ Underskrift: _____

Ønsker du at blive informeret om forskningsprojektets resultat samt eventuelle konsekvenser for dig?:

Ja _____ (sæt x) Nej _____ (sæt x)

**Erklæring fra den, der afgiver information:**

Jeg erklærer, at forsøgspersonen har modtaget mundtlig og skriftlig information om forsøget.

Efter min overbevisning er der givet tilstrækkelig information til, at der kan træffes beslutning om deltagelse i forsøget.

Navnet på den, der har afgivet information:

Dato: _____ Underskrift: _____

# F) Experimental Protocol

**Title:**

Method validation of MOTI as a tool for estimating balance

**Experiment managers and contact persons:**

Christian Mikkelsen - cmikke19@student.aau.dk

Malik Gaardbo - mgaard19@student.aau.dk

## Aim and Hypotheses

This project aims to:

- Investigate the validity of using MOTI when assessing standing balance by comparing it to a gold standard.
- Investigate MOTI's test-retest reliability when assessing standing balance.

The hypotheses are:

H01: The two-way mixed single measures intraclass correlation coefficient with consistency is equal to or higher than 0.75 between MOTI and the force platform for each individual stance.

HA1: The two-way mixed single measures intraclass correlation coefficient with consistency is less than 0.75 between MOTI and the force platform for each individual stance.

For MOTI's test-retest reliability:

H02: The two-way mixed single measures intraclass correlation coefficient with consistency is equal to or higher than 0.75 between the second and third measurement for each individual stance for MOTI.

HA2: The two-way mixed single measures intraclass correlation coefficient with consistency is less than 0.75 between the second and third measurement for each individual stance for MOTI.

## Background

Falls are a common and widespread problem among the elderly, and a third of people over the age of 65 and up to half of the people over 85 falls each year (Pfortmueller et al 2014, Villumsen et al 2020, Park 2018, Gillespie et al 2012, Sun & Sosnoff 2018). It is estimated that the number of injuries caused by falls will increase significantly in the coming years due to the aging population, and the incidence of falls and the related injuries increase with age (Florence et al. 2018, Freiberger et al 2013, Gillespie et al. 2012, Park 2018, Pfortmueller et al 2014, Rubenstein 2006).

Many of the currently used assessment tools are subjective, qualitative, and use threshold assessment scores to either categorize people as fallers or non-fallers (Howcroft et al 2013). This approach may oversimplify the fall risk amongst the elderly, which is more accurately represented by a continuum of fall risk, ranging between multiple risk categories, such as low, moderate, and high fall risk (Howcroft et al 2013). Subjective tests rely on the knowledge and experience of the assessor, decreasing the accuracy of the balance assessment which calls for more objective assessment tools (Kis 2020, Zakeri et al 2017, Heebner et al 2015, Howcroft et al 2013).

Force platforms are considered the gold standard for the assessment of balance and postural stability (Clark et al. 2010, Haas & Burden 2006, Zakeri et al. 2017). However, the feasibility of routinely using them in clinical settings relates to their immobility, high cost, and require longer setup times (Zakeri et al 2017, Heebner et al 2015). As a proxy to measure postural stability, accelerometry may be a convenient method for acquiring clinically-relevant measures for balance, comparable with those from force platforms (Heebner et al. 2015, Hsieh & Sosnoff et al., Sun & Sosnoff et al. 2018, Whitney et al 2011, Dewan et al 2019, Hsieh et al 2018, Mancini et al 2012, Ozinga et al 2017, Sun et al. 2018, Seimetz et al. 2012). However, this is not a universal finding as Lindemann et al. 2012 had less promising results, which were related to the suboptimal placement of the accelerometer, which regards to balance strategy employed in the study. These findings indicate a need for further investigation for the use of accelerometry as a method of evaluating balance compared to a force platform and the use of this information as a prediction tool for estimating fall risk among the elderly.

## Strategy for Literature Search

The free-text search of the project was found among publically available articles in Google scholar and peer-reviewed articles accessed with an Aalborg University account. The databases used for the systematic literature search were PubMed and Embase. The searches were made using relevant keywords from similar articles and chain searches on relevant articles. Two structured searches were performed with two and three blocks respectively. The first search was divided into two blocks. Block one: Elderly, Block two: Fall prediction. The two blocks were searched with related synonyms. This search had the following search limits: English, Danish, Humans, Systematic Review, and Meta-analysis. The second search was divided into three blocks. Block one: Force platform, Block two: Accelerometer, Block three: Balance. All three blocks were also searched with related synonyms. This search had the following search limits: English, Danish, Humans.
In both structured searches, duplicates were removed when screening for the title. After title screening, the studies' abstracts were screened and in- or excluded. Lastly, full-text screening of the remaining studies was performed and 27 studies from the two searches were included in this project.

## Purpose

The purpose of this project is to investigate whether MOTI is a valid tool for assessing standing balance by comparing it to a force platform (gold standard).

## Subjects

A sample of convenience consisting of 30 healthy subjects (7 females) over the age of 18.

On the day of the session, the subjects' demographic data will be collected. The data are age, height, weight and sex.

## Methods

The subjects will take part in an experimental session lasting approximately 30 mins. The session will take place in a quiet setting with a stable room temperature.

### 4.3.3 Practical execution

Two trained physiotherapists conducted all tasks related to the data collection in this study. Pilot testing was performed on three subjects to familiarize the students with the equipment, procedures, to evaluate the time required to complete each trial, and to refine the assessment methods.

**Oral instructions and informed consent:**

The subject was informed of the purpose of the project and allowed to ask questions regarding their participation. Subsequently, the subject was asked to sign the informed consent (Appendix E). After registering demographic information, the subject was instructed in the execution of the trial.

**Placement of the accelerometer:**

MOTI was placed at L5 on the lower back using a MOTI mounting sticker. MOTI was placed so the logo was oriented horizontally on all subjects. The lower back was chosen based on previous recommendations for assessing changes in CoM (Ghislieri et al. 2019, Howcroft et al 2013, Heebner et al 2015, Mancini et al 2012, Whitney et al 2011, Hsieh et al 2018, Sun et al 2018, Moe-Nilssen & Helbostad 2002). Prior to placing MOTI, the skin was prepared by removing all hair and dead skin with a disposable shaver followed by cleaning the skin with a single-use alcohol swab. This was to improve adherence of MOTI to the skin. After the placement of MOTI, the distance between MOTI and the floor was measured.

**Placement on the force platform:**

For all balance measurements, the subject stood without shoes and faced the “Front” mark, written on the platform. The subject was instructed to stand in each position for approximately five seconds before data collection started where each position was then held for 15 seconds. This was done with eyes both open and closed in a sequence from easiest (open eyes double-leg stance) to most difficult (closed eyes, single-leg stance). For each condition, three consecutive measures were performed with approximately 30-second intervals. The reason for the different stances with and without visual feedback is to confirm that this affects balance, as demonstrated in previous studies (Heebner et al 2015, Dewan et al 2019, Hsieh et al 2018) and to confirm that the effect hereof is detected similarly by MOTI and the force platform.

Data collection from the force platform was performed by starting the recording without the subject standing on the force platform to ensure that the inbuilt offset was recorded. After a

few seconds, the subject was instructed to take a position on the force platform. After 10 seconds of recording on the force platform, the recording started with MOTI which lasted an additional 15 seconds. Hereafter, data collection was stopped on both units.

***Double-leg stance***

The subject stood with legs together and arms down the side of the body while looking straight forward onto a fixed point at eye level. The subject stood in the middle of the force platform. This stance was performed with both open and closed eyes.

*The double-leg stance position*

***Single-leg stance***

The subject stood on one leg with the knee of the opposite leg bent at a 90-degree angle. The subject was allowed to use their arms for balance. Afterward, the subject switched to the other leg. The subject stood in the middle of the force platform. This stance was performed with eyes both open and closed.

*The single-leg stance position*

### 4.3.4 Safety and ethical considerations

The protocol was exempt from requiring approval from the regional Ethical Committee as it falls under a category of methodological validation (NVK). The study was nevertheless conducted in accordance with the Helsinki Declaration where all participants provided their informed consent after receiving information about the study and their rights as participants in writing and orally. The study was reported under the University's collaborative agreement with the national data protection agency.

## Equipment:

As gold-standard for measuring standing balance, a force platform (*Flintec Type: BK2-200 kg-™-GP, Hudson, MA*) with four channels and COP was extracted from each direction. Data were collected via a Bluetooth connection and processed using OpenSignals software (*BioSignals Plux v. 2.1.1, Lisbon*).

MOTI Digital Goniometer (*MOTI ApS, Aalborg*) was placed at the level of L5 on the lower back of the participants and used to collect accelerator data in the AP and ML directions from each participant. All data were collected through a wireless connection on a smartphone (*P Smart 2019, Huawei, Shenzhen*).

The following equipment was used in this project:

| |
|---|
| Force Platform: Flintec Type: BK2-200 kg-™-GP |
| OpenSignals Software 2.1.1 |
| HP Envy Notebook laptop |
| MOTI Digital Goniometer |
| MOTI Mounting Stickers |
| MOTI Research Application |
| Huawei P Smart 2019 |
| Disposable shaving blades |
| Single-use alcohol swabs |

## Statistics

Data were imported from Excel into IBM SPSS statistic version 27 (*IBM Corp. Armonk, NY*). Data for each stance were initially analyzed for normal distribution with the Shapiro-Wilk test. If data was not normally distributed Log transformation was performed and then analyzed for normality again. If data were still not normally distributed, appropriate non-parametric tests were performed. The ICC values of MOTI compared to the force platform and the test-retest reliability were investigated by using a Two-way mixed single measures, consistency analysis (ICC $_{3,1}$) with associated confidence intervals (CI). The test-retest reliability was determined using trial 2 and 3 for both technologies.
ICC values lower than 0.5 are considered poor, between 0.5-0.75 are considered moderate, between 0.75-0.90 are considered good, and greater than 0.90 are considered excellent (Koo and Li, 2016). The Standard Error of Mean (SEM) was used to calculate the Minimal Detectable Change 95 (MDC95) for MOTI ($SEM\ x\ 1.96\ x\ \sqrt{2}$). MDC is a statistical estimate of the smallest amount of change that can be detected (Huang et al., 2011). The MDC was in this project calculated on the average of all measurements from each stance for MOTI.
Lastly, a mixed model repeated measures ANOVA was performed to investigate whether the force platform and MOTI could differentiate between the conditions with open and closed eyes and the different stances. As the dataset had an over representation of the single-leg

stances (60 cases of single-leg measurements vs. 30 cases of double-leg measures), the right-leg stance was used to represent single-leg stance postural stability in the ANOVA for investigating the differences between double-leg stances and single-leg stances. If the assumption of sphericity was violated, the Greenhouse-Geisser correction was used. The Bonferroni post hoc test was used to control for multiple comparisons. A significance level of $P < 0.05$ was set to determine significant differences.

## Risks, side effects, and short-term disadvantages

There are no known risks or side effects for this project.

## Economy

None of the involved students have any economic interests in this project and there will not be any economic compensation for the subjects.

## Benefits

This project has the potential to determine whether MOTI can be used to validly estimate standing balance. The findings from this study may therefore be further developed and used as part of screening tools for fall risk in the future.

## Publication of results

The results of this project will be made publicly available regardless of the outcome.

## Justification for the project

This project is justified by the factor that common screening tools for fall prediction lack accuracy, sufficient sensitivity, and specificity to be useful for such purposes (Da Costa et al. 2012, Gates et al. 2008, Lee et al. 2013 Lusardi et al. 2017, Park 2017, Matarese et al. 2015, Villumsen et al 2020, Sun et al 2018, Kozinc et al. 2020). Force platforms are the gold standard for an objective assessment of balance but are expensive, immobile and require long setup time, and are therefore unsuited for clinical practice (Zakeri et al 2017, Heebner et al 2015). For these reasons, this project aims to investigate whether MOTI can be an equivalent alternative for assessing standing balance to force platforms.

# G) SOP - MOTI

**Anvendelsesområde:**

Registrering af acceleration.

**Formål:**

Formålet med denne SOP er at standardisere og dokumentere proceduren for registrering af acceleration for MOTI.

**Instruktion:**

1. Sikre at MOTI og telefon er opladt samt at telefonen har WIFI forbindelse.
2. Åbn MOTI research app og tryk “Find MOTI”.
3. Kan der ikke oprettes forbindelse til MOTI, stryges en magnet over MOTI. Forsøg derefter at oprette forbindelse igen.
4. Navngiv filen i feltet “Enter an exercise”.
5. Navngiv forsøgspersonen med et ID nr. i feltet “Client ID”.
6. Preparer huden ved L5, hvis nødvendigt
7. Påsæt MOTI mounting sticker på L5 og påsæt MOTI herpå.
8. Der optages tre målinger på hver af de fire udgangsstillinger jvf. protokollen
9. Tryk på “Send data” og vælg derefter Gmail samt modtager.
10. Åbn filen fra mailen og gem som .txt
11. Åbn et tomt Excel dokument og vælg “Hent data” og klik på “Fra tekst/CSV”

**Rapportering:**

Afsendes fra MOTI og konverteres fra en Microsoft Excel fil til .txt fil

# H) SOP - Kraftplatform og Opensignals

**Anvendelsesområde:**

Registrering af kraft

**Formål:**

Formålet med denne SOP er at standardisere og dokumentere proceduren for registrering af ændret BoS gennem udsving i CoP

**Instruktion:**

For komplet gennemgang af alle procedure henvises der til OpenSignals Manual
(“OpenSignals Manual,” n.d.)

**Kort instruktion:**

1. Juster fødderne på kraftplatformen så den ikke vipper
2. Isæt strømforsyning til kraftplatformen.
3. Tænd computeren.
4. Åbn OpenSignals programmet på computeren.
5. Åbn device manager.
6. Tænd for bluetooth på din computer.
7. Forbind din computer med kraftplatformen.
8. Ved grønt indikeres det at de er forbundet.
9. Tjek at kanal 1-4 er valgte og en sampling på 1000 hz er valgt.
10. Tjek at indstillingen “platform” er valgt for kanal 1-4.
11. Foretag en baselinemåling uden forsøgsperson på platformen. Klik på live for at starte optagelsen.
12. Der optages tre målinger for hver af de fire udgangsstillinger jvf. protokollen.
13. Efter hver optagelse navngives og gemmes filen i .txt format.

**Rapportering:**

Gemmes som .txt fil og behandles i Matlab

# I) Correlation for each trial

Trial 1:

| Stance | ICC (95% CI) |
|---|---|
| DLS EO | 0.682 (0.431-0.835) |
| DLS EC | 0.891 (0.785-0.947) |
| SLS R EO | 0.254 (-0.111-0.558) |
| SLS L EO | 0.508 (0.187-0.731) |
| SLS R EC | 0.618 (0.337-798) |
| SLS L EC | 0.558 (0.247-0.765) |

Trial 2:

| Stance | ICC (95% CI) |
|---|---|
| DLS EO | 0.685 (0.436-0.837) |
| DLS EC | 0.808 (0.635-0.904) |
| SLS R EO | 0.440 (0.100-0.687) |
| SLS L EO | 0.459 (0.124-0.700) |
| SLS R EC | 0.644 (0.375-0.813) |
| SLS L EC | 0.593 (0.289-0.789) |

Trial 3:

| Stance | ICC (95% CI) |
|---|---|
| DLS EO | 0.738 (0.519-0.866) |
| DLS EC | 0.776 (0.576-0.888) |
| SLS R EO | 0.542 (0.231-0.752) |
| SLS L EO | 0.386 (0.029-0.655) |
| SLS R EC | 0.745 (0.525-0.871) |
| SLS L EC | 0.685 (0.431-0.839) |