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Validity and reliability of pressure-measurement insoles for vertical ground reaction force assessment in field situations

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This study aimed to test the validity and reliability of pressure-measurement insoles (medilogic® insoles) when measuring vertical ground reaction forces in field situations. Various weights were applied to and removed from the insoles in static mechanical tests. The force values measured simultaneously by the insoles and force plates were compared for 15 subjects simulating work activities. Reliability testing during the static mechanical tests yielded an average interclass correlation coefficient of 0.998. Static loads led to a creeping pattern of the output force signal. An individual load response could be observed for each insole. The average root mean square error between the insoles and force plates ranged from 6.6% to 17.7% in standing, walking, lifting and catching trials and was 142.3% in kneeling trials. The results show that the use of insoles may be an acceptable method for measuring vertical ground reaction forces in field studies, except for kneeling positions.

1. Introduction

Mechanical exposures at work (e.g., lifting and manual materials handling) are associated with the occurrence of musculoskeletal disorders (Yassi and Lockhart, 2013). These exposures are common and occur in, for instance, construction work and the health care sector. The majority of previous studies have been based on subjective reports of mechanical occupational exposure (manual material handling). Recent studies indicate that previously established risk factors, such as forward-bending work posture, may be considered untenable by studies based on objective measurements of work exposures (Villumsen et al., 2015) and that subjective reports may be inadequate for assessing physical activity (Dyrstad et al., 2014). Hence, it is crucial to obtain valid and reliable measurements of exposure to learn which specific aspects of such mechanical work exposure contribute to musculoskeletal disorders.

Mechanical exposures are characterized by the type of work executed, including the posture, movements, and exerted forces involved (Westgaard and Winkel, 1996; van der Beek and Frings-Dresen, 1998). Although valid and reliable methods for measuring posture and movements with accelerometers are available, there are not a sufficient number of objective assessments for forces exerted during tasks involving lifting in a field setting.

The forces exerted by workers during lifting and carrying can be estimated by measuring ground reaction forces using force plates, shoes instrumented with force sensors, or pressure measurement insoles. Force plates measure ground reaction forces with a high level of accuracy in the horizontal and vertical directions (3D), but their use is limited in laboratory conditions. Shoes instrumented with force sensors may suitable for the measurement of forces in 3D at work sites. To our knowledge, the XSENS ForceShoe (XSENS North America Inc., Culver City, CA, USA) is the only commercially available system. However, due to the shoe's 3.2 cm sole height and total weight of 1.1 kg, this shoe may hinder normal working tasks and is inadequate when safety shoes are compulsory. Several researchers have used self-constructed force measurement insoles (Faivre et al., 2004; Liedtke et al., 2007; Saito et al., 2011; Razak et al., 2012); however, this approach is time consuming and requires a validation process. Therefore, commercial pressure measurement insoles may be a more practical choice (Forner Cordero

Abbreviations: 3D, 3-dimensional; ICC, intraclass correlation coefficient; MaxE, maximum error; RMSE, root mean square error.

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et al., 2004; Forner-Cordero et al., 2006; Fong et al., 2008). Commercial systems discussed in the literature or found on the market include Footscan pressure insoles (RSscan International, Paal, Belgium), Pedar® insoles (Novel GmbH, Munich, Germany), F-Scan pressure measurement insoles (Tekscan Inc., Boston, USA), and medilogic® insoles (T&T medilogic Medizintechnik GmbH, Schönefeld, Germany).

The validity, reliability or applicability differs depending on the system. Footscan pressure insoles showed high test-retest reliability but low validity during walking trials (Low and Dixon, 2010). Measured force values with Pedar® insoles increased up to 17% during 3-h walking trials (Arndt, 2003), by 43.2% during a static loading experiment and by 19% during an 8-h repeated load application (Hurkmans et al., 2006). Up to 30% lower peak forces during walking trials were observed for F-Scan insoles (Nicolopoulos et al., 2000). El Kati observed a rapid decrease in sensitivity in running trials and a frequent need for calibration with the F-Scan insoles (El Kati et al., 2010). The poor durability of the F-Scan insoles (El Kati et al., 2010; Woodburn and Helliwell, 1996) renders this system inefficient for measurements at the workplace. In general, the differences in validity and reliability compared to force platforms may be due their construction. Pedar® insoles are based on capacitive sensors, whereas the three other pressure measurement insoles mentioned above are based on resistive sensors.

Medilogic® insoles were chosen because they were considered applicable for field measurements at the worksite due to their durability and because they allow for 8-h collection of the raw data for each sensor of the insoles on a data logger (with SD-card). This study aimed to examine the validity and reliability of these pressure-measurement insoles for use in simulated work tasks relevant for construction and health care work.

2. Material and methods

2.1. Study design

To evaluate the applicability of pressure-measurement insoles for the field measurement of vertical ground reaction forces, medilogic® insoles were tested for validity and reliability via mechanical static tests during loading and unloading of the insoles as well as via tests in which participants simulated field situations with insoles placed in their shoes. During the simulated field situations, force plate measurements were carried out simultaneously for comparison.

2.2. Study population

Insoles were tested in simulated field situations using 15 healthy subjects (6 female, 9 male) with a mean age, weight, and height of 31.2 years (range: 21–50 years), 69.4 kg (range: 50–98 kg), and 169.3 cm (range: 157–193 cm), respectively. All of the participants were free of musculoskeletal problems for at least two months prior to participation. The participants were informed of the general aim of the study, the order and content of the measurements, and possible risks. All of the subjects signed an informed consent form prior to participation. The experiment was approved by the Regional Committee for Medical and Health Research Ethics (Ref. no.: 2013/2160 A) and conducted in accordance with the Helsinki Declaration.

2.3. Procedure for mechanical static tests

Mechanical static tests were performed by loading the insoles with weights ranging from 0 to 80 kg in steps of 5, 10 or 20 kg. Starting from an unloaded state, additional weight was placed on the insoles every 25 s until 80 kg was reached. The same procedure was then followed in the reverse order, reducing the weight every 25 s until the insole was unloaded (Fig. 1B). The procedure was repeated five times for each insole. Pressure values were recorded with a sampling frequency of 30 Hz. During the loading procedure, the insoles were placed in a self-constructed tripod between two triangular aluminum plates that were connected by a guide rail at each corner (Fig. 1A). Two 1-cm-thick rubber mats with sizes matched to the insoles were used between the insoles and the aluminum plates to prevent damage to the insoles and obtain a uniform pressure distribution.

2.4. Procedure for the simulation of field situations

Starting from an upright standing position with each foot placed on a separate force platform, the participants performed the following six working tasks: *Standing*: The participant was asked to stand as still as possible and look straight ahead for 1 min. *Walking*: Each participant walked on a straight 5-m track that had two separate force platforms in it. Both the left and right feet naturally stepped on one of the force platforms along the path. *Lifting an object*: A weight was placed on the floor in front of the force plates, with its position marked with tape. The participant lifted the object when given the command to lift it and then stood still in an upright position for 5 s. After 5 s, the weight was placed back on the floor, and the participant re-assumed the upright position. Trials were performed without weights and with weights of 10 and 15 kg. *Kneeling*: From a standing position (position 1), the participant knelt with their trunk in a vertical position with feet on the platforms and knees on the floor next to the force platforms (position 2). Next, the subjects put both hands in front of their knees and moved their trunk into a horizontal position (position 3). Finally, they moved back to the kneeling position (position 2) and rose back to the upright position (position 1). Instructions for new positions were given every 5 s. *Catching an object*: In the standing position, the subject had to catch a thrown 5-kg ball with both hands. *Free walking on even ground*: The participant walked freely in the laboratory without stepping on the force platforms while carrying a weight object. Trials were performed for 30 s each, and the weights carried ranged from 0 to 30 kg in steps of 5 kg.

All of the trials were repeated three times in a randomized order. One jump was performed at the beginning of each measurement to synchronize the times of both systems through the peak force at landing, except in the free walking trials, where no synchronization was needed. During the tasks, the pressures under the participant's feet were measured with insoles placed in their shoes on top of the regular insoles. The sampling frequency was 30 Hz. Simultaneous ground reaction forces were measured bilaterally by the force platforms (AMTI LG6-4-1, size: 120×60 cm^2, Watertown, MA, USA) with a sample frequency of 6000 Hz. Various sizes of the insoles were tested bilaterally in three different subjects (EUR: 37/38, 39/40, 41/42, 43/44, and 45/46). The size of the insoles was chosen based on the participant's shoe size. Prior to testing, each participant had to perform a standard calibration procedure for the insoles. To account for pre-existing pressure due to the tightness of the shoe, the participant was asked to sit in a chair with their feet lifted off the ground for 10 s. They then stood upright for 10 s on the left foot followed by 10 s on the right foot to normalize the measured pressure of each insole to their body weight.

2.5. Data analysis

Time synchronization and calculations of forces, correlations, and root mean square errors (RMSEs) were performed using Matlab

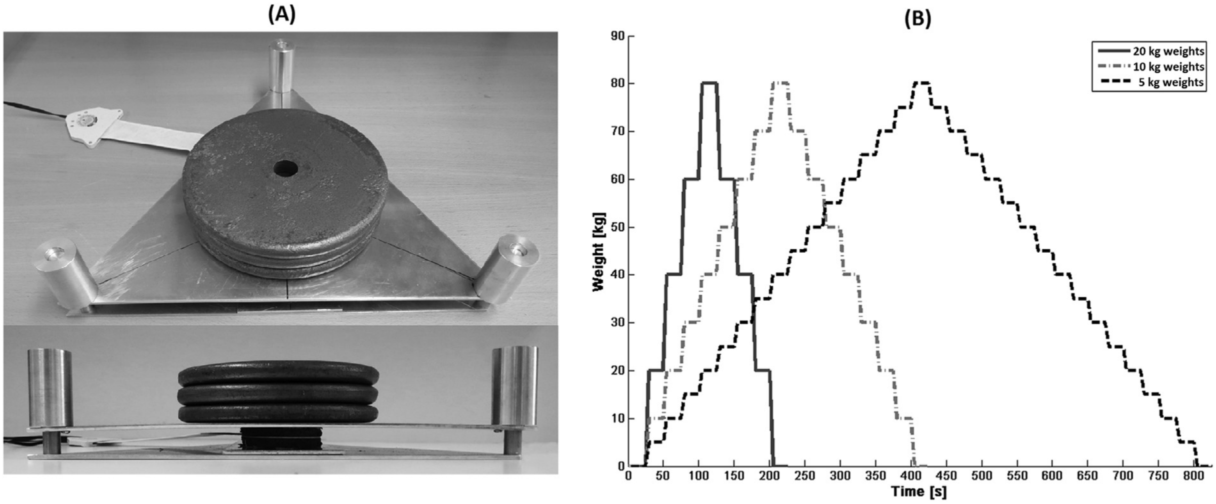

Fig. 1. Self-constructed tripod (A) and procedure of the mechanical static tests (B). A: The insoles were sandwiched between two rubber mats and the aluminum plates of the tripod. B: Weights of 5, 10 or 20 kg were placed on the insoles every 25 s until 80 kg was reached and then removed in reverse order.

R2013b (Math Works Inc., Natick, USA) and the raw measurement data. The sum of the pressures from all of the individual sensors in each insole was used to calculate the force values. Statistical analyses were performed using Matlab R2013b and IBM Statistical Package for Social Science (SPSS) Statistics 22 (IBM Corporation, New York, USA). For the static mechanical tests, regression formulas were calculated using the method of least squares for each insole. The test-retest reliability between the five tests for each insole was analyzed using an intraclass correlation coefficient (ICC 2,5: two-way random average measures, $n = 5$). The force values from the insoles and force plates in tests simulating field situations were compared by calculating the RMSE and maximum error (MaxE). For each trial, the RMSE and MaxE were calculated for three chosen characteristic time points or periods in the force pattern. Comparisons between the observed maximum, minimum and mean values from the force plates and insoles were evaluated using Wilcoxon tests. Ranking of the force values of the insoles at different load levels was examined using Friedman tests.

3. Results

3.1. Validity and reliability in the mechanical static tests

Use of the self-constructed tripod and the rubber mats around the insoles resulted in a uniform pressure distribution on the insoles that could be observed during the mechanical static tests (Fig. 2). Placing various weights (5, 10, and 20 kg) on the insoles led to an increase in the measured loads. An individual response pattern to the applied loads was observed for each insole; specifically, we discovered time-dependent creeping that was based on the amount of weight applied. Load values increased with time after placing weight on the insoles (Fig. 3A). The creeping patterns could be described by a potential function ($F(t) = a^*t^b$) and had to be calculated individually for each insole. Large weights produced a greater relative amount of creeping compared with smaller weights. A creeping pattern that was also dependent on the replaced weight was observed when removing weight. Load values decreased with time after the removing weight from the insoles (Fig. 3B).

For example, for the 'EU 47/48 left' insole, the measured load difference 23 s after placing the weights on the insoles was 2.89, 3.78, and 5.73 kg for weights of 5, 10, and 20 kg, respectively. When replacing the weights (5, 10, and 20 kg) from the insoles, the load differences were −2.25, −2.70, and −3.06 kg, respectively. The differences in load changes when increasing and decreasing the loads suggested a hysteresis of the measured forces that was compensated for when the load returned to 0 kg.

In the validation tests for the insoles, hysteresis and creeping effects were subtracted from the measured load values. The observed dependency between the applied loads (0–80 kg in 10 kg steps) and the measured loads was not linear for all of the insoles (Fig. 4). A cubic regression equation best fitted by the sum of least square errors could be calculated individually for each insole, including the left and right sides of individual insole pairs. For example, for the size EU 35/36 insoles, the equations $Y_{left}(x) = -0.288^*x + 0.026^*x^2 + 0.0001^*x^3$ and $Y_{right}(x) = -0.113^*x + 0.019^*x^2 + 0.0002^*x^3$ could be derived, where x is the measured force and Y is the calculated force.

When testing the reliability of the measured force values at various weights for all of the insoles, the mean ICC (2, 5) was 0.995. The lowest ICC coefficient was found for the size EU 39/40 right insole, with a value of 0.983. All of the ICC coefficients were significant ($p < 0.05$), and Cronbach's alpha ranged from 0.998 to 1 for the tested insoles (Table 1).

3.2. Validity in tests simulating field situations

Different force patterns were observed for each trial simulating field situations executed on force platforms (Fig. 5). *Standing*: The force patterns were nearly constant, with small variations due to weight shifts between feet. *Walking*: The forces displayed the typical pattern of the contact period of a step cycle. The force rose during heel strikes, decreased at midstance, rose again when rolling over the forefoot and thereafter gradually decreased until the end of the contact period. *Lifting an object*: Two force peaks were observed when picking up and putting down weights (when lowering and raising the body). The amplitude of the force plateau between the movements for picking up and replacing the weights depended on the amount of weight lifted. *Kneeling*: A short and rapid force peak was observed when the participants moved from standing (position 1) into the kneeling position (position 2). While the knees were placed outside the force platforms (positions 2 and 3), the forces measured under the feet were lower than in the standing position. Leaning forward from the kneeling position and

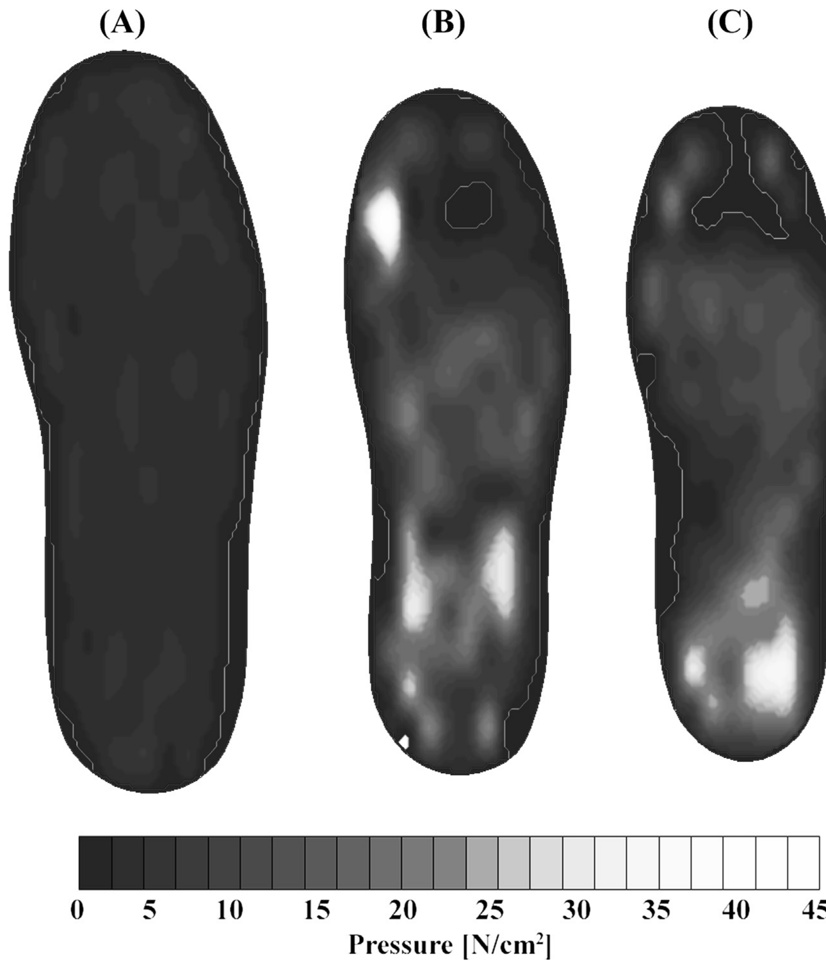

Fig. 2. Pressure distribution when using rubber mats in the tripod on an insole of size EU 43/44 (A), standing with one foot on an insole of size EU 41/42 (B), and standing with one foot on an insole of size EU 39/40 (C). For all situations (A–C), the total weight on the insoles was 70 kg.

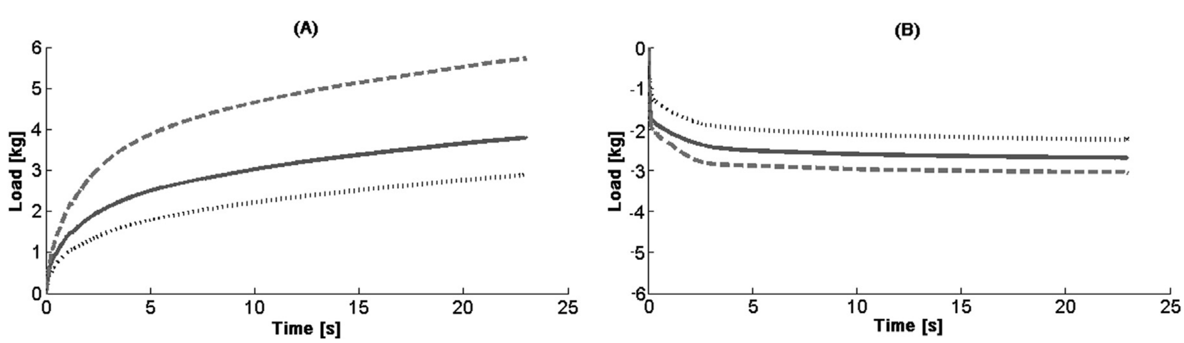

Fig. 3. Slope in the measured force values from the initial measured value (t = 0) for a 25-s static measurement period using insole size EU 47/48. The different colored lines show the mean values for trials with different weights placed on the insoles (Gray dots-5 kg, black solid-10 kg, gray dashed-20 kg). A: Trials with increasing weights; B: Trials with decreasing weights.

using the hands to partially support the body weight led to even lower force values. The force increased again when returning to the kneeling position. A rapid peak was observed when rising to the upright position. *Catching an object*: The force pattern showed a small increase followed by a decrease and then an increase to an absolute maximum. After reaching the maximum, the force values stabilized and reflected the added load of the object.

Table 2 shows the calculated RMSE values for all of the situations tested. Moderate RMSE/MaxE values were found for standing (RMSE: 13.9 ± 2.8%/MaxE: 19.8 ± 3.7%), walking (17.7 ± 1.3%/22.0 ± 1.7%), lifting (11.2 ± 1.6%/14.7 ± 1.8%), and catching an object (6.6 ± 2.3%/8.9 ± 2.5%). The RMSE and MaxE values were high when kneeling (142.3 ± 126.7%/160.3 ± 179.5%).

For lifting with additional weights, no significant differences in force values between the insoles and force plates were found for trials with loads of 0, 10 and 15 kg ($p > 0.05$). The measured force values increased significantly ($p < 0.001$) in the trials with 0–15 kg of weight added.

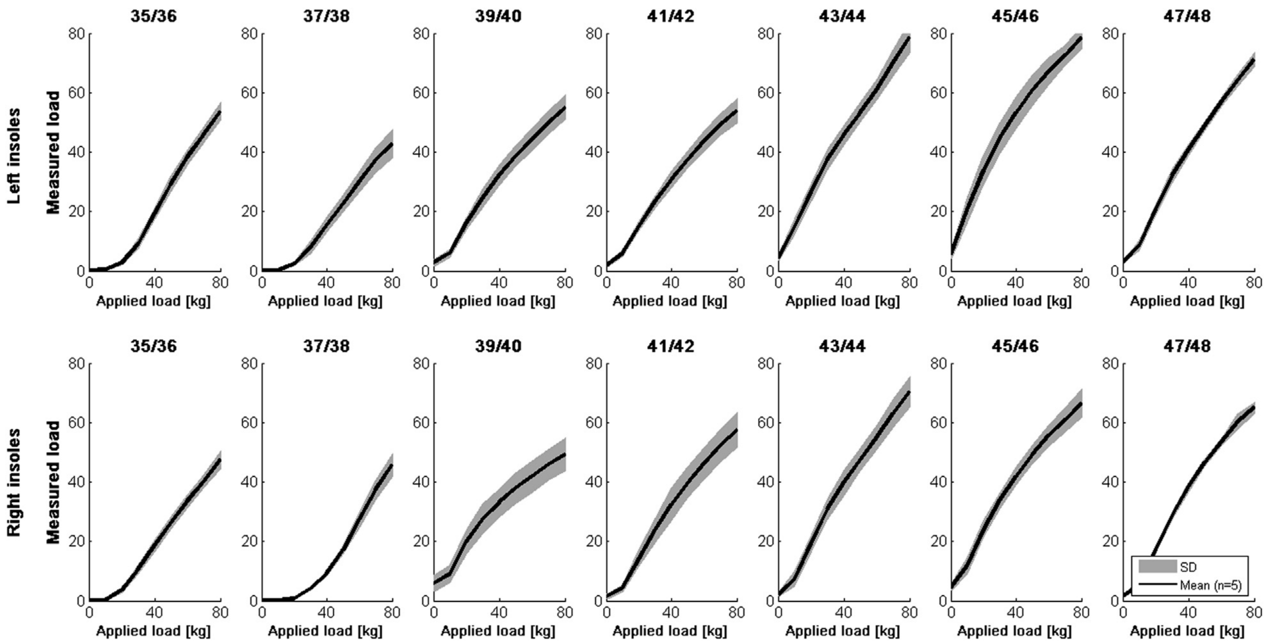

Fig. 4. Comparison of applied loads and measured loads after subtracting the time-dependent creeping: upper plots-left insoles, lower plots-right insoles; black solid line: mean values, gray area: standard deviation (n = 5).

Table 1
Results of the reliability and intraclass correlation coefficient analyses for all of the tested insoles in the static mechanical tests (ICC 2, 5: average measures, 5 values for weight steps from 0 to 80 kg were tested). The significances of the F-tests for all of the insoles tested were $p < 0.001$.

Insole size	Left insoles		Right insoles	
	Cronbach's alpha	Intraclass correlation	Cronbach's alpha	Intraclass correlation
35/36	0.999	0.998	0.999	0.998
37/38	0.998	0.994	0.998	0.997
39/40	0.999	0.994	0.999	0.983
41/42	0.999	0.996	0.998	0.991
43/44	1.000	0.996	0.999	0.995
45/46	0.999	0.993	0.999	0.994
47/48	1.000	0.999	1.000	0.999

3.2.1. Free walking on even ground

The forces measured during trials with different amounts of carried weight increased significantly from 0 to 30 kg ($p < 0.001$). The measured force values relative to body weights could be attributed to the additional weight carried ($p > 0.05$).

4. Discussion and conclusion

To evaluate the measurement of vertical ground reaction forces in field situations using pressure-measurement insoles, one type of commercial insoles was examined for validity and reliability. Mechanical static tests performed by gradually loading and unloading the insoles revealed three main results. First, each insole has an individual response pattern to the applied load. The relationship between the applied weight and measured load of each insole can be described through cubic regression equations. Second, continuous static loads lead to time-dependent changes in the measured loads. The observed creeping of the measured signal has a potential characteristic and is also dependent on the amount of load added. The differences between time changes when increasing and decreasing the loads lead to a hysteresis that is equalized when the load returns to 0 kg. Third, all of the tested insoles show a high level of reliability in repeated measurements. In tests simulating field situations, the mean RMSE results between the measured force values of the insoles and force plates ranged from 6.6% (MaxE: 8.9%) to 17.7% (MaxE: 22%) in standing, walking, lifting and catching trials. In kneeling trials, the average RMSE was 142.3% (MaxE: 160%). The highest MaxE for one insole in the kneeling trials was as high as 360%. The results of the additional trials with various weights applied in lifting and walking tasks show that it is possible to observe differences between loads in 5 kg steps.

When comparing the findings of the mechanical static and field simulation tests, the fact that mechanical static tests do not truly represent the use of the insoles in a shoe must be considered. When using insoles in real situations, the center of pressure is not static, and the pressure distribution changes rapidly due to minimal movements of the human body. Thus, each insole sensor may have the ability to “recover” in between exposures. This ability may be one reason why the time-dependent drift observed during the mechanical static tests was not observed during the field situation trials. After the calculated force values of the insoles were normalized to the body weights of the participants, the RMSE for all trials, with the exception of those for kneeling, had an average of 12.3% (MaxE: 16.3%). The high RMSE in the kneeling trials (mean: 142%) may have been caused by the insoles being bent, which may have led to increased pressure in only a part of the insole, causing high force values.

Compared to results reported in the literature, the tested insoles

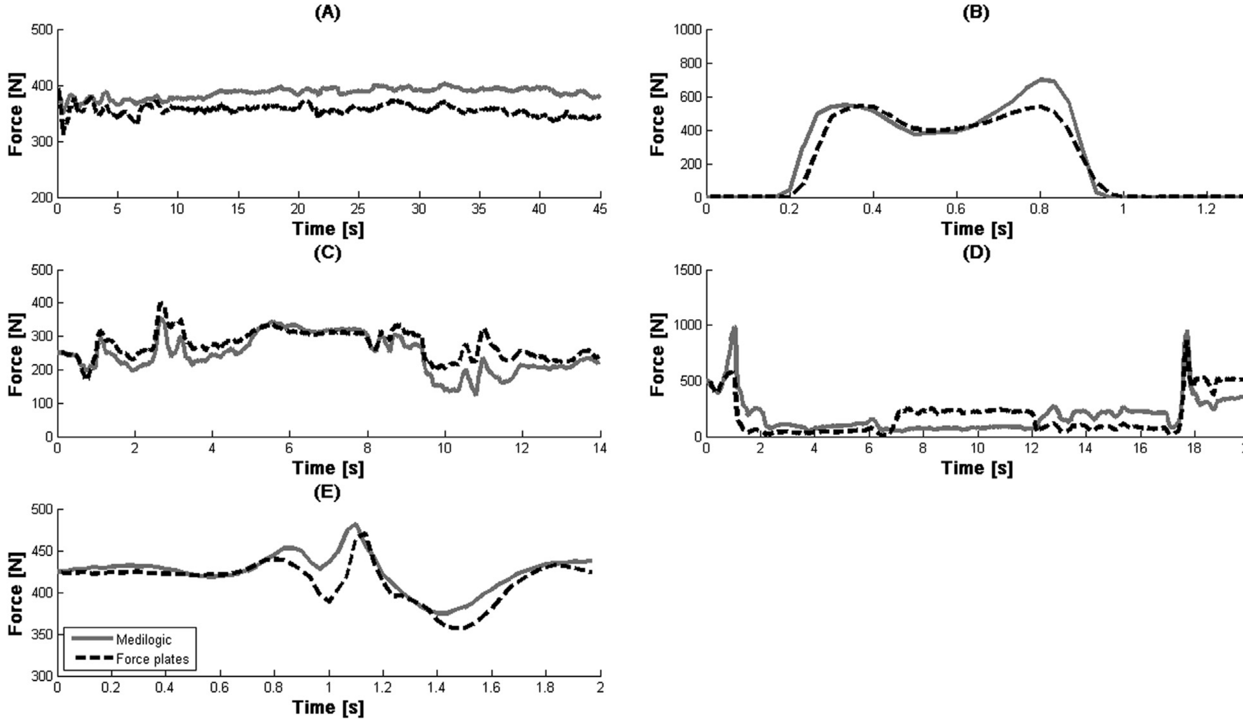

Fig. 5. Measured forces for one participant in various field situations (one trial for each). The different colored lines show the measured force patterns of medilogic® insoles (gray solid line) and force plates (black dashed line). A: Standing; B: Walking; C: Lifting an object; D: Kneeling; and E: Catching an object. Force values from the medilogic® insoles were normalized to the wearer's body weight before the trial began.

Table 2
RMSE and MaxE results for various field situations [% of measured force plate values]. For each simulated field situation, three characteristic sections in the force pattern were chosen, and the force values for these sections were measured. The RMSE and MaxE results were calculated from all of the participants for Sections 1–3. The mean RMSE and MaxE (last column) values are the mean values of Sections 1–3.

Trial	Section 1		Section 2		Section 3		Mean value	
	RMSE	MaxE	RMSE	MaxE	RMSE	MaxE	RMSE	MaxE
Standing	10.8 ± 6.2	15.6 ± 11.1	14.9 ± 8.9	21.1 ± 16.0	16.1 ± 9.7	22.7 ± 17.4	13.9 ± 2.8	19.8 ± 3.7
Walking	17.2 ± 11.3	20.5 ± 11.7	16.7 ± 10.6	21.8 ± 12.3	19.2 ± 13.0	23.8 ± 14.3	17.7 ± 1.3	22.0 ± 1.7
Lifting an object	11.0 ± 8.4	14.9 ± 10.8	9.7 ± 8.9	12.8 ± 11.8	12.8 ± 11.8	16.4 ± 14.8	11.2 ± 1.6	14.7 ± 1.8
Kneeling	10.3 ± 2.4	12.3 ± 2.2	321.7 ± 156.6	360.0 ± 179.6	94.9 ± 29.1	108.7 ± 40.3	142.3 ± 161.2	160.3 ± 179.5
Catching an object	4.4 ± 3.0	6.4 ± 4.6	8.9 ± 3.7	11.4 ± 4.3	6.5 ± 4.3	9.0 ± 5.9	6.6 ± 2.3	8.9 ± 2.5

(medilogic® insoles) show an accuracy similar to other systems. However, they achieve better results in measurements made in field situations. In mechanical tests performed using iron weights, pneumatic bladders and similar devices, measurement errors of 2.7% and 5.8% have been observed for Pedar® insoles and F-Scan insoles, respectively (Hsiao et al., 2002). For walking, the RMSE of 17.7% found in our study was lower than the results obtained with insoles from other manufacturers. Specifically, a measurement error of 30% was observed for F-Scan insoles (Nicolopoulos et al., 2000). F-Scan pressure insoles showed a measurement error of 49.94% for peak impact forces and 48.56% for peak propulsive forces in walking (Low and Dixon, 2010). Whereas all previous studies validated various types of pressure-measurement insoles in situations with frequent changes of loading and unloading the insoles (walking, running, or jumping), the present study evaluated the use of pressure-measurement insoles in various situations relevant for construction or healthcare work. The measurement errors varied depending on the specific situation in which the insole was tested. Hence, pressure measurement insoles should be validated for all specific measurement conditions.

The results show that the tested insoles are suitable for measuring vertical forces provided that certain restrictions are considered. The relative light and low restrictive insoles are a cost-efficient method for measuring loads outside of a laboratory environment. These devices enable the measurement of loads at work sites under realistic working conditions and for different occupations over an entire work shift. The tested insoles are of most interest to evaluate work exposure in construction or healthcare work, including manual handling while standing, carrying loads, or moving patients.

The limitations of medilogic® insoles include the lower accuracy compared with force plates. The maximum pressure limit of 64 N/cm^2 for each force sensor in the insoles should be considered in situations where high dynamic forces occur (e.g., fast movements or jumping). Nicolopoulos et al. (2000) and Woodburn and Helliwell (1996) noted bending, temperature, and shear effects as possible reasons for measurements errors when validating F-Scan insoles. We observed large measurement errors when the insoles were strongly bent, as was observed during kneeling, or were exposed to point loads restricted to small areas of the insoles (e.g., a stone in the shoe). The manufactures of Pedar® insoles as well as of medilogic® insoles recommend a minimum bending radius of

20 mm. This limit can be exceeded, for instance, when kneeling. Thus, the participant's movements should be measured or recorded over the entire measurement time to remove periods with strongly bended insoles from the data. Another possibility to avoid measurement errors due bending of the insoles is the use of less flexible shoes during measurements. Furthermore, the insoles must fit within the shoe without wrinkles.

The in-shoe temperature varies from 19.7 °C to 36.0 °C depending on the outside temperature (Covill et al., 2003) and work intensity. Dairy farmers exhibited temperatures varying from 24.1 °C to 31.6 °C at the dorsal foot and from 16.0 °C to 27.3 °C at the toes (Kuklane et al., 2001). With physical activity, the in-shoe temperature can increase by 3.6 °C during running (Barkley et al., 2011) and by 2.8 °C during walking (Herbert-Copley et al., 2013). For F-Scan insoles, a significant correlation between increasing in-shoe temperature (from 33.9 °C to 35.7 °C) and decreasing forces during 140-min walking trials was observed (Herbert-Copley et al., 2013). The temperature effect on medilogic® insoles is still unclear and may require further investigation; if there is an effect, the additional recording of the in-shoe temperature or a continuous calibration of the insoles during long-time measurements should be considered. The outside temperature appears to have a larger effect on in-shoe temperature than physical activity. It is recommended to wear the insoles a few minutes prior to calibration and measurements, to ensure a temperature closer to the temperature expected during measurements (Koch, 1993).

Shear effects are always a problem when measuring forces with pressure measurement insoles. The sensors in the insoles measure forces normal to the sensor surface. Because the insoles follow the regular shape of the shoe insoles, some of the sensors may be positioned with an angle to the floor. Thus, vertical ground reaction forces may differ between force plates and pressure measurement insoles (Mortin et al., 2002). Errors due shear effects in the shoe may be attenuated by using flat insoles under the pressure measurement insoles during the measurements. However, the ground surface can be non-horizontal, introducing an error that cannot be eliminated.

In conclusion, the present study supports the notion that the insoles (medilogic® insoles) enable the measurement of vertical forces with acceptable validity and reliability when calibrated to the wearer's body weight and using a relatively stiff shoe with flat regular insoles during measurements. In situations of walking, catching an object, standing or lifting, a measurement error of 17.7% must be considered. In walking with various weights carried, the measured force was similar to the weights carried, which indicates that it is possible to measure exposure gradually during a situation in which the subject is moving. In research situations where it is necessary to determinate forces with a specifically high level of precision, the use of systems with higher accuracy, such as force plates in a laboratory environment, may be necessary. However, in measurements over an entire working shift in an occupational setting, the accuracy of 17.7%, and the fact that is possible to distinguish between measured exposures may be sufficient. The findings from the static mechanical tests indicate that correction algorithms should be implemented when analyzing raw data from field measurements. Because the effect of temperature on the force output of the medilogic® insoles is still unclear, regular calibrations during long time measurements may be necessary.

Until durable force sensors that provide precise measurements become available, pressure-measurement insoles constitute an acceptable alternative for assessing vertical ground reaction forces as a proxy for the objective measurement of manual material handling. In general, independent of the type of pressure-measurement insoles selected, the user should examine the validity and reliability of the insoles in the expected field situations. Assessment of vertical forces during work provides a promising method for research on the role of occupational mechanical exposure for health.

Author's contributions

All of the authors contributed to the study design. MK and LKL carried out the technical measurements. MK was responsible for analyzing and interpreting the data and writing the first draft of the presented paper. ME, LKL, KBV and SK reviewed, edited and approved of the final version of the manuscript.

Conflict of interest statement

The authors declare that they have no conflicts of interests. Specifically, none of the authors have any personal or financial interests in T&T medilogic Medizintechnik GmbH. The manufacturer of the medilogic® insoles did not support the study in any financial, personal or other manner (the insoles were purchased at the regular price).

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