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Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

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To cite this article: Steven Visser, Henk F. van der Molen, P. Paul F. M. Kuijer, Judith K. Sluiter & Monique H. W. Frings-Dresen (2016) Stand up: comparison of two electrical screed levelling machines to reduce the work demands for the knees and low back among floor layers, Ergonomics, 59:9, 1224-1231, DOI: 10.1080/00140139.2015.1122233

To link to this article: https://doi.org/10.1080/00140139.2015.1122233

Published online: 04 Jan 2016.

ERGONOMICS, 2016
VOL. 59, NO. 9, 1224–1231
http://dx.doi.org/10.1080/00140139.2015.1122233

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Stand up: comparison of two electrical screed levelling machines to reduce the work demands for the knees and low back among floor layers

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ABSTRACT
Electrical screed levelling machines are developed to reduce kneeling and trunk flexion of sand–cement-bound screed floor layers. An observational intervention study among 10 floor layers was performed to assess the differences between a self-propelled and a manually moved machine. The outcome measures were work demands, production time, perceived load, discomfort and applicability. Compared to the self-propelled machine, the duration of kneeling (Δ13 min; $p = 0.003$) and trunk flexion (Δ12 min; $p < 0.001$) was shorter using the manually moved machine, and the duration of pushing and pulling increased (Δ39 min; $p < 0.001$). No significant or relevant differences were found for production time, perceived load and discomfort. Nine out of ten floor layers found the manually moved machine applicable and three out of ten found the self-propelled machine applicable. When compared with the traditional manner of floor laying, both electrical machines reduced the exposure towards kneeling and trunk flexion.

Practitioner Summary: Electrical machines may help to reduce high physical work demands on floor layers. A manually moved machine is better applicable for the installation of screed floors in residences with smaller floor areas. A self-propelled machine is better applicable on large floor areas with a minimum width of 4 m.

ARTICLE HISTORY
Received 9 September 2014
Accepted 13 November 2015

KEYWORDS
Ergonomic measures; floor layers; work demands; low back; knees

1. Introduction

Sand–cement-bound screed floor layers are exposed to high physical work demands, especially of kneeling and trunk flexion for long periods (e.g. Burdorf et al. 2007; Visser et al. 2013; McGaha et al. 2014). These work demands are risk factors for work-related knee complaints (Da Costa and Vieira 2010; Reid et al. 2010; Palmer 2012) and low back complaints (Da Costa and Vieira 2010; Coenen et al. 2012; Griffith et al. 2012). To reduce these physical work demands, new working methods are recommended to optimise working postures (Visser et al. 2013; McGaha et al. 2014). Among linoleum, carpet and vinyl floor layers, it was found that working in a more upright posture reduced self-reported knee complaints (Jensen and Friche 2007).

To reduce the risk of developing work-related knee and low back complaints, the Dutch Labour Inspectorate has stated that laying sand–cement-bound screed floors is only accepted when the work is performed in an upright working posture. Electrical screed levelling machines enable screed floor layers to level and equalise the screed floor in a more upright working posture and can be divided into two types, self-propelled machines (Figure 1) and manually moved machines (Figure 2). Although the second type of machines is manually moved, it needs electrical power to level and equalise the floor. Besides the difference in the way of propelling, the costs to purchase a self-propelled machine are around 10 times higher compared to the manually moved machine. Additionally, differences in the width of the machines might affect the applicability of the machines and consequently the potential to reduce physical work demands. The self-propelled machine can be twice the width of the manually moved machine, resulting in a larger floor area covered by the machine. Due to the width and technical aspects of both machines, the machines are not applicable on all floor areas. For instance, screed floors on slopes, in bathrooms or in smaller areas are still installed manually.

The use of ergonomic measures is not only beneficial for reducing physical work demands, but also for increasing productivity (van der Molen, Bulthuis, and van Duivenbooden 1998; Burdorf et al. 2007; Jensen and Friche 2007). Productivity is mostly referred to as the amount of labour per hour or per day. For floor layers, the amount per hour is dependent on the location where a screed floor must be laid. It is therefore better to express productivity as

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Figure 1. The self-propelled electrical screed levelling machine.

Figure 2. The manually moved electrical screed levelling machine.

the production time to cover a typical floor area, for example, the floor area of the attic or living room. Besides differences in production time and physical work demands, floor layers may experience differences in perceived discomfort and perceived load due to the varying working techniques as a result of the different means of propulsion of the machines.

This research was performed to investigate the differences in physical work demands, workload, productivity and applicability while working with the self-propelled machine and the manually moved machine. Our hypothesis was that, due to the expected broader applicability of the manually moved machine on smaller areas, the exposure to kneeling and trunk flexion will be higher with the self-propelled machine compared to working with the manually moved machine. However, due to the differences in propelling manners of the machines, it is hypothesised that working with the self-propelled machine results in less work demands on the shoulders as a result of the pushing and pulling demands for the manually moved machine. In addition, it is expected that while working with the self-propelled machine, the perceived load will be higher compared to working with the manually moved machine due to the expected greater exposure towards kneeling and trunk flexion. Finally, we wanted to know how the floor layers experience the applicability of working with the self-propelled machine and the manually moved machine. This is an important prerequisite for the implementation to be successful.

Therefore, the research questions of this study are: (1) What is the difference in duration of kneeling, trunk flexion, and pushing and pulling of floor layers between the self-propelled and manually moved machine? (2) What is the difference between the two machines regarding the production time of a screed floor? and (3) What is the difference between the two machines in perceived discomfort, perceived load and applicability of the machines among floor layers?

2. Method

To answer the three research questions, an observational experimental field study within subjects was performed.

2.1. Participants and procedure

The National Board of Employers in the Finishing Sector asked their members to participate. One company in the floor trade participated voluntarily. The director of this company selected the sand–cement-bound screed floor layers with at least two days of working experience with both types of electrical machines to participate in the observation intervention study. Before participating, all floor layers were informed about the purpose of the study and the assessment methods to be used. Floor layers agreed to participate by signing a written informed consent form.

The floor layers were observed twice – once while installing a screed floor in a residence using the self-propelled machine, and once while installing a screed floor in a similar residence using the manually moved machine. The two observations per floor layer were conducted in houses or apartments and had similar floor areas and shapes of the floor area. During each observation, the duration of kneeling, trunk flexion, pushing and pulling, and installing a screed floor and the perceived discomfort, perceived load and perceived applicability were assessed. The locations for the observations were selected in consultation with the director of the company. The electrical machine to be used during the first observation was randomly selected.

2.2. Sample size

From an earlier study among floor layers, it was expected that installing a screed floor in one residence would require three hours, of which one hour would be spent in a kneeled posture (Visser et al. 2013). It was estimated that 60% of the floor area in a residence can be mechanically laid using the self-propelled machine. For the manually moved machine, this percentage is expected to be 70%. This led to an estimation of the duration of kneeling of 24 min for the self-propelled machine (60 min (1–0.6) = 24 min), and 18 min for the manually moved machine (60 min (1–0.7) = 18 min). Based on a power calculation using the nQuery Advisor software (Fleiss, Tytun, and Ury 1980), observations of 10 floor layers are needed to find a statistically significant difference of 6 min (24 min – 18 min) with a joint standard deviation of 6 min, an alpha of 0.05 and a power of (1-beta) = 0.80.

2.3. Description of the electrical machines

As can be seen in Figure 1, the self-propelled machine is set on rails. As a consequence, it can only move linearly forwards and backwards. Every change in another direction must be done manually by lifting the 47-kg self-propelled machine, adjusting the rails in the desired direction and lowering the self-propelled machine onto them. Due to the weight of the self-propelled machine, this must be done by two floor layers. The width of the machine can be adjusted, and ranged from 2.5 to 3.7 m. The control panel to operate the self-propelled machine – switching the machine on and off, changing the forward or backward moving direction and moving speed – was below knee height.

The manually moved machine (Figure 2) is 2-m wide, weighs 24 kg and can be lifted by one floor layer. To change the direction, the manually moved machine can be lifted or pushed and pulled in the desired direction during the process of levelling the screed floor. The button to switch the manually moved machine on and off was just below the handlebar of the machine.

2.4. Observation protocol

2.4.1. Physical work demands

Using a real-time hierarchical task analysis (Task Recording and Analysis Computer system (TRAC), Frings-Dresen and Kuijer 1995), the duration of kneeling, trunk flexion, and pushing and pulling of one floor layer was observed by one observer. The observer was trained in real-time observations with the help of video fragments of floor layers working with the electrical machines. The intra-observer reliability for the main tasks (manual levelling of a screed floor, mechanised levelling of a screed floor) and activities (kneeling, trunk flexion, pushing and pulling) was sufficient and the intra-class coefficient ranged from 0.7 to 1.0.

2.4.2. Production time

Production time was defined as the time required installing a screed floor for each room (living room and bedrooms) in apartments or for each floor (ground floor, first floor and attic) in houses. The production time for a screed floor in an entire apartment or house was calculated by totalling the time per room or per floor. The time for each room or each floor was measured using TRAC. In addition, the production time per room or per floor was compared between the two electrical machines.

2.4.3. Perceived discomfort

During the production of a screed floor in one residence, the floor layers were asked to rate their momentary perceived discomfort of the lower back, both shoulders, both arms and both knees. The definition of discomfort was 'experiencing local aches, stiffness, fatigue and/or pain', and was assessed with an adapted version of the Borg CR-10 scale (Borg 1982) ranging from 0 (no discomfort at all) to 10 (extremely strong discomfort). The perceived discomfort was assessed four times during the installation process of a screed floor in houses: at the start of the measurement (T0), after the installation of a screed floor on the attic (T1), on the first floor (T2) and on the ground floor (T3). For the installation of a screed floor in apartments, the perceived discomfort was assessed three times: at the start of the measurement (T0), after the installation of a screed floor in the bedrooms (T2) and in the living room (T3).

2.4.4. Perceived load

Floor layers were asked to rate their perceived load during the installation of a screed floor of a room or level, and for the entire apartment or house. For the assessment of perceived load, another adapted version of the Borg CR-10 scale (Borg 1982) was used, ranging from 0 (no load at all) to 10 (extremely large load). For the installation of a screed floor in houses, perceived load was assessed after the installation of a screed floor on the attic (T1), the first floor (T2) and the ground floor (T3). In apartments, the perceived load was assessed after the installation of a screed floor in the bedrooms (T2), and in the living room (T3).

2.4.5. Perceived applicability

After installing a screed floor in the apartment or house using an electrical machine, floor layers were asked if they found the specific electrical machine suitable to use (applicable) in the apartment or house in which a screed floor had to be installed. Floor layers could answer with a 'yes' or 'no' and were asked to justify their answer.

2.4.6. Statistics

The data recorded with TRAC were corrected for obvious errors, such as incorrectly registered tasks or activities identified with an 'Error-button' during the observations or incorrect changes in the hierarchy of the tasks. After correction, the total duration (in minutes) of kneeling, trunk flexion, pushing and pulling, and production time was calculated. Differences in the mean duration of kneeling, trunk flexion, and pushing and pulling between the two machines were tested with a one-sided paired-samples *t*-test. The difference in production time between the two machines was tested with a two-sided paired-samples *t*-test. For the perceived discomfort, a difference score was calculated between the T0 and T1 (or T2 for apartments), T1 and T2 (for houses only), T2 and T3, and the differences between the two machines were tested with a two-sided paired-samples *t*-test. The differences in perceived load between the two machines for each moment of measurement were tested with a Wilcoxon signed-rank test. For the perceived applicability of each machine, the relative frequency was described of floor layers who said yes or no. Statistical analysis was performed with IBM SPSS Statistics 20. A *p*-value of 0.05 was considered statistically significant.

3. Results

3.1. Participants

The mean (SD) values of age, body height, and body weight of the 10 floor layers were 36 (8) years, 183 (10) cm, and 87 (13) kg, respectively. The 10 floor layers worked for an average of 11 (7) years as a screed floor layer. In total, the observations were performed in 8 houses and 12 apartments.

3.2. Duration of kneeling, trunk flexion, and pushing and pulling

No significant differences between the two machines were found for the duration of working with an electrical machine. Floor layers worked 70 (SD 29) minutes with the self-propelled machine and 62 (SD 21) minutes with the manually moved machine ($p = 0.108$) during the production of a screed floor in one residence, this is, respectively, 48 (9) % and 47 (10) % ($p = 0.349$) of the total production time. The length of time to manually level a screed floor differed significantly between the self-propelled (23 (SD 10) minutes) and the manually moved machine (14 (SD 10) minutes; $p = 0.011$). Expressed as the percentage of the total production time, manually levelling a screed floor occurred for 18 (9) % of the time while working with the self-propelled machine compared to 11 (8) % while working with the manually moved machine ($p = 0.024$).

The durations of the activities are presented in Table 1. The duration of kneeling ($p = 0.003$) and trunk flexion

Table 1. Mean (SD) duration (in minutes) and percentage of the production time of kneeling, trunk flexion, pushing and pulling of sand–cement-bound screed floor layers (n = 10) and production time per floor/room using the self-propelled machine or the manually moved machine. The duration of the physical work demands is representative for the installation of a screed floor in one residence.

	Self-propelled machine		Manually moved machine		Difference (Δ)		
Physical work demands (minutes)	Mean	SD	Mean	SD	Mean	SD	p-value
Lower back							
Trunk flexion (>40°)	27	(9)	14	(7)	−13	(7)	0.000
% of production time	21	(9)	11	(6)			0.005
Shoulders							
Pushing and pulling	0	(0)	39	(12)	+39	(12)	0.000
% of production time	0	(0)	30	(8)			0.000
Knees							
Kneeling	25	(12)	13	(9)	−12	(10)	0.003
% of production time	19	(10)	10	(8)			0.002
Production time (minutes)							
Ground floor/living room	56	(21)	49	(18)			0.090
First floor/bedrooms	61	(19)	63	(16)			0.780
Attic (n = 4)	69	(19)	52	(19)			0.082

(p = 0.000) was significantly longer using the self-propelled machine compared with using the manually moved machine, 13 (SD 7) and 12 (SD 10) minutes, respectively. Additionally, relative to the total production time, the duration of kneeling (19 (SD 10) and 10 (SD 8) %, respectively) and trunk flexion (21 (SD 9) and 11 (SD 6) %, respectively) was also longer while using the self-propelled machine compared to the manually moved machine. Pushing and pulling only occurred during the installation of a screed floor with the manually moved machine for 39 (SD 12) minutes and was therefore longer compared with the self-propelled machine.

3.3. Production time

For an entire residence, the production time of a screed floor was 2 h 25 min (SD 48 min) with the self-propelled machine compared to 2 h 13 min (SD 36 min) with the manually moved machine (p = 0.308). No significant differences were found for the production time of a screed floor per room/floor of an entire house or apartment (Table 1).

3.4. Perceived discomfort

On average, the floor layers perceived no discomfort (0 on the Borg CR-10 scale) for the lower back, both shoulders, both arms and both knees while using the self-propelled machine or the manually moved machine at start of the measurements and after finishing the different floors or rooms. Discomfort ratings ranged between 0 and 2 for the self-propelled machine and between 0 and 3 for the manually moved machine.

3.5. Perceived load

No differences were found for the perceived load between using the self-propelled machine and the manually moved machine, except for working in the attic. The average perceived load was 2 (on a scale from 0 to 10) for installing a screed floor on the ground floor/living room, on the first floor/bedroom and in the entire residence using either the self-propelled machine or the manually moved machine. The four floor layers installing a screed floor in houses rated their perceived load for installing a screed floor in the attic significantly lower (p = 0.033) using the self-propelled machine (0.5, SD 1.0) compared to the manually moved machine (1.6, SD 1.1).

3.6. Perceived applicability

Three out of ten floor layers found the applicability of the self-propelled machine good for the residence at which they installed a screed floor. Their main objection against its use was that the width of the self-propelled machine and the moving direction had to be changed often while installing a screed floor in a residence. For the change of direction, the self-propelled machine had to be lifted by two floor layers due to its weight. During the lifting and carrying, and changing the width of the self-propelled machine, the floor layers had to bent and twist their trunk. In comparison, nine out of ten floor layers found the manually moved machine applicable because it can be handled by one person and it is easy to turn. One person found the manually moved machine difficult to work with.

4. Discussion

Compared to the self-propelled machine, floor layers worked with the manually moved machine 12 min shorter in a kneeled position and 13 min shorter with a flexed trunk while installing floors in a residence. However, due to the propelling technique, pushing and pulling time was 39 min longer with the manually moved machine compared to the self-propelled machine. No significant or relevant differences were found for production time, perceived discomfort or perceived load between the self-propelled machine and the manually moved machine. Most floor layers reported that the manually moved machine was better applicable in the residences than the self-propelled machine, especially on smaller floor areas.

4.1. Differences between the self-propelled machine and the manually moved machine

The shorter duration of manual levelling (11 min) while working with the manually moved machine in comparison with the self-propelled machine does not explain the total difference in duration of kneeling and trunk flexion between the electrical machines. Kneeling and trunk flexion also occurred while using the self-propelled machine. The control panel was below knee height and floor layers were kneeling, squatting or bending their trunk while operating this panel. In comparison, floor layers were switching the manually moved machine on and off while standing. Moreover, in order to change the moving direction of the self-propelled machine, the rails had to be adjusted. This was also done kneeling. These demanding working postures probably also influenced negatively the perceived applicability of the self-propelled machine.

Contradictory to our hypotheses, the differences in kneeling, trunk flexion, and pushing and pulling, and applicability of the machines did not lead to differences in perceived load and discomfort. Perceived discomfort of the body regions and perceived load for both electrical screed levelling machines were low and in line with the traditional manner of floor laying (Visser et al. 2013). So even a strong reduction in knee and low back demanding activities and working postures did not result in a lower perceived discomfort of the knees and the low back and the perceived load during the installation of a screed floor. Floor layers did not perceive their traditional – manually – manner of installing screed floors as physical demanding neither rated their discomfort as high during the installation of a screed floor (Visser et al. 2013). Therefore, a reduction of these outcomes as a result of working with the electrical screed levelling machines might have been less likely. However, the exposure to the risk factors at stake – like kneeling and bending of the trunk – is strongly reduced. Therefore, the incidence and prevalence of work-related knee and low back disorders among floor layers is expected to reduce on the longer term.

4.2. Methodological considerations

The observations of the individual floor layers occurred in daily practice in apartments and houses. In addition, the study was controlled for variance due to personal differences by making a within-subject comparison and including 10 floor layers with data about work demands of more than two hours. This means that the results of this study are generalisable for the work demands of a floor layer installing screed floors in residences. However, the observations were performed for individuals and not for a team of floor layers. Introducing an ergonomic measure for one person in a team might affect the work demands of other members in the team (Burdorf et al. 2007). As a result of the observations, the observed floor layer worked with the electrical machine, another floor layer was the hodman and distributed the sand–cement mixture on the floor, and a third-floor layer set out the height of the screed floor by manual levelling the screed floor around the walls. It can be expected that in a non-research setting, task rotation will occur between the three workers, resulting in a change in work demands for all three floor layers. Therefore, the effect of the electrical machines on the change of work demands of all team members could be the subject of future research.

To assess the perceived discomfort and perceived load, an adjusted version of the Borg CR-10 scale (Borg 1982) was used. Although this scale is frequently used to assess general physical exertion, the advantage of this scale is that the Borg CR-10 scale has – besides the lower and upper boundaries – also written descriptors of the in-between levels of intensity. It was thought that the Borg CR-10 scale with more written descriptors would support the floor layers to distinguish between these levels of intensity; however, no differences were found. Since perceived discomfort and perceived load were low and did also not differ in other studies (e.g. Visser et al. 2013, 2014), it can be argued whether construction workers perceive their work as physical demanding and whether assessing perceived discomfort and perceived load might be relevant when evaluating ergonomic measures with relatively low contrast in exposure measurement. It might be more beneficial to assess workers' experiences with the ergonomic measures to make adjustments on the ergonomic measures or the environmental circumstances like larger floor areas by installing inner walls after the installation of a screed floor.

4.3. Implications for practice

When the work demands were adjusted for an entire working day, the exposure criteria for work-related knee disorders (kneeling >60 min per day; Coggon et al. 2000; Baker et al. 2003) and lower back disorders (trunk flexion of more than 40° >30 min per day; Kuiper et al. 2005) were exceeded while working with the self-propelled machine. For the manually moved machine, the exposure to trunk flexion exceeded the exposure criterion. However, the duration of kneeling was below the exposure criterion. Although the exposure criteria of kneeling and trunk flexion were exceeded with the self-propelled machine, an estimated reduction of the exposure to kneeling and trunk flexion compared to the traditional manner of floor laying (Visser et al. 2013) is 21 and 27 min, respectively, for one floor layer operating the machines. For the manually moved machine, the estimated reduction is 60 min for kneeling and 61 min for trunk flexion when one floor layer operates the machines. As stated in section 4.2, floor layers work in teams and as a consequence, the reduction of the duration of kneeling and trunk flexion is expected to be less, although especially the reduction in kneeled body postures might be sufficient to reduce the risk of work-related knee disorders of all floor layers in a team.

Jensen and Friche (2007, 2008, 2010) concluded that an upright working posture adopted by linoleum, carpet and vinyl floor layers resulted in fewer knee complaints. In addition, the more upright back postures might result in fewer lower back complaints (McGaha et al. 2014). Both electrical screed levelling machines reduced the exposure towards kneeling and trunk flexion in comparison with the traditional manner of floor laying and are therefore recommended to be used for the prevention work-related knee and lower back complaints.

Besides the reduction of the duration of kneeling and trunk flexion, pushing and pulling the manually moved machine might introduce a new risk, namely for shoulder complaints (Hoozemans et al. 2014). To establish whether or not pushing and pulling is indeed a risk factor, the hand forces during the pushing and pulling activities should be measured and could be compared to exposure criteria such as Mital, Nicholson, and Ayoub (1997) or used to calculate shoulder moments (Kuijer, Hoozemans, and Frings-Dresen 2007).

The manually moved machine is more easy to use in smaller areas and thereby reduces the exposure of kneeling and trunk flexion more compared to the self-propelled machine, the manually moved machine is more useful for the installation of a screed floor in residences and forsmall floor areas. Since kneeling and trunk flexion occur while working with the self-propelling machine when changing direction and operating the machine, the self-propelling machine might be more useful for the installation of screed floor on large open floor areas where almost no change of moving direction is required.

5. Conclusions

Using the self-propelled machine resulted in longer duration of kneeling and trunk flexion compared with using the manually moved machine, while pushing and pulling was longer when using the manually moved machine. Both electrical machines reduced the exposure towards kneeling and trunk flexion compared with the traditional manner of floor laying. No differences were found between the self-propelling machine and manually moved machine for the production time, perceived load and perceived discomfort. Both electrical machines may help to reduce the risk of work-related knee and low back complaints among floor layers.

Acknowledgements

The authors would like to thank the director and employees of the floor laying company that participated in this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

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