Ergonomic measures in construction work: enhancing evidence-based implementation
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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
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 ten floor layers was performed to assess the differences between a self-propelled- and a manual 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 manual machine, and the duration of pushing and pulling increased (Δ39 min; p<0.001). No significant nor relevant differences were found for production time, perceived load and discomfort. Nine out of ten floor layers found the manual 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.
INTRODUCTION

Sand-cement bound screed floor layers are exposed to high physical work demands, especially of kneeling and trunk flexion for long periods. These work demands are risk factors for work-related knee complaints and low back complaints. To reduce these physical work demands, new working methods are recommended to optimize working postures. Among linoleum, carpet and vinyl floor layers, it was found that working in a more upright posture reduced self-reported knee complaints.

In recent years, ergonomic measures have become available to floor layers that enable them to perform their work in a more upright working posture by means of two electrical screed levelling machines. The first machine is self-propelled (figure 1) and will be referred to as the ‘self-propelled machine’. The second machine must be moved manually (figure 2) and will be called the ‘manual machine’. The self-propelled machine is broader than the manual machine, resulting in a larger surface of screed being able to be levelled by the machine. However, the smaller manual machine will probably be more easily applied in smaller rooms or areas.

Ergonomic measures are not only beneficial for reducing physical work demands, but also for increasing productivity. Productivity is 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 better to express productivity as the production time of a screed floor in a predetermined object. Besides differences in production time, floor layers may experience differences in perceived discomfort and load due to the varying working techniques.

Our hypothesis was that, due to the broader applicability of the manual machine, the exposure to kneeling and trunk flexion will be greater with the self-propelled machine compared to working with the manual machine. However, due to the differences in propelling manners of the machines, it is hypothesized that working with the self-propelled machine results in less work demand on the shoulders as a result of the pushing and pulling demands for the manual machine. In addition, it is expected that while working with the self-propelled machine, the perceived load will be higher compared with working with the manual 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 manual 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 manual 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, load and applicability among floor layers?
METHODS

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

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 using the self-propelled machine, and once while installing a screed floor using the manual machine. The observations were performed while installing a screed floor in one residence. The duration of kneeling, trunk flexion, pushing and pulling and installing a screed floor and the perceived discomfort were assessed for each floor layer in two similar residences, i.e. a house or an apartment. 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.

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. It was estimated that 60% of the surface in residences can be mechanically laid
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using the self-propelled machine. For the manual 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 manual machine (60 min × (1-0.7)=18 min). Based on a power calculation using the nQuery Advisor software, observations of ten 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.

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 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 metres.

The manual machine (figure 2) weighs 24 kg and is lifted by one floor layer. To change the direction, the manual machine can be lifted or pushed and pulled in the desired direction during the process of levelling the screed floor.

Observation protocol

Physical work demands

Using a real-time hierarchical task analysis (Task Recording and Analysis Computer system (TRAC)), the duration of kneeling, trunk flexion, and pushing and pulling of one floor layer were 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 intraclass coefficient ranged from: 0.7 to 1.0.

Production time

Production time was defined as the time required to install 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.

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 a Borg CR-10 scale\(^\text{13}\) 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).

**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, the Borg CR-10 scale\(^\text{13}\) 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), the ground floor (T3), and the entire house (T4). In apartments, the perceived load was assessed after the installation of a screed floor in the bedrooms (T2), in the living room (T3), and the entire apartment (T4).

**Perceived applicability**

After installing a screed floor in the apartment or house using the two machines, floor layers were asked if they found the specific electrical machine 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.

**Statistics**

The data recorded with TRAC were corrected for obvious errors, such as incorrectly registered tasks or activities. 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), 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 was 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.
RESULTS

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

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) min with the self-propelled machine and 62 (SD 21) min with the manual machine (p=0.108) during the production of a screed floor in one residence. The length of time to manually level a screed floor differed significantly between the self-propelled (23 (SD 10) min) and the manual machine (14 (SD 10) min; p=0.011).

The durations of the activities are presented in table 1. The duration of kneeling (p=0.003) and trunk flexion (p=0.000) were significantly longer using the self-propelled machine compared with using the manual machine, 13 (SD 7) and 12 (SD 10) min, respectively. Pushing and pulling only occurred during the installation of a screed floor with the manual machine for 39 (SD 12) min and was therefore longer compared with the self-propelled machine.

Production time
For an entire residence, the production time of a screed floor was 2 hours 25 min (SD 48 min) with the self-propelled machine compared to 2 hours 13 min (SD 36 min) with the manual machine (p=0.323). No significant differences were found for the production time of a screed floor per room/floor of an entire house or apartment (table 1).

Perceived discomfort
On average, the floor layers perceived no discomfort (0 on the Borg scale) for the lower back, both shoulders, both arms, and both knees while using the self-propelled machine or the manual machine. Discomfort ratings ranged between 0 and 2 for the self-propelled machine and between 0 and 3 for the manual machine.

Perceived load
No differences were found for the perceived load between using the self-propelled machine and the manual 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 manual machine. The four floor layers installing a screed floor in houses rated their perceived load for installing a screed floor in the attic significantly different.
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(p=0.033) between using the self-propelled machine (0.5 (SD 1.0)) and the manual machine (1.6 (SD 1.1)).

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 assume bent and twisted trunk postures. In comparison, nine out of ten floor layers found the manual machine applicable because it can be handled by one person and it is easy to turn. One person found the manual machine difficult to work with.

Table 1  Mean (SD) duration (in minutes) 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 manual machine.

The duration of the physical work demands is representative for the installation of a screed floor in one residence.

<table>
<thead>
<tr>
<th>Physical work demands (min)</th>
<th>Self-propelled machine</th>
<th>Manual machine</th>
<th>Difference (Δ)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
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<tr>
<td>Lower back</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk flexion (&gt;40°)</td>
<td>27 (9)</td>
<td>14 (7)</td>
<td>-13 (7)</td>
<td>0.000</td>
</tr>
<tr>
<td>Shoulders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pushing and pulling</td>
<td>0 (0)</td>
<td>39 (12)</td>
<td>+39 (12)</td>
<td>0.000</td>
</tr>
<tr>
<td>Knees</td>
<td>25 (12)</td>
<td>13 (9)</td>
<td>-12 (10)</td>
<td>0.003</td>
</tr>
<tr>
<td>Production time (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground floor / living room</td>
<td>56 (21)</td>
<td>49 (18)</td>
<td>0.090</td>
<td></td>
</tr>
<tr>
<td>First floor / bedrooms</td>
<td>61 (19)</td>
<td>63 (16)</td>
<td>0.780</td>
<td></td>
</tr>
<tr>
<td>Attic (n=4)</td>
<td>69 (19)</td>
<td>52 (19)</td>
<td>0.082</td>
<td></td>
</tr>
</tbody>
</table>

(p=0.033) between using the self-propelled machine (0.5 (SD 1.0)) and the manual machine (1.6 (SD 1.1)).
DISCUSSION

Compared to the self-propelled machine, floor layers worked with the manual 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 manual machine compared to the self-propelled machine. No significant or relevant differences were found for productivity, perceived discomfort or perceived load between the self-propelled machine and the manual machine. Most floor layers reported that the manual machine was better applicable to work with than the self-propelled machine, especially on smaller surfaces.

Differences between the self-propelled machine and the manual machine

The shorter duration of manual levelling (11 min) while working with the manual 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. 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 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 did not lead to differences in perceived load and discomfort. Perceived load for both electrical screed levelling machines was low and in line with the traditional manner of floor laying. So even a strong reduction in knee and low back demanding activities and working postures does not result in a lower perceived load. Perceived load seems therefore not a useful outcome measure for the comparison of different ergonomic measures among construction jobs when workers do not perceive their load as high.

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 ten 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. 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.

**Implications for practice**

When the work demands were adjusted for an entire working day, the exposure criteria for work-related knee disorders (>60 min per day\(^{14,15}\)) and lower back disorders (>30 min per day\(^{16}\)) were exceeded while working with the self-propelled machine. For the manual 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\(^2\) is 21 and 27 min, respectively. For the manual machine, the estimated reduction is 60 min for kneeling and 61 min for trunk flexion. Jensen and Frichet\(^9,17,18\) 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.\(^3\) 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 manual machine might introduce a new risk namely for shoulder complaints.\(^19\) 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 \textit{et al.}\(^20\) or used to calculate shoulder moments.\(^21\)

Due to the better applicability of the manual machine in smaller areas, this machine is more useful for the installation of a screed floor in residences and for small surfaces. 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 surfaces where almost no change of moving direction is required.
CONCLUSIONS

Using the self-propelled machine resulted in longer duration of kneeling and trunk flexion compared with using the manual machine, while pushing and pulling was longer when using the manual 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 manual 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.
REFERENCES


