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2024

Ergonomic Evaluation of Spineband for Carpet Installers – A Pilot Study

Report of Results

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14.06.2024

Extended Abstract for Practitioners

Construction workers, especially carpet installers, face an increased risk of developing musculoskeletal disorders (MSDs) due to awkward postures, repetitive movements and heavy lifting at work. These disorders affect muscles, nerves, joint and tendons and are mostly prevalent in the upper body. Carpet installers therefore often suffer from strains, tears and pain in the neck, back and shoulders. Occupational exoskeletons are wearable devices that are designed to support movements at work and reduce the physical workload. They have been tested as ergonomic intervention and studies suggest that they can be effective in improving workers' posture and decrease strain on the muscles. Spineband is a Swedish passive exoskeleton that works through an elastic band on the back that is attached to a headband. It is designed to reduce the strain on the neck muscles by promoting a neutral posture of the head. This study examines this effectiveness as well as the user experience of Spineband on carpet installers.

The research thereby compares working with Spineband to not working with Spineband for several typical carpet installation tasks. Those included preparing (cutting) the carpet, scraping off dirt from the floor, spreading liquid glue on the floor or laying out the carpet. Six carpet installers were recruited for the study and asked to perform their usual work approximately 30 minutes with and without the usage of Spineband in a randomized order. The study uses a combination of technical data collection and subjective ratings as well as user interviews. The participants' postures were thereby measured with sensors that measure the angles of the head and trunk (bending forward). The muscle activity of the neck was also measured through electrodes attached to the neck. The participants filled in questionnaires on usability, rating scales on comfort, performance and exertion, and they were interviewed regarding their experiences.

The results show that Spineband significantly reduced muscle activity of the neck which points to a decrease of the physical load. It also promoted a more neutral posture of the head as the forward bending angles of the head were significantly lower when the carpet installers worked with Spineband. However, the participants bended their trunk slightly more when using Spineband. The ratings of work performance were slightly better on average for those cases when Spineband was used, but the difference was not significant. Regarding the user experience, the participants evaluated Spineband's comfort generally positive for most aspects, though some of them felt restricted in the movements at work. At the same time, the physical effort was subjectively perceived slightly higher when working with Spineband, although this difference was not significant. The usability questionnaires revealed neutral to slightly positive responses. The user interviews showed overall positive experiences of the experiment and of working with Spineband, with some participants noticing a clear improvement in neck comfort. However, the usage of Spineband appears to vary as some carpet installers reported to use it frequently at work, some prefer to wear it during leisure activities while others never use it.

The study demonstrates Spineband's effectiveness in decreasing load on the neck for carpet through lower muscle activity levels and more neutral head postures. Interestingly, the bending of the trunk increased when working with Spineband. As the body naturally compensates for the supported areas with other muscle groups, this is a common observation with exoskeletons. At the same time, the increased bending angles of the trunk do not directly refer to increased load on the back as the carpet installers often work on their knees using their hands for support. In terms of user experience, some challenges of using Spineband were identified from the user interviews and the researchers' observations during the data collection. Such are the initial difficulty of mounting Spineband, sliding of the headband due to sweat and restriction in twisting the head. These findings may account for the spread in the comfort ratings. The overall variability in the usability evaluation was expected as the subjects had different amount of work practice with Spineband prior to the experiment. This was also reflected in a participant's statement that time is needed to get used to Spineband. The performance ratings furthermore reveal that Spineband does not hinder work productivity as it is feared by employers for other occupational exoskeletons. Working with Spineband even resulted in slightly better perceived performance for some participants.

The limitations of this pilot study need to be considered. With a small sample of six participants and real work settings during the experiments, the similarity of work tasks that were performed with and without Spineband varied somewhat. Though the reduction in muscle activity and head flexion indicate potential benefits, the study cannot assess preventative or long-term effects of Spineband, since all participants reported neck discomfort prior to the experiment. Furthermore, social desirability bias (participants expect positive outcomes and might want to please researchers) could impact survey and interview responses.

In conclusion, this pilot study reveals Spineband's promising potential in decreasing neck strain and improving posture for carpet installers. While the user experience was generally positive and Spineband seems to maintain work performance, there are some usability challenges to address. Further research with a larger sample size and longer use could strengthen these findings and explore strategies to optimize Spineband for carpet installers.

1. Introduction

The construction domain is subject to various ergonomic risk factors: Most dominantly, working in an awkward posture, movements, repetitions and working with intensive force and vibration increase the probability of developing musculoskeletal disorders (MSDs) (1). Work-related MSDs (WMSDs) affect muscles, nerves, joints, tendons or discs in the spine from work activities or work conditions and occur mostly in the areas of the upper body (2). As they can impact work productivity, they are related to high costs for workers' injuries, healthcare and compensation for work absences. Carpet installers represent a large amount of the construction industry and they are one of the most affected risk groups (3). Their work tasks include heavy lifting, prolonged periods on kneeling and extensive back and head bending and their most common WMSDs are strains, tears or back pain as well as neck and shoulder pain (4).

Occupational Exoskeletons (OE) are designed to mechanically support the worker's movements to decrease their physical workload (5). They have therefore been used as ergonomic intervention to support reducing these risk factors in the construction industry (6). Studies have demonstrated their potential in decreasing the load of specific muscle groups (7). Passive exoskeletons (those that use elastic materials or spring force) for the upper extremities were furthermore shown to lower muscular activity and postural angles of selected body parts as well as decrease perceived efforts and discomforts (8). Despite the increasing interest and commercial growth of exoskeletons there is a shortage of research on the effectiveness and safe usage in construction (9).

Spineband is a patented and CE-marked exoskeleton system from Sweden that is designed to minimize neck strain and pain (Spineband, Sweden). It acts through an elastic band on the back that is strapped around the body and attached to a headband. Spineband supports a neutral posture of the head and thereby aims at decreasing stress on the neck. It comes in two different sizes and can be adjusted to fit individual body sizes and postures. Spineband is thought to be effective both for preventing and mitigating neck pain and can be worn for work as well as leisure. It is recommended to be used 30 minutes to up to one hour per day. (10)

This study's aim was to evaluate the effectiveness and user experience of the exoskeleton Spineband in decreasing the load on the neck of carpet installers. Working with the Spineband was thereby compared to not working with the Spineband in a controlled environment during a variety of common work activities of carpet installers through technical measurements together with subjective assessments.

2. Methods

2.1. Study design

A randomized cross-over study design was used to evaluate the Spineband for carpet installers in a controlled environment. Therefore, the participants were performing their ordinary work for two cases of each approximately 30 minutes with and without Spineband in a random order on a variation of job tasks. The most common activities were the following: Scraping of dirt from the floor, preparing (cutting) the carpet, spreading the glue on the floor, laying out the carpet and finishing the carpet (measuring distances, cutting the carpet into smaller shapes to fit floor structure and smoothing of the carpet with a hand-held heater and a broom-like stick). Other tasks consisted of tearing out the old carpet, hoovering, lifting and carrying the carpet over short distances, polishing wooden floor or moving of trash, equipment or furniture. For a comparison of the cases, it was aimed at having the participants either work on two similar sized rooms or working on job tasks with similar posture and physical load in the same room.

During the experiment, the posture of the participants' head and trunk were recorded by IMUs, and their muscular activities of the neck were measured with surface EMGs. The participants wore the full Spineband equipment for both cases with the only difference in the connection of the headband to the back part of the Spineband for a good comparison of usability (see Figure 1). Furthermore, each case was video recorded for further potential analysis of mechanical load. Each case was followed by a survey on subjective ratings of physical exertion, work performance as well as a final usability questionnaire of Spineband and a short semi-structured interview.

Figure 1 Experiment set-up of working without connecting Spineband to the headband (left) and working with Spineband connected (right)

2.2. Participants

Six carpet installers participated in this study, and all were informed of the general aims of the study before their written consent was collected. Their characteristics are displayed in Table 1. Even though it was aimed at recruiting participants with differing levels of neck pain, all participants reported having had discomfort in the neck within the last seven days of medium intensity on average. Most subjects had discomfort in the neck on 1-7 days within the last three months (see Figure 2). The experience of working with Spineband varied, ranging from three to ten hours. The Regional Ethics Committee in Stockholm gave ethical approval to conduct this study as part of a larger research project (Dnr 2022-06827-02).

Table 1 Descriptive characteristics of the participants

Characteristics		Value
Sex, N (%)		
	Male	5 (83)
	Female	1 (17)
Age (y), median [IQR]		37 [26–46]
Height (cm), median [IQR]		181 [175–184]
Weight (kg), median [IQR]		88 [81–92]
Work experience (y), median [IQR]		10 [5–9.75]
Frequency of using Spineband (h), median [IQR]		19 [3–10]
BORG CR10 Rating of discomfort in the neck in the last 7 days, median [IQR]		4 [3–5]
Prevalence of discomfort in the neck in the last 7 days, %		100

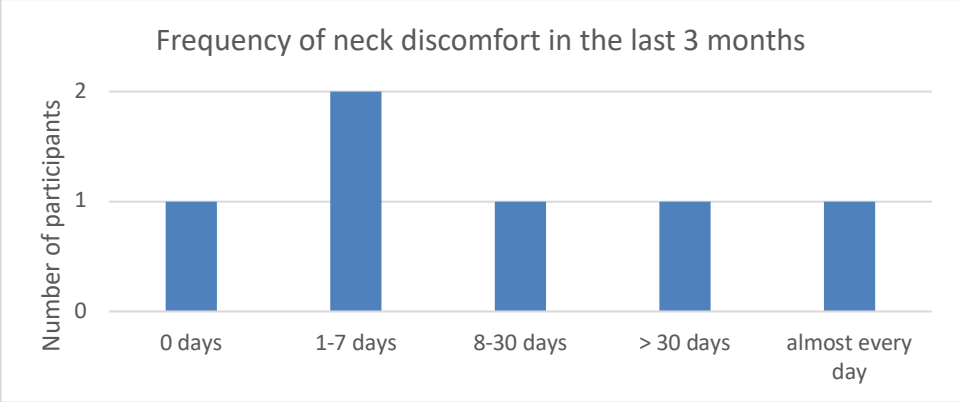

Figure 2 Frequency of neck discomfort in the last 3 months over number of participants

2.3.Physical workload

Postural data of the trunk and head was collected as well as recordings of muscle activity of the neck extensors (bilateral splenius capitis) using technical measurement methods. Furthermore, the participants were asked to provide subjective ratings of their perceived physical exertion. The fully mounted equipment can be seen in Figure 5 while the participant is wearing Spineband.

2.3.1. Inclination angles

For collecting the postural data, a part of the Wergonic kit was used, a smart workwear system designed to perform objective ergonomic risk assessment (Wergonic, Sweden) (see Figure 3). The system consists of a t-shirt with small integrated pockets for sensors, IMU sensors and a phone application (and a cloud-based analysis platform). For this project, two of the IMU sensors were mounted on the subjects' trunk (on the upper back below C7 level) and head (in the center of the forehead). The trunk sensor was placed into the back pocket of the Wergonic t-shirt, and the head sensor was attached to Spineband's headband with Velcro and an additional adhesive tape. The postural angles of the trunk and head and were defined as the sagittal inclination angle relative to a neutral reference posture (standing upright, looking straight ahead). The data was sampled at 12,5 Hz.

Figure 3 Wergonic Kit consisting of two IMU sensors and a phone application to measure postural data

2.3.2. Muscular activities

To measure the muscle activity of the neck extensors, surface electromyography (sEMG) was used from Biosignals' Researcher kit (Biosignalsplux, Portugal) together with their OpenSignals (r)evolution phone application (PLUX Wireless Biosignals, Portugal) (see Figure 4). Five EMG electrodes (Ag/AgCl electrodes, N-00-S/25, Ambu A/S, Copenhagen, Denmark) were therefore placed on the muscle pair of the neck extensor (on the muscle belly between C3 to C4 of splenius capitis muscles) and on C7 for the ground cable, following the SENIAM guideline (11) (see Figure 5). For an optimal signal, the skin was scrubbed with an alcohol patch before each pair of electrodes was placed with a distance of 2 cm from center to center (12). The electrodes were then connected to a small logger and the cables were secured with adhesive tape.

To calibrate the EMG sensors, the participants performed three repetitions of maximum voluntary contraction of the neck muscles. The subjects were therefore asked to press the back of their heads into their folded hands. Each maximum contraction was sustained for three seconds, and the subject rested the neck muscles for approximately one minute in between each repetition. The sampling rate was set to 2000 Hz and the calibration data was processed with a custom MATLAB 2022a (Mathworks, USA) script.

Figure 4 EMG equipment from Biosignalsplux' Researcher kit, consisting of a phone application, three cables and a logger

Figure 5 Full set-up of EMG and IMU equipment while wearing Spineband

2.3.3. Perceived physical workload and performance

As the perception of a work's exertion is individual, the technical measurements of physical workload were combined with survey questions about the participants' perceived effort of each work case (13). Therefore, the Borg Rating of Perceived Exertion (RPE) scale was filled in after each case for comparing the subject's perceived exertion of the cases where Spineband was used versus when Spineband was not used. The scale ranges from 6 ("no exertion at all") to 20 ("maximum exertion"). To collect background information about the cases, the participants were asked to fill out additional survey questions: A comparison of the workload of the finished case to an average one on a five-point Likert scale (ranging from "much less" to "much more" workload), whether or not there was a moment or task of physical discomfort during the just performed work case and if so, the participants were asked to state the worst task and rate it again on the RPE scale.

Furthermore, the participants' perceived work performance was assessed for comparison between working with and without Spineband. Therefore, a survey question was taken from the validated Task Load Index by NASA (NASA-TLX) which is measured on a 21-point visual scale ranging from "very bad" (0) to "very good" (20) performance (14,15).

All survey questions were formulated in Swedish and later translated to English for analyses. The survey outline can be found in the Appendix B.

2.4. Comfort and usability

Besides the measurements of physical workload, the comfort and usability of Spineband was evaluated (see Appendix C). Knight and Baber's (16) reliable CRS (Comfort Rating Scale) was used and adjusted to fit the scope of the project. The question on of "Perceived change" was thereby excluded as this aspect is captured in the following usability survey. The other groups of the CRS are "Emotion", "Attachment", "Harm", "Movement" and "Anxiety". Two of them ("Attachment" and "Anxiety") were turned into a positive statement for a better understanding and suitability for Spineband. The CRS was measured on a 21-point visual scale from "very low or not at all" (0) to "very much" (20) from left to right.

For the usability assessment, two survey questions were therefore taken from the UMUX-LITE, a short version of the validated Usability Metric for User Experience (17). The first question was slightly altered to fit the content of this study by asking to which extent Spineband has decreased the load on the neck. The five item Likert scale (from 'strongly disagree' to 'strongly agree') was used to evaluate the level of agreement (18). In addition, the standardized Net Promoter Score (NPS) was used to measure the participants' level of satisfaction with Spineband by stating a likelihood-to-recommend question in the standardized form *"How likely is it that you would recommend Spineband (our company) to a friend or colleague?"* with a scale ranging from 0 (not likely at all) to 10 (very likely) (19). Both the CRS and usability questions were provided to the participants in Swedish and translated to English later for data processing.

Lastly, a semi-structured user interview was performed at the end of the measurement of asking about the participants' overall impression of the experiment, their evaluation and usage of Spineband system as well as suggestions for improvement. After having been given the consent of the participant, the interview was recorded with an iPhone (Apple Inc, USA). The interviews were conducted in Swedish and later translated to English for the analysis. The interview guideline is attached in the Appendix D.

2.5. Data processing

For the EMG, the data were first filtered with a bandpass filter (fourth-order Butterworth filter) (20–400 Hz) (20). After baseline removal a full-wave rectification was conducted and the data were transformed to root mean square (RMS) values (16 Hz) (21). Then, the data were normalized as percentages of maximal voluntary electrical activation (%MVE) for the neck extensors. Therefore, the maximum RMS values of the three maximum voluntary contractions (MVC) from the three calibration rounds were used. The extracted main parameters from the EMG data are the different levels of muscular activities (10^{th}, 50^{th} and 90^{th} percentiles), where higher values represent more activation of the muscle (22). The percentiles represent the static (10^{th}), mean (50^{th}) and peak (90^{th}) levels of muscle activation and thereby denote that 10 percent of the data is less or equal to the value of the 10^{th} percentile, 50 percent is less or equal to the value of the 50^{th} percentile and so on (23).

The IMU data were pre-processed by Wergonic's phone application based on the processing calculations as described by Fan et al. (24). The inclination angles of the head and trunk are defined and calculated as the inclination angles relative to the I-calibration posture (standing upright, looking straight ahead) in the sagittal plane (25). Further processing was conducted with a custom MATLAB 2022a script through corrections of the quadrant alignment of the head angles and clearance of outliers. The extracted main parameters are the different levels of inclination angles, distributed in the 10^{th}, 50^{th} and 90^{th} percentiles (see explanation for EMG data above).

2.6. Statistical analysis

Due to the small sample, no conclusion about the distribution of the EMG and IMU data could be drawn (20). Therefore, a non-parametric statistical test was applied to compare using Spineband to not using Spineband: The Wilcoxon Signed-Rank test for related samples was thereby performed with an alpha level at 0.05 for both the technical data (EMG and IMU) as well as the subjective ratings from the surveys (26). All statistical analyses were conducted with the SPSS software (SPSS Inc, v27.0, Chicago, USA). The semi-structured interviews were coded and analyzed following the steps of Braun and Clarke's (27) method for thematic analysis. The interview answers were thereby inductively analyzed with a semantic approach.

3. Results

3.1. Physical workload

This chapter demonstrates the results of the physical workload of the participants, both from technical measurements (IMU and EMG) as well as subjective ratings of perceived workload. The results thereby contain seven data points for six participants, because one of them was measured working with and without Spineband for two cases each instead of one. This deviation was decided during the measurement as this participant switched more often between similar working tasks, so he was working shorter cases with and without Spineband but an additional pair of cases instead. The boxplots show the distribution of the measurement values for each percentile and thereby compare the overall averages while the statistical test for significance from Friedman compares the rankings of the data points to evaluate the impact of using Spineband. Therefore, the significant difference might not be visually obvious in the boxplots.

3.1.1. The inclination angles

Figure 6 displays the distribution of the head angles as comparison between those work cases when Spineband was used (exo) versus when Spineband was not used (no exo) as well as the angle definition. The results show that the participant's head was significantly less bent when having worn Spineband for all percentiles. This means that the lowest, the median and the peak head angle values were decreased from using Spineband. For instance, on average, when the subjects were using Spineband their head had a forward bending of 37,5° in comparison to 50,5° when not wearing Spineband (50th percentile). The highest single forward bending of the head was measured when not using Spineband with a value of 80° while the absolute lowest head tilting happened when using Spineband with a value of 4°.

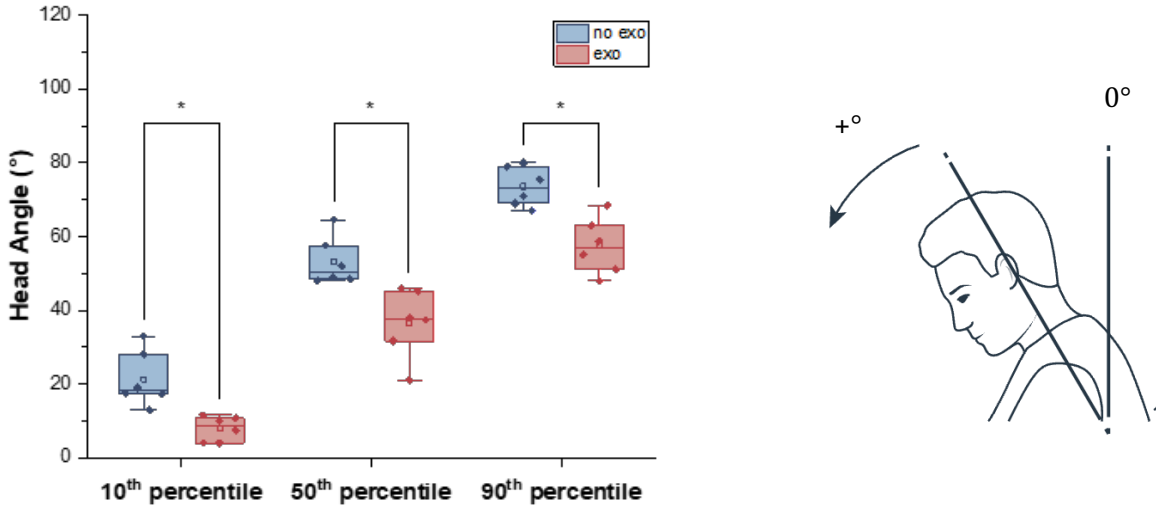

Figure 6 Distribution of the head angles in 10th, 50th and 90th percentile. *p* values for the 10th percentile are denoted as *<0.028, for the 50th percentile as *<0.075 and for the 90th percentile as *<0.046 (left) and definition of the forward bending head angle (taken from RAMP assessment on cloud.wergonic.com) (right)

While the head angles decreased significantly when using Spineband, the forward bending of the trunk slightly increased (see Figure 7). On average, the subjects had 4° more flexion of their trunk when wearing Spineband (54,5° in comparison to 50,5°). For the median (50th percentile) and the peak values (90th percentile) the increase in trunk inclination has statistical significance.

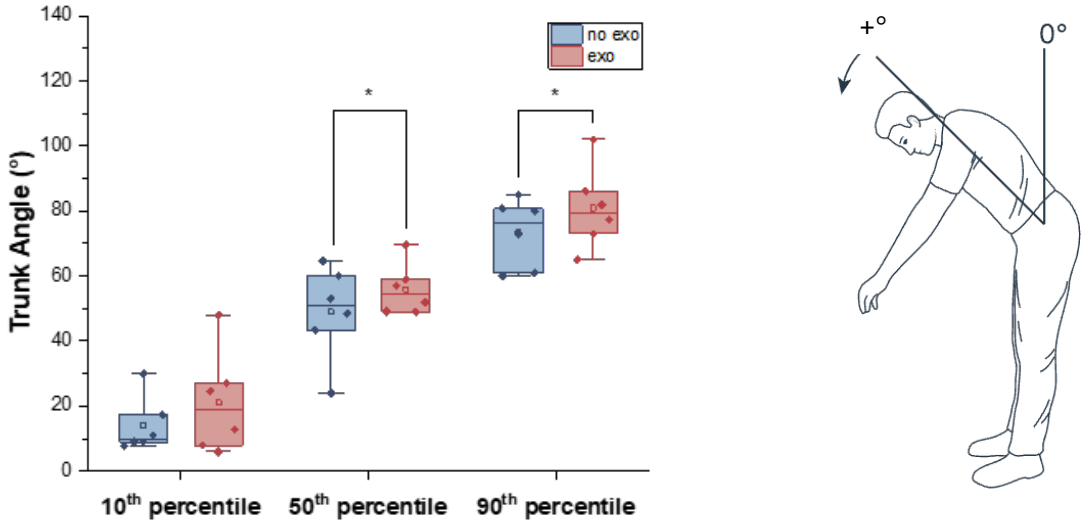

Figure 7 Distribution of the trunk angles in 10th, 50th and 90th percentile. p values are denoted as *<0.34 for the 10th percentile, *<0.046 for the 50th percentile and *<0.027 for the 90th percentile (left) and definition of forward bending trunk angle (taken from RAMP assessment on cloud.wergonic.com) (right)

3.1.2. Muscular activities

As Figure 8 depicts the distribution of the muscle activity of the neck extensors, the results demonstrate that the neck muscles are significantly less active when using Spineband (exo) in comparison to not wearing Spineband (no exo) for all percentiles. On average, the subjects use about 18% of their maximum voluntary exertion (MVE) of their neck muscles when using Spineband in comparison to 23% MVE. The peak values of muscular activity in the neck have reached around 36 %MVE on average which were found for those work cases when the subjects were not wearing Spineband with the single maximum value of 54% MVE. The absolute lowest neck muscle activation was measured for a case of wearing Spineband with a value of 3% MVE.

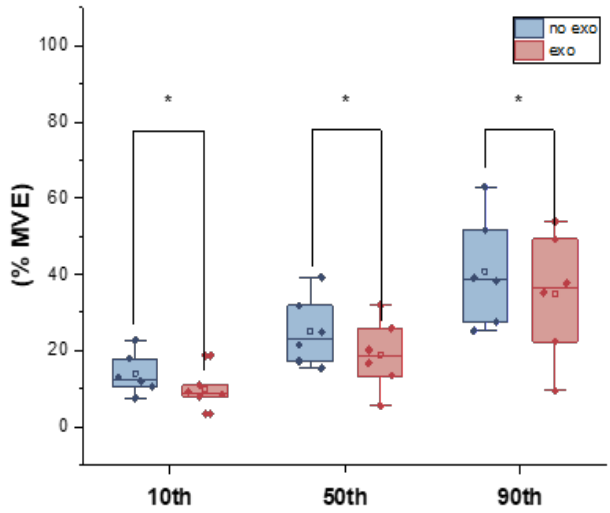

Figure 8 Muscular activities (in %MVE) of the neck extensors in the 10th, 50th and 90th percentile. p values are denoted as *<0.028

3.1.3. Biomechanical load

The influence of Spineband on the biomechanical load of the neck muscles was also estimated from a typical work posture. The calculations show that Spineband has a potential to decrease neck muscle forces, depending on the tension in the Spineband cord. Further details can be found in Appendix A.

The results illustrate the principle that the neck muscle force can be decreased with increased tension in the Spineband cord, and that the relationship is linear. However, the magnitude of the tension in the Spineband cord is adjusted in each case by the user.

3.1.4. Perceived physical workload and performance

Besides the technical measurements, the subjective assessments of the perceived physical effort were somewhat higher for using Spineband, but the difference was not significant (see Figure 9).

The performance ratings furthermore show that the participants evaluated their own work performance slightly better when they were using Spineband in comparison to those cases when they were not using it (see Figure 10). As the difference is relatively small (16,86 for using Spineband compared to 16,14 when not using Spineband), the participants thought well of their work performance regardless of using Spineband or not. The statistical test also revealed no statistical significance (p = 0.102).

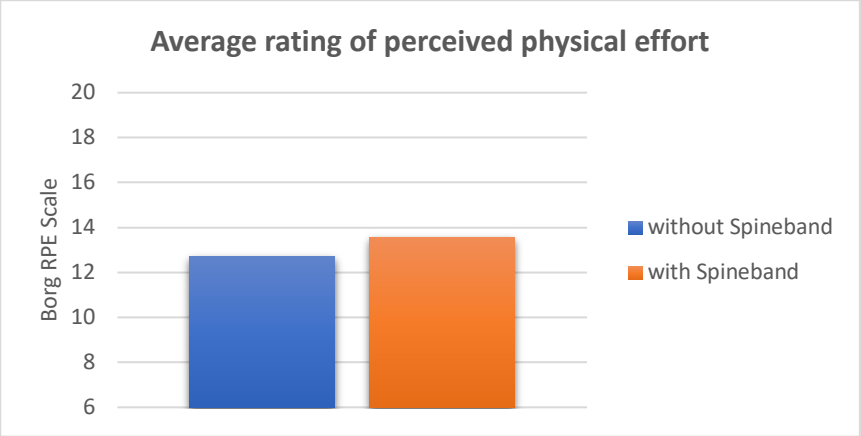

Figure 9 Comparison of average perceived physical exertion on Borg's RPE scale between cases with Spineband and without Spineband. The difference is not significant (p=0.496)

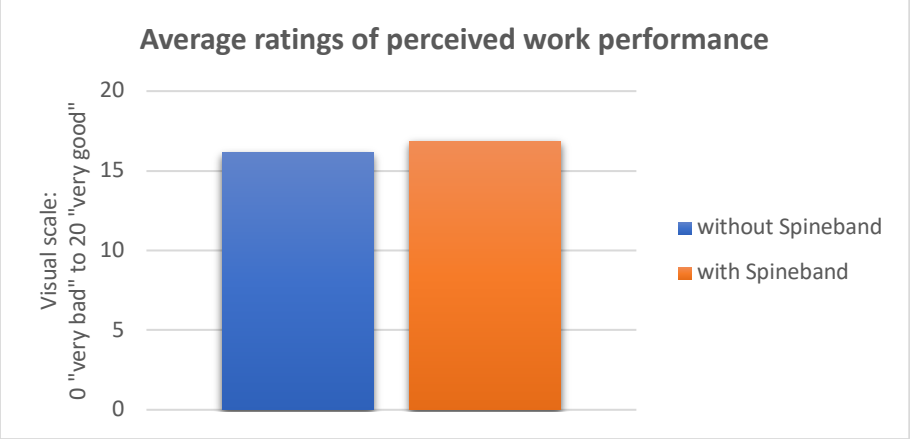

Figure 10 Comparison of average ratings on work performance between working with Spineband and working without Spineband along 21-point scale "very bad" (0) to "very good" (20). The difference is not significant (p=0.102)

3.2. Comfort and usability

3.2.1 Comfort Rating Scale (CRS)

The results from the comfort evaluation of Spineband are displayed in Figure 11. All five categories are presented as the original CRS in a negative statement, for instance, the “Emotion” aspect states that “I feel that I look strange when wearing Spineband.” Therefore, for all aspects a lower rating from 0 (“very little / not at all”) is a positive evaluation of comfort. The boxplots show that four of five categories were rated on average below 10 on the 21-point scale, demonstrating a good evaluation of their feeling and attachment of the shirt with no or little feeling of harm and anxiety. Only the category of “Movement” (“Spineband limits or restricts my movements.”) was rated with 13 on average which is closer to a neutral grade on the CRS scale and suggests minor feeling of discomfort for this aspect. The best average rating of comfort was given for the category of “Anxiety”, which shows that the participants generally felt safe using Spineband.

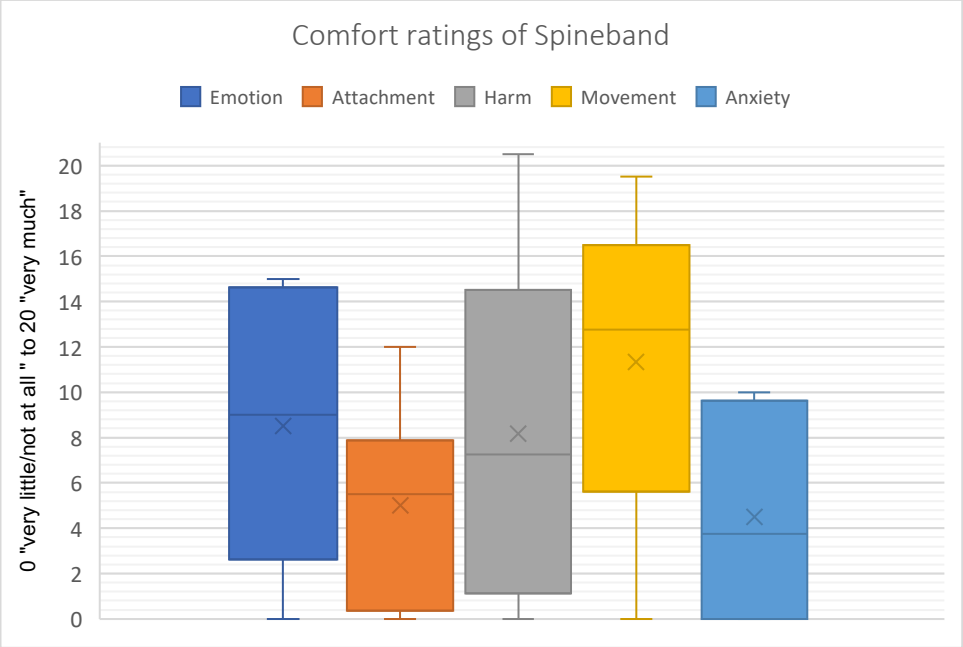

Figure 11 Overview of ratings for 5 CRS aspects on 21-point scale from "very little or not at all" (0) to "very much" (20) for negatively formulated statements (e.g., “I feel that I look strange when wearing Spineband” for the Emotion aspect). Low ratings therefore represent high levels of comfort.

3.2.2 Usability

The usability evaluation shows an overall good usability as the results from the UMUX-LITE show a slight positive sentiment for both statements as the most common answer. The overall feeling was even more positive for the easy usage of Spineband (mean of 0.67) but is also reflected in a slightly positive tendency towards the feeling that Spineband has decreased the load on the neck (mean of 0.5). As the boxplots in Figure 12 depict furthermore, the subjects gave more differing answers for whether Spineband has decreased the load in the neck, with a minimum response value of -1 (“disagree”) and maximum value of 2 (“strongly agree”).

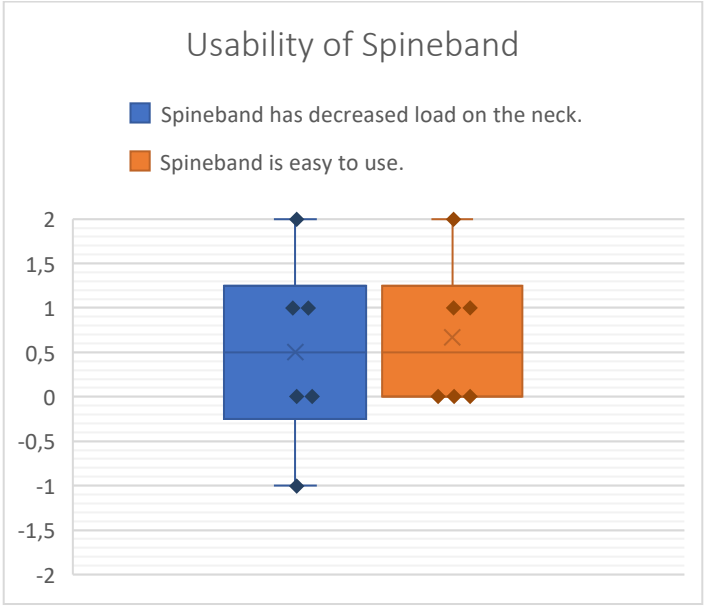

Figure 12 Overview of ratings for UMUX-LITE statements on five-point Likert scale from 'strongly disagree' (-2) to 'strongly agree' (2). The crosses symbolize the mean (average) of the statements.

In addition, the answers on the Net Promoter Score (NPS) are displayed in Figure 13. Two participants are revealed as "promoters" of Spineband as they rated with 9 and 10, while one subject can be interpreted as "passive" (score of 8) and the remaining three subjects as "detractors". As the scale ranges from 0 to 10 and is commonly interpreted as higher scores meaning overall higher level of satisfaction with the product (Spineband), it can also be observed that five out of six participants have scored equal or greater than the central rating of 5 which shows mostly positive attitudes for Spineband's usability and the willingness to recommend it to others (19).

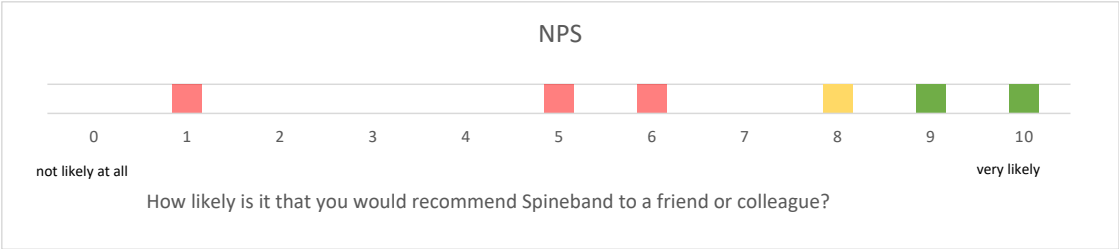

Figure 13 Distribution of answers for the NPS

3.2.3 Interview results

The thematic analysis of the user interviews revealed five main themes of which three contain multiple sub-themes. The initial codes as well as the overview of all themes can be found in the Appendix E. **User experience of Spineband** was identified as the first main theme and consisted of the categories of Good Usability of Spineband & Equipment, Usability Challenges and Discomfort and Restriction of Movement. The first category demonstrates positive statements of the participants saying that Spineband is easy to use and "*it feels good*" to wear it. One subject also mentioned that the fixation of the Spineband to the trousers with the belt straps worked well and another one reported an affinity for the cap as adjunctive equipment ("*the cap has worked well*"). The second category revealed usability challenges, with the most prevalent being the fixation of Spineband. Multiple subjects reported sliding of the headband (and then not knowing whether Spineband works properly) and the difficulty of adjusting the Spineband to their trousers with the straps ("*It's a bit of a hassle to put on Spineband*"). It was wished for the mounting of Spineband to be "*quick and easy*". Another subject furthermore mentioned that *"it takes a bit to get used to Spineband".* The last category revealed that some participants felt restricted in twisting movements and when looking downwards while wearing Spineband and one reported that the tightness of the headband

gave him a slight headache: "*Spineband restricted the work a little. It was hard to look down. It was uncomfortable."*

The second theme **Measurement Experience** contains both Enjoyment of the experiment, saying that it was *"fun"* and *"interesting"* and they were grateful for the participation. The other category of Perceived Impact showed that the subjects thought it was good to test Spineband in real work scenarios, they are curious to see the results of the study and one participant even mentioned increased awareness of his body due to the experiment: *"The Spineband measurement gave (a little more) awareness of my own body - which is great"*

The third theme of **Perceived Benefits of Spineband** contains several positive statements about the effectiveness of Spineband, saying that "*it helps a lot*" and that they can "*feel a difference in the neck*" when using Spineband. The participants were hopeful for its "*potential to be useful*" and likeliness that it gives good results in the long term. It was furthermore found that Spineband is thought to be good to use when having pain in the neck or shoulders.

Another theme was identified as **Application and Use of Spineband** which consists of three subcategories. The first describes the participants' varying Use Cases of Spineband. Some mentioned it can be worn for many different tasks, while one subject suggested that Spineband is better used only for static work with bent head. Another participant reported his usage of Spineband to be mostly at home: *"I use Spineband almost every day at home sitting in front of the computer (for gaming) or watching TV, before sleeping."* The second category of Frequency of Usage also varies in the subjects' statements ranging from not using Spineband at all, little and frequent usage up until using it "*quite a lot*". The Reasons for Using or Not Using Spineband were also identified: One subject reasoned his little usage of Spineband with the nature of the carpet installing job to be too dynamic and involving heavy movements. Another mentioned the difficulty of mounting Spineband as reason for not using it, while one participant explained that his motivation is simply based on the recommendation of use: "*I use Spineband almost every day at home due to recommendation from Spineband representative*."

4. Discussion

This pilot study's aim was to evaluate the effectiveness and user experience of the exoskeleton Spineband in decreasing the load on the neck of carpet installers. Both technical and subjective measurement methods were used to generate substantial results. The collected EMG data thereby show significantly lowered activity of the neck muscles for those cases when Spineband was used. At the same time, the forward bending angle of the head was significantly decreased when Spineband was used. However, the postural data of the trunk revealed increased forward bending when using Spineband. This finding is in line with the common observation that exoskeletons can work effectively on target areas (in this study the neck) but affect non-target areas (the trunk) (28). This can be explained by the modification of kinematics with the trunk being used more to bend down as compensation for the head being held back by Spineband (7). Furthermore, it needs to be considered that most of the carpet installers' work tasks were performed on their knees with support of one or two hands or forearms (on all fours). Therefore, high trunk bending angles do not directly correspond to higher load of the back as the body weight is distributed onto the hands/forearms and knees. The positive trend of the head posture and neck activity is in line with insights from the user interviews where noticeable effectiveness in lowering neck pain was mentioned several times. This effectiveness is thereby demonstrated in various measures: Besides the lowered muscle activity levels and decreased head bending, the first question of the usability survey that asks about the effect of lowering the neck load was answered by several participants with statements of agreement. In addition, the interviews revealed that the carpet installers found Spineband to help them and making a noticeable difference in neck comfort.

The study also shows relatively good usability of Spineband. As the usability survey was answered with a slight tendency towards good usability the interviews also revealed that most participants had a positive user experience and found Spineband to be easy to use. While the participants' use cases and frequency of Spineband varied, several of them were quite eager to use Spineband frequently, either at the job or for leisure activities at home. At the same time, the interviews gave good insights about the facilitators and challenges when using Spineband. Regarding the facilitators, the perceived effectiveness of Spineband, recommendations of use and having neck pain has been found as motivators for using Spineband. The initial mounting of Spineband and fixation with the holsters on the trousers, the sliding of the headband due to sweating and feeling restricted when twisting the head are examples of such challenges. Despite the positive comfort evaluation on average, these challenges are reflected in the spread of their ratings on the comfort scale and were furthermore observed during the data collections. As the subjects had different amount of work practice with Spineband prior to the experiment, the variability in usability evaluation was expected. This fact was also reflected in one participant's comment that it needs time to get used to wearing and working with Spineband. From observations during the measurements it was found that the adjustment of Spineband seem to be more difficult in those tasks where the trunk and the neck bends forward simultaneously, and easier when only the head bends forwards.

The subjective performance ratings show furthermore that Spineband does not hinder work productivity as it is feared by contractors for other occupational exoskeletons (3). Working with Spineband even resulted in slightly higher ratings of their own performance. Even though the difference is not significant, the result is relevant since the order in which the participants used Spineband was random, and the work tasks were aimed to be similar.

The limitations of this study also need to be taken into account: As the measurements were performed in real-life work setting of the carpet installers, the similarity of the work tasks that were compared between wearing Spineband and not wearing Spineband varied. Therefore, those cases in which the Spineband was used could have included more kneeling postures with a bent trunk than the cases without Spineband. As all subjects have reported discomfort in the neck prior to the experiment and due to the nature of this pilot study is it not possible to draw conclusions about the preventative and long-term effects of Spineband. However, the lowered values of neck muscle activity and head bending support the potential. This study was a pilot study and was performed with a small sample size of six participants. The results are therefore affected by inter-individual variability. Furthermore, social desirability bias that is based on expecting positive outcomes from using Spineband and desires to please the field researchers can also impact the participants' survey and interview answers.

5. Conclusion and practical implications

This study aimed at evaluating the exoskeleton Spineband's usability and effectiveness in decreasing the load on the neck of carpet installers at their work. Technical measurements of muscle activity of the neck, postural measurements of the head and trunk as well as subjective ratings of comfort and usability were thereby collected. The results revealed significantly lower activity of the neck muscles for those work cases in which Spineband was worn and used. The postural data also show significantly lower forward bending angles of the head when Spineband was used. At the same time the trunk flexion was slightly increased when the participants were using Spineband. The subjective data furthermore show relatively good ratings of the participants' perceived work performance with slightly better results for the cases in which Spineband was used. The comfort of Spineband gave also overall positive evaluations for four out of five dimensions, although there was a clear spread among the participants. Only the movement dimension revealed that the carpet installers felt some restrictions of movement from Spineband during their work. The usability of Spineband was evaluated with neutral to slightly positive statements in the survey. The user interviews furthermore showed that the participants overall had a good experience participating in the study and working with Spineband. Several found it to be effective in decreasing load in the neck, feeling a noticeable difference. However, it takes time to get used to working with Spineband, and some carpet installers hesitate to use it because of the extra effort needed to take it on. Lastly, the interviews revealed varying type and frequency of usage of Spineband with some participants wearing it frequently at the job, some never, and some at home during leisure activities.

Practical implications

Even though this study had a small sample, the results are relevant. While the trunk flexion slightly increased when using Spineband, the carpet installers had significantly lower muscle activity of the neck and significantly less forward bending of the head. Together with the positive ratings of performance when working with Spineband and its usability the exoskeleton shows potential for being effective in decreasing the neck load of carpet installers. As the work tasks and therefore working postures varied in this study as well as the experience of the participants in working with Spineband, a larger research project is needed to further evaluate Spineband's ergonomic benefits and long-term effects.

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Appendix

Appendix A Results from Biomechanical Calculations

The representation is an illustration showing the principle of the influence on the biomechanical load from Spineband from this particular posture. The head was considered as a free body and torque equilibrium was calculated at C1-Atlas (see Figure A1) using the following Equation:

$$BW \times hs \times 9.81 \times Lh = Nf \times Ln + Sf \times Ls \quad \text{(Equation 1)}$$

where:
BW - body weight in kg (Here assumed 80 kg)
hs - head weight as ratio of body weight (Here assumed 0.062)
9.81 - gravity in m/s2
Lh - lever arm for the head (Here assumed 0.12 m)
Nf - neck muscle force
Ln - lever arm for the neck muscles (Here assumed 0.02 m)
Sf - force in the Spineband cord
Ls - lever arm for the Spineband cord (Here assumed 0.04 m)

According to Equ. (1), if Sf = 0, then Nf = 300N
The equation will result in the following combinations (Force in N):

Force in Spineband	0	50	100	150
Force in neck muscles	300	200	100	0

Figure A1 A photograph of a typical work posture and the basis for the biomechanical calculation (right) with the torque equilibrium at the neck (orange) and the gravitational force of the head (blue).

The results illustrate the principle that the neck muscle force can be decreased with increased tension in the Spineband cord, and that the relationship is linear. However, the magnitude of the tension in the Spineband cord is adjusted in each case by the user.

Appendix B Survey on perceived physical workload

Page **2** of **5** Case ID (EXXYYYYMMDD):

ENKÄT FÖR GOLVLÄGGARE

CASE 1/2

INFORMATION OM MÄTTILLFÄLLET (FYLLS I AV FORSKAREN)

Spineband ja nej

UPPLEVD FYSISK ANSTRÄNGNING

1. **Hur ansträngande upplevde du arbetspasset? (English: Physical exertion, effort)**

Skattning	Beskrivning
6	Ingen ansträngning alls
7	Extremt lätt
8	
9	Mycket lätt
10	
11	Lätt
12	
13	Något ansträngande
14	
15	Ansträngande
16	
17	Mycket ansträngande
18	
19	Extremt ansträngande
20	Maximal ansträngning
Borgs RPE-skala. Bygger på en normalpersons puls vid olika ansträngningar.	

Välj en siffra från Skalan till vänster ”Borg RPE skalan”

2. **Hur ansträngande upplevde du arbetspasset i jämförelse med ett genomsnittligt pass?**

☐ mycket mindre ☐ mindre ☐ samma / liknande ☐ mer ☐ mycket mer

3. **Finns det moment som medför fysiskt obehag (t.ex. i muskler eller leder)?**

☐ ja ☐ nej

3.1. Om "Ja" på fråga 2, vilket är det värsta momentet?

_____

Välj en siffra från ”Borg RPE skalan” för detta momentet

mycket dåligt mycket bra

4. **Prestanda:**
Hur skulle du bedöma din egen prestation?

Appendix C Survey on Comfort and Usability

Page **4** of **5** Case ID (EXXYYYYMMDD):

After both cases

KOMFORTBETYG AV SPINEBAND

Det finns sju skalor för att utvärdera din erfarenhet under uppgiften. Vänligen utvärdera proceduren genom att markera "X" på varje skala som bäst passar din upplevelse. Läs beskrivningarna noggrant.

	väldigt lite eller inget	väldigt mycket
Känsla: Jag ser konstig ut när jag har på mig Spineband		
Passform: Spineband passar bra och sitter bra på min kropp		
Skada: Spineband ger mig obehag och lite smärta att bära		
Rörelse: Spineband hämmar eller begränsar hur jag rör mig		
Känsla av säkerhet: Jag känner mig säker när jag bär utrustningen.		

ANVÄNDBARHET AV SPINEBAND

	Stämmer mycket dåligt	Stämmer ganska dåligt	Stämmer i viss mån	Stämmer ganska bra	Stämmer mycket bra
1. Spineband har minskat belastningen på nacken.	☐	☐	☐	☐	☐
2. Systemet är lätt att använda.	☐	☐	☐	☐	☐

3. Hur troligt är det att du kommer att rekommendera Spineband till vänner eller kollegor?

Inte troligt										Mycket troligt
0	1	2	3	4	5	6	7	8	9	10

Appendix D Interview Guideline

 Case ID (EXXYYYYMMDD):

FRÅGOR EFTER EXPERIMENT

- **Vad tycker du om dagens tester och Spineband? (How do you feel about today's test and the Spineband?)**

- **Vad tror du kan förbättras med Spineband? (What do you think can be improved with the Spineband?)**

- **Hur mycket tror du att du kommer att använda Spineband i framtiden? (How much do you think will you use the Spineband in the future?)**
    - **I vilka situationer? (in which situations?)**

- **Har du några andra kommentarer? (Do you have any other comments?)**

Appendix E Initial codes from interview transcripts

Refined initial codes	**Refined themes (MH)**
Effectiveness of Spineband (Usage of Spineband when having pain (in neck or upper back) "is a wonderful thing")	**Perceived benefits of Spineband** (good to use when having pain in neck/upper back, feeling difference in the neck, "helps a lot", good for neck and shoulders, quite likely that it will give good long-term results", potential "to be useful")
Positive feeling of measurement ("good to test in real job")	**User Experience with Spineband** (*Good usability of Spineband & equipment* (easy usage, good feeling, "works pretty well", "good as it is", Effectiveness of cap, good fixation of Spineband on belt (with belt fasteners), *Usability challenges* (Difficulty with mounting & fixation of Spineband (to be sure it works properly, sliding of headring, challenge of using holsters on pants in the beginning, mounting needs to be quick and easy, is "a bit of a hassle" to mount due to adjustments & headring), need time to get used to Spineband)), (*Discomfort and restriction of movement* (in twisting motions of trunk, looking down/to the side, tight headring gave slight headache)))
Usage of Spineband (more) at home instead of job	**Measurement Experience** (*Enjoyment* (fun, interesting, grateful, "good to test in real job"), *Perceived impact* : increased body awareness, curiosity about results, results determine usability of Spineband)
Need for improvement of fixation of Spineband	**Application and Use of Spineband** (*Frequency of use* in the future (no usage, "a little now and then", frequent ("several times", "quite a lot"), *Use cases* (at home instead of job (gaming/watching TV, good for many tasks, better for certain tasks (static load or bent head)), *Reasons for using/not using Spineband* (due to recommendation from Spineband representative to use daily, difficulty of usage, dynamic nature of job with heavy movements,)
Good fixation of Spineband on belt (with belt fasteners)	**User Knowledge and Expectations** (Openess to aids for prolonging job capability, No awareness of MSDs (neck injuries) from posture/heavy lifting, Assumption that restrictions of head movement is purpose of Spineband)
Frequent usage of Spineband at home (gaming, watching TV) "almost every day"	
Frequent usage of Spineband at home due to recommendation from Spineband personell	
No usage of Spineband at work due to heavy/many movements	
Positive feeling of measurement ("grateful for the project and measurements")	
Effectiveness of Spineband (Feeling difference)	
Effectiveness of Spineband (Feeling difference in neck (from the beginning))	
Positive feeling of measurement ("fun to test")	
Need for time to get used to Spineband	
Seeing potential in Spineband ("to be useful")	
Challenge of Spineband/restricting movement in twisting motions	
Effectiveness of Spineband (for many tasks)	
Need for improvement of fixation of Spineband (to be sure it works properly)	
Need for improvement of easy and quick mounting of Spineband	
Effectiveness of Spineband ("works pretty well")	
Need for improvement of easy and quick mounting of Spineband / Challenge ("a bit of a hassle") to mount Spineband due to adjustments and headring	
Little usage of Spineband in the future ("a little now and then" (when I "feel like it"))	
Understanding that Spineband is good for the neck	
Little usage of Spineband in the future due to difficulty of usage	
Need for improvement of fixation of Spineband	
Measurement increased body awareness during work	
Positive feeling of measurement ("went well")	
Challenge of Spineband/restricting movement (when looking down)	
Discomfort of Spineband (when looking down)	
Discomfort of headring (too tight, gave slight headache)	
Challenge of using holsters on pants in the beginning	
No usage of Spineband in the future	
Easy usage of Spineband	
Effectiveness of Spineband ("helps a lot at work")	
Good feeling of Spineband	
Good feeling of Spineband from the beginning	
Frequent usage of Spineband in the future ("several times")	
Frequent usage of Spineband in the future ("in all situations")	
Positive feeling of measurement ("grateful for measurement/Spineband")	
Positive feeling of measurement ("was interesting")	
Curiosity about results from measurement	
Positive feeling of Spineband depends on effectiveness/results	
Openess to aids for prolonging job capability	
No awareness of MSDs (neck injuries) from posture/heavy lifting	
Effectiveness of Spineband longterm likely ("quite likely that it will give good long-term results")	
Usage of Spineband better for certain tasks (static load or bent head)	
Little usage of Spineband in the future due to dynamic nature of carpet laying job	
Effectiveness of Spineband ("good for neck and shoulders")	
Effectiveness of Spineband ("good as it is")	
Need for improvement of fixation of Spineband (sliding of headring)	
Effectiveness of cap	
Frequent usage of Spineband in the future ("quite a lot") due to neck problem	
Frequent usage of Spineband in the future ("for any task")	
Challenge of Spineband/restricting movement (when looking down) ("it's a bit annoying")	
Discomfort of Spineband (when looking down/to the side) ("a bit irritating")	
Assumption that restrictions of head movement is purpose of Spineband	