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Title

A better way of fitting clips? A comparative study with respect to physical workload

Abstract

The clip fitting task is a frequently encountered assembly operation in the car industry. It can cause upper limb pain. During task laboratory simulations, upper limb muscular activity and external force were compared for 4 clip fitting methods: with the bare hand, with an unpowered tool commonly used at a company and with unpowered and powered prototype tools. None of the 4 fitting methods studied induced a lower overall workload than the other three. Muscle activity was lower at the dominant limb when using the unpowered tools and at the non-dominant limb with the bare hand or with the powered tool. Fitting clips with the bare hand required a higher external force than fitting with the three tools. Evaluation of physical workload was different depending on whether external force or muscle activity results were considered. Measuring external force only, as recommended in several standards, is insufficient for evaluating physical workload.

Keywords: engineering, physical workload, surface electromyography

Highlights:

The study compared muscular activity and external force for 4 clip fitting methods.

Muscle activity of the dominant limb was lower when using the unpowered tools.

Non-dominant limb muscle activity was lower with bare-hand or powered-tool fitting.

However, fitting clips with the bare hand required a higher external force.

Thus, measuring the external force alone may give rise to an erroneous interpretation.

1. INTRODUCTION

The current trend, in manufacturing industries, of seeking productivity gains combined with a high level of quality has resulted in a willingness on the part of designers to ensure an uniformity in the ways in which operators work (Gold et al., 2009; Parent-Thirion et al., 2007; Neumann et al., 2006; Domkin et al., 2005; Chassaing, 2004; Andersen et al., 2003; Neumann et al., 2002). Workstation designers define a single succession of postures and movements to be performed by the operator, without offering any alternative. Assembly lines are no exceptions to this rule. Such lines are made up of series of workstations on which tasks are performed in succession and repeatedly (Carnahan et al., 2001). Many of these tasks are performed manually, with the bare hand or using a tool, powered or unpowered (Byström et al., 1995). In view of the repetitiveness of the movements, of the level of force required to perform an action, of extreme joint amplitudes and/or of activity maintained for long periods, neck and upper limb pain or indeed musculoskeletal disorders occur frequently in the workers performing such tasks (Ferguson et al., 2013; Ferguson et al., 2012; Jansen et al., 2012; Xu et al., 2012; Spallek et al., 2010; Nordander et al., 2009; Landau et al., 2008; Buckle and Devereux, 2002; Silverstein et al., 2002; Sluiter et al., 2001; Fransson-Hall et al., 1995). In ergonomics, workplace exposure to such physical workload is often evaluated by measuring muscular activity, which has been correlated with pain or musculoskeletal disorder symptoms (Ferguson et al., 2012; Porter et al., 2010; Bao et al., 2009; Ostensvik et al., 2009; Southard et al. 2007). Conversely, designers mostly use standards as a basis for evaluating physical workload, such standards recommending assessment of external force or posture (CEN 1005-4, 2004; CEN 1005-3, 2002; CEN 894-3, 2008).

One of the tasks that are frequent in automotive assembly processes is insert fitting. The inserts are small components of different shapes, made of metal, plastic or composite material. They are referred to by various names including clips, staples, nuts, rings or

bushings. They are used to secure two parts together, for example a glove compartment and a dashboard. This task can be performed manually or in automated manner. As in other assembly tasks, automation is considered in order to reduce musculoskeletal disorders related to manual fitting. However, investment in automated machinery is costly and requires considerable expertise (Andrews et al., 2008). Usually, it is not considered to be cost-effective in view of the lifespan of such a part and of alterations that are often performed half way through its life. Therefore, insert fitting is generally performed manually, with or without a tool.

An ergonomic investigation conducted at an automotive supplier specialized in designing and producing dashboards preceded this study (Gaudez, 2008a; Gaudez, 2008b). The request from that company involved objectifying physical workload exerted during the insert fitting operation, which was a source of neck and upper limb pain or of musculoskeletal disorders. In that company, the insert fitting operation was combined with other operations such as deflashing, visual quality inspection, and packaging of the dashboards. The company had developed an unpowered tool. Its aim was to reduce the physical workload during the insert fitting operation. But it was observed that, when fitting the particular variety of clip-type inserts, most of the operators performed the operation with the bare hand despite the fact that the workstation working procedure recommended fitting them with the tool. In that company, the operators suffering from upper limb pain fitted the clips sometimes with their bare hand and sometimes with the tool. Operators changing their working practices depending on their physical conditions, such as depending on whether they feel tired or in pain, has already been observed during work activities (Derosier et al., 2008). Those operators explained that alternating the two fitting methods allowed them to vary their movements and reduced the physical workload on different parts of the body. In addition, many operators found that the tool was too heavy and that its handle was too large, cold, hard, and slippery when sweaty.

This laboratory study simulated the clip fitting activity. Its aim was to use muscular activity and external force measurements to evaluate the physical workload on the neck and upper limbs. Four different insert fitting methods were analyzed: two used in the company, namely bare hand and unpowered tool, as well as two prototype tools, one unpowered and one powered. The first objective of this study was to determine whether any one of these four methods generated lower physical workload than the other ones, thereby demonstrating its benefit to the musculoskeletal health of workers. The second was to compare the results of muscular activity measurements with the results of external force measurements.

This laboratory study supplemented the initial ergonomic investigation. Indeed, this simulation offered the advantage of isolating the insert fitting operation and thus of satisfying the initial request of the automotive supplier. It also allowed the use of prototype tools and techniques that were difficult to apply out in the company such as measuring resultant force, which would have required the workstation to be transformed.

2. METHOD

2.1. Subjects

Eleven right-handed male volunteers took part in the experiment. Those subjects did not work in the company in which the ergonomic investigation had been conducted, due to economic and social difficulties present at the time of the laboratory study and to the distance between the company and INRS (National Research and Safety Institute), where the laboratory was located. The volunteers were professionally experienced in performing precision assembly work.

The 11 subjects had not suffered from any musculoskeletal pain during the month preceding the experiment. Their average age was 27 years (ranging from 19 to 60 years), their average height was 178 cm (ranging from 171 to 191 cm), their average weight was 77 kg (ranging from 57 to 111 kg) and their body mass index was 19 (ranging from 19 to 37). The subjects

gave their informed consent to the experiments, which were approved by the local ethics committee.

2.2. Test bench

An experimental test bench was used to simulate the clip fitting task. The shape, dimensions, and material of the clip supports were identical to those making up a dashboard in the company. Ten clip supports were fixed to a rule (Figure 1). The clips were purchased from the same manufacturer as the one used by the automotive supplier. The supports were inclined such that the subjects inserted the clips forward and downward at a 45° angle in the sagittal plane. This inclination of the supports was frequently to be found on the dashboards. The rule was fixed to an elevating table simulating the height-adjustable workstations of the company. The table height was adjusted to the anthropometry of each subject. It was set at 90% of the elbow-to-floor height of the subject, corresponding to working in a standing position requiring average normal vision and precision (CEN ISO 14738, 2008).

2.3. Task

Standing and facing the rule, each subject fitted clips to each support using four different methods: with the bare hand, with an unpowered tool commonly used at the company, with an unpowered prototype tool, and with a powered prototype tool (Figure 1). The prototype tools were developed at INRS with the help of the company's methods department that worked with the operators.

The unpowered tool commonly used at the company was circular in cross-section and cylindrical in longitudinal section. Its length was 120 mm, its diameter was 32 mm and its weight was 200 g. It had a magnetic cavity at its end that was preformed to match the geometrical shape of the clip for subsequent positioning on the support. The clip was held by magnetization in that cavity. An unpowered prototype tool featuring merely a modified handle was therefore developed from that commonly used tool. Various studies bear witness to the

importance of the ergonomics of the handle of the hand tool in terms of performance, comfort, and physical stress for the operator (Harish and Dolsak, 2014a, 2014b; Ng and Saptari, 2014; Garneau and Parkinson, 2012; Eksioğlu, 2004). Its handle had a shape that was circular in cross-section and conical in longitudinal section. That shape appeared to be optimum for hand tools requiring handling with precision or with force (Kong et al., 2008; Dong et al. 2007). Its length was 115 mm. Its largest diameter was 36 mm and its smallest diameter was 20 mm. The diameter of the handle splayed to 25 mm in the vicinity of the cavity to form a guard and was made of slightly rough, hard plastic in order to prevent the fingers and hand from slipping, and the handle from feeling cold. This prototype tool weighed 130 g. The cavity located at the tool tip was identical to that on the tool commonly used at the company. The magnetic force of the cavity was identical for both tools. The subjects were told to hold the unpowered tools with a full hand grip in their dominant hand with the thumb directed towards the cavity to ensure consistency between subjects. That way of holding the tool was the one that was observed most frequently during the ergonomic investigation. The powered prototype tool was developed from a pneumatic stapler, whose nose and loading magazine were modified. Its loading magazine contained 10 clips. Urged by a spring, the clip went into place automatically in the cavity of the tool. The handle extended at right angles and was held in the dominant hand, with the forearm extended in alignment with the hand. The handle was 140 mm long, oval (40 mm X 30 mm) in cross-section and cylindrical in longitudinal section. A trigger that was 45 mm long, was actuated by the index finger and the middle finger of the dominant hand. It weighed 970 g and was sheathed in slightly rough plastic. The tool tip featured the same cavity as that of both of the unpowered tools and a position mark was added to the cavity so as to make it possible to pre-position the tool tip above the support. The subject pulled the trigger, to discharge a jet of compressed air that initiated percussion on the top of the clip, allowing the clip to be inserted into its vacant support.

The upper limbs were mobilized differently depending on the 4 fitting methods. The clips were placed at the center of the table. When fitting with the bare hand, subjects picked up

the clip with their dominant hand and then inserted it in the vacant support. With unpowered tools, subjects picked up the clip with their non-dominant hand and positioned it in the cavity of the tool. The tool was held in a full hand grip with the dominant hand. Thus, subjects inserted it with the tool into the vacant support. Using these tools, each limb was mobilized to perform different actions. The powered tool was held in the dominant hand. Unlike with unpowered tools, the operator did not have to place the insert in the cavity. The subject triggered insertion of the clip by pulling the trigger with the index and middle finger of his dominant hand.

2.4. Experimental design

Prior to starting the experiment, each of the 11 subjects practiced fitting clips using the four methods until each of them declared he was fitting the inserts with ease. Then, each of the subjects fitted clips at a regular pace set by a metronome of one every 4 seconds, which was close to the fitting rate at the company. The order in which each subject passed from one of the four fitting methods to another was randomized. For each of the four methods, each subject fitted in succession 10 clips on the rule, starting with the supports at its left-hand end. Each subject therefore fitted 40 clips in all (4 fitting methods x 10 clips).

2.5. Instrumentation

The resultant external force exerted, when fitting clips, was measured using a force platform located between the rule and the elevating table (AMTI BP 600900-1000). The subjects were asked not to touch the table with any part of their body to avoid influencing the measured data.

A portable surface electromyography (sEMG) signal analysis system (Wave wireless EMG, COMETA, Italy) was used to record the subject's myoelectric activity. The sampling rate was 2 Ks/sec - 16 bits. The signals were band-pass filtered in the 10-1000 Hz frequency range, sampled at 2000 Hz and amplified 1000 times. All sEMG signals were post-processed. The

root mean square values of each signal were calculated over consecutive time windows (10 ms). Flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), biceps brachii (BIC), triceps brachii (TRI), deltoideus anterior (DEL) and trapezius pars descendens (TRA) muscular activities in both upper limbs were measured by surface electromyography. Bipolar sEMG electrodes (Ambu® Blue Sensor N-00-S/25, Denmark) were aligned on abraded cleaned skin along the direction of the muscle fibers. The inter-electrode distance was set at 2 cm. The impedance was checked to be below 5 k Ω . The electrodes were placed according to Zipp (1982). Two maximum (5 s) reference contractions were performed for each muscle to standardize the EMG signals with respect to their corresponding maximal voluntary electrical (MVE) activity. Each of the contractions was separated by a pause of 3 minutes to avoid any risk of muscular fatigue appearing. The subject was provided with verbal encouragement. For taking measurements on the FDS and the EDC muscles, the subject was seated with his forearm resting horizontally on a table. The subject's upper arm remained in a vertical position and his hand was unsupported. For the FDS and EDC muscles, the back and the palm of the subject's hand faced the floor respectively (Delisle et al., 2006). A non-elastic strap was placed around his hand at the metacarpal-phalangeal joints. For the FDS muscle, the subject was required to perform a maximum wrist and finger flexion and, for the EDC muscle, he had to perform a maximum wrist and finger extension. The non-elastic strap enabled the subject to perform maximum movements against a static resistance. For the BIC and TRI muscles, the subject was seated with his forearm horizontal and elbow flexed to 90°, with his wrist in a neutral position and his hand unsupported. A non-elastic strap was placed around his wrist perpendicular to his forearm. For the biceps muscle, the subject was required to perform a maximum elbow flexion and, for the triceps muscle, a maximum elbow extension. For the DEL muscle, the subject sat with his elbow flexed to 90° and his shoulder flexed to 45°. A non-elastic strap attached to the floor behind the subject, passed just over his elbow joint, perpendicular to the arm. The subject was required to perform a maximum shoulder flexion (Delisle et al., 2006). For the TRA muscle, the subject stood with his arms abducted to 90°. A non-elastic strap attached to the floor was

placed around his arm at the elbow joint (Mathiassen et al., 1995). He was required to perform a maximum abduction of both upper limbs. For each muscle, myoelectric activity was expressed as a percentage of the MVE activity.

2.6. Statistical analysis

In order to avoid any border effect, the first and the last clip fitting were excluded.

For the resultant external force, the 90th percentile was analyzed. This was compared with the values recommended by CEN 894-3 (2008). According to that standard, the recommended maximum actuation force for manual control parts is 20 N, when using a finger grip to perform a forward movement along the forearm axis; this movement is similar to that the movement that was performed for fitting the clips with a bare hand. The recommended maximum actuation force for manual control parts is 55 N, when using a full hand grip to perform a forward movement along the forearm axis; this movement is similar to of the movement that was performed for fitting the clips with a tool.

For the muscular activities, the amplitude probability distribution function (APDF: Jonsson, 1978) was used to determine the 10th, 50th and 90th percentiles for the EMG signal. These were compared with thresholds proposed by Jonsson (1978) to prevent muscular fatigue occurring. According to that author, the 10th percentile for the muscular activity must not exceed 5% and/or the 50th percentile must not exceed 14% and/or the 90th percentile must not exceed 70% of the MVE.

Prior to statistical modeling, the measured percentiles of the EMG signal were log-transformed to give approximately symmetrical residual distributions. The data were analyzed based on a 2-way mixed-effects ANOVA including main effects for tools and subjects, and tool-subject interaction. Tool was a fixed factor whereas subject and thus tool-subject interaction were random factors. Thus, the differences between tools took into account possible differences between subjects, due to age, height or weight. Model assumptions were checked by graphical inspection of the residual distributions. The statistical analysis was performed using the Stata 12 software (College Station Tx).

A difference between two fitting methods was considered interpretable when the 90th percentiles for the resultant external force or the 10th, 50th and 90th percentiles for the activity of a muscle deviated by more than the model-based estimate of its within-subject residual error. To ensure a higher reproducibility of the results, only the differences apparent in at least 8 out of the 11 subjects taking part in the experiment were interpreted.

3. RESULTS

3.1. Resultant external force

The mean 90th percentiles for the resultant external forces measured when fitting with the bare hand and with unpowered tools were higher than the thresholds recommended by CEN 894-3 (2008) (with the bare hand: 132 +/-52 N compared with 20 N for a finger grip; with the unpowered tool commonly used at the company: 77 +/-33 N and with the unpowered prototype tool: 65 +/-32 N compared with 55 N for a full hand grip) (Figure 2). The mean 90th percentile for the resultant external force measured when fitting with the powered prototype tool (53 +/-27 N) was closer to the force recommended by the above standard (55 N). Fitting clips with the bare hand required a higher external force than fitting with the three tools ($p<0.001$) (Table 1).

3.2. Muscular activity

Fitting with the powered tool was the only investigated method where the recommended values given by Jonsson (1978) were exceeded. The 10th percentile values for EDC and TRA activity in the dominant limb exceeded 5% of the MVE (Figure 3).

With regard to the dominant limb muscles, clip fitting methods involving the powered prototype tool and the bare hand generally induced higher muscle activities than fitting with the unpowered prototype tool (Table 1). Compared with the unpowered tool used at the company, and/or the unpowered prototype tool and/or the bare hand, clip fitting with the powered tool produced higher 10th percentile values for the FDS ($p\leq 0.001$), the TRI

($p=0.002$) and the DEL ($p\leq 0.001$) muscles, and 50th percentile values for the FDS ($p\leq 0.001$) and the DEL ($p=0.003$) muscles. Moreover, fitting with the bare hand generated 90th percentile values for the EDC ($p=0.002$), the BIC ($p\leq 0.001$), the TRI ($p\leq 0.001$) and the DEL ($p\leq 0.001$) muscles higher than those generated when fitting with the unpowered tool used at the company and/or with the unpowered prototype tool and/or with the powered tool. Furthermore, fitting with the tool commonly used at the company generated 10th percentile ($p\leq 0.001$) and 50th percentile ($p\leq 0.001$) values for the BIC muscle higher than those generated when fitting with the powered tool. Regardless of which muscle of the dominant limb was considered, the unpowered prototype tool generated no percentile values higher than those generated when using the other three fitting methods.

With regard to the muscles of the non-dominant limb, fitting with the unpowered tool commonly used at the company, and with the unpowered prototype generated higher muscular activities than fitting with the bare hand or with the powered prototype tool (Table 1). Fitting with the unpowered tool commonly used at the company generated a 50th percentile value for the DEL muscle ($p=0.002$) and 90th percentile values for the EDC ($p\leq 0.001$), the BIC ($p\leq 0.001$), the TRI ($p\leq 0.001$), the DEL ($p\leq 0.001$) and the TRA ($p=0.016$) muscles higher than those generated when fitting with the powered tool. The 90th percentile value for the FDS muscle ($p\leq 0.001$) was higher when fitting with the unpowered tool commonly used at the company than when fitting with the bare hand. The 50th percentile value for the EDC muscle ($p\leq 0.001$) and 90th percentile values for the FDS ($p\leq 0.001$), the EDC ($p\leq 0.001$) and the DEL ($p\leq 0.001$) muscles were higher when fitting with the unpowered prototype tool than when fitting with the powered prototype tool.

Muscular activities presented no significant difference between both unpowered tools. However, compared with the unpowered prototype tool, clip fitting with the unpowered tool commonly used at the company produced higher mean values for the 90th percentile of the external force, and the 10th, 50th et 90th percentiles of the FDS, the BIC, the TRI and the TRA muscles of the dominant limb, of the FDS, the EDC, the TRI, the DEL and the TRA muscles of the non-dominant limb, the 50th and 90th percentiles of the EDC muscle of

the dominant limb and of the BIC muscle of the non-dominant limb and the 90th percentile of the DEL muscle of the dominant limb.

4. DISCUSSION

None of the four clip fitting methods induced a lower overall physical workload, as estimated from muscular activities and resultant external force, than the other three. Muscle activity of the dominant limb was lower when using unpowered tools in comparison to using the bare hand or the powered tool. However, fitting with the bare hand or with the powered tool generated lower muscular activity at the non-dominant limb in comparison to unpowered tools. There was a risk for operator health, whatever the method used. Fitting clips with the bare hand, with the unpowered tool commonly used at the company and with the unpowered prototype tool effectively required resultant external forces that exceeded those recommended by CEN 894-3 (2008). Moreover, fitting clips with the powered prototype tool resulted in a risk of muscular fatigue, according to Jonsson (1978).

Therefore, the improvements in the 2 prototype tools, unpowered and powered, developed by INRS, need to be continued in order to reduce the physical workload on operators. For the unpowered prototype tool, the ergonomics of the handle and the cavity receiving the insert could be improved. Furthermore, mechanical assistance to gear down the force exerted for the insertion could also be integrated into this tool. When fitting with the powered tool, the 10th percentile values for the EDC and the TRA muscles of the dominant limb exceeded the thresholds proposed by Jonsson (1978). The 10th percentile value represents the static workload (Ankrum, 2000) and, when this is high, certain muscular fibers are continuously active, allowing no, or only little, muscular rest and thereby compromising muscular integrity. Weighing nearly 1 kg, the powered tool was the heaviest of the studied tools. A high and continuous activity of the EDC and TRA muscles of the dominant limb was associated with holding the tool. Moreover, this weight difference between tools explained the significantly higher 10th percentile values for FDS, EDC and DEL muscles, when using the powered tool,

compared with the three other fitting methods. For this reason, the powered tool cannot be used in its current state. A feasible solution would be to optimize its design by trying to reduce its weight or by suspending it.

This study also reveals possible mismatch between the results from resultant external force and surface electromyography. When fitting clips with the powered tool, the resultant external force value was smaller with this tool compared with the other three fitting methods, while the muscular activity measurement results indicated that the method involving the powered tool was the only one to cause a risk of muscular fatigue. Holding the tool requires a co-contraction of agonist-antagonist muscle. This physical load is measured by surface electromyography, and not by resultant external force. Resultant external force is a mechanical measurement recorded in the environment close to the subject, while muscular activity is a physiological measurement recorded directly on the subject. Measuring muscular activity reflects the real loads exerted on the subject to a greater extent than resultant external force does and it would therefore seem more relevant for evaluating an operator health-related risk. Nevertheless, resultant external force is used often by designers (Delleman and Dul, 2007; Karger and Bayha, 1987) while muscular activity measurement is used only exceptionally.

Depending on the clip fitting methods, the upper limbs moved differently. This led to different physical workload of the upper limbs. Clip fitting with unpowered tools required less muscular activity of the dominant limb than fitting with the bare hand or with the powered tool, while clip fitting with the bare hand or with the powered tool required less muscular activity of the non-dominant limb than fitting with the two unpowered tools. Thus, although the initial objective of the study was to reduce the physical workload by identifying the insert fitting method that was least stressful, these results lead us to consider exploring another way for reducing the physical workload: diversifying the ways in which the task of inserting clips is performed at the same workstation. Out in the company, the operators who were suffering from aches and pains alternated between fitting with the tool and fitting with the bare hand. This proposal involving alternation of different ways of performing the same work activity

goes against the current design practices, which tend to promote uniformity and standardization of the ways in which operators work. Multiple studies reveal that existence of variability in muscular activity can have a preventive effect on fatigue development (Srinivasan and Mathiassen, 2012; Bosch et al., 2011; Van Dieën et al., 2009; Farina et al., 2008; Andersson et al., 1974). Furthermore, this proposal to alternate various different ways of fitting the inserts might bring to mind the technique of changing to different workstations. It is based on the assumption of reducing physical stress of operators by varying the parts of the body that are stressed. However, in practice, it can have the opposite effect and even be harmful to worker health (Comper and Padula, 2014; Luger et al., 2014; Horton et al., 2012; Keir et al., 2011). The protocol put in place in this study does not make it possible to validate this proposal. A future study will need to be performed in order to demonstrate this benefit for worker health.

5. LIMITATIONS AND FUTURE WORK

In this laboratory-based study, the activity was simulated and focused on insert fitting. It differed from the real work activity partly due to the absence of other activities generally associated with insert fitting, such as deflashing, part packaging or quality control, due to the workstation design and to the visual and acoustic conditions. These differences between laboratory and real working conditions may lead to different results (Moriguchi et al., 2012). This study comparing physical workloads for different fitting methods requires validation in relation to real work activity.

This study analyzed only one of the very many types of inserts. Future studies could focus on analyzing physical workload associated with fitting other types of inserts and implementation of other fitting methods. Moreover, the prototype tools used in this study may be further improved, for example to reduce the resultant external force and the muscular activity required for inserting clips.

The study population was exclusively masculine yet, women do perform this activity at manufacturers. A study combining a masculine and feminine population could be envisaged. The results of the present study lead us to propose alternating between different clip fitting methods. However, these methods have been analyzed separately. Future research could focus on the benefit to operator health based on a protocol comparing clip fitting method alternation with fitting based on each of these methods. It could also attempt to define the best method alternation frequency in relation to employee health.

6. CONCLUSION

This study shows different results depending on which technique was used to measure the physical workload: muscular activity versus resultant external force. It highlights the risk of erroneous interpretation when only resultant external force is taken into account. That measurement is recommended in several standards for evaluating the physical load on operators.

The results of this study show that none of the four clip fitting methods studied was preferable in relation to benefitting operator health. None induced lower activities on all the recorded muscles than the other three. Each of the 4 clip fitting methods exceeded the recommended thresholds, be they Jonsson's (1978) for muscular activity, or the thresholds of CEN 894-3 (2008). Thus, the improvement of the prototype tools needs to be continued.

Alternating different insert fitting methods with a view to varying upper limb muscular activities could have a preventive effect on the risk of occurrence of fatigue or musculoskeletal pain. However this proposal needs to be validated in a future study.

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Figures and Table

Figure 1: The 4 ways of fitting the clips

Figure 2: Mean and standard deviation of the 90th percentile for the resultant external force recorded for each of the 4 clip fitting methods. Fitting methods: Bare hand=h; Unpowered tool used at company=tuc, Unpowered prototype tool=ut; Powered tool=pt.

Figure 3: Mean and standard deviation of the 10th, 50th and 90th percentiles for flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), biceps brachii (BIC), triceps brachii (TRI), deltoideus anterior (DEL) and trapezius pars descendens (TRA) muscle activity of both limbs recorded for each of the 4 clip fitting methods. Fitting methods: Bare hand=h; Unpowered tool used at company=tuc, Unpowered prototype tool=ut; Powered tool=pt.

Table 1: ANOVA-based statistical test results on effect of fitting method (Bare hand=h; Unpowered tool used at company=tuc, Unpowered prototype tool=ut; Powered tool=pt): Value of p, difference between two fitting methods greater than fitting method residual error (fitting method X > fitting method Y indicating that method X induces muscular activity or resultant external force at least greater than the fitting method residual error for fitting method Y) and number of subjects affected by this difference

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