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DeltaSuit
Performance Sheet

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Introduction

Ergonomic evaluation of the support provided by the DeltaSuit shoulder exoskeleton during power tool handling and object manipulation above shoulder level in men and women of working age.

The DeltaSuit is a passive lightweight exoskeleton that supports the arm, shoulder, neck and back muscles when working at or above shoulder level. It features integrated elastic elements that store energy to support the user and reduce the workload. Scientific evaluation performed at the Swiss Federal Institute of Technology/ETH Zurich has shown that wearing the DeltaSuit reduces muscle activity and delays the process of fatiguing. When muscles fatigue slower the user will experience less tiredness and can perform the same task longer.

Study Information

Thirty-two participants (15 female) of working age (20 to 65 years) visited the Rehabilitation Engineering Laboratory to perform work with and without the DeltaSuit. Tasks included using a powered drill above shoulder level, manipulating small objects above shoulder level, and holding various arm positions with and without power tool.

During these tasks the participants' heart rate, muscle activity, muscle fatigue, perceived fatigue and user experience were measured to compare working with and without the DeltaSuit.

Different Support Levels

The user can choose from two levels of support: level 1 provides 5.2 Nm of peak support, while level 2 provides 6.6 Nm. Depending on the position of the arms level 1 support relieved the shoulder and neck muscles between 20 and 50%. When switching to level 2 support another 20% of relief could be obtained during the laboratory measurements. The suitable support level for any tasks depends on the weight of the tool that is used, the arm position and the amount of experience the user has working with the DeltaSuit.

Muscle Load

- The DeltaSuit reduced muscle activity in the neck and shoulder muscles up to 65%.
- Muscle load in the shoulder was 33% lower when using a power tool and 36% lower when manipulating small objects.
- The reduced muscle load made working overhead significantly more comfortable.
- When the muscles are working less hard they fatigue less fast.

Muscle Fatigue

- The DeltaSuit reduced fatigue by 45% in the shoulder muscles, 60% and the upper arm and 75% in the neck while holding a power tool above the head.
- Changes in muscle fatigue are associated with changes in how exhausted the user feels and how long they can perform the task.

Cardiac Cost

- When muscles are working less hard they use less oxygen, which can lower the heart rate.
- When wearing the DeltaSuit while using a power tool cardiac cost was reduced by 15%.
- When using the DeltaSuit while manipulating objects above the head cardiac cost was reduced by 12%.

Ergonomics

- Overhead work can be uncomfortable. The DeltaSuit reduced reported discomfort in the shoulder, neck and upper arm.
- The users reported little to minor constraint of their movement by the exoskeleton.
- Users rated device weight, safety and ease of use with an average 5/5 satisfaction.

Effects on Muscle Load

In the study the support of the DeltaSuit reduced shoulder muscle load by 33% when using a power tool and by 36% during an assembly task. Shoulder muscle activity was reduced up to 65% during static tasks.

Scientific Method

Muscle activity was measured using surface electromyography. Specifically, muscles in the arm (biceps brachii), shoulder (anterior deltoid), neck (upper trapezius) and lower back (erector spinae at lumbar level) were measured.

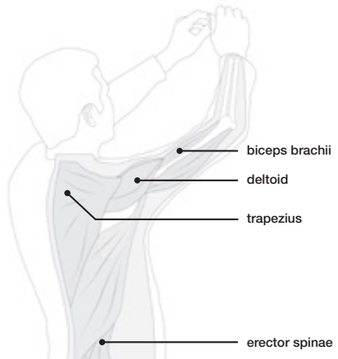
The signal was recorded and processed according to European guidelines (SENIAM). Prior to the tasks participants performed maximal voluntary contractions. The muscle activity was normalized to the highest of two maximal voluntary contraction attempts.

As an indication of how hard the muscles are working during each task we report the root mean square of the normalized muscle activity.

Effect of DeltaSuit use on Muscle Load

Using the DeltaSuit significantly reduced the muscle activity in the arm, shoulder and neck muscles across tasks. The average reduction in shoulder muscle activity was as high as 65% when holding the arms at a 90° angle in front of the body. No negative effects, such as additional activation of the lower back muscles, were observed. Back muscle activity was even significantly reduced when holding a 1.8 kg power drill.

When the muscles need to work less hard, the movements become more precise, and muscles fatigue slower.



Benefits when using a power tool

While fastening screws with a powered drill, using the DeltaSuit significantly reduced muscle load in the shoulder by 33%, muscle load in the neck by 22% and muscle load in the arm by 17%.



Benefits when manipulating objects

While manipulating small objects above shoulder level without a tool, the support provided by the DeltaSuit significantly reduced upper body muscle load. Specifically, muscle load in shoulder was reduced by 36%, the neck by 34% and the arm by 37%.



Effects on Fatigue

In the study the support of the DeltaSuit reduced fatigue by 45% in the shoulder muscles, 60% in the upper arm and 75% in the neck while holding a power tool above the head.

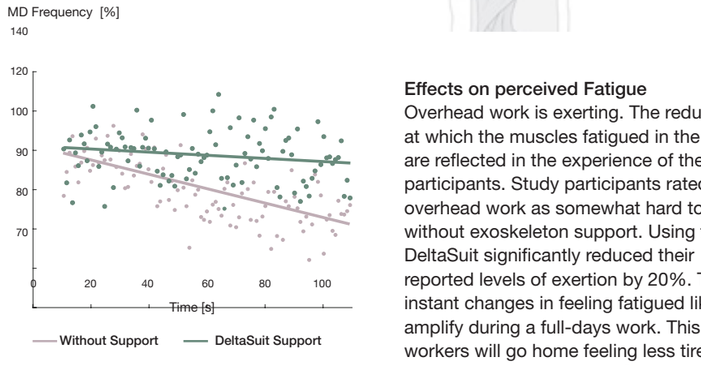
Scientific Method
Muscle activity was measured using surface electromyography. Specifically, muscles in the arm (biceps), shoulder (deltoid), neck (upper trapezius) and back (erector spinae) were measured.

The signal was recorded and processed according to European guidelines (SENIAM).

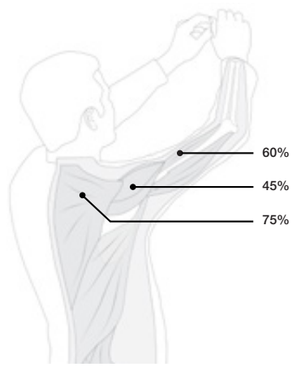
As an indication of how quickly muscles are fatiguing during the task, we looked at the rate at which the median frequency of the muscle activity reduces over time.

Participants rated their perceived exertion on a 10-point scale from no exertion to maximal effort.

Effect of DeltaSuit use on Muscle Fatigue
When muscles fatigue the ratio between activated fast-twitch and slow-twitch muscle fibers changes. This results in a shift in the frequency content of the muscle activity signal. The lower the median frequency compared to the start of the task the more the muscles are fatigued.
In the figure you see that the deltoid muscle of one example participant fatigues overtime when doing the task without support. With DeltaSuit support hardly any fatiguing occurs during the task.



Over all participants the rate in which the median frequency sinks was significantly lower when wearing the DeltaSuit. In the study the support of the DeltaSuit reduced fatigue by 45% in the shoulder muscles, 60% in the upper arm and 75% in the neck while holding a power tool above the head.



Effects on perceived Fatigue
Overhead work is exerting. The reduced rate at which the muscles fatigued in the study are reflected in the experience of the participants. Study participants rated overhead work as somewhat hard to hard without exoskeleton support. Using the DeltaSuit significantly reduced their reported levels of exertion by 20%. These instant changes in feeling fatigued likely amplify during a full-days work. This means workers will go home feeling less tired after a days work with the DeltaSuit.

Reported Exertion up to 20%



Effects on Cardiac Cost

When muscles are working less hard they use less oxygen, which lowers our users heart rate. Wearing the DeltaSuit while using a power tool led to a reduction in the cardiac cost of 15%.

Scientific Method
Heart rate was recorded using an optical heart rate sensor. Participants wore the heart rate sensor on their non-dominant wrist. The signal was processed using the accompanying software to obtain beats per minute (bpm).

Cardiac cost is calculated as heart rate during the task minus resting heart rate. It reflects the additional beats per minute the heart needs to make to complete the task at hand.

When starting a task our muscles immediately activate and use oxygen. To supply the muscles with the extra needed oxygen and to remove waste products the heart starts beating faster. After a few minutes of uninterrupted work, the heart rate stabilizes and the cardiac cost of the task can be calculated.

In the figure one can see the heart rate of one participant while using a powertool

Cardiac cost of fastening screws with a powered drill above the head was 21 bpm. During the study the support of the DeltaSuit reduced the cardiac cost by 15% to 18 bpm.

The cardiac cost of manipulating small objects above shoulder height was 23 bpm without exoskeleton support. During the study the support of the DeltaSuit reduced the cardiac cost by 12% to 20 bpm.

Cardiac Cost up to 15%

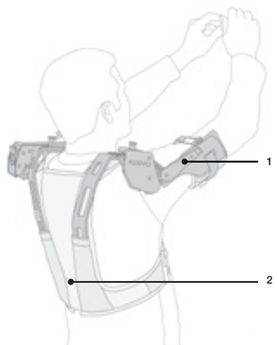
Ergonomics and Comfort

The DeltaSuit reduced reported discomfort in the shoulder, neck, and upper arm, while causing little to minor movement constraint. Users rated device weight, safety, and ease of use as optimal.

Scientific Method
Users were asked to rate their perceived constraint and discomfort on a 10-point scale.

System usability was assessed using a standardized questionnaire: the Quebec User Evaluation of Satisfaction with Assistive Devices.

Freedom of movement
To provide meaningful support during various of tasks, unconstrained movements are important. Because the DeltaSuit attaches to the chest, instead of the hip, movement of the torso is completely unconstrained. The telescopic mechanism in the arm and elasticity in the vest minimize misalignment between the joints of the users and the exoskeleton. This is reflected by the study participants reporting feeling only little to minor constraint across tasks.



Minimal misalignment and auto-adjustment of size through (1) telescopic arm mechanism and (2) elasticity in the vest

Optimal fit
To test the fit of the DeltaSuit participant with a range of body dimensions were included in the study. Participants with a weight between 44 and 98 kg and body height between 1.60 and 1.94 m were fit with the two sizes of the exoskeleton. Through the elasticity in the vest the vest adjusted well to a wide range of shoulder widths (36-64 cm) and the telescopic mechanism in the upper arm allows the exoskeleton to automatically adjusts to a range of upper arm lengths.

Usability
At the end of the 1.5-hour study protocol, participants reported being satisfied with the device (4.3/5). Weighing ca. 2 kg, the DeltaSuit was perceived as very light. The exoskeleton automatically adjusts to users' shoulder width and arm length, making the exoskeleton intuitive and easy to use. Participants were very satisfied (5/5) with the weight of the DeltaSuit, the ease of use, and their sense of safety when using the device.

Reported Satisfaction 4.3/5



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