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Sustained attention when squatting with and without an exoskeleton for the lower limbs

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ABSTRACT

Twelve Royal Marines participated in a laboratory study of a passive lower limb exoskeleton. Participants stood for 5 min in a semi-squatting posture in the laboratory while performing the Sustained Attention to Response Test (SART), repeated on separate days while wearing and without the exoskeleton. Performance on the SART was degraded when the semi-squatting posture was adopted and did not recover after 15 min of rest. The SART was rated as less frustrating when the exoskeleton was worn, while less time pressure and task conflict were reported and the need to exert self-control to maintain the posture was rated lower. There was no effect of the exoskeleton on SART performance. However, subjects' increase in heart rate when squatting, without the exoskeleton, was positively correlated with an increase in their SART error rate. The findings are discussed in relation to the cognitive demands of performing physically demanding tasks and the possibility that new technologies designed to enhance human physical ability may also improve cognitive capacity.

Practitioner summary

The ability to sustain attention was impaired when subjects adopted a knee straining posture for 5 min and did not recover after 15 min rest. An exoskeleton reduced the physical demands of standing but not the ability to sustain attention.

1. Introduction

A recent review of the use of exoskeletons for industrial applications by De Looze et al. (2016) concluded that exoskeletons have the potential to reduce exposure to the stressors associated with musculoskeletal injuries in industrial jobs, but there was both a lack of research on their effectiveness and a lack of safety standards for their design. A review of the literature by the authors also revealed a lack of research on the benefits that might be of practical relevance when exoskeletons are used to augment human physical capacity.

In the present paper, the term 'exoskeleton' is used to describe devices attached externally to the body to augment the ability of healthy individuals, in contrast to braces that are used to compensate for disability or restore function in injured individuals. Exoskeletons may be passive (using springs or counterweights to aid performance) or active (using powered actuators) and fall into a number of categories: tool holding exoskeletons, as are used in automobile assembly; 'chairless chairs' fitted to the legs that exert an extension moment around the knee joint or fully support the mass of the upper body when sitting or crouching (Fig. 1a and b); trunk stabilisers that maintain asymmetric postures of the trunk when working in stressful postures; powered gloves to enhance grip force; powered body suits and 'extra' limbs. De Looze et al. found in their review that passive exoskeletons designed to support the lower back achieved 10–40 percent reductions in back muscle activity during dynamic lifting and active exoskeletons had the ability to reduce muscle activity by up to 80 percent.

Lower limb exoskeletons have a number of potential areas of application. They have been developed to aid recreational skiers (Fig. 1a) and to aid the adoption of a static semi-squatting postures in industry setting while carrying out discrete tasks (Fig. 1b). Another potential area of application is for users of high speed craft (HSC) who are required to stand and cannot use suspension seats - the legs tend to be used in a manner akin to spring damper units to absorb shock and vibration, the knee joints are flexed and there is constant 'bracing' of the axial skeleton in readiness for the next exposure to shock or vibration. The physical stress of travelling on HSC is sufficient to degrade physical and cognitive performance at the end of transits lasting several hours (McMorris et al., 2009). Reductions in performance of 15–25% have been found at sea states 2–4 (smooth wavelets to moderate seas with waves up to 2.5 m). Installation of suspension seats on HSC can prevent these decrements because the shock and vibration are absorbed by the seat mechanism (Myers et al., 2012). In those instances where suspension seats cannot be used, and the occupants have to stand,

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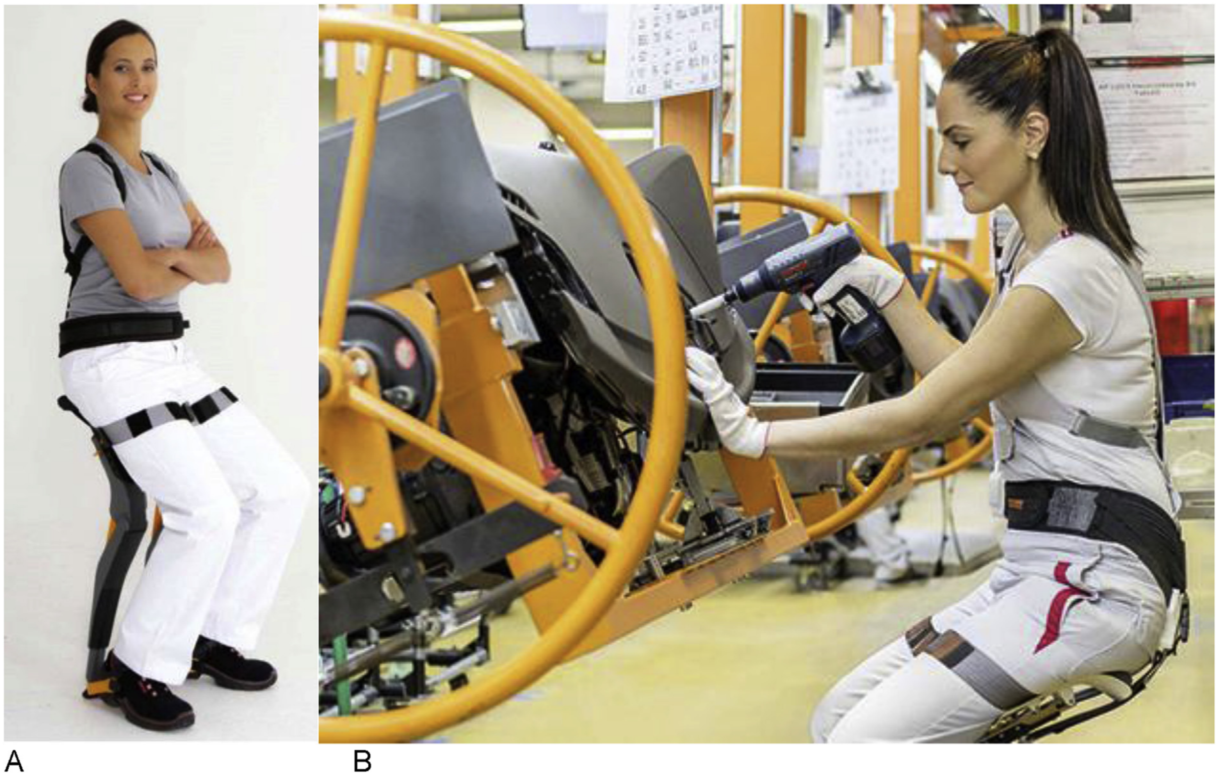

Fig. 1. Examples of passive exoskeletons for the lower limbs to aid the maintenance of semi-squatting postures (courtesy of AUDI AG and nooni plc).

alternative methods of reducing exposure to vibration and shock are needed. Exoskeletons that exert an extension moment about the knee joint during flexion are one possibility.

1.1. Endurance times for static postures

The literature on occupational risk factors for musculoskeletal disorders is mature and has been extensively reviewed (see, for example, Bridger, 2018). High forces, static postures, rapid repetition rates, excessive task durations and exposure to psychosocial stressors are all associated with increased risk of injury. It would seem likely then that effective design of exoskeletons would enable physical work to be conducted more effectively and more safely.

Static work postures have long been known to be associated with fatigue, discomfort and injury in industrial work and the International Standards Organisation has published guidance in the form of time limits for the maintenance of a variety of static postures (ISO 11226, 2000). In a similar vein, Dul et al. (1993) recommended maximum holding times for static postures.

1.2. Physical stress and cognitive performance

In addition to the potential health benefits of exoskeletons, cognitive performance may also be improved. There is evidence that a variety of physical stressors can degrade cognitive performance. Alomari et al. (2015) investigated the effect of cold stress on cognitive performance. Subjects had to keep their hands immersed in cold water for three minutes while carrying out the sustained attention to response test (SART, Robertson et al., 1997). The SART is a computerised test that requires sustained attention to a series of 225 targets presented sequentially. Performance on the test was degraded when the hands were immersed in cold water, compared to a control condition. The experiment was based on a dual-task paradigm – if two tasks do not exceed the subject's capacity to perform them and if they do not compete for a common resource, then it should be possible to conduct both of them at the same time to the same standard without decrements in the performance of either. If the performance of one or both of the tasks is degraded when they are performed concurrently, then it may be concluded that they compete for a common resource. The SART requires that attention be focussed and sustained on a rapid sequence of stimuli for four minutes, while suppressing the impulse to respond to infrequent (one in every nine) targets. Keeping the hand immersed in cold water requires self-control to ignore the discomfort caused by the lowered skin temperature and to resist the impulse to remove the hand. The degradation in SART performance when the hand is immersed in cold water is therefore thought to be due to the two activities competing for limited cognitive resources in the form of attention.

Physical stress in the form of exercise appears to affect cognitive performance selectively. Dietrich and Sparling (2004) gave cognitive tests to subjects running on treadmills at 70–80% of their maximum heart rate. Performance of tasks requiring short term memory and attention (such as the Wisconsin Card Sorting Task) were degraded when running whereas tests of general attention and picture identification were not. The former tasks are thought to require pre-frontal cognitive processing which is resource intensive, whereas the latter tasks do not.

1.3. Attentional demands of maintaining posture

Maintenance of posture is almost effortless under ideal conditions and places no demands on attention. In a standing posture, when the base of support is narrowed and when visual feedback is impaired, conscious attention is required to maintain posture. Remaud et al. (2012) used the dual task paradigm to investigate whether reaction time was degraded by an attentionally demanding standing task. They found that reaction time to an auditory stimulus was greater when standing than when sitting down and greater when standing with the feet together or on one leg when the eyes were closed. Changes in postural steadiness were positively associated with changes in reaction time. These effects were only observed when subjects stood with their eyes closed (the attentional demands of standing are increased when