**Exertion**

There are many articles in the literature that evaluate the use of robotic exoskeletons and their effect on exertion across a variety of diagnoses. Most of these publications cover the Ekso 1.1/GT/NR device (47), referred to as “Ekso” in this paper. Other devices used include ReWalk (7), Indego (4), HAL (2), UAN.GO (2), and SuitX Phoenix (1), among others. The most widely studied diagnosis was Spinal Cord Injury (44), followed by Multiple Sclerosis (10), stroke (8) and brain injury (3). The most commonly reported outcome measures in regards to exertion were Borg Rating of Perceived Exertion (RPE) (23), Physiological Cost Index (4), Fatigue Impact Scale (3), and Fatigue Severity Scale (2).

*Spinal Cord Injury (SCI)*

Some studies that looked at exertion in a population with SCI examined whether exoskeletons could be used as exercise. Thirteen wheelchair users with SCI used Ekso 2-3x/week for 10 weeks and it was found that their cardiorespiratory measures increased 22-52% while walking in the device; oxygen cost, relative HR, relative O2 consumption, respiratory exchange ratio, and RPE achieved 0.29 mL/kg/m, 82.9%, 41.8%, 0.9 and 3.2/10, respectively, indicating that these users were able to reach a moderate-intensity level of exercise while walking in the Ekso.1 Another Ekso study with 7 SCI subjects demonstrated that participants were able to achieve mild-to-moderate intensity exercise while using the device, based on heart rate changes and RPE scores ranging from light to somewhat hard.2 A third Ekso study that compared individuals with SCI to a control group reported RPE scores of “light to moderate” indicating that using the device correlates to “light” exercise. The authors note that although the American College of Sports Medicine recommends moderate to vigorous intensity activity for most adults, there may still be benefits from light to moderate exercise for deconditioned persons with SCI.3 Two more Ekso studies with a combined 7 subjects also reported “light-to-moderate” RPE scores4,5 in addition to an 11 subject SCI Ekso study that demonstrated an average “moderate” RPE score.6 In a randomized controlled trial comparing Ekso to standard care in subjects with SCI, the Ekso group reported Borg RPE scores were as high as 14-15 (rated on a scale of 6-20) which correlates to a high level of effort and thus, higher intensity exercise7. Another randomized study in 16 subjects compared Ekso training to activity based therapy and reported lower RPE scores (i.e. less exertion) in the activity based therapy group when compared to the Ekso group at the end of the study.8 Two individuals with SCI and different baseline functionalities in terms of walking were compared after using the Ekso and it was found that the individual with lower baseline walking capability was able to achieve a higher cardiometabolic challenge while using the device than the individual with a higher baseline walking capability.9 In a single subject SCI Ekso case study, both assistance from the device and spinal cord epidural stimulation while using the device were varied and it was found that walking with higher levels of spinal cord epidural stimulation in combination with lower assistance levels from the device resulted in the highest RPE (i.e. more exertion) scores of the study; as high as 17.4 ± 1.5 which correlates to “very hard”.10 A 6 subject SCI study with the ReWalk reported “moderate” fatigue after using the device on a fatigue visual analogue scale (VAS).11 A second ReWalk study in 5 individuals with SCI reported that fatigue was more severe after ReWalk training sessions based on a VAS fatigue scale.12 Lastly, the SuitX Phoenix was utilized in a 40 subject SCI study and exertion was measured by both Borg RPE and fatigue.13 When analyzing single session data, it was found that both fatigue and exertion increased from pre-session to post-session.13

In contrast, other studies examined exertion over the whole intervention period and showed that using an exoskeleton required less exertion overtime. An eight subject SCI Ekso study showed a decrease in effort (demonstrated by Borg scores) required to use the device throughout the study which they concluded was an amelioration of gait ability and performance.14 Another 52 subjects who utilized Ekso reported a significant decrease in RPE scores (i.e. less exertion) over the course of the study and the authors concluded that these results indicate that it isn’t overly taxing to use the device, therefore it can be used by individuals with SCI for longer periods of time.15 A third Ekso study in 3 SCI subjects showed a decrease in both Borg RPE scores (i.e. less exertion) and VAS Fatigue scores by the end of the study.16 A 4 subject SCI ReWalk study demonstrated a decrease in Energy Expenditure in using the device over the course of the study17 and another SCI ReWalk study noted that only 1 out of 11 subjects reported that using ReWalk caused fatigue.18 Borg scale scores (rated on a scale of 6-20) decreased from an average of 15 (hard (heavy)) to 11 (light) for eleven subjects in a 12 session ABLE exoskeleton SCI study.19 A 45 subject SCI study with the Indego device reported a significant decrease in Borg RPE scores (rated on a scale of 6-20) for indoor walking from 11.7±2.1 at the beginning of the study to 10.4±2.2 at the end of the study indicating that less exertion was required to use the device by the end of the study.20 In a single subject case study comparing the Indego exoskeleton to long leg braces, it was found that the subject was able to walk faster with less exertion in the Indego.21 A 10 subject ReWalk study that compared the exoskeleton to KAFOs reported that the ReWalk had a higher energy efficiency.22 These results indicate that with practice, using an exoskeleton becomes easier, and comparatively is easier than bracing, which together could make a case for the use of home exoskeletons.

While most of the research agrees that exoskeletons can be used for exercise and that longer term use of the device causes the body to acclimate to this exercise, some research opposes this. In a case study for an individual with SCI using the UAN.GO device, it was found that Borg RPE scores remained consistent as it was measured at the end of each 6 minute walk test throughout the study.23 However, it was also noted that the individual reported fatigue due to upper limb overload while using the device.24 A randomized SCI study that compared Lokomat to Ekso in 5 subjects found minimal or no change in RPE for all participants with the exception of one Ekso subject whose RPE scores increased slightly (i.e. more exertion was required) from the beginning to the end of the study.23 A study looking at Phoenix demonstrated that when evaluating the data from entirety of the study, both fatigue and exertion appeared to increase then decrease slightly and then increase again slightly.13

A couple of review articles focus on persons with SCI. One review looking specifically at individuals with SCI using various devices (ReWalk, Ekso, Lokomat, and others) concluded that walking in an exoskeleton does not improve energy expenditure compared to other exercise.25 Another review focusing on persons with SCI offered an explanation for the wide range of reported Borg RPE scores; dosage and exposure to the device may influence Borg RPE scores as newness of a device may yield higher Borg RPE scores (i.e more exertion).26 The authors also concluded that most studies generally report a decrease in effort and fatigue after using an exoskeleton.26

*Stroke (CVA)*

There are a few articles that examine exertion in persons post CVA and they largely disagree. A fourteen subject study utilizing several different devices reported an average category-ratio Borg score of 4 (rated on a scale of 0-10) which correlates to “somewhat severe” exertion and thus fairly high intensity exercise.27 In contrast, a twenty-six subject Ekso study in persons with CVA noted that users experienced “light” exertion while using the device, which the authors conclude indicates that the Ekso is less tiring than overground walking and feasible to use in persons with severe functional deficits in therapy.28 Another Ekso study that compared able-bodied individuals to those with CVA concluded that the physical training intensity associated with device usage may not be high enough, however, this could also lead one to infer that the device is easy to use which is also important.29

*Multiple Sclerosis (MS)*

Fatigue and exertion are very important outcome to examine in persons with MS due to the nature of the disease. A 36 subject study in persons with Multiple Sclerosis compared Ekso use to conventional therapy and found that individuals in the Ekso group maintained their 10 meter walk test (10MWT) speeds in addition to improving their TUG test scores without increasing fatigue as measured by the Modified Fatigue Impact Scale.30 The conventional therapy group had slower 10MWT times and reduced fatigue.30 A single subject MS case study using the Ekso reported a decrease in the shortened Modified Fatigue Impact Scale (sMFIS) from 11 at baseline to 10 post-Ekso therapy, where scores range from 0-20 with higher numbers indicating greater fatigue.31 The Fatigue Severity Scale (FSS), which rates fatigue on a scale of 1-7 where higher scores indicate greater fatigue, was used to assess fatigability in 14 persons with Multiple Sclerosis in an Ekso study.32 This study reported FSS scores of 5.01 at the start of the study, 4.89 at the end of the therapy portion without the device, and 4.37 at the end of the Ekso training part of the study.32 A single subject case study where an individual with Multiple Sclerosis used the Ekso noted a decrease in fatigue from 11 at the start of the study to 10 at the end of the study, as measured by the shortened Modified Fatigue Impact Scale (sMFIS) on a scale of 0-20 where higher scores indicates greater fatigue.31 Borg RPE scores decreased from 15 (hard (heavy)) at the beginning of the study to 11 (fairly light) at the end of the study in a single subject with MS who utilized the UAN.GO device.33 A review article examining the effect of various robotic and exoskeleton gait training devices in individuals with MS concluded that these devices did not appear to have an adverse effects on fatigue.34 Another Ekso study in 10 persons with MS reported Borg RPE scores ranging from 9 (very light) to 15 (hard(heavy)) which indicated that the training was overall not intensive.35 A 54 subject Ekso study in individuals with Multiple Sclerosis reported an average Modified Fatigue Impact Scale (MFIS) score of 42.38 (rated on a scale of 0-84 where greater numbers indicate greater fatigue)36 compared to a baseline MFIS score of 33 for persons with Multiple Sclerosis at rest as reported by Téllez et al, 2005.37

*Review Articles*

One review article compared individuals with SCI and CVA to able-bodied persons using a wide variety of devices from treadmill based devices (Lokomat) to exoskeletons and ankle exoskeletons determined that, in general, robotic walking required less energy than overground walking.38

*Conclusions*

The literature regarding exertion with exoskeleton usage in individuals with various diagnoses resulting in lower limb weakness is inconclusive. Some studies report low exertion, which may be beneficial for those using their devices in their homes and communities, while other studies report higher exertion, which may be desirable for those wishing to use the device as a form of exercise. It is important to note that very few of these studies specify the software configuration that the exoskeleton was used in, which could significantly alter how much work the subject is completing. For example, a lower Borg RPE score (i.e. less exertion) would be expected for a participant who has the exoskeleton device set to provide them full assistance, as opposed to the expectation of a higher Borg RPE score (i.e. more exertion) when removing some or all of the robotic assistance of the exoskeleton which would require the participant to work harder.

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CVA = stroke, MS = multiple sclerosis, SCI = spinal cord injury