

## **Patient and Therapist Satisfaction**

There are 37 known articles that examine patient and therapist satisfaction with using an exoskeleton. Seven of the articles include therapists' perspectives. Of the articles that ask for patient perspectives, the majority (22) analyzed people with spinal cord injury (SCI) while seven used participants with stroke (CVA). Different tools were used to assess perspectives and satisfaction. The most frequently used assessment method was questionnaire/survey, used in 16 articles. This was followed by interviews and focus groups which were used in 12 articles. The most commonly used device was Ekso 1.1/GT/NR, referred to as "Ekso" in this paper, though many articles encompassed participants who used a variety of stationary or overground exoskeletons.

Overall, most of the feedback garnered by both patients and therapists was positive, with recommendations that these stakeholders be involved with future developments of exoskeleton technology.<sup>1,2</sup>

### **Review Articles**

There are 3 known review articles that examine satisfaction in overground exoskeleton users. In one, 23 articles were reviewed including 19 clinical trials.<sup>3</sup> These utilized 14 different exoskeleton devices and patients with SCI, CVA, and MS.<sup>3</sup> Overall, satisfaction was high.<sup>3</sup> For those studies that utilized the Quebec User Evaluation of Satisfaction with Assistive Technology (quest) scale, the average individual question score was 3.7/5 regardless of patient diagnosis.<sup>3</sup> The highest rated aspects of exoskeletons included safety, efficacy, and comfort.<sup>3</sup> The worst rated aspects were ease of adjustment, size and weight, and ease of use.<sup>3</sup> A second review reported no true satisfaction results, but instead noted the importance of including consumer priorities for continued development of exoskeleton technologies, as well as identifying barriers to use.<sup>4</sup> A review article which looked at 15 articles examined just that: It included 480 patients with the goal of identifying barriers and facilitators to using lower extremity exoskeletons.<sup>5</sup> Facilitators included age, age at injury, BMI, and active lifestyle, while barriers were more fear based including fear of skin lesions and loss of balance.<sup>5</sup>

### **Spinal Cord Injury (SCI)**

Patients with SCI were the most surveyed and interviewed patients in the research. Most patients had positive perceptions of using an exoskeleton. Patients reported improvements in both physical and psychological areas. Participants enjoyed being eye level with family and friends.<sup>6</sup> Other perceived improvements included strength<sup>7-9</sup>, endurance<sup>7</sup>, balance<sup>7</sup>, flexibility<sup>7,10</sup>, blood circulation<sup>7</sup>, mental health<sup>8,9,11</sup>, intestinal transit<sup>6,7,12,13</sup>, and spasticity<sup>14</sup>, though some users also reported worsening spasticity with use.<sup>6</sup> On a scale from 0-100, respondents were unanimously satisfied with a locomotor training program using an exoskeleton (95.7±0.7%) and provided positive feedback about the exoskeleton itself (82.3±6.9%).<sup>8</sup> On the same scale, they also averaged low scores (i.e. disagreed or were dissatisfied) regarding perceived risks including fear of falling (22.2±30.4%) and fear of exacerbating neurogenic pain (3.1±4.2%).<sup>8</sup> Another study noted an average satisfaction score of 6.6±2.2/10 for Ekso compared to 7.2±1.9/10 for Lokomat.<sup>15</sup> Patients felt safe using a device, scoring an average of 4.67±0.58 out of 5.<sup>13</sup> Happiness with the weight and comfort of the device itself was also noted<sup>8,12,16-18</sup>, though

some expressed that these could still be improved. In a sample of patients who largely had not trialed an exoskeleton themselves, devices were seen as positive and desirable by 74.4% of survey respondents while 60% desired an exoskeleton for home use.<sup>19</sup> A negative observed in one study where participants completed between 13-25 sessions of Ekso was that the treatment was too short, indicating that participants felt this treatment was enjoyable and useful to them.<sup>9</sup>

A unique study examined 14 participants who utilized ReWalk in their home and community for up to three weeks. They were mostly satisfied with D-QUEST scores of  $3.7 \pm 0.4$  (scale is out of 5) and System Usability Scale score of 72.5 (scale is out of 100).<sup>20</sup> Participants also anecdotally noted improvements in mental and social health, spasticity, pain, and range of motion.<sup>20</sup> Twenty-eight experienced exoskeleton users reported that exoskeletons were not yet ready for home use, however it is important to note that this article is from 2020.<sup>6</sup>

Another study examining 25 participants with spinal cord injuries conducted focus groups for potential users of exoskeletons to determine their perceptions of device benefits and limitations.<sup>21</sup> Some participants had no knowledge of robotic exoskeletons, many had questions about the future of these devices and their usability, and others were able to identify perceived benefits of using an exoskeleton.<sup>21</sup>

### Stroke (CVA)

Patients with a CVA were very positive regarding use of an exoskeleton. In a study of 46 participants between 13 and 155 days post-CVA, they were very positive of their experience regarding comfort, enjoyment, and usefulness, and also agreed that they would recommend exoskeleton treatment to others.<sup>22</sup> In another study, using a scale from 1-5, median scores of two items (patient satisfaction and usefulness of training) for the 26 patients were both 5, indicating a level of very satisfied/very useful.<sup>23</sup> The median score on the same scale for the item asking about disadvantages experienced as a result of training was 1, indicating no inconvenience was noted by participants.<sup>23</sup> Patients reported fatigue from the exoskeleton training but agreed that it accelerated their recovery.<sup>24</sup> Patients tolerated sessions well and reported their time in an exoskeleton was well spent (mean score  $>3.5$  out of 4).<sup>25</sup> They also noted that they were able to move better after sessions (mean score  $>3$  out of 4), and some patients preferred it to other gait training methods.<sup>26</sup> Likert scales in another study showed that device comfort was rated highly (7.95 out of 10), as was naturalness of walking (7.05 out of 10).<sup>25</sup> A study that examined technology assisted training using a variety of technology for the upper and lower extremities including Ekso, HAL, and Lokomat had 7 of the 14 participants reporting meaningful improvements, while 5/14 noted a clinically meaningful change.<sup>27</sup>

### Multiple Sclerosis (MS)

There is one known article examining patient satisfaction using the Ekso in persons with MS. After at least 3 sessions with Ekso, high levels of satisfaction were found with scores of  $31.3 \pm 5.70$  out of 40 for patients.<sup>28</sup> There was a moderate correlation between number of sessions and satisfaction.<sup>28</sup>

A second article using participants with a variety of neurological diagnoses with the majority (42.86%) having MS had participants trial both the Ekso and Rex devices with a washout period in between.<sup>29</sup> They were more satisfied with the ease of transferring into Rex and the



## RESEARCH EVIDENCE ON EXOSKELETON TECHNOLOGY

transportability of Ekso.<sup>29</sup> In regards to expectations for home use, they believe the Ekso would be a better option over the Rex.<sup>29</sup>

### Therapists

Some therapists reported high levels of satisfaction. Therapists working with patients with MS who utilized the Ekso reported a high level of satisfaction (38.50±3.67 out of 45 points) with an excellent correlation between their length of experience in neurological rehabilitation and satisfaction.<sup>28</sup> All three therapists who were interviewed in one study commented on how using Ekso has enhanced their practice and increased what they can do with their patients, which in turn has benefited patient outcomes.<sup>30</sup> They also reported that exoskeletons allow them to walk further with patients because they do not become exhausted as quickly as other gait training methods.<sup>30–32</sup> Another study pointed out the advantage of having the objective data that the exoskeleton provides.<sup>31</sup>

Some therapists were utilizing devices as part of a research study. Six therapists who were interviewed spoke on some common themes including an initial learning hurdle, the ability to achieve earlier and better-quality walking practice, and challenges foreseen with implementation in subacute CVA rehabilitation.<sup>24</sup> Another mixed-result study provided online surveys and interviews to 5 Rex and ReWalk therapists, though two therapists only had 1–3 months of exposure to the exoskeleton and reported infrequent use.<sup>32</sup> The whole sample reported the importance of the exoskeleton aligning with the patient's goals and enjoyed the ability to perform activities with patients that wouldn't otherwise be possible.<sup>32</sup>

Others had more negative views of exoskeletons. In one study that assessed 10 therapists, some who were formally trained and others who only had clinical exposure to a device, a steep learning curve was noted to be a big barrier to implementation.<sup>33</sup> It is important to note that the training and software described in this article have been improved and modified since this time.

Therapists also commented that their facility needs to have certain infrastructure to run a successful exoskeleton program including time<sup>26,30,33</sup>, personnel<sup>33</sup>, support for training<sup>30</sup>, and storage space for the device<sup>26</sup>. Cost was also identified as a barrier.<sup>31,34</sup> Other impediments to successful implementation include patient population<sup>30</sup> (some patients are anxious and unwilling to try a device) and length of stay<sup>26,35</sup> (patients with short stays may need to focus mostly on family training leaving minimal time for other interventions). Notably, one study that provided a survey about feasibility directly after training on the Ekso and 6 months later showed improvement in feasibility at the six month mark, indicating that initial barriers to implementation may be improved or resolved with time.<sup>26</sup>

### Conclusion

Patients and therapists overall reported satisfaction using an exoskeleton device in therapy and the community. There were many perceived health benefits of using an exoskeleton. Some barriers were also recognized. It is important that patient and therapist feedback be taken into account when manufacturers continue to develop robotic technology.

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## All known articles assessing patient satisfaction in participants using an exoskeleton

Title	Authors	Journal	Device	Diagnosis
Barriers and facilitators to exoskeleton use in persons with spinal cord injury: a systematic review	Pinelli E, Zinno R, Barone G, Bragonzoni L	Disabil Rehabil Assist Technol. 2024 Aug;19(6):2355-2363	Unknown	SCI
Clinical Uptake of Pediatric Exoskeletons: A Pilot Study Using the Consolidated Framework for Implementation Research	Herold L, Bosques G, Sulzer J	Am J Phys Med Rehabil. 2024 Apr 1;103(4):302-309	Unknown	Therapists
"Are we there yet?" expectations and experiences with lower limb robotic exoskeletons: a qualitative evaluation of the therapist perspective	Postol N, Barton J, Wakely L, Bivard A, Spratt NJ, Marquez J	Disabil Rehabil. 2024 Mar;46(5):1023-1030	ReWalk, Rex	Therapists
Perspectives of wheelchair users with chronic spinal cord injury following a walking program using a wearable robotic exoskeleton	Vincent C, Dumont FS, Rogers M, Hu T, Bass A, Aubertin-Leheudre M, Karelis AD, Morin SN, McKerral M, Duclos C, Gagnon DH	Disabil Rehabil. 2024 Feb 15:1-9	Ekso	SCI
A qualitative study to elicit user requirements for lower limb wearable exoskeletons for gait rehabilitation in spinal cord injury	Herrera-Valenzuela D, Díaz-Peña L, C Redondo-Galán 4, José Arroyo M, Cascante-Gutiérrez L, Gil-Agudo A, Moreno JC, Del-Ama AJ	J Neuroeng Rehabil. 2023 Oct 17;20(1):138	Unknown	SCI
Utilization of overground exoskeleton gait training during inpatient rehabilitation: a descriptive analysis	Gillespie J, Arnold D, Trammell M, Bnennett M, Ochoa C, Driver S, Callender L, Sikka S, Dubiel R, Swank C	J Neuroeng Rehabil. 2023 Aug 4;20(1):102	Ekso	SCI, CVA, ABI
Satisfaction analysis of overground gait exoskeletons in people with neurological pathology. a systematic review	Cumplido-Trasmonte C, Molina-Rueda F, Puyuelo-Quintana G, Plaza-Flores A, Hernández-Melero M, Barquín-Santos E, Destarac-Eguizabal MA, García-Armada E.	J Neuroeng Rehabil. 2023 Apr 18;20(1):47	Multiple – Review Article	SCI, CVA, MS
Design recommendations for exoskeletons: Perspectives of individuals with spinal cord injury	van Silfhout L, Hosman AJF, van de Meent H, Bartels RHMA, Edwards MJR	J Spinal Cord Med. 2023 Mar;46(2):256-261	Unknown	SCI
Patients' and therapists' experience and perception of exoskeleton-based physiotherapy during subacute stroke rehabilitation: a qualitative analysis	Louie DR, Mortenson WB, Lui M, Durocher M, Teasell R, Yao J, Eng JJ	Disabil Rehabil. 2022 Dec;44(24):7390-7398	Ekso	CVA, Therapists

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Stroke survivor perceptions of using an exoskeleton during acute gait rehabilitation	McDonald C, Fingleton C, Murphy S, Lennon O	Sci Rep. 2022 Aug 19;12(1):14185	Ekso	CVA
Feasibility and cost description of highly intensive rehabilitation involving new technologies in patients with post-acute stroke	Schuster-Amft C, Kool J, Moller JC, Schweinfurther R, Ernst MJ, Reicherzer L, Ziller C, Schwab ME, Wieser S, Wirz M	Pilot Feasibility Stud. 2022 Jul 5;8(1):139	Ekso, HAL, Lokomat	CVA
Implementing the exoskeleton Ekso GT for gait rehabilitation in a stroke unit – feasibility, functional benefits and patient experiences	Høyer E, Opheim A, Jørgensen V	Disabil Rehabil Assist Technol. 2022 May;17(4):473-479	Ekso	CVA
Therapists' experience of training and implementing an exoskeleton in a rehabilitation centre	Mortenson WB, Pysklywec A, Chau L, Prescott M, Townson A	Disabil Rehabil. 2022 Apr;44(7):1060-1066	Ekso	Therapists
Energy cost and psychological impact of robot-assisted gait training in people with spinal cord injury: effect of two different types of devices	Corbianco S, Cavallini G, Dini M, Franzoni F, D'Avino C, Gerini A, Stampacchia G	Neurol Sci. 2021 Aug;42(8):3357-3366	Ekso, Lokomat	SCI
Wearable Robotic Gait Training in Persons with Multiple Sclerosis: A Satisfaction Study	Fernández-Vázquez D, Cano-de-la-Cuerda R, Gor-García-Fogeda MD, Molina-Rueda F	Sensors (Basel). 2021 Jul 20;21(14):4940	Ekso	MS
Outcomes of a Multicenter Safety and Efficacy Study of the SuitX Phoenix Powered Exoskeleton for Ambulation by Patients with Spinal Cord Injury	Koljonen PA, Virk AS, Jeong Y, McKinley M, Latorre J, Caballero A, Hu Y, Wong YW, Cheung K, Kazerooni H	Front Neurol. 2021 Jul 19;12:689751	Phoenix	SCI
Clinician Perceptions of Robotic Exoskeletons for Locomotor Training after Spinal Cord Injury: A Qualitative Approach	Ehrlich-Jones L, Crown DS, Kinnett-Hopkins D, Field-Fote E, Furbish C, Mummidisetty CK, Bond RA, Forrest G, Jayaraman A, Heinemann AW	Arch Phys Med Rehabil. 2021 Feb;102(2):203-215	Ekso, ReWalk, Indego	SCI, Therapists
Appraisals of robotic locomotor exoskeletons for gait focus group insights from potential users with spinal cord injuries	Heinemann AW, Kinnett-Hopkins D, Mummidisetty CK, Bond RA, Ehrlich-Jones L, Furbish C, Field-Fote E, Jayaraman A	Disabil Rehabil Assist Technol. 2020 Oct;15(7):762-772	Ekso, HAL, lokomat	SCI



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Exoskeleton home and community use in people with complete spinal cord injury	van Dijsseldonk RB, van Nes IJW, Geurts ACH, Keijzers NLW	Sci Rep. 2020 Sep 24;10(1):15600	ReWalk	SCI
Users with spinal cord injury experience of robotic locomotor exoskeletons: a qualitative study of the benefits, limitations, and recommendations	Kinnett-Hopkins D, Mummidisetty CK, Ehrlich-Jones L, Crown D, Bond RA, Applebaum MH, Jayaraman A, Furbish C, Forrest G, Field-Fote E, Heinemann AW	J Neuroeng Rehabil. 2020 Sep 11;17(1):124	Ekso, Indego, ReWalk	SCI
Feasibility of integrating robotic exoskeleton gait training in inpatient rehabilitation	Swank C, Sikka S, Driver S, Bennett M, Callender L.	Disabil Rehabil Assist Technol. 2020 May;15(4):409-417	Ekso	SCI, CVA, Therapists
User satisfaction with lower limb wearable robotic exoskeletons	Poritz JMP, Taylor HB, Francisco G, Chang SH	Disabil Rehabil Assist Technol. 2020 Apr;15(3):322-327	Ekso, Rex	SCI, ABI, MS
Physiotherapists' Experiences Using the Ekso Bionic Exoskeleton with Patients in a Neurological Rehabilitation Hospital: A Qualitative Study	Read E, Woolsey C, McGibbon CA, O'Connell C	Rehabil Res Pract. 2020 Jan 8;2020:2939573	Ekso	Therapists
Combining robotic exoskeleton and body weight unweighing technology to promote walking activity in tetraplegia following SCI: A case study	Chang SH, Zhu F, Patel N, Afzal T, Kern M, Francisco GE.	J Spinal Cord Med. 2020 Jan;43(1):126-129	Ekso	SCI
Overground wearable powered exoskeleton for gait training in subacute stroke subjects: clinical and gait assessments	Goffredo M, Guanzioli E, Pournajaf S, Gaffuri M, Gasperini G, Filoni S, Baratta S, Damiani C, Franceschini M, Molteni F	Eur J Phys Rehabil Med. 2019 Dec;55(6):710-721	Ekso	CVA
"Back at the same level as everyone else"- user perspectives on walking with an exoskeleton, a qualitative study.	Thomassen GK, Jørgensen V, Normann B.	Spinal Cord Ser Cases. 2019 Dec 13;5:103	Ekso	SCI
Satisfaction and perceptions of long-term manual wheelchair users with a spinal cord injury upon completion of a locomotor training program with an overground robotic exoskeleton	Gagnon DH, Vermette M, Duclos C, Aubertin-Leheudre M, Ahmed S, Kairy D	Disabil Rehabil Assist Technol. 2019 Feb;14(2):138-145	Ekso	SCI
Questionnaire results of user experiences with wearable exoskeletons and their preferences for sensory feedback	Muijzer-Witteveen H, Sibum N, van Dijsseldonk R, Keijzers N, and van Asseldonk E	J Neuroeng Rehabil. 2018 Nov 23;15(1):112	ReWalk	SCI

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Examining the Effects of a Powered Exoskeleton on Quality of Life and Secondary Impairments in People Living with Spinal Cord Injury	Juszczak M, Galle E, Bushnik T	Top Spinal Cord Inj Rehabil. 2018 Fall;24(4):336-342	Indego	SCI
What Are User Perspectives of Exoskeleton Technology? A Literature Review	Hill D, Holloway CS, Ramirez DZM, Smitham P, Pappas Y	Int J Technol Assess Health Care. 2017 Jan;33(2):160-167	Multiple – Review Article	SCI, CVA
Walking with a powered robotic exoskeleton: Subjective experience, spasticity and pain in spinal cord injured persons.	Stampacchia G, Rustici A, Bigazzi S, Gerini A, Tombini T, Mazzoleni S	NeuroRehabilitation. 2016 Jun 27;39(2):277-83	Ekso	SCI
Effects on mobility training and de-adaptations in subjects with Spinal Cord Injury due to a Wearable Robot: a preliminary report.	Sale P, Russo EF, Russo M, Masiero S, Piccione F, Calabrò RS, Filoni S	BMC Neurol. 2016 Jan 28;16:12	Ekso	SCI
Device-Training for Individuals with Thoracic and Lumbar Spinal Cord Injury Using a Powered Exoskeleton for Technically Assisted Mobility: Achievements and User Satisfaction.	Platz T, Gillner A, Borgwaldt N, Kroll S, Roschka S.	Biomed Res Int. 2016;2016:8459018	ReWalk	SCI
Safety and tolerance of the ReWalk™ exoskeleton suit for ambulation by people with complete spinal cord injury: a pilot study.	Zeilig G, Weingarden H, Zwecker M, Dudkiewicz I, Bloch A, Esquenazi A.	J Spinal Cord Med. 2012 Mar;35(2):96-101	ReWalk	SCI

CVA = stroke, SCI = spinal cord injury, MS = multiple sclerosis, ABI = acquired brain injury