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Effects of a Passive Back Support Exoskeleton on Balance While Walking

Masood Khan[1], JoonOh Seo[1], Maxwell Fordjour Antwi-Afari[3], Yuan Zhou[1]
[1]Department of Building and Real Estate, Hong Kong Polytechnic University, Hong Kong SAR.
[3]Department of Civil Engineering, College of Engineering and Physical Sciences, Aston University, United Kingdom. masood2.khan@connect.polyu.hk, joonoh.seo@polyu.edu.hk, m.antwiafari@aston.ac.uk, zhouyuan1117@msn.cn,

Abstract

Passive back support exoskeletons (PBSEs) have been promoted as a means of alleviating the physical strain associated with manual tasks in industrial settings. These devices are known to influence the wearer's kinematics, muscle activation, and balance. Slips and trips, which are frequent precursors to falls, often occur during construction tasks. The effects of PBSEs on balance and the ability to recover from slip- and trip-like perturbations during walking have not been thoroughly examined. The present study aimed to investigate the effects of a PBSE on ground reaction forces (GRF) after slip and trip-like perturbations during walking on an instrumented treadmill. Nine male participants walked on an instrumented treadmill under two conditions: without wearing a PBSE (WOE) and after wearing a PBSE (WE). Each participant experienced normal walking, slip, and trip events, presented in a random order. GRFs were recorded using a force plate integrated into the treadmill. Fx (force in the mediolateral direction) was higher ($p = 0.003$) in WE (mean, 166.32 N) than in WOE (mean, 140.52 N) by 18.36 % after slip perturbations. Fy (force in the anteroposterior direction), Fz (force in the vertical direction), and Fr (the resultant force) did not show statistically significant differences between WE and WOE after slip perturbations. Following trip perturbations, a statistically significant increase was observed in Fz ($p<0.001$) and Fr ($p<0.001$). Fz and Fr were higher in WE than WOE by 25.24 % and 8.88 %, respectively. Wearing a PBSE may alter the GRF in a mediolateral or vertical direction that may predispose the wearer to fall. Construction workers should be provided with balance training while wearing a PBSE and then exercise caution while walking on a construction site.

Keywords: Fall, Recovery, Slip, Trip, Ground Reaction Forces, Treadmill, Construction.

1 Introduction

The most common cause of disability among construction workers is work-related musculoskeletal disorders (WMSD) (Millennium 2003, Wang, Dong et al. 2017). The prevalence rates of WMSD were 36%, 68%, 76%, and 41% in Ethiopia (12-month prevalence) (Lette, Ambelu et al. 2018), Taiwan (12-month prevalence) (Leung, Chan and Yu 2012), Malaysia (12-month prevalence) (Deros, Daruis et al. 2014), and Hong Kong (3-month prevalence) (Yi and Chan 2016) respectively. According to a study, more than 77% of American construction workers reported having at least one musculoskeletal ailment in the previous 12 months [7]. WMSDs can cause severe financial hardships and absenteeism in the construction industry in addition to physical suffering (Cheng, Leu et al. 2010). According to Okenwa Emegwa's (2014) research, WMSDs were linked to over 85% of sick leave cases in the Swedish construction sector (Okenwa Emegwa 2014). Workers in construction are subjected to a physical workload that includes heavy lifting, crouching, kneeling, working with hands above shoulder level, and vibration. During construction, adopting non-neutral body positions may raise the chances of acquiring WMSD (Punnett and Wegman 2004, Takala, Pehkonen et al. 2010).

To mitigate WMSDs, the use of an exoskeleton as an additional intervention has gained more attention in recent years (De Looze, Bosch et al. 2016, Antwi-Afari, Li et al. 2021). This may be due to the fact that it is wearable, can support the wearer without requiring modifications to current work environments, and may be used in situations where other approaches are impractical. As a possible occupational intervention to reduce the risk of overexertion injuries related to manual material handling, passive back-support exoskeletons (PBSEs) are gaining popularity (Nussbaum, Lowe et al. 2019, Kermavnar, de Vries et al. 2021). Because they are less expensive and easier to install in the workplace, PBSEs, as opposed to active ones, are now more developed for application in occupational settings (Nussbaum, Lowe et al. 2019). With a PBSE, the wearer can lower the metabolic expenditure and levels of back muscle activation during a variety of symmetric and asymmetric lifting exercises (Alemi, Geissinger et al. 2019, Baltrusch, Van Dieën et al. 2019, Koopman, Kingma et al. 2020, Anwer, Li et al. 2023).

However, previous research has expressed concern that the usage of a PBSE may have unanticipated (or unwanted) impacts on the wearer (Masood, ANTWI-AFARI et al. 2024). This concern was likely brought on by the external torques that the PBSE created around the hip and back, as a PBSE typically engages when hip flexion occurs (Baltrusch, Van Dieën et al. 2018, Baltrusch, Van Dieën et al. 2019). Exoskeleton parts supporting or encircling the thighs, waist, and chest are inflexible structures present in PBSEs. The masses of commercially available passive PBSEs vary from 2.8 to 4.5 kg. Using a PBSE while doing a holding or lifting action has been linked to an increase in leg muscular activity (Sadler, Graham and Stevenson 2011, Ulrey and Fathallah 2011). The concerns of unwanted effects on wearers have been linked particularly to more rigid movements (Koopman et al., 2019b), reduced ROM (Abdoli-Eramaki, Stevenson et al. 2007), more physical strain in situations that the PBSE is not meant for (von Glinski, Yilmaz et al. 2019), and deviation from the kinematics and anatomy of wearers (Huysamen, Power and O'Sullivan 2018). The inflexible structure and external hip extension torque of the PBSE may impede corrective postural movements, and the device's additional weight may put additional load on the postural control system. Employing PBSEs may be necessary in situations where the wearer must lift, move, carry a load, or ascend or descend stairs. These activities are more likely to cause the wearer to lose their postural balance than stationary PBSE use. The majority of walking-related falls result from outside disruptions that impair equilibrium, such as trips and slips (Berg, Alessio et al. 1997, Heijnen and Rietdyk 2016). Risk factors for trips and falls in work environments include uneven or slick surfaces, dim illumination, and unstable footwear (Afanuh, Anderson and Bell 2012). Given the growing prevalence of PBSE technologies in the workplace (Nussbaum, Lowe et al. 2019) and the fact that slips, trips, and falls remain a major concern in workplaces worldwide, it is imperative to determine whether and to what extent PBSEs negatively impact the postural balance of the wearers. Therefore, this study aimed to assess the effects of a PBSE on ground reaction forces

(GRFs) after slip- and trip-like perturbations. The study hypothesized that due to the added mass and movement restriction imposed by PBSE, the GRFs will increase after wearing a PBSE.

2 Method

The study was approved by the Human Subjects Ethics Sub-committee (HSESC) of The Hong Kong Polytechnic University (HSESC Reference Number: HSEARS20231101001). A total of 9 participants (mean age: 31.33 years, height: 175.55 cm, weight: 77.11 kg, BMI: 25.05 kg/m^2) participated in the study. Only male participants (age 25-45 years) were recruited, as most of the construction workers are males. The recruited participants had no current history of musculoskeletal pain or deformities. Prior to starting the experiment, the risks and benefits of the study were discussed with each participant, and written informed consents were obtained.

2.1 Protocol

Each participant underwent three conditions:

1. Normal walking: Participants walked at a speed of 3 kilometres per hour (kph).
2. Slip: The treadmill's speed increased from 3 kph to 8 kph.
3. Trip: The treadmill's speed reduced from 3 kph to 0 kph.

An instrumented treadmill integrated with force plates (gaitway® 3D, h/p/cosmos sports & medical, Nussdorf-Traunstein, Germany) was used to induce slip- and trip-like perturbations. Slips and trips were repeated thrice at intervals of 10–30 seconds. First, participants were provided with a description of the experiment. A safety harness was used to prevent participants from falling. The Ottobock back (Ottobock, Germany) exoskeleton was used for the experiment. The appropriate use of this PBSE was demonstrated to each participant. This PBSE had two modes: 'On' (activated) and 'Off' (deactivated). The 'On' mode was used in the experiment. This resulted in two experimental conditions: a. WE (with PBSE): Participants wore the activated PBSE, which means the PBSE supported the wearer's back. b. WOE (without wearing the PBSE): The participant did not wear the PBSE. Figures 1 and 2 show PBSE and the treadmill used in the study. Figure 3 shows the study's complete activity protocol.

Figure 1. The passive back support exoskeleton used in the study.

Figure 2. Participant walking on the treadmill integrated with force plates.

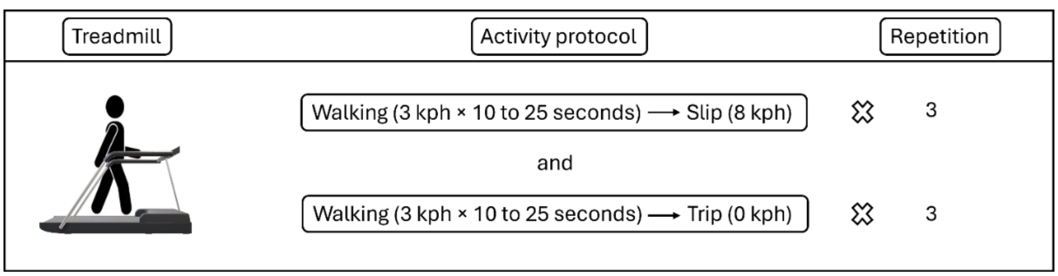

Figure 3. The activity protocol used in the study.

2.2 Statistical analysis

The GRF data were collected at a frequency of 2000 Hz. The raw data was low-pass filtered (4th order zero-phase-shift Butterworth) at 300 Hz using the application MATLAB (Version R2024a, The MathWorks, Inc., US). Normal distribution was assessed using the Shapiro-Wilk test of normality. This test revealed that data was not normally distributed. Therefore, a non-parametric test, i.e. the Mann-Whitney U test, was used to compare WE and WOE conditions using SPSS software (version 29). The results were considered significant for $p \leq 0.05$. The mean of the first three steps after slip and trip events were used for analysis.

The data were divided into two groups: Slip and Trip. In each group, two conditions were created and compared: With the PBSE (represented as WE) and without any PBSE (represented as WOE). A statistically significant difference was considered with $p \leq 0.05$. Three components of GRFs, i.e. Fx, Fy, Fz and Fr were compared between WE and WOE conditions. Fx represented the horizontal force exerted by the ground on a body in the mediolateral direction, Fy represented the horizontal force exerted by the ground on a body in the anteroposterior direction, Fz represented the vertical force exerted by the ground on a body and Fr represented the resultant force of these three forces.

3 Results

Table 1 includes the GRF descriptive data for WE and WOE conditions after slip and trip events. Table 2 shows z and p-values obtained after performing the Mann-Whitney U test to compare both exoskeleton conditions (WE vs. WOE). Figures 4, 5, 6, and 7 depict the amplitudes of Fx, Fy, Fz, and Fr after slip and trip perturbations.

Table 1. Ground reaction forces (GRF) after slip and trip perturbations.

GRF component	Slip		Trip	
	WE	WOE	WE	WOE
F_x (N)	166.32±69.84	140.52±74.56	123.46±47.29	112.30±44.91
Fy (N)	203.22±79.49	184.04±55.21	185.24±61.03	182.21±57.91
Fz (N)	1327.12±243.69	1262.93±209.44	1219.41±198.81	973.65±376.46
Fr (N)	1355.86±249.64	1286.85±212.14	1241.12±203.88	1139.89±165.97

WE: With Exoskeleton; WOE: Without Exoskeleton; GRF: Ground reaction forces.

Table 2. Comparison of exoskeleton conditions (WE vs. WOE).

GRF component	Slip		Trip	
	Z	p-value	Z	p-value
Fx	-2.979	0.003*	-1.796	0.073
Fy	-.810	0.418	-0.474	0.635
Fz	-1.490	0.136	-4.898	<0.001*
Fr	-1.505	0.132	-3.360	<0.001*

*Significant p≤0.05
WE: With Exoskeleton; WOE: Without Exoskeleton;
GRF: Ground reaction forces.

A statistically significant difference (p=0.003) was observed in Fx after slip perturbations. Fx (i.e. force in the mediolateral direction) was 18.36% higher in WE (mean, 166.32) than in WOE (mean, 140.52). Fy, Fz, and Fr increased in WE after slip perturbation; however, these increments were not statistically significant (p>0.05).

A statistically significant increase was observed in Fz (p<0.001) and Fr (p<0.001) after trip perturbation. Fz was higher in WE (mean, 1219.41) than WOE (mean, 973.65) by 25.24 %. The Fr was also higher in WE (mean, 1241.12) than WOE (mean, 1139.89) by 8.88 %.

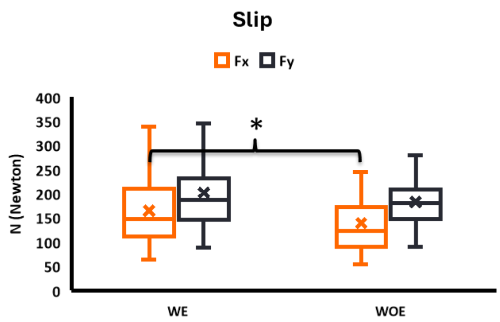

Figure 4. Comparison of exoskeleton conditions after slip perturbation: Fx and Fy.
WE: With Exoskeleton; WOE: Without Exoskeleton.
*Significant; p ≤ 0.05

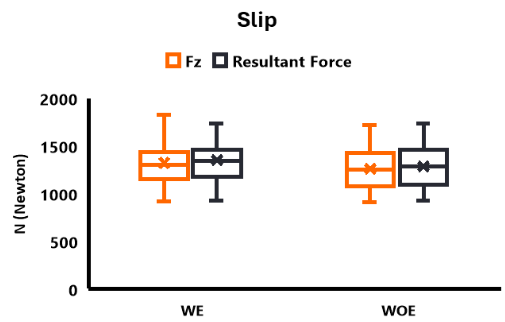

Figure 5. Comparison of exoskeleton conditions after slip perturbation: Fz and resultant force.
WE: With Exoskeleton; WOE: Without

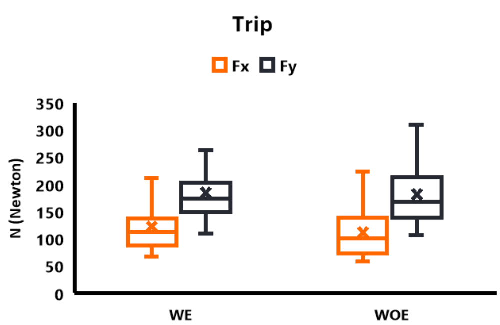

Figure 6. Comparison of exoskeleton conditions after trip perturbation: Fx and Fy.
WE: With Exoskeleton; WOE: Without Exoskeleton.

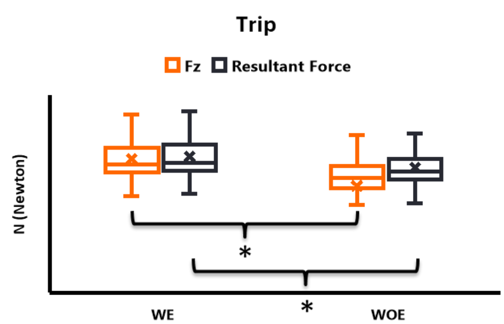

Figure 7. Comparison of exoskeleton conditions after trip perturbation: Fz and resultant force.
WE: With Exoskeleton; WOE: Without Exoskeleton.
*Significant; p ≤ 0.05

4 Discussion

Walking is an important activity performed by the construction workers at the construction sites. A PBSE may raise the risk of falls by negatively impacting gait (Park, Kim et al. 2022) and reactions to significant postural disturbances (Park, Lee et al. 2022, Dooley, Kim et al. 2023). There are concerns that PBSEs will affect the balance of the wearers. Particularly, these concerns have been linked to more rigid movements (Koopman, Kingma et al. 2019), reduced ROM (Abdoli-Eramaki, Stevenson et al. 2007), more physical strain in situations that the PBSE is not meant for (von Glinski, Yilmaz et al. 2019), and deviation from the kinematics and anatomy of humans (Huysamen, Power and O'Sullivan 2018). This study aimed to investigate the effects of a PBSE on balance after slip and trip-like perturbations. The study hypothesized that PBSE would adversely affect the recovery following slip and trip perturbations. The slip and trip perturbations were induced on an instrumented treadmill, and the balance was measured using GRF data from the force plate. The results of the present study showed changes in the GRF components (Fx, Fy, and Fz) between WE and WOE conditions after slip and trip perturbations. After slip perturbations, Fx was higher in WE compared to WOE; however, Fy, Fz, and Fr were not statistically different from WOE. After trip perturbations, the Fz and the Fr were higher in WE compared to WOE. Fx and Fy were not statistically different from WOE.

A recent study performed by Dooley et al. (Dooley, Kim et al. 2024) to assess the impact of arm and PBSE on changes in reactive balance following perturbations also reported adverse changes in recovery kinematics. However, they reported that these passive exoskeletons do not increase the probability of falls. In the present study, the PBSE increased the mediolateral as well as vertical GRF. The net Fr were also higher after wearing the PBSE than without wearing it. A possible reason for these changes could be that after wearing a PBSE, weight is added to the wearer’s body. This added mass may increase the weight transfer time from one leg to another while walking, thereby resulting in increased GRF. The PBSE restricts the movements at the back and hip joints; therefore, the wearer may have to make compensatory movements for stability after perturbations. Due to these compensatory movements, the wearers’ bodies may exert more force to navigate the restrictions at these joints. Another possible reason could be that the PBSE’s function is to assist the wearer in lifting an object from the ground. Therefore, it applies hip extension force. This hip extension torque counters the hip flexion torque required to recover following the slips and trip perturbations (Park, Lee et al. 2022). Since hip flexion torque is difficult, the wearer's body may shift his/her body weight laterally. There are a few limitations worth acknowledging. First, the results in the present study were obtained from a controlled environment (laboratory); however, the actual construction sites are different from laboratories. At the actual construction sites, there are objects, machines or other workers on the path. Moreover, the participants in the present study did not fully cover their bodies. In addition to these, the construction workers wear PPEs, including hard hats, protective clothing, high visibility clothing, etc., which may affect the functioning of PBSE and thus the response of the workers to slip or trip events after wearing the PBSE. Therefore, the results of the present study should be interpreted in the context of a laboratory.

5 Conclusions

Passive exoskeletons have been recommended to use to ease the construction tasks. Slips and trips occur frequently at construction sites that may result in falls and can cause injuries. The effect of a PBSE on balance while walking has not been fully investigated. This study aimed to evaluate the effects of a PBSE on balance after slip-and-trip-like perturbations. A total of 9 male participants participated in the study. An instrumented treadmill with integrated force plates was used to induce the slip- and trips and to collect the GRF data. During the slip perturbation, the treadmill speed increased and then became normal without the participants knowing, so they had to take a few quick steps to balance themselves. During the trip perturbation, the treadmill suddenly stopped and then resumed normally without the participant's knowledge. The participants were not told the timings of the perturbations so that their natural responses could be achieved.

The PBSE was found to affect the mediolateral and vertical components of the GRFs. Interestingly, the anteroposterior component was not significantly different between wearing and not wearing a PBSE. The possible reason for no change in anteroposterior GRF after wearing the PBSE could be the movement restrictions imposed in the sagittal plane. The hip flexion was restricted. Therefore, the participants might have put less force in this direction. Due to limitations in the sagittal plane, the participant might have shifted their weight laterally, resulting in increased GRF in the mediolateral direction. Also, since the wearer's weight increased after wearing a PBSE and they had difficulty freely moving their lower extremities, their weight transfer time from one leg to another could have increased, increasing vertical GRF. The findings suggest that balance training should be provided to construction workers while wearing a PBSE and should be trained to walk so that they can adopt precautions and strategies to offset the increased GRFs and avoid falling. It will be advisable to use passive exoskeletons that are lighter and offer fewer movement restrictions at the back and hip joints.

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References

Abdoli-Eramaki, M., J. M. Stevenson, S. A. Reid and T. J. Bryant (2007). "Mathematical and empirical proof of principle for an on-body personal lift augmentation device (PLAD)." Journal of biomechanics **40**(8): 1694-1700.

Afanuh, S., V. P. Anderson and J. Bell (2012). "Preventing slips, trips, and falls in wholesale and retail trade establishments."

Alemi, M. M., J. Geissinger, A. A. Simon, S. E. Chang and A. T. Asbeck (2019). "A passive exoskeleton reduces peak and mean EMG during symmetric and asymmetric lifting." Journal of Electromyography and Kinesiology **47**: 25-34.

Antwi-Afari, M. F., H. Li, S. Anwer, D. Li, Y. Yu, H.-Y. Mi and I. Y. Wuni (2021). "Assessment of a passive exoskeleton system on spinal biomechanics and subjective responses during manual repetitive handling tasks among construction workers." Safety science **142**: 105382.

Anwer, S., H. Li, M. Abdul-Rahman and M. F. Antwi-Afari (2023). Development and evaluation of a low-cost passive wearable exoskeleton system for improving safety and health performance of construction workers: A pilot study. ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, IAARC Publications.

Baltrusch, S., J. Van Dieën, S. Bruijn, A. Koopman, C. Van Bennekom and H. Houdijk (2019). "The effect of a passive trunk exoskeleton on metabolic costs during lifting and walking." Ergonomics.

Baltrusch, S., J. Van Dieën, C. Van Bennekom and H. Houdijk (2018). "The effect of a passive trunk exoskeleton on functional performance in healthy individuals." Applied ergonomics **72**: 94-106.

Berg, W. P., H. M. Alessio, E. M. Mills and C. Tong (1997). "Circumstances and consequences of falls in independent community-dwelling older adults." Age and ageing **26**(4): 261-268.

Cheng, C.-W., S.-S. Leu, C.-C. Lin and C. Fan (2010). "Characteristic analysis of occupational accidents at small construction enterprises." Safety science **48**(6): 698-707.

De Looze, M. P., T. Bosch, F. Krause, K. S. Stadler and L. W. O’sullivan (2016). "Exoskeletons for industrial application and their potential effects on physical work load." Ergonomics **59**(5): 671-681.

Deros, B. M., D. D. Daruis, N. K. Khamis, D. MOşHAMAD, S. F. M. Daud, S. M. Amdan, R. Abd Aziz and N. Jamal (2014). "Prevalence of work related musculoskeletal disorders SympČtoms among construction workers: a case study in MalayČsia." Iranian Journal of Public Health **43**(Supple 3): 53-57.

Dooley, S., S. Kim, M. A. Nussbaum and M. L. Madigan (2023). "A passive leg-support exoskeleton adversely affects reactive balance after simulated slips and trips on a treadmill." Journal of Biomechanics **151**: 111533.

Dooley, S., S. Kim, M. A. Nussbaum and M. L. Madigan (2024). "Occupational arm-support and back-support exoskeletons elicit changes in reactive balance after slip-like and trip-like perturbations on a treadmill." Applied Ergonomics **115**: 104178.

Heijnen, M. J. H. and S. Rietdyk (2016). "Falls in young adults: Perceived causes and environmental factors assessed with a daily online survey." Human movement science **46**: 86-95.

Huysamen, K., V. Power and L. O'Sullivan (2018). "Elongation of the surface of the spine during lifting and lowering, and implications for design of an upper body industrial exoskeleton." Applied ergonomics **72**: 10-16.

Kermavnar, T., A. W. de Vries, M. P. de Looze and L. W. O'Sullivan (2021). "Effects of industrial back-support exoskeletons on body loading and user experience: An updated systematic review." Ergonomics **64**(6): 685-711.

Koopman, A. S., I. Kingma, M. P. de Looze and J. H. van Dieën (2020). "Effects of a passive back exoskeleton on the mechanical loading of the low-back during symmetric lifting." Journal of biomechanics **102**: 109486.

Koopman, A. S., I. Kingma, G. S. Faber, M. P. de Looze and J. H. van Dieën (2019). "Effects of a passive exoskeleton on the mechanical loading of the low back in static holding tasks." Journal of biomechanics **83**: 97-103.

Lette, A., A. Ambelu, T. Getahun and S. Mekonen (2018). "A survey of work-related injuries among building construction workers in southwestern Ethiopia." International journal of industrial ergonomics **68**: 57-64.

Leung, M.-y., I. Y. S. Chan and J. Yu (2012). "Preventing construction worker injury incidents through the management of personal stress and organizational stressors." Accident Analysis & Prevention **48**: 156-166.

Masood, K., M. F. ANTWI-AFARI, S. JoonOh, S. ANWER and K. HEUNG (2024). Applications, Challenges, and Future Research Directions for Passive Exoskeletons in the Construction Industry: A Critical Review. International conference on construction engineering and project management, Korea Institute of Construction Engineering and Management.

Millennium, W. S. G. o. t. B. o. M. C. a. t. S. o. t. N. (2003). "The burden of musculoskeletal conditions at the start of the new millennium." World Health Organization technical report series **919**: i.

Nussbaum, M. A., B. D. Lowe, M. de Looze, C. Harris-Adamson and M. Smets (2019). An introduction to the special issue on occupational exoskeletons, Taylor & Francis. **7:** 153-162.

Okenwa Emegwa, L. (2014). "Determinants of sick leave duration following occupational injuries among workers in the county of Gävleborg, Sweden." Occupational medicine & health affairs **2**(4).

Park, J.-H., S. Kim, M. A. Nussbaum and D. Srinivasan (2022). "Effects of back-support exoskeleton use on gait performance and stability during level walking." Gait & Posture **92**: 181-190.

Park, J.-H., Y. Lee, M. L. Madigan, S. Kim, M. A. Nussbaum and D. Srinivasan (2022). "Wearing a back-support exoskeleton impairs single-step balance recovery performance following a forward loss of balance–An exploratory study." Journal of Biomechanics **144**: 111352.

Punnett, L. and D. H. Wegman (2004). "Work-related musculoskeletal disorders: the epidemiologic evidence and the debate." Journal of electromyography and kinesiology **14**(1): 13-23.

Sadler, E. M., R. B. Graham and J. M. Stevenson (2011). "The personal lift-assist device and lifting technique: a principal component analysis." Ergonomics **54**(4): 392-402.

Takala, E.-P., I. Pehkonen, M. Forsman, G.-Å. Hansson, S. E. Mathiassen, W. P. Neumann, G. Sjøgaard, K. B. Veiersted, R. H. Westgaard and J. Winkel (2010). "Systematic evaluation of observational methods assessing biomechanical exposures at work." Scandinavian journal of work, environment & health: 3-24.

Ulrey, B. L. and F. A. Fathallah (2011). Biomechanical effects of a personal weight transfer device in the stooped posture. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, SAGE Publications Sage CA: Los Angeles, CA.

von Glinski, A., E. Yilmaz, S. Mrotzek, E. Marek, B. Jettkant, A. Brinkemper, C. Fisahn, T. A. Schildhauer and J. Geßmann (2019). "Effectiveness of an on-body lifting aid (HAL® for care support) to reduce lower back muscle activity during repetitive lifting tasks." Journal of Clinical Neuroscience **63**: 249-255.

Wang, X., X. S. Dong, S. D. Choi and J. Dement (2017). "Work-related musculoskeletal disorders among construction workers in the United States from 1992 to 2014." Occupational and environmental medicine **74**(5): 374-380.

Yi, W. and A. Chan (2016). "Health profile of construction workers in Hong Kong." International journal of environmental research and public health **13**(12): 1232.