The Effect of Speed Variation on Initial and Sustained Forces During Pushing and Pulling Activities: A Preliminary Study

Lucia Botti[1(✉)], Cristina Mora[1], Giorgio Zecchi[2], and Giulia Baruffaldi[1]

[1] Department of Industrial Engineering, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy
{lucia.botti5, cristina.mora, giulia.baruffaldi2}@unibo.it
[2] Azienda Unità Sanitaria Locale AUSL Reggio Emilia, Via Giovanni Amendola 2, 42122 Reggio Emilia, Italy
giorgio.zecchi@ausl.re.it

Abstract. Push and pull activities characterize a significant part of manual material handling tasks in industry. Epidemiological studies show that pushing and pulling activities are associated with shoulder and low back pain. The International Standard 11228-2 describes the approach for risk assessment of push/pull activities, providing the maximum acceptable initial and sustained forces for pushing and pulling. The Standard defines maximum acceptable forces, requiring not to push/pull faster than a prescribed speed limit (0.1 m/s for initial force and 0.3 m/s for sustained force). Previous studies and current practice show that workers push carts faster.

The purpose of this study is to evaluate the relationships between speed variation and push forces for pushing tasks in industry. An industrial cart was pushed at different speed values. Maximum initial and sustained push forces were measured. Results show that increasing speed was highly correlated to increasing push forces. The findings have practical value for researchers, occupational physicians and ergonomics practitioners.

Keywords: Pushing tasks · Increasing speed · Increasing push force Industrial safety · Human factors

1 Introduction

Current practice shows that the pressure to meet work demands and the lack of human and material resources lead to strenuous work conditions. Conventional working conditions are not able to satisfy the needs of current manufacturing systems, which are required to ensure high product variety and speed of delivery (e.g. manual picking, logistics, etc.). Furthermore, such organisational and job factors have been associated with human factors as stress, fatigue, repetition, which influence people's behaviour at work in a way which can affect health and safety [1, 2].

W. Karwowski et al. (Eds.): AHFE 2018, AISC 793, pp. 169–178, 2019.
https://doi.org/10.1007/978-3-319-94196-7_16

This study investigates the ergonomics of manual material handling in industry, with focus on pushing of carts. Push and pull activities characterize a significant part of manual material handling tasks in industry, from manufacturing and agriculture, to construction and healthcare [3, 4]. Several studies proved that redesign strategies often call for changing lifting, lowering, and carrying tasks to pushing tasks [5, 6]. Current research has not yet proven whether pushing or pulling should be favoured [6]. A properly designed cart can allow the replacement of heavy weights with lower forces, which are acceptable to a high percentage of males and females [7]. However, lifting and lowering tasks may expose the workers to the risk of developing occupational diseases and injuries. Epidemiological studies show that pushing and pulling activities are associated with shoulder and low back pain. Furthermore, the 9–18% of the low back injuries are associated with pushing and pulling activities [6]. The design of workstations and tasks must include the analysis of risk factors and biomechanical models of maximum pull/push force to prevent work-related musculoskeletal disorders, over-exertion and repetitive strain injury [3].

Previous studies have analysed the factors of musculoskeletal strain originating from pushing and pulling tasks in industry [8]. Several researches have shown the impact of pushing and pulling activity in increasing the risk of low back pain [9–14]. Lee et al. [15] have analysed the effect of work experience and the risk factors for work-related low back disorders during dynamic pushing and pulling. Marras et al. [16] have investigated the influence of physical factors on spine loads during pushing tasks. Such physical factors include, among others, the load magnitude, the handle height and the speed of push. The results showed that anterior/posterior shear was influenced by all experimental, confirming that pushing and pulling is a complex biomechanical activity. Specifically, the findings of the research indicate that increasing speed of push had a dramatic impact on the shear force magnitude with peak anterior-posterior shear increasing by nearly 30% as subjects increased push speed from 0.7 m/s to 1 m/s.

The International Standard Organization (ISO) provides the directions for identifying the potential hazards and risks associated with whole-body pushing and pulling. Specifically, the ISO standard 11228-2 describes two risk estimation and evaluation methods. The first, referred as "Method 1" in the ISO standard, is a generalized methodology, based on the approach developed by Snook and Ciriello in 1991 [17]. The latter, referred as "Method 2" in the same standard, is a specialized risk estimation and risk assessment approach that determines whole-body pushing and pulling force limits according to specific characteristics of the population and the task.

Following the generalized approach for risk assessment in the ISO 11228-2, this paper investigates the effect of the adopted speed during push tasks on push forces. The purpose of this study is to investigate the increase in push force with increasing speed of motion while pushing industrial carts. Measurements refer to a first study conducted in Italy in 2010. The workplace conditions were simulated in the aisle of an Italian hospital. A two-level flat shelf cart with different loads was pushed at different speed values. Maximum initial and sustained push force were measured during the push tasks. Results show that both initial and sustained forces vary when pushing the cart with different speed values. Specifically, increasing the push speed is correlated to increased push forces. The findings of this study have practical value for researchers and ergonomics practitioners in addressing the research on the risks associated with whole-body pushing and pulling.

2 Materials and Methods

In this preliminary study, an industrial cart was pushed at different speed values to investigate the increase in push force. The International Standard Organization (ISO) provides the directions for risk estimation and assessment of whole-body pushing and pulling. The ISO standard 11228-2 [18] defines the two approaches for analysing risks associated with push/pull tasks, providing the maximum acceptable forces for pushing and pulling. The first approach is generalized method for risk assessment and it is based on the Snook and Ciriello approach [17]. The second describes a specialized approach that determines whole-body pushing and pulling force limits according to specific characteristics of the population and the task. This study adopted the first method, referred as "Method 1" in the ISO 11228-2. Specifically, Method 1 requires to take both the initial push force measurements and the sustained push force measurements. The initial force is the minimum force required to start the dolly, trolley or cart in motion. The sustained force is the minimum force required to maintain the dolly, trolley or cart in motion. Safety professionals and ergonomics practitioners are required to take the force measurements on site and compare actual force values with force limits provided on the Liberty Mutual Tables [18].

The procedure described in the standard gives the steps for taking correct force measurements. Two different conditions are required for the initial force. The swivel casters are positioned in line with the direction of motion of the dolly, trolley or cart for the first condition. The second condition requires to position the swivel casters at right angles to the direction of motion. The right-angle condition produces higher forces compared to the in-line condition. The sustained force is measured with the swivel casters in the in-line position. Maximum acceptable push and pull forces are defined regardless the speed of the push/pull action.

Table 1 shows the ISO requirements for push and pull forces measurements.

Table 1. ISO requirements for push and pull forces measurements.

	Initial force	Sustained force
Swivel casters position	In-line direction Right -angle direction	In-line direction
Speed [m/s]	Maximum 1 m in 10 s (0.1 m/s).	Take 2–3 s to reach the speed of 1 m in 3 s (0.3 m/s).
Consistency	Measurements should not differ from each other by more than about 15%.	

The ISO 11228-2 requires to pull or push the dolly, trolley or cart at least 1 m in 3 s for the sustained force measurement. The standard states that such speed limit (0.3 m/s) equates to a slow walk. Previous studies showed that operators select appropriate speeds under different conditions, ranging from 0.25 to 1.5 m/s [19–21]. The standard requires to take 2–3 s to reach this speed and not to push or pull faster than 1 m/10 s when measuring initial force. Such speed limit is low and does not reflect the actual working conditions in industry. Finally, measurements should be repeated until at least three consistent measurements are recorded. Consistent measurements should not differ from each other by more than about 15%.

Current practice shows that pushing carts at high speed is preferred than pulling carts in industry. This study investigated push forces and the correlation between the speed variation during pushing and the increase in push force. Force measurements refer to a preliminary study conducted in 2010. A two-level flat shelf cart was pushed at different speed values (Fig. 1).

Fig. 1. Experimental setup (*Condition 1*).

Figure 1 shows the experimental setup, while Table 2 reports the characteristics of the preliminary study. The actual speed reached when measuring initial force was higher than the speed limit defined in the ISO 11228-2 (0.1 m/s). The aim was to reproduce the actual working conditions in industrial workplaces. The travel distance was 10 m for each trial. The travel direction was linear. The cart handle was horizontal and positioned at 95 cm. The cart weight was 8 kg. The measurement point was located at the midpoint of the handle. A gauge attachment was set to give a stable push point on the handle.

Twenty-six trials have been conducted. Four different load conditions were realized depending on the load on the cart: 0 kg (empty cart), 24 kg, 48 kg and 72 kg (Table 2). Different speed values have been reached in each trial. Minimum and maximum speed values for each condition are in Table 2. An electronic dynamometer (model DIN96E, capacity 50 kg, accuracy 0.1%) for tension and compression force measurements was used to measure the push force during each trial. At first, casters position was set in line with the direction of motion then at right angle, for initial force measurements. The casters were in the in-line direction during sustained force measurements.

Table 2. Experimental setup.

	Condition 0	Condition 1	Condition 2	Condition 3
Load on the cart [kg]	0 (Empty cart)	24	48	72
Number of measurements	3	8	7	8
Travel distance [m]	10	10	10	10
Handle height [cm]	95	95	95	95
Minimum speed* [m/s]	0.88	0.60	0.53	0.49
Maximum speed* [m/s]	1.37	1.18	1.45	1.41

*The first meter required to reach the desired speed is included in the 10 m pushing distance. The speed value is the result of the ratio between the distance of motion (10 m) and the travel time.

Three multi-year career occupational safety and health professionals (two men: forty-nine years old and forty-five years old, 1.62 m and 1.85 m height, 72 kg and 75 kg weight; a woman: fifty-nine years old, 1.65 m height, 60 kg) performed the measurements. Maximum initial and sustained push force were measured for each trial. The stopping force was not measured, i.e. the cart deceleration started after the end of the 10 m distance. Each trial has been repeated until three consistent measurements have been recorded. Consistent measurements did not differ from each other by more than about 15%, as required by the ISO 11228.2.

3 Results

Medium initial and sustained force measurements in each condition are reported in Table 3. The reference Condition 0 was omitted as the cart was empty and the force measurement was not relevant.

Table 3. Results of pushing measurements.

	Condition 1	Condition 2	Condition 3
Load on the cart	24 kg	48 kg	72 kg
Average initial force [kg]	4.34	9.13	10.01
SD initial force [kg]	1.55	3.72	2.44
Average sustained force [kg]	1.78	3.61	5.29
SD sustained force [kg]	0.42	1.07	0.93
Increase in initial force from minimum to maximum speed [%]	110%	150%	69%
Increase in sustained force from minimum to maximum speed [%]	25%	85%	34%

Table 3 shows that both the initial and the sustained force measurements increase with increasing load on the cart. Furthermore, the percentage increase in initial and sustained force measurements is positive in each condition. Specifically, the increase in initial force measurement is higher than the increase in sustained force measurement.

Figures 2, 3 and 4 show the increase in push force with increasing speed, for each condition. The growing trend is visible in all the investigated conditions. The different anthropometric and gender characteristics conditioned the measurements variation. However, such differences are present in workplaces among workers.

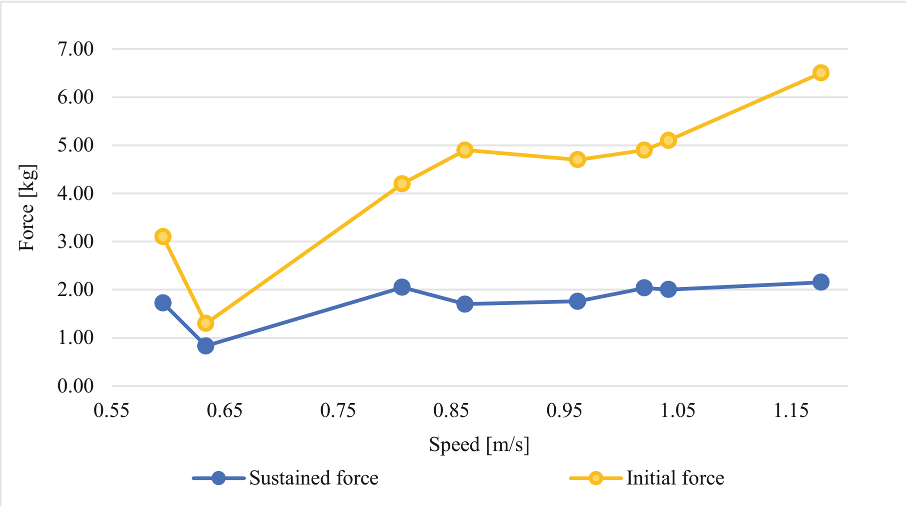

Fig. 2. Increase in push force with increasing speed in Condition 1 *(24 kg on the cart*).

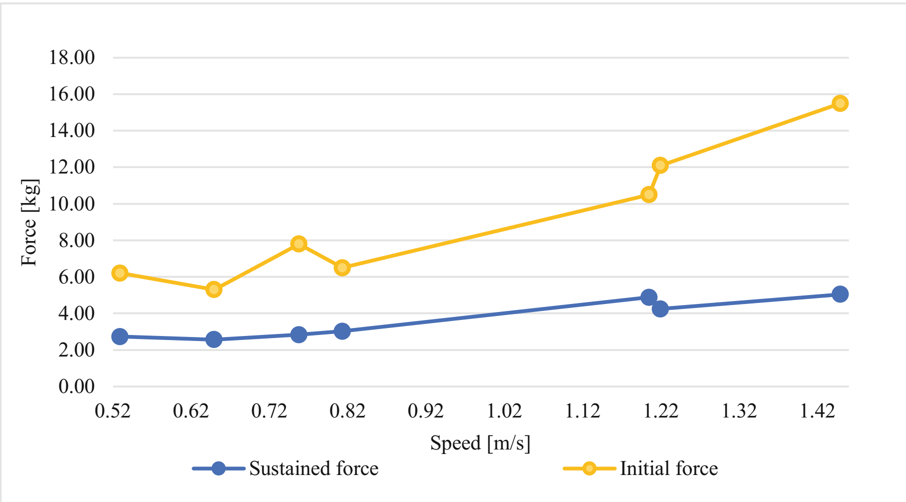

Fig. 3. Increase in push force with increasing speed in Condition 2 *(48 kg on the cart*).

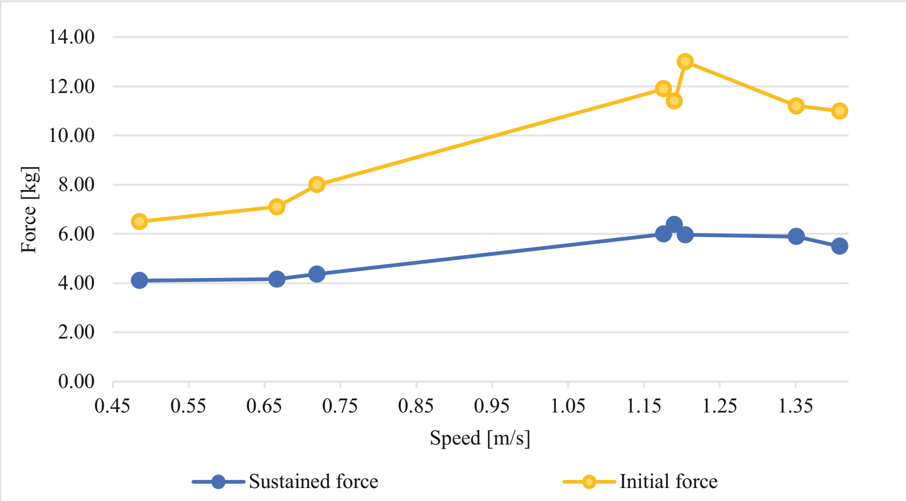

Fig. 4. Increase in push force with increasing speed in Condition 3 *(72 kg on the cart*).

4 Discussion

The results in Table 3 confirm that the increase in speed during pushing tasks leads to increased force values. Such trend is strongly marked for the initial force. The coefficients of correlation (R^2) for the force measurements and push speed values are presented in Table 4.

Table 4. Coefficient of determination R^2 for the speed value and the initial and sustained force measurements. Values larger than 0.8 are identified in bold.

Speed	Initial force	Sustained force
Condition 1	**0.807**	0.478
Condition 2	**0.909**	**0.923**
Condition 3	**0.816**	0.784

For Condition 1 (24 kg on the cart), initial force was highly correlated with speed. Sustained force demonstrated less consistent correlation with speed. For Condition 2 (48 kg on the cart) and Condition 3 (72 kg on the cart), both initial and sustained force were highly correlated with speed. These findings suggest further investigation to evaluate the relationships between the increase in push force with increasing speed.

Past and recent research have wildly investigated the increase in force with increasing load in pushing activities, and the effect of the mechanical load on the shoulder and low back pain [7, 17, 22–24]. The effect of increasing push speed on the push force has not been investigated in past studies. Furthermore, the methodology for risk assessment described in the ISO 11228-2 for pushing and pulling tasks prescribes not to push faster than 0.1 m/s when measuring initial force and 0.3 m/s for sustained force. Such speed limits do not reflect the current practice in workplaces. Empirical measurements showed that workers push carts at about 1 m/s. Conversely, pulling tasks are usually performed at lower speed, since pulling requires walking backwards and paying attention to obstacles.

The results of this study are limited to pushing activities. Pulling tasks have not been investigated. Furthermore, a limited number of trials has been realized. The anthropometric and gender differences of the safety professionals who took the measurements may have affected the results. A higher number of trials will be realized to further investigate the increase in push force with increasing speed. Finally, the Liberty Mutual Tables for maximum acceptable push/pull forces in the ISO 11228-2 refer to specific values of travel distance, i.e. 2 m, 8 m, 15 m, 30 m, 45 m and 60 m. The 10 m travel distance used in this study is not considered in the ISO standard. Future developments of this work may investigate the increase in push force and speed for the travel distance ranges adopted in the ISO 11228-2.

5 Conclusions

This study has investigated the effect of push tasks in industry. Pushing and pulling are common activities required in workplaces in many industries, from manufacturing to construction industry and healthcare. The ISO 11228-2 requires to pull or push dollies, trolleys or carts at least 1 m in 3 s. Such speed limit (0.3 m/s) equates to a slow walk. The ISO standard requires to take 2–3 s to reach this speed and not to push or pull faster than 1 m/10 s when measuring initial force. Such speed limits are low and do not reflect the actual working conditions in industry. Previous studies and experimental measurements showed that operators select appropriate speeds under different conditions, ranging from 0.25 to 1.5 m/s [19–21].

These considerations encouraged this preliminary study and the measurements conducted in 2010. A two-level flat shelf cart with different loads was pushed at different speed values. The adopted speed values reflect the common pushing conditions in workplaces, where workers push carts at about 1 m/s. Maximum initial and sustained push force were measured during pushing.

Results showed that both the initial and the sustained force measurements increase with increasing load on the cart. Furthermore, the percentage increase in initial and sustained force measurements due to the increased speed is positive in each load condition. Specifically, the increase in initial force measurement is higher than the increase in sustained force measurement.

Increasing speed was highly correlated to increasing initial push force. Sustained force measurements demonstrated less consistent correlation with speed when the load on the cart was limited. Both initial and sustained force were highly correlated with speed in case of high load on the cart. These findings suggest further investigation to evaluate the relationships between the increase in push force with increasing speed of motion. The anthropometric and gender differences of the safety professionals who took the measurements may affect the results. However, such differences are present among workers performing cart pushing and pulling in industry. A higher number of trials may be realized to further investigate the increase in push force with increasing speed. Furthermore, the Liberty Mutual Tables for maximum acceptable push/pull forces in the ISO 11228-2 refer to specific values of travel distance, i.e. 2 m, 8 m, 15 m, 30 m, 45 m and 60 m. The 10 m travel distance used in this study is not considered. Future developments of this study may explore the increase in push force and speed for travel distance ranges adopted in the ISO 11228-2. Additional load conditions (e.g. 18 kg, 36 kg and 72 kg) will be investigated and different push speed values will be tested (e.g. 1 m/s, 1.5 m/s and 2 m/s).

It is concluded that the recommendations of Snook and Ciriello [17] for push and pull forces adopted in the ISO 11228-2 are valid and provide reasonable recommendations for ergonomics practitioners. However, the Liberty Mutual Tables provide push and pull force limits considering a push speed limit lower than the values adopted by workers in current practice. The findings of this study suggest that the speed of motion impacts on initial and sustained forces during pushing. It may be worthwhile to study an additional factor that allows the conversion of push force limits in the Liberty Mutual Tables to include the effect of the speed variation.

Acknowledgments. The data used in this study were recorded in 2010 in Boretto (RE), Italy. The Italian company M2 & Associati Srl (www.m2servizi.it) provided the dynamometer for force measurements and actively participated in the study. Martinelli M., MD, provided expertise that assisted the research. The authors are grateful for this support.

References

1. Michie, S.: Causes and management of stress at work. Occup. Environ. Med. **59**, 67–72 (2002)
2. HSE: Human factors/ergonomics – Introduction to human factors. http://www.hse.gov.uk/humanfactors/introduction.htm
3. Seo, N.J., Armstrong, T.J., Young, J.G.: Effects of handle orientation, gloves, handle friction and elbow posture on maximum horizontal pull and push forces. Ergonomics **53**, 92–101 (2010)
4. Garg, A., Moore, J.S., Kapellusch, J.M.: The revised strain index: an improved upper extremity exposure assessment model. Ergonomics **60**, 912–922 (2016)
5. Laursen, B., Schibye, B.: The effect of different surfaces on biomechanical loading of shoulder and lumbar spine during pushing and pulling of two-wheeled containers. Appl. Ergon. **33**, 167–174 (2002)
6. Garg, A., Waters, T., Kapellusch, J., Karwowski, W.: Psychophysical basis for maximum pushing and pulling forces: A review and recommendations. Int. J. Ind. Ergon. **44**, 281–291 (2014)
7. Ciriello, V.M., McGorry, R.W., Martin, S.E., Bezverkh Ny, I.B.: Maximum acceptable forces of dynamic pushing: comparison of two techniques. Ergonomics **42**, 32–39 (1999)
8. Argubi-Wollesen, A., Wollesen, B., Leitner, M., Mattes, K.: Human body mechanics of pushing and pulling: analyzing the factors of task-related strain on the musculoskeletal system. Saf. Health Work **8**, 11–18 (2017)
9. Kelsey, J.L.: An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral discs. Int. J. Epidemiol. **4**, 197–205 (1975)

10. Frymoyer, J.W., Pope, M.H., Clements, J.H., Wilder, D.G., MacPherson, B., Ashikaga, T.: Risk factors in low-back pain. an epidemiological survey. J. Bone Joint Surg. Am. **65**, 213–218 (1983)
11. Damkot, D.K., Pope, M.H., Lord, J., Frymoyer, J.W.: The relationship between work history, work environment and low-back pain in men. Spine (Phila. Pa. 1976) **9**, 395–399 (1984)
12. Hoozemans, M.J., van der Beek, A.J., Frings-Dresen, M.H., van Dijk, F.J., van der Woude, L.H.: Pushing and pulling in relation to musculoskeletal disorders: a review of risk factors. Ergonomics **41**, 757–781 (1998)
13. Hoozemans, M.J.M., Van der Beek, A.J., Frings-Dresen, M.H.W., Van der Woude, L.H.V., Van Dijk, F.J.H.: Pushing and pulling in association with low back and shoulder complaints. Occup. Environ. Med. **59**, 696–702 (2002)
14. Plouvier, S., Renahy, E., Chastang, J.F., Bonenfant, S., Leclerc, A.: Biomechanical strains and low back disorders: quantifying the effects of the number of years of exposure on various types of pain. Occup. Environ. Med. **65**, 268–274 (2008)
15. Lee, J., Nussbaum, M.A., Kyung, G.: Effects of work experience on work methods during dynamic pushing and pulling. Int. J. Ind. Ergon. **44**, 647–653 (2014)
16. Marras, W.S., Knapik, G.G., Ferguson, S.: Loading along the lumbar spine as influence by speed, control, load magnitude, and handle height during pushing. Clin. Biomech. **24**, 155–163 (2009)
17. Snook, S.H., Ciriello, V.M.: The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics **34**, 1197–1213 (1991)
18. 11228-2, I.S.O.: System of standards for labor safety. Ergonomics. Manual handling. Part 2. Pushing and pulling (2007)
19. Lee, K.S., Chaffin, D.B., PARKS, C.: A study of slip potential during cart pushing and pulling. IIE Trans. **24**, 139–146 (1992)
20. Resnick, M.L., Chaffin, D.B.: An ergonomic evaluation of handle height and load in maximal and submaximal cart pushing. Appl. Ergon. **26**, 173–178 (1995)
21. Jung, M.-C., Haight, J.M., Freivalds, A.: Pushing and pulling carts and two-wheeled hand trucks. Int. J. Ind. Ergon. **35**, 79–89 (2005)
22. Ciriello, V.M., Dempsey, P.G., Maikala, R.V., O'Brien, N.V.: Revisited: Comparison of two techniques to establish maximum acceptable forces of dynamic pushing for male industrial workers. Int. J. Ind. Ergon. **37**, 877–882 (2007)
23. Nimbarte, A.D., Sun, Y., Jaridi, M., Hsiao, H.: Biomechanical loading of the shoulder complex and lumbosacral joints during dynamic cart pushing task. Appl. Ergon. **44**, 841–849 (2013)
24. Wiggermann, N.: Effect of a powered drive on pushing and pulling forces when transporting bariatric hospital beds. Appl. Ergon. **58**, 59–65 (2017)