Published in final edited form as:
J Occup Environ Hyg. 2023 ; 20(3-4): 136–142. doi:10.1080/15459624.2023.2180512.

The relationship between ratings of perceived exertion (RPE) and relative strength for a fatiguing dynamic upper extremity task: A consideration of multiple cycles and conditions

Zahra Vahedi[a], **Setareh Kazemi Kheiri**[a], **Sahand Hajifar**[a], **Saeb Ragani Lamooki**[b], **Hongyue Sun**[a], **Fadel M. Megahed**[c], **Lora A. Cavuoto**[a]

[a]Department of Industrial and Systems Engineering, University at Buffalo, Buffalo, New York

[b]Department of Mechanical and Aerospace Engineering, University at Buffalo, Buffalo, New York

[c]Farmer School of Business, Miami University, Oxford, Ohio

Abstract

The goal of this study was to evaluate the relationship between ratings of perceived exertion (RPE) and relative strength with respect to baseline for a fatiguing free dynamic task targeting the upper extremity, namely simulated order picking, and determine whether the relationship remains the same for different conditions (i.e., pace and weight) and with fatigue. Fourteen participants (seven males, seven females) performed four sessions that included two 45-min work periods separated by 15 min of rest. The work periods involved picking weighted bottles from shoulder height and packaging them at waist height for four combinations of bottle mass and picking rate: 2.5 kg–15 bottles per minute (bpm), 2.5 kg–10 bpm, 2.5 kg–5 bpm, and 1.5 kg–15 bpm. Participants reported their RPEs every 5 min and performed a maximum isometric shoulder flexion exertion every 9 min. Pearson product-moment correlation was used to evaluate the linear relationship between RPE and relative strength for each subject and work period. Then, the effects of condition and work period on the average relationship were assessed using a repeated-measures analysis of variance (ANOVA). For the first 45-min period, there were no significantly different correlations between RPE and relative strength across conditions (average $r = -0.62$ (standard deviation = 0.38); $p = 0.57$). There was a significant decrease in average correlation for the second work period $(r = -0.39(0.53))$. These results suggest that individual subjective responses consistently increase while relative strength declines when starting from a non-fatigued state. However, correlations are weaker when re-engaging in work following incomplete recovery. Thus, starting fatigue levels should be accounted for when considering the expected relationship between RPE and relative strength.

Keywords

Distribution center; fatigue; order picking; shoulder

CONTACT Lora A. Cavuoto loracavu@buffalo.edu Department of Industrial and Systems Engineering, University at Buffalo, 211 Mary Talbert Way, Buffalo, NY 14260-1660, USA.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/15459624.2023.2180512. AIHA and ACGIH members may also access supplementary material at http://oeh.tandfonline.com.

Introduction

Physically demanding work, such as repetitive tasks of prolonged duration, can result in localized muscle fatigue when not accompanied by adequate recovery (Kumar 2001). Localized muscle fatigue results in decreased muscle capacity, declining work performance, and increased occupational injury risk (Kumar 2001). For example, those with shoulder disorders were three times more likely to have had jobs involving repetitive shoulder movements (Frost et al. 2002). Thus, considering fatigue development based on factors such as work pace and timing of rest breaks is vital for reducing the subsequent risk of injuries. The change in relative strength (the ratio of absolute strength at a specific time to the baseline strength) over time is a widely accepted objective measure/indicator of localized muscle fatigue (Gandevia 2001; Féasson et al. 2006; Mehta and Agnew 2012; Cavuoto and Megahed 2016; Gang et al. 2021). However, relative strength measurement can be impractical in occupational settings since it requires expensive instrumentation and cannot be assessed while workers perform tasks.

Instead, physical fatigue assessments in the workplace often rely on ratings of perceived exertion (RPE) (e.g., Borg 6–20 or Borg CR-10 scales). The use of RPE scales for occupational physical fatigue measurement can be justified by Borg (1982): (a) their ease of use, (b) their ability to “integrat[e] various information, including the many signals elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions, and from the central nervous system” (377), and (c) their high correlations with heart rate and other physiological variables. More recently, RPEs have been used, as response variables, to assess whether wearable sensors (e.g., IMUs) can be used to model/monitor/predict physical fatigue at the workplace (Sedighi Maman et al. 2017; Baghdadi et al. 2018; Maman et al. 2020; Hajifar et al. 2021; Lamooki et al. 2022).

Despite the widespread use of RPE and the acceptance of relative strength as a primary indicator of localized physical/muscle fatigue (Vøllestad 1997; Gandevia 2001), only a few studies examined the relationship between RPE and relative strength. A linear relationship between RPE and endurance time has been shown for static tasks (Grinten and Smitt 1992; Douwes et al. 1999; Frey Law et al. 2010). In a dynamic and concentric isokinetic test for elbow flexion, Frey Law et al. (2010, 13–14) showed that the linearity of the relationship between RPE and endurance time is “questionable” and “the use of self-reported task perceptions appears to be substantially weaker for predicting dynamic task fatigue than static task fatigue.” For two dynamic localized tasks requiring isometric flexion at the distal interphalangeal (DIP) joint of the thumb, Whittaker et al. (2019) showed that a linear regression model could be used to explain 82% of the variance in mean maximal voluntary contraction strength (MVC) with the use of the Borg CR-10 scale, task plateau (a 12-sec submaximal exertion followed by a 2 sec MVC and 2 sec of rest), and their interactions as predictors.

Based on these few published studies, the focus was on relatively short tasks (with Whittaker et al. (2019) being the longest, around 20 min), posture controlled (with Velcro or other experimental restraints), and utilizing smaller joints/muscle groups (elbow and thumb). It is unclear whether RPEs can be used to estimate relative strength in dynamic, free-form, long-duration tasks that are widely present in the workplace. Our current understanding of the suitability of RPEs as a proxy measure for more widely accepted measures of fatigue, such as relative strength, is limited, which has implications for determining suitable methods that can be used reliably to monitor fatigue in field environments.

The overarching goal of this short report is to examine the relationship between RPE (Borg CR-10 scale) and relative strength in a free-form dynamic task. The task we selected is a simulated order-picking scenario since it: (a) is prevalent in many warehousing and advanced manufacturing applications and (b) fatigues a larger muscle group (shoulder). To examine the overarching relationship, the following research questions were investigated:

1. Is there an association between RPE and relative strength for our more complex and realistic occupational task?
2. Does the relationship between RPE and relative strength remain the same for different conditions (i.e., changing the pace and weight)?
3. How does the relationship between RPE and relative strength change with repeated work and recovery periods (e.g., after a 15-min rest break)?

Methods

Participants

Seventeen participants were recruited from the university and local communities. Two participants did not complete all study sessions due to scheduling issues, and one participant’s data were excluded because of inconsistencies with the measurements across sessions (e.g., a doubling of strength during the work period, and >100% difference in starting strength). Therefore, 14 participants (seven males and seven females) were included in the final dataset. The demographics of those participants that completed the study are shown in Table 1. The study was approved by the University at Buffalo Institutional Review Board, and all participants provided written informed consent at the beginning of their first session.

Procedures

Each participant completed four sessions on separate days. The sessions were separated by at least four days to allow for fatigue recovery between sessions. Each session consisted of three consecutive 1-hr blocks of 45 min of work and 15 min of rest. For this short report, the analysis is limited to the first two work periods to focus on a single work-rest-work cycle. Due to exhaustion, some participants only completed part of the first and second work periods. Thus, there were varying durations of work and rest periods before the third block. During the work period, participants performed simulated order picking, where they picked weighted bottles using their right hand from approximately shoulder height and placed them into a carton at waist height (Figure 1). In each session, the bottle mass and picking rate were varied in four combinations − 2.5 kg × 15 bottles per minute (bpm), 2.5 kg × 10 bpm, 2.5 kg × 5 bpm, and 1.5 kg × 15 bpm—with each bottle mass and picking rate combination representing a condition. Each participant completed one condition per day, and the order of the conditions was varied, with all conditions occurring at least twice in each session number. The bottle masses and picking rates were chosen based on typical values observed at standing packaging workstations in distribution centers (Otto et al. 2017; Boysen et al. 2019). A metronome was used to guide the pacing. After five bottles were placed in a box, the participant placed the box onto a conveyor at knee height before continuing to fill the following box. Participants reported their RPE for the shoulder using a Borg CR-10 scale every 5 min during work and rest periods. If the participant reached a rating of 10 for the shoulder or expressed exertion at a level of 10 for any other body parts, the work period ended, and the rest period started.

At the start and end of each 45-min work period, and every 9 min within, participants performed a maximum voluntary isometric contraction (MVIC) for shoulder flexion. For the MVIC, participants stood in front of the force gauge (Mark-10 digital force gauge, Mark-10 Corporation, Copiague, NY) with their right shoulder flexed 90 degrees and their elbow fully extended. Participants exerted maximum force in the flexion direction by pulling upward on a handle attached to the force gauge for 6 sec. Verbal cues from the experimenter indicated the start and end of the exertion. This exertion was selected to measure shoulder fatigue development for the primary motion of the simulated order picking (Boettcher et al. 2008). The separation between exertions was chosen to balance the collection of relative strength data with the impact of the MVIC testing on fatigue development (in terms of both task disruption and added muscle exertion).

Statistical analyses

Relative strength was defined as the ratio of each strength test to the participant's baseline for each 45-min period. To align the RPE and relative strength data, linear interpolation was used to estimate RPE values at each strength test point. Fractional values for the estimated RPEs were permitted between the Borg CR-10 minimum and a maximum of 0 and 10, respectively.

Pearson product-moment correlation was used to evaluate the linear relationship between RPE and relative strength for each subject and work period (r_{ij}). Since the correlation coefficient is bounded by [−1,1] and cannot be modeled using parametric statistical methods, a Fisher's z-transformation was used to normalize the correlation coefficients using Equation (1),

$$z_{r_{ij}} = \frac{ln\left(\frac{1 + r_{ij}}{1 - r_{ij}}\right)}{2}, \tag{1}$$

where:

r = Pearson product-moment correlation coefficient

i = is the subject number

j = is the work period (1 or 2)

The transformed values were then used in a repeated measures analysis of variance (ANOVA) to investigate the effects of the within-subject factors of condition (combining bottle mass and picking rate; four levels), work period (two levels), and the interaction between them on the average relationship of RPE and relative strength across subjects. The statistical analyses were performed using IBM SPSS Version 28 (IBM Corporation, Armonk, NY) and reproduced using the open-source R programming language (see our supplementary materials for the knitted markdown containing our code, data, and results/analysis). The significance level was set at $\alpha = 0.05$.

Results

Table 2 shows the mean and standard deviation of strength and RPE over conditions and work periods (across all participants), along with the results of the statistical comparisons. Across sessions, the average starting strength ranged from 64.1 to 67.4 N for the first work period and from 58.8 to 61 N for the second work period. Thus, participants returned to ~90% of their baseline strength following the rest period, and differences were statistically significant between periods ($p < 0.01$). After one 45-min period, participants had similar relative strength levels regardless of condition ($p = 0.35$). Across conditions, participants started the first 45-min period with similar RPE values (< 0.15, $p = 0.99$), then, following rest, the starting RPE ranged from 1.43 to 1.64 ($p < 0.01$ for the main effect of the work period). Condition and work period were significant main effects for the final RPE values.

The relative strength versus RPE values across all participants for the 1.5 kg–15 bpm condition is shown in Figure 2. Figure 3 shows box plots of the correlation coefficients by individual, condition, and work period. Most individual correlations were significant for the first work period (30 out of 56 correlations), particularly for the 1.5 kg–15 bpm condition (10 out of 14 participants). The average correlation between RPE and relative strength across conditions for the first work period was −0.62 (standard deviation = 0.38; $p = 0.57$). There was a significant main effect of the work period, with the average correlation = −0.39 (0.53) for the second work period ($p = 0.043$). The interaction between the condition and work period was not statistically significant ($p = 0.11$).

Discussion

This study is the first reported in the literature to analyze the relationship between RPE (Borg CR-10 scale) and relative strength in a free-form dynamic shoulder fatigue task, focusing on simulated order picking involving a work-rest-work cycle. From the first 45-min work period, the average linear correlation between RPE and relative strength across all conditions was −0.62, which is consistent with the reported absolute value of the correlation of 0.57 reported in Whittaker et al. (2019) for the front-loaded condition for the distal interphalangeal (DIP) thumb joint (where all tasks were performed before an extended rest period). When considering individual correlations, 26 of the 56 cases equaled or exceeded −0.8 for the first period. This addresses the first research question, indicating a moderate negative association between RPE and relative strength (Asuero et al. 2006). The negative direction is expected since, as a participant gets fatigued, one expects the RPE value to increase and strength to decrease.

The ANOVA results indicate no statistically significant differences in the correlations between RPE and relative strength across conditions. The lack of statistical differences in the correlations extends previous findings that focused on controlled isometric or isokinetic tasks (Frey Law et al. 2010; Whittaker et al. 2019). Thus, based on this experimental setup, the answer to the second research question is that the relationship between RPE and relative strength remained the same for the specific conditions considered. However, from a practical perspective, it is important to note that the strength of the linear relationship was only moderate. Thus, there may not be sufficient evidence to support using RPE instead of MVIC measurement for such dynamic order picking. While linear relationships between perceived exertion/fatigue and fatigue accumulation have been reported in the literature for varying sustained and intermittent static tasks (Iridiastadi and Nussbaum 2006; Frey Law et al. 2010; Whittaker et al. 2019), the relationship may vary depending on the nature of the task, supporting the need to investigate a broader range of static and dynamic tasks.

As for the impact of the rest break on the correlation between RPE and relative strength across conditions, there was a significant main effect of the work period (−0.62 vs. −0.39). The weakest average correlations were observed for the 2.5 kg–5 bpm and 1.5 kg–15 bpm conditions. This is an unexpected result. Micklewright et al. (2017) showed that traditional physiological indicators of muscle fatigue were elevated; however, their study showed that participant RPE dropped to zero when resting. Here, the results showed that the initial RPE at the start of the second work period of ~1.5 is higher than the RPE of ~0.1 at the start of the first period (see Table 2). Hence, participant RPE did not reset to baseline for the second period, which is different from the reported results in Micklewright et al.'s (2017) findings and consistent with the ratings of perceived fatigue results in Whittaker et al.'s (2019) findings. Similarly, as shown in Table 2, participant MVIC strength did not reset following the rest period. With this information, there are three possible contributors to the change in correlation between RPE and relative strength in the second work period. First, neither the RPE scale nor relative strength measurements explicitly account for motivation. Thus, the impact of the nonphysical experimental fatigue (e.g., boredom, discomfort) may differ between indicators. For example, participants may provide RPE values that only partially reflect their true RPE as the experiment continues. Second, the Borg CR-10 scale is designed to be linear; however, relative strength with fatigue may be nonlinear (e.g., it may be better represented using an exponential decay function). Third, to prevent participant injuries, the experiment was stopped whenever a participant reported an RPE value of 10. Suppose RPE is a leading indicator of relative strength, then we may have yet to fully capture the impact of the perceived exhaustion level on relative strength (i.e., the perceived exhaustion level may have manifested over multiple MVIC measurements rather than just the subsequent MVIC measurement).

Limitations and future work

First, the participant pool utilized in this study has resulted in a convenience sample of mostly younger adults (average age of 26.8) who may differ from the general U.S. working population. It is unclear whether the reported results would be similar across different age groups (e.g., older participants), particularly for those with experience in similar tasks. Second, the study was limited to four conditions, which can affect the generalizability of the findings. Future studies should consider the relationship between RPE and relative strength for different duty cycles and a range of load levels. Third, there is a possible training effect with the choice of a convenience sample. Using a varying order for the conditions per participant presents a well-recognized statistical approach to counter any immediate training effects. However, longer-term strength and endurance gains from repeated order picking on the job may impact the rate of fatigue as measured by both RPE and relative strength. This is something that is not possible to account for in this study. Fourth, the number of MVIC and RPE measurements was designed to be different in the study as the research team tried to minimize the impact of MVIC strength testing on accelerating fatigue development. A linear fit was used to interpolate MVIC measurements to align with the more frequently sampled RPE to account for the differences. As a sensitivity analysis, the team examined the impact of a different (cubic) fit and observed that it had a minimal effect on both the correlations and the reported p-values. Nevertheless, the limited sampling of six MVIC observations per condition and the fact that 12 of 56 and 18 of 56 trials (from 7 participants – 5 female, 2 male) were stopped due to exhaustion (RPE = 10) before the 45-min completion time in the first and second work periods, respectively, may have impacted the reported results. Finally, the isometric strength test at 90° shoulder flexion may not capture the full effect of fatigue on the shoulder musculature since it targets only the anterior deltoid. This posture was chosen as the position of the highest shoulder moment for the order-picking task. However, since the task was dynamic and posture was not controlled during picking, participants could vary their movements and may have fatigued different muscles or experienced some recovery within the task.

Conclusions

This study was designed to identify the relationships between RPE and relative strength across different conditions simulating order-picking tasks over two 45-min work periods separated by 15 min of rest. The results indicate that subjective responses to the task at the group level were consistently related to relative strength. Hence, this study provides some support for using RPEs as the outcome measure of choice for fatigue prediction/modeling wearable-based studies (Lim and D’Souza 2020; Chan et al. 2022). However, there was wide variability in the correlations at the individual level, which were dependent on the work period. Thus, the fatigue level at the start of a task or workday should be considered when modeling expected strength loss and RPE values. Future work should evaluate different durations of recovery to determine whether this difference remains when an individual returns to a baseline level.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding

The study was supported by the National Institute for Occupational Safety and Health (NIOSH) through Grant 5 R21OH011749–02.

Data availability statement

Our data file and R code are available at: https://github.com/blindedResearch/corr_analysis/. A knitted R Markdown, combining our code, analysis, and results, is hosted at: https://blindedresearch.github.io/RPE-Strength_Corr_Final.html.

References

Asuero AG, Sayago A, González AG. 2006. The correlation coefficient: an overview. Crit Rev Anal Chem. 36(1):41–59. DOI: 10.1080/10408340500526766.

Baghdadi A, Megahed FM, Esfahani ET, Cavuoto LA. 2018. A machine learning approach to detect changes in gait parameters following a fatiguing occupational task. Ergonomics. 61(8):1116–1129. DOI: 10.1080/00140139.2018.1442936. [PubMed: 29452575]

Boettcher CE, Ginn KA, Cathers I. 2008. Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. J Orthop Res. 26(12):1591–1597. DOI: 10.1002/jor.20675. [PubMed: 18528827]

Borg GA. 1982. Psychophysical bases of perceived exertion. Med Sci Sports. 14(5):377–381.

Boysen N, de Koster R, Weidinger F. 2019. Warehousing in the e-commerce era: a survey. Eur J Oper Res. 277(2):396–411. 10.1016/j.ejor.2018.08.023

Cavuoto L, Megahed F. 2016. Understanding fatigue and the implications for worker safety. Paper presented at: Conference and Exposition, Atlanta, GA. https://www.onepetro.org/conference-paper/ASSE-16-734.

Chan VCH, Ross GB, Clouthier AL, Fischer SL, Graham RB. 2022. The role of machine learning in the primary prevention of work-related musculoskeletal disorders: a scoping review. Appl Ergon. 98:103574. DOI: 10.1016/j.apergo.2021.103574. [PubMed: 34547578]

Douwes M, Miedema MC, Dul J. 1999. Methods based on maximum holding time for evaluation of working postures. In: Karwowski W, Marras WS, editors. The occupational ergonomics handbook. London (UK): CRC Press. p. 229–246.

Féasson L, Camdessanché J-P, El Mhandi L, Calmels P, Millet GY. 2006. Fatigue and neuromuscular diseases. Ann Readaptation Med Phys. 49(6):375–384. DOI: 10.1016/j.annrmp.2006.04.015.

Frey Law LA, Lee JE, McMullen TR, Xia T. 2010. Relationships between maximum holding time and ratings of pain and exertion differ for static and dynamic tasks. Appl Ergon. 42(1):9–15. DOI: 10.1016/j.apergo.2010.03.007. [PubMed: 20462566]

Frost P, Bonde JPE, Mikkelsen S, Andersen JH, Fallentin N, Kaergaard A, Thomsen JF. 2002. Risk of shoulder tendinitis in relation to shoulder loads in monotonous, repetitive work. Am J Ind Med. 41(1):11–18. DOI: 10.1002/ajim.10019. [PubMed: 11757051]

Gandevia SC. 2001. Spinal and supraspinal factors in human muscle fatigue. Physiol Rev. 81(4):1725–1789. DOI: 10.1152/physrev.2001.81.4.1725. [PubMed: 11581501]

Gang R, Nagarajan SM, Anandhan P. 2021. Mechanism of the effect of traditional Chinese medicine fumigation on blood lactic acid in exercise body. J Ambient Intell Humaniz Comput. 12(3):3295–3301. DOI: 10.1007/s12652-020-02356-6

Grinten V, Smitt P. 1992. Development of a practical method for measuring body part discomfort. London (UK): Taylor and Francis.

Hajifar S, Sun H, Megahed FM, Jones-Farmer LA, Rashedi E, Cavuoto LA. 2021. A forecasting framework for predicting perceived fatigue: using time series methods to forecast ratings of perceived exertion with features from wearable sensors. Appl Ergon. 90:103262. DOI: 10.1016/j.apergo.2020.103262. [PubMed: 32927403]

Iridiastadi H, Nussbaum MA. 2006. Muscle fatigue and endurance during repetitive intermittent static efforts: development of prediction models. Ergonomics. 49(4):344–360. DOI: 10.1080/00140130500475666. [PubMed: 16690564]

Kumar S 2001. Theories of musculoskeletal injury causation. Ergonomics. 44(1):17–47. DOI: 10.1080/00140130120716. [PubMed: 11214897]

Lamooki SR, Hajifar S, Kang J, Sun H, Megahed FM, Cavuoto LA. 2022. A data analytic end-to-end framework for the automated quantification of ergonomic risk factors across multiple tasks using a single wearable sensor. Appl Ergon. 102:103732. DOI: 10.1016/j.apergo.2022.103732. [PubMed: 35287084]

Lim S, D’Souza C. 2020. A narrative review on contemporary and emerging uses of inertial sensing in occupational ergonomics. Int J Ind Ergon. 76:102937. DOI: 10.1016/j.ergon.2020.102937 [PubMed: 33762793]

Maman ZS, Chen YJ, Baghdadi A, Lombardo S, Cavuoto LA, Megahed FM. 2020. A data analytic framework for physical fatigue management using wearable sensors. Expert Syst Appl. 155(20):113405. DOI: 10.1016/j.eswa.2020.113405.

Mehta RK, Agnew MJ. 2012. Influence of mental workload on muscle endurance, fatigue, and recovery during intermittent static work. Eur J Appl Physiol. 112(8):2891–2902. DOI: 10.1007/s00421-011-2264-x. [PubMed: 22143842]

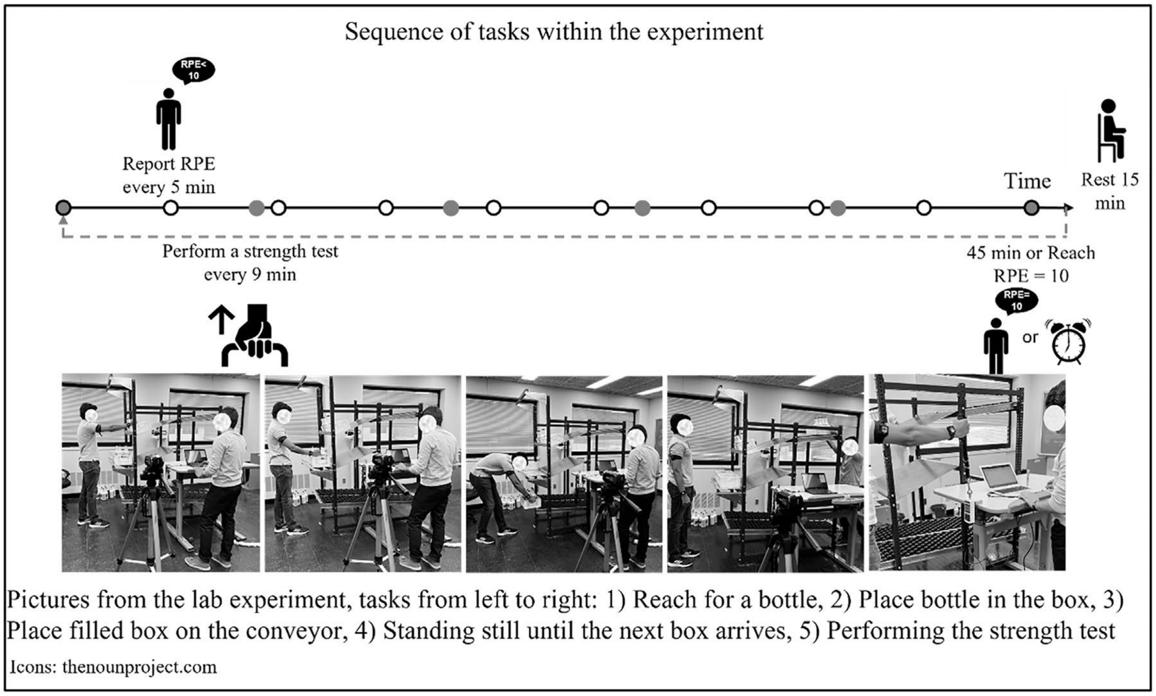
Micklewright D, St Clair Gibson A, Gladwell V, Al Salman A. 2017. Development and validity of the rating-of-fatigue scale. Sports Med. 47(11):2375–2393. DOI: 10.1007/s40279-017-0711-5. [PubMed: 28283993]

Otto A, Boysen N, Scholl A, Walter R. 2017. Ergonomic workplace design in the fast pick area. OR Spectrum. 39(4):945–975. DOI: 10.1007/s00291-017-0479-x.

Sedighi Maman Z, Alamdar Yazdi MA, Cavuoto LA, Megahed FM. 2017. A data-driven approach to modeling physical fatigue in the workplace using wearable sensors. Appl Ergon. 65:515–529. DOI: 10.1016/j.apergo.2017.02.001 [PubMed: 28259238]

Vøllestad NK. 1997. Measurement of human muscle fatigue. J Neurosci Methods. 74(2):219–227. DOI: 10.1016/s0165-0270(97)02251-6. [PubMed: 9219890]

Whittaker RL, Sonne MW, Potvin JR. 2019. Ratings of perceived fatigue predict fatigue induced declines in muscle strength during tasks with different distributions of effort and recovery. J Electromyogr Kinesiol. 47:88–95. DOI: 10.1016/j.jelekin.2019.05.012. [PubMed: 31136944]



Pictures from the lab experiment, tasks from left to right: 1) Reach for a bottle, 2) Place bottle in the box, 3) Place filled box on the conveyor, 4) Standing still until the next box arrives, 5) Performing the strength test

Figure 1.

Example participant posture for the picking and placing motions. Filled blue circles represent the strength test, and non-filled circles represent the RPE rating reporting.

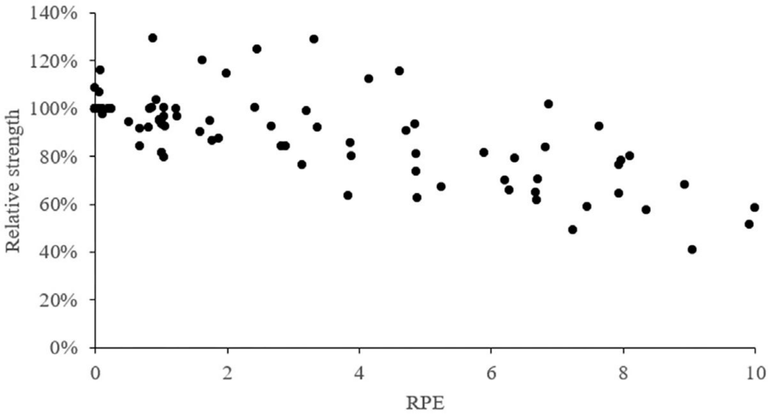


Figure 2.

Data on the relationship between RPE and relative strength across all participants for the 1.5 kg–15 bpm condition.

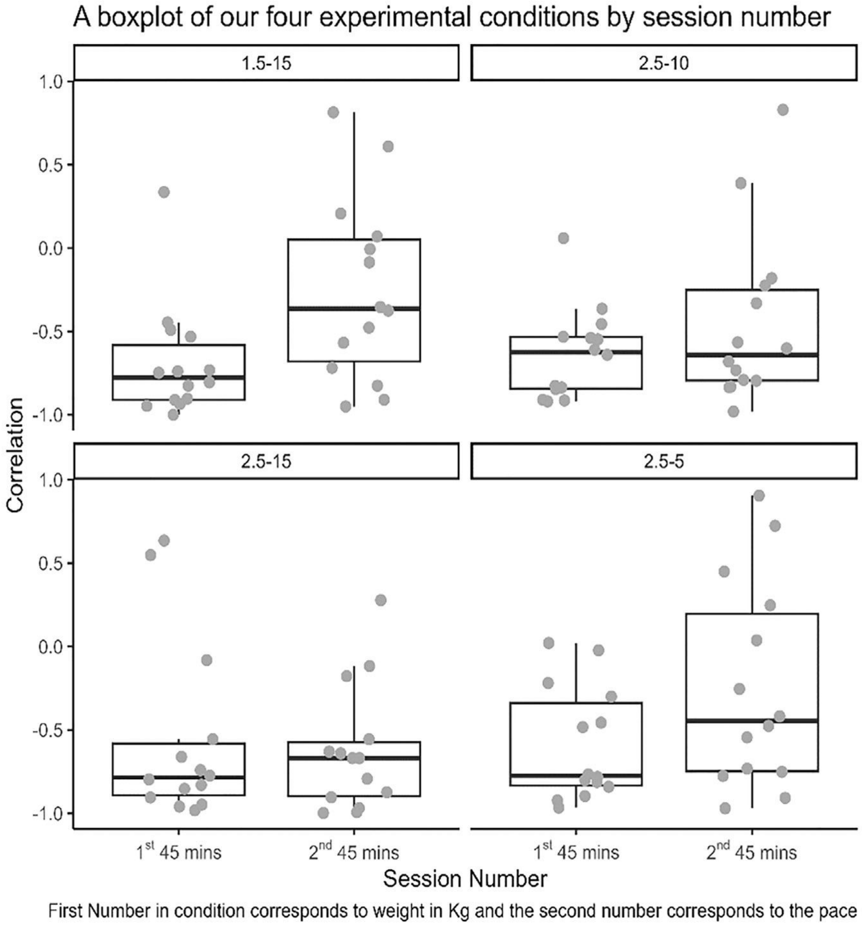


Figure 3.

Box plots, with underlying data points, of the correlation coefficients by condition and work period.

Table 1.

Participant demographics.

	Females	Males	Overall
Age (years)	26.9 (3.9)	26.7 (5.5)	26.8 (4.6)
Height (cm)	160.7 (9.5)	178.9 (7.3)	169.8 (12.5)
Body mass (kg)	63.5 (11.3)	86.2 (18.8)	74.8 (19.0)
Waist circumference (cm)	80.5 (12.5)	92.9 (16.1)	86.7 (15.3)
Hip circumference (cm)	103 (9.7)	103 (16.0)	103 (12.7)
BMI (kg/m^2)	24.7 (4.5)	27.1 (7.3)	25.9 (6.0)

Numbers in parentheses indicate standard deviations.

Table 2.

Mean (standard deviation) strength and RPE by work period and condition along with the results of the repeated measures ANOVA

	2.5 kg–15 bpm		2.5 kg–10 bpm		2.5 kg–5 bpm		1.5 kg–15 bpm		Statistical comparison (*p*-value)	
Condition Work period	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**Condition**	**Work period**
Starting strength (N)	64.1 (28.1)	60.2 (31.6)	67.4 (26.8)	60.2 (30.2)	66.2 (29.2)	58.8 (24.1)	67.3 (30.3)	61.0 (26.8)	0.75	<0.01 *
Ending strength (% start)	83.2 (18.1)	80.7 (15.1)	85.1 (10.2)	90.3 (17.7)	84.5 (13.6)	91.6 (21.5)	78.4 (19.0)	90.5 (19.4)	0.37	0.055
Starting RPE	0.14 (0.53)	1.5 (0.85)	0.07 (0.27)	1.5 (1.51)	0.07 (0.27)	1.64 (1.55)	0.14 (0.36)	1.43 (1.5)	0.99	<0.01 *
Final RPE	7.1 (2.9)	8.1 (2.4)	5.8 (3.2)	6.6 (3.2)	4.8 (3.5)	5.3 (3.7)	5.6 (3.4)	6.4 (3.5)	<0.01 *	0.01 *

[*] indicates statistical significance.