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Effects of Pause Design on the Decline in Pulling Effort and the Evaluation of Perceived Effort in Pulling Tasks

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Abstract: Pulling is one of the manual material handling activities that could lead to work-related musculoskeletal disorders. The objectives of this study were to explore the development of muscular fatigue when performing intermittent pulling tasks and to establish models to predict the pull strength decrease due to performing the tasks. A simulated truck pulling experiment was conducted. Eleven healthy male adults participated. The participants pulled a handle with a load of 40 kg, which resulted in a pulling force of approximately 123 N. The pulling tasks lasted for 9 or 12 min with one, two, or three pauses embedded. The total time period of the embedded pauses was 3 min. The pull strength after each pull and rest was measured. Ratings of the perceived exertion on body parts after each pull were also recorded. The results showed insignificant differences regarding the development of muscular fatigue related to rest frequency. We found that the development of muscular fatigue for pulling tasks with embedded pauses was significantly slower than that for continuous pulls. The forearm had a higher CR-10 score than the other body parts indicating that the forearm was the body part suffering early muscle fatigue. An exponential model was developed to predict the pull strength of the pulling tasks with embedded pauses. This model may be used to assess the developing of muscular fatigue for pulling tasks.

Keywords: musculoskeletal disorders; pulling tasks; muscular fatigue; pull strength

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1. Introduction

Musculoskeletal disorders (MSDs) have been a significant burden for both workers and industries worldwide. In 2017, there were 1.3 billion MSD cases and 138.7 million disability-adjusted life years, a measure of lifetime with disability and the time lost due to premature mortality, in the world [1]. These numbers highlight the significance of MSD problems.

There is a huge amount of literature discussing work-related MSD problems. Manual materials handling has been blamed as the leading causes for those problems at workplaces [2]. MSDs occur primarily because the repetitive and/or forceful loading on the joints and body tissues while performing physical demanding tasks, such as lifting, lowering, pushing, pulling, carrying, and so on [3–5]. Lower back, shoulder, and wrist are the primary body parts that suffer from MSDs [6–9].

In order to reduce lifting, lowering, and carrying, carts, trolleys, and other material handling aids are widely used. These aids may be operated manually or powered. Powered material handling aids, such as forklift trucks, are used to handle materials in batches or are very heavy, and may not be handled by a person manually. Manual material handling aids, such as carts and trolleys, are used to handle materials in relatively small amount. However, using manual material handling aids, such as a pallet jack, to handle a large amount of materials or heavy loads are also common.

Pushing or pulling is normally required to maneuver those material handling aids. The literature has shown that about 10% of all working processes in the automotive industry involve pushing and pulling on a regular and repetitive basis. The total mass required for those pushing and pulling ranged between 200 and 1000 kg [3]. In addition to the automotive industry, pushing and pulling are also common in industries, such as the manufacturing of other goods, agricultural, healthcare, and so on [10–13].

A fundamental of job design in ergonomics is that the job design should not exceed the capability of workers. Pushing and pulling strengths have been recognized as indicators of workers' capability in performing pushing and pulling tasks [10,11,14]. Frequent muscular fatigue at work has been identified as one of the early symptoms of MSDs. Assessments of muscular fatigue for pushing and pulling tasks are essential to quantify the risk of MSDs. Pushing/pulling task-induced muscular fatigue may be assessed via developing empirical models [15–17] and studying the decrease of muscular strength [18], the electromyogram activities of muscles involved [19,20], the subjective responses of muscle fatigue [21], the endurance time [18,20,22], and metabolic responses [23,24] of the participants performing the tasks under specific conditions.

A pallet jack is one of the commonly used material handling aids. Pulling is required while using this aid. Studies have been performed to investigate muscular strength decrease, perceived muscular fatigue, and maximum endurance time for simulated pallet jack pulling tasks to enhance our understanding of the developing of muscle fatigue for pallet jack pulling tasks [18,21,22]. The pulling tasks in those studies were completed without pause.

In practice, pulling tasks may be intermittent due to job assignment or worker fatigue problems. When pulling tasks are performed intermittently, the involved muscles are also contract intermittently. The literature has reported that, for intermittent muscle contractions, a high duty ratio (the ratio between the exertion period and the period including force exertion and pause) led to higher rates of muscle fatigue and decreased endurance time [25].

This implies that the muscle strength decreases and perceived muscular fatigue of pulls without pause or break arrangements could be different from the pulls with embedded pauses. It was anticipated that pause(s) within a pull task could impede the decrease of both muscular strength and rating of muscle fatigue. The objective of the current study was to test this hypothesis. Another objective of this study was to develop a regression model to predict the pulling strength for pulling tasks with embedded breaks to assess the developing of muscle fatigue.

2. Methods and Materials

An experiment was performed in the laboratory. The temperature and humidity in the laboratory were 16.2 (±1.4) °C and 79.7% (±7.3)%, respectively.

2.1. Participants

Eleven male adults were recruited. They reported no history of upper limb problems within a year of the study and were all right handed. They were requested to refrain from strenuous physical exercise within 24 h of each trial. The basic data of the participants are shown in Table 1.

Table 1. Demographic details of the participants.

Variables	Mean (SD)
Age (years)	19.82 ± 1.83
Weight (kg)	61.22 ± 4.10
Stature (cm)	165.41 ± 2.85
Body mass index (kg/m^2)	22.40 ± 1.77
Arm length (cm)	67.82 ± 5.44
Leg length (cm)	93.64 ± 2.57
Knee height (cm)	47.27 ± 3.35
Shoulder height (cm)	136.14 ± 4.26

2.2. Apparatus and Materials

A manual pallet jack was purchased from a local retailer. The length and the diameter of the handle, the length and the tilting angle of the stick under normal usage were measured. A T-bar including a handle and a stick, mocking the stick of that pallet jack, was fabricated and installed (see Figure 1). This bar had a length of 85 cm. The diameter of the handle was 3 cm. This T bar was mounted to the ceiling using two metal wires.

The wires were adjusted so that the bar was tilted with an angle of 40° with the floor and was similar to the handle of a pallet jack when pulled by a person. There was a cast iron (40 kg) suspended in the middle of the stick to generate a backswing force while being pulled. A force of 123 N, in the direction of the shaft of the stick, was required to resist this back-swing force and to maintain the 40° tilting angle of the handle. A stopwatch was used to measure the time of the pulling tasks.

Figure 1. T bar and simulated pulling task.

A pull strength measuring apparatus, including a loadcell (Lutron® Inc., FG-5100, Taipei, Taiwan), an iron chain, and a handle (Ø3 cm), was used. The participant pulled the handle with their maximal voluntary contraction (MVC) for approximately 5 s (see Figure 2). The reading was recorded as the pull strength. The Borg CR-10 [26] was used to record the subjective ratings of muscular fatigue of body parts. This scale, from 1 to 10, is suited in measuring the sensation arising from a specific area of the body, for example, the muscle pain or fatigue in the arm [26].

Figure 2. Pull strength apparatus and measurement.

2.3. Independent and Dependent Variables

The number of breaks within a trial was denoted as n, where n was equal to 1, 2, or 3. For trials with n breaks, there were (n + 1) pull sessions. The total time periods (TT) were either 9 or 12 min. The TT may be split into time periods of pull (PT) and pause or break (BT). A PT is the total time period of pull in one trial, which were either 6 or 9 min. This time period might be split into periods of (n + 1) pulls (P), where n was equal to 1, 2, or 3.

The time period of a pull (P) before or between a pause was then the PT divided by (n + 1), which was in the range of 1.5 to 4.5 min (see Table 1). All the trials had a BT of 3 min. The participants took a break of B min for trials with n breaks. B was equal to 3, 1.5, and 1 min for n was equal to 1, 2, and 3, respectively. The T-n combination was used to denote the trial condition. For example, 12-2 indicates the condition of a 12-min trial with two breaks within. Table 2 shows the time period arrangements of the experiment.

Table 2. Time period of pulls and breaks.

TT (min)	n	PT (P × (n + 1)) (min)	BT (B × n) (min)
9	1	6 (3 × 2)	3 (3 × 1)
9	2	6 (2 × 3)	3 (1.5 × 2)
9	3	6 (1.5 × 4)	3 (1 × 3)
12	1	9 (4.5 × 2)	3 (3 × 1)
12	2	9 (3 × 3)	3 (1.5 × 2)
12	3	9 (2.25 × 4)	3 (1 × 3)

Note: TT is the total time period; PT and BT are the time of pull and pause, respectively. P and B are the times of one pull and one pause, respectively. N is the number of pauses.

2.4. Procedure

Each participant had a practice of pulling a real pallet truck before the experiment to become familiar with the gripping and maneuvering of the truck. Participants were requested to adopt the same posture and maintain this posture in the pulling strength measurements and while pulling the T bar to mimic a pulling task.

Each participant performed six pulling trials (see Table 2) and performed only one trial per day. Figure 3 shows the pull-pause arrangements. The trials for each participant were randomly arranged.

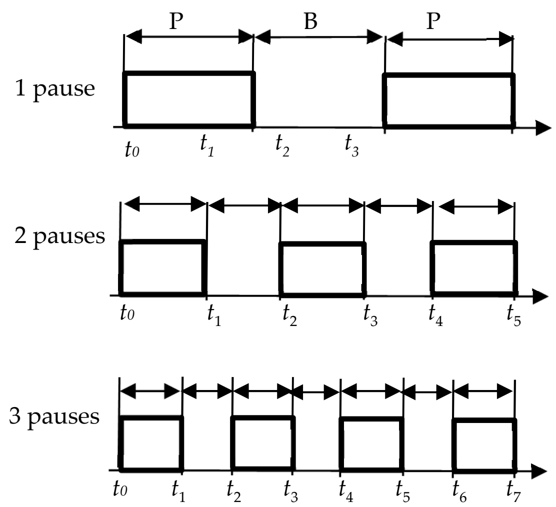

Figure 3. Pull and break allocations: t_0, t_1, t_2, . . . , and t_n are the time: P and B are the time periods for one pull and one pause, respectively.

Before one trial, the participant took a warm-up exercise for 5 min. After this, the participant pulled the strength measuring apparatus to have his pull strength measured. Three pulls were conducted and the maximum reading was denoted as his MVC. There was a pause of two minutes between each strength test. After the MVC was determined, the participant took a break for 5 min again. Then, the participant pulled the T bar (see Figure 1) following one of the arrangements in Table 1.

In addition to the pull strength test at the beginning of the trial, the pull strengths before and after each pause and at the end of the trial were also measured. In other words, one reading of pull strength was collected at each t_i for each trial in Figure 3. These strength measurements were measured by asking the participant to pull the handle one time (see Figure 2), instead of three pulls. The CR-10 scores of the forearm and upper arm of their dominant hand and right leg after each pull were recorded to indicate the muscular fatigue.

2.5. Data Processing

A total of 396 pull strength trials and 594 CR-10 scores were measured. Descriptive statistics were performed to show the changes of pull strength and CR-10 score over time. Analyses of variance (ANOVA) were conducted to determine the effects of TT and number of breaks on the pull strength and CR-10 score. Regression analyses were performed to establish the PS models. The data were analyzed using the SAS® 9.0 (Cary, NC, USA). A significance level of $\alpha = 0.05$ was adopted.

3. Results

3.1. Pull Strength

Table 3 shows the pull strength (PS) data at t_i for all the test conditions. The pull strength decreases from the beginning to the end of a trial are shown in Table 4. The pull strength decreased rapidly during the first pull of all the test conditions. After the first break for all conditions, the pull strength fluctuated, and fatigue and recovery were found. The ANOVA results indicated that TT had a significant effect on the strength decrease ($p < 0.01$), but the number of breaks was insignificant. The pull strength decrease of 9 min (78.60 ± 39.40 N) was significantly smaller ($p < 0.05$) than that of 12 min (102.13 ± 30.18 N).

Table 3. The means and standard deviations of pull strength (PS).

Test Conditions	*t* (min)	PS (N)	Test Conditions	*t* (min)	PS (N)
9-1	0	269.10 ± 40.86	12-1	0	269.10 ± 40.86
	3	194.31 ± 35.33		4.5	183.22 ± 32.54
	6	217.76 ± 21.84		7.5	207.09 ± 26.35
	9	203.39 ± 28.54		12	160.81 ± 23.48
9-2	0	269.10 ± 40.86	12-2	0	269.10 ± 40.86
	2	206.69 ± 30.43		3	205.14 ± 27.14
	3.5	209.50 ± 33.23		4.5	216.13 ± 25.25
	5.5	187.09 ± 28.25		7.5	198.23 ± 34.18
	7	205.67 ± 31.63		9	201.17 ± 38.03
	9	194.13 ± 25.50		12	172.61 ± 28.57
9-3	0	269.10 ± 40.86	12-3	0	269.10 ± 40.86
	1.5	199.83 ± 29.41		2.25	204.20 ± 43.67
	2.5	209.14 ± 29.42		3.25	216.45 ± 27.03
	4	196.00 ± 30.52		5.5	205.53 ± 22.19
	5	199.23 ± 26.44		6.5	207.44 ± 30.10
	6.5	195.33 ± 34.26		8.75	194.89 ± 32.33
	7.5	204.15 ± 43.60		9.75	193.73 ± 24.46
	9	173.99 ± 25.47		12	167.49 ± 26.35

Table 4. Pull strength decreases for all test conditions.

Test Conditions	Pull Strength Decrease (N)	Pull Strength Decrease (%)
9-1	65.70 ± 42.92	23.29 ± 12.47
12-1	108.29 ± 28.39	39.86 ± 6.26
9-2	74.97 ± 31.06	23.39 ± 6.25
12-2	96.49 ± 29.21	25.13 ± 8.25
9-3	95.11 ± 40.79	34.37 ± 11.32
12-3	101.61 ± 34.32	37.12 ± 9.47

3.2. CR-10 Score Results

ANOVA analysis was conducted for the CR-10 score. The results showed that TT had significant effects on the CR-10 score of the upper arm ($p < 0.05$). The CR-10 score of the 12 min condition (4.67 ± 1.38) was significantly higher than that of the 9 min condition (3.82 ± 1.38). TT was insignificant to the CR-10 score of the forearm. The CR-10 score of 12 min (6.27 ± 1.10), however, was higher than that of 9 min (5.70 ± 1.55).

ANOVA was conducted to compare the CR-10 score results among the test conditions. The CR-10 score of the forearm, upper arm, and leg at the beginning (t_0) and at the end of the trial (t_3, t_5, and t_7 for n is equal to 1, 2, and 3, respectively) among test conditions were not significantly different. Pair-wised comparisons of the CR-10 scores were performed to compare the subject ratings between the three body parts. The CR-10 score of the forearm was significantly ($p < 0.0001$) higher than that of the upper arm and then followed by that of the leg at each time point within each trial.

The mean CR-10 score values of upper arm were less than 5 except for test condition 12-1 (see Figure 4b, 5.09 ± 1.45). The mean CR-10 score values of the leg for all the test conditions were less than 3. The mean CR-10 score of the forearm were 5.55–5.82 and 6.09–6.55 for a TT of 9 and 12 min, respectively. The CR-10 score of the forearm and the upper arm changed over time. As the number of breaks increased, the difference of the CR-10 scores of both the forearm and upper arm between any two adjacent pulls was not significant. The CR-10 scores on the right leg, however, were not insignificantly ($p > 0.05$) different over test conditions.

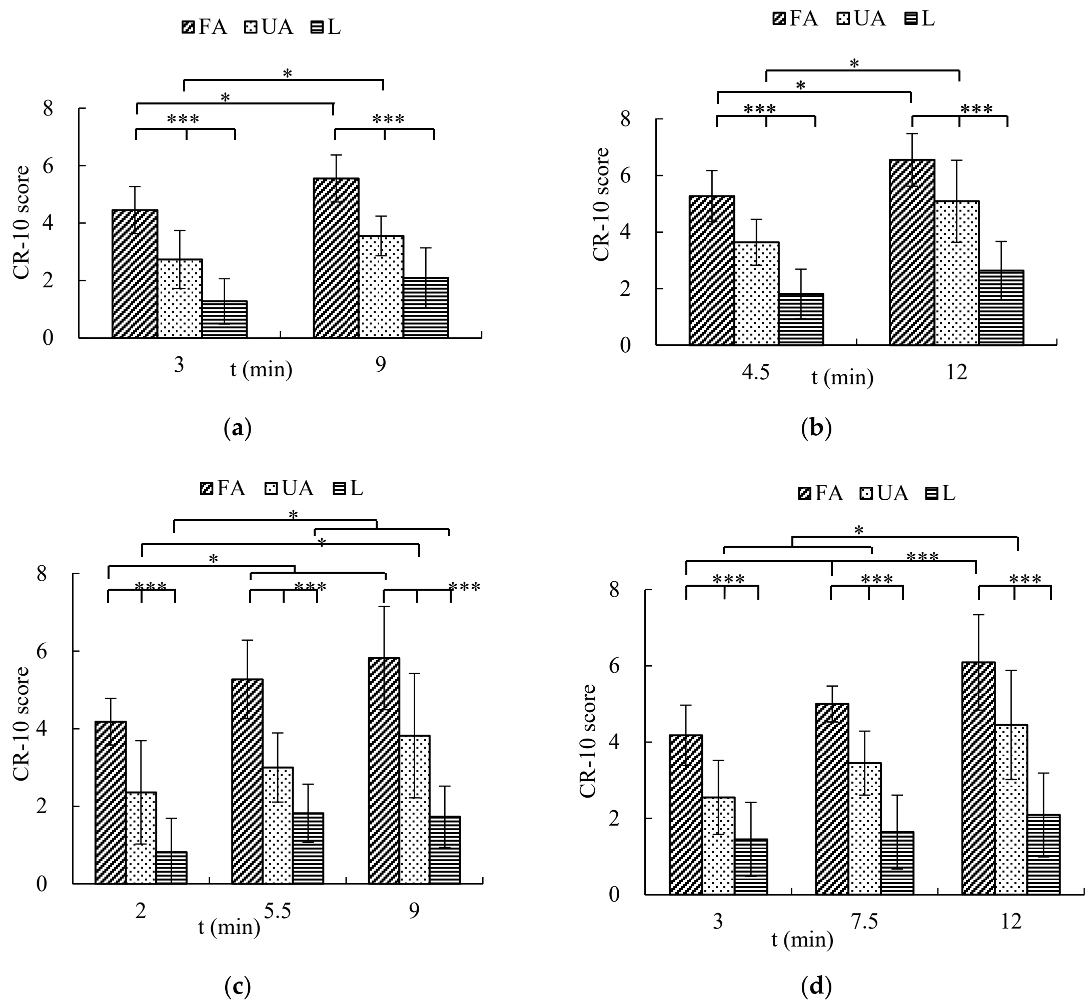

Figure 4. *Cont.*

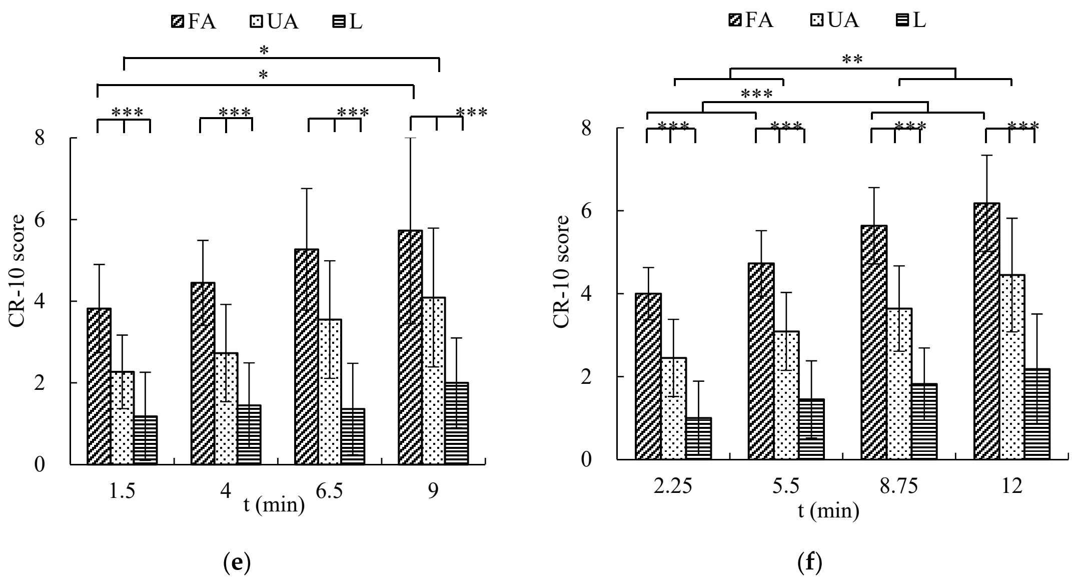

Figure 4. Comparisons of the CR-10 scores between body parts for each test condition: FA: right forearm, UA: right upper arm, and L: right leg; * $p < 0.05$, ** $p < 0.001$, and *** $p < 0.0001$. (**a**) 9-1 condition, (**b**) 12-1 condition, (**c**) 9-2 condition, (**d**) 12-2 condition, (**e**) 9-3 condition, and (**f**) 12-3 condition.

3.3. Regression Modeling

Ma et al. [16] proposed a muscle fatigue prediction equation for pushing tasks. We expanded this equation to predict the pull strength (PS) for pull tasks for a time period t with embedded breaks:

$$\mathrm{PS} = \mathrm{MVC} \times e^{-k \times \frac{F_{load}}{\mathrm{MVC}} \times t} \tag{1}$$

where k is the fatigue rate for intermittent pulling task, which depends on the force exertion and break arrangement (min^{-1}), F_{load} is the external load, and t is the time in min.

If $y = \ln(\frac{\mathrm{PS}}{\mathrm{MVC}})$, $b = -k \times \frac{F_{load}}{\mathrm{MVC}}$, then

$$y = b \times t \tag{2}$$

By performing linear regression analysis without intercept for the six test conditions on Equation (2), we obtained regression models for pull strength (see Table 5).

Table 5. Regression models for pull strength under test conditions.

Test Conditions	Model	R^2
9-1	y = −0.03759t	0.63
12-1	y = −0.04471t	0.81
9-2	y = −0.04651t	0.79
12-2	y = −0.03888t	0.85
9-3	y = −0.0524t	0.75
12-3	y = −0.04006t	0.80

Note: All the models were significant at $p < 0.0001$. R^2 is the coefficient of determination of the model.

In the current study, the F_{load} was 123 N, and the mean MVC was 269.1 N. By substituting these values into $b = -k \times \frac{F_{load}}{\mathrm{MVC}}$, b is equal to $-0.4571k$. The time period for a single pull was P and was determined using this equation:

$$\mathrm{P} = \frac{\mathrm{TT} - \mathrm{BT}}{n+1} \tag{3}$$

k may be calculated using $b/(-0.4571)$ (see Table 5). By performing a linear regression analysis without intercept, we have:

$$k = 0.03057 \times \mathrm{P} \quad (4)$$

Thus,

$$\boldsymbol{k} = 0.03057 \times \frac{\mathrm{TT} - \mathrm{BT}}{n+1} \quad (5)$$

By substituting Equation (5) to Equation (1), we obtained the following model:

$$\mathrm{PS} = \mathrm{MVC} \times e^{-0.03057 \times \frac{\mathrm{TT}-\mathrm{BT}}{n+1} \times \frac{F_{load}}{\mathrm{MVC}} \times t} \quad (6)$$

For the data and test conditions in the current study,

$$\mathrm{PS} = 269.1 \times e^{-0.01397 \times \frac{\mathrm{TT}-\mathrm{BT}}{n+1} \times t} \quad (7)$$

Table 6 shows the intra-class correlation coefficient (*ICC*) and Pearson's correlation coefficient (*r*) of the predicted and measured pull strength. The predicted and measured pull strength data for all test conditions are shown in Figure 5.

Table 6. Intra-class correlation coefficient (*ICC*) and Pearson's correlation coefficient (*r*) for the measured and predicted pull strength.

Test Condition	*ICC*	*r*	Test Condition	*ICC*	*r*
9-1	0.71 **	0.72 **	12-1	0.81 **	0.83 **
9-2	0.79 **	0.80 **	12-2	0.84 **	0.86 **
9-3	0.64 **	0.65 **	12-3	0.75 **	0.76 **

** $p < 0.0001$.

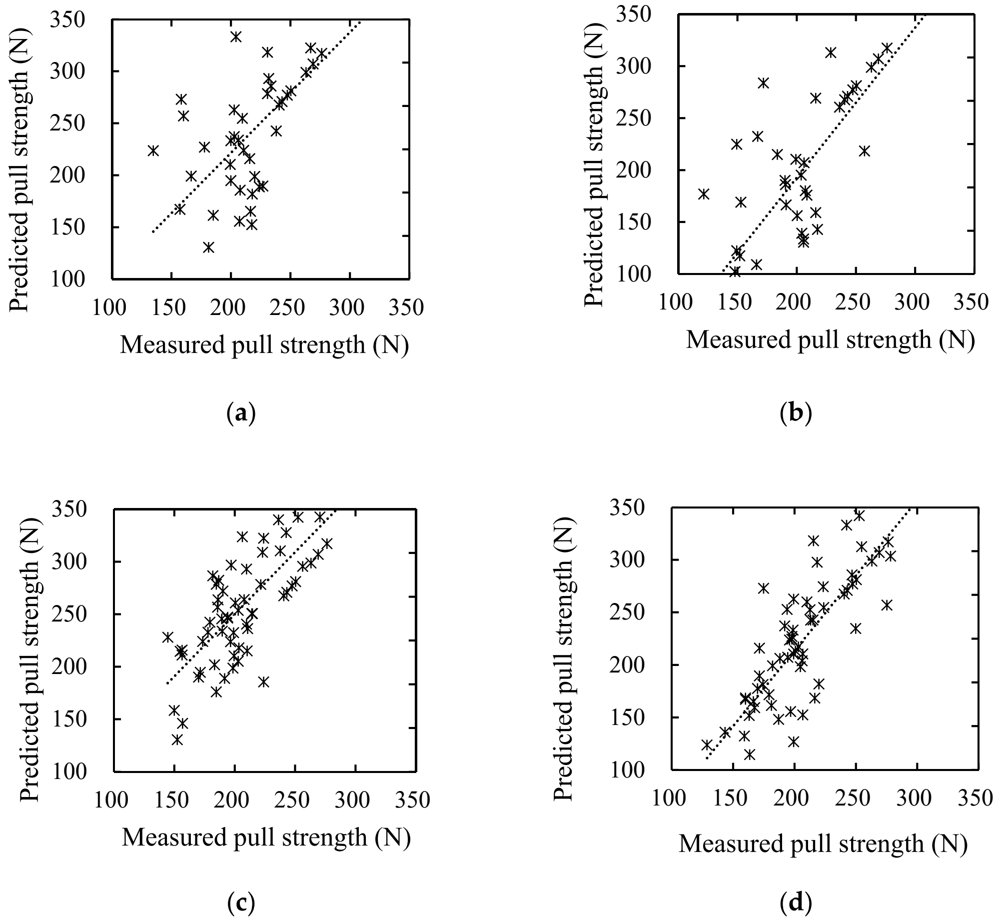

Figure 5. *Cont.*

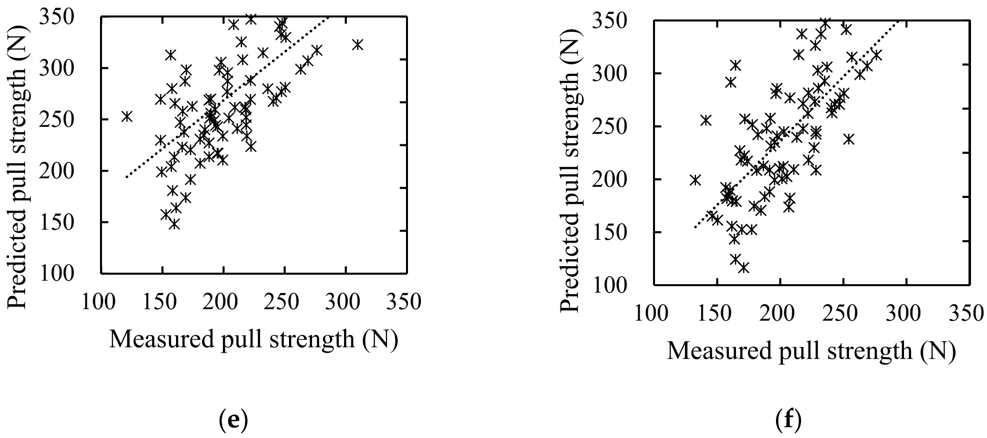

Figure 5. The predicted and measured pull strength for six test conditions. (**a**) 9-1 condition, (**b**) 12-1 condition, (**c**) 9-2 condition, (**d**) 12-2 condition, (**e**) 9-3 condition, and (**f**) 12-3 condition.

4. Discussion

In the experiment, the participant grasped the handle and pulled. The muscles on the forearm were recruited to resist the back-swing force, followed by the muscles on the upper arm, shoulder, and legs. The CR-10 scores on the forearm were the highest, followed by those on the upper arm, and then the leg. This implies that the forearm was the body part with earliest onset of muscular fatigue. The time period of one pause of the 9-3 condition was 1.5 min, and the CR-10 score of the forearm changed slightly over time.

The time period of one pause of the other test conditions were more than 2 min and the CR-10 score of the forearm changed significantly over time, which alluded that the accumulation of muscular fatigue was significant. The time periods of one pause of the 9-2 and 9-3 conditions were 2 and 1.5 min, respectively. The CR-10 scores of upper arm of these conditions changed slightly over time. The time periods of one pause of all other conditions were more than 2.25 min, the CR-10 score of the upper arm changed over time, which implied that the accumulation of muscular fatigue was significant.

During the pulling tasks, participants reported little muscular fatigue on the lower back (less than 2). Therefore, the CR-10 score on lower back was excluded. This was inconsistent with that in the literature [3,14,27,28]. This might be attributed to the pause arrangement in our study. The mean CR-10 score of the forearm was less than 7 (very strong). The mean CR-10 score of the upper arm was less than 5 (strong) except for in condition 12-1. The mean CR-10 score of the leg was less than 3 (median).

A significant ($p < 0.05$) difference was found on the CR-10 score of the upper arm between the 12 and 9 min trials. For the forearm and leg, the difference between the 9 and 12 min trails was insignificant. This might be attributed to the gap of trials of 12 and 9 min, which was not long enough to lead to different fatigue accumulation. For test condition 12-1, the CR-10 score of the forearm was 5.27 after a 4.5 min pulling.

After a rest of 3 min and then pulling for 4.5 min, the CR-10 became 6.55. It might be deduced that the CR-10 score would exceed 7 after having another rest of 3 min and then pulling for 4.5 min. Therefore, work schedules, such as 12-1 are not recommended because they could lead to significant muscular fatigue. For other test conditions, muscular fatigue progressing was relatively slow.

In one of our previous studies [21], the scores of CR-10 on the hand/wrist, elbow, low back, leg/ankle, and shoulder were 6.9, 6.45, 5.68, 4.90, and 4.40, respectively, at the end of pulling tasks. In current study, the CR-10 score on the forearm was the highest. The CR-10 scores on the forearm for test conditions 12-1, 12-2, 12-3, 9-1, 9-2, and 9-3 were 6.55, 6.09, 6.18, 5.55, 5.82, and 5.73, respectively. The CR-10 scores on the upper arm were below 5 except in the 12-1 test condition. The CR-10 scores on the leg were below 3. The CR-10 scores on the forearm, upper arm, and leg for our pulling tasks with embedded pauses were lower than for those without pause arrangements [21]. It is apparent that pulling tasks with pause(s) allow better blood circulation and, hence, lead to lower perceived muscle fatigue [15,29].

There are limitations in this study. The pulling tasks in the current study were static without movement, while pulling tasks in practice are commonly performed while walking. When pulling and walking, the gait pattern and walking speed might affect the development of muscular fatigue. Future research may be performed to explore the effects of gait on the developing of muscle fatigue due to pulling.

In addition, the time period of a single pull and a pause may be too short as compared to those that actually occur at workplaces. Various pull and pause arrangements may be considered in future research. Finally, electromyography (EMG) data are commonly used to assess physical efforts of manual material handling tasks. Future research may also consider incorporating EMG data in assessing the effects of pause arrangements on the decline of the pulling capability of human participants.

5. Conclusions

Pulling strengths with embedded breaks, simulating those of pallet truck handling, were measured. The total time period of each trial was either 9 or 12 min. These trials were embedded with one, two, or three pauses. The pulling strengths were measured at the beginning and before each pause. The results showed that performing those tasks led to 23% to 37% declines of pulling strength, indicating the significance of muscle fatigue. The number of pauses did not affect the decline of pulling strength despite a certain amount of muscle strength recovery after each pause. An exponential model, considering the pause arrangement, was constructed to predict the pulling strength for pulling tasks. The pulling strength predicted using this model was highly correlated with the actual data collected in this study.

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Conflicts of Interest: The authors declare no conflict of interest.

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