ORIGINAL ARTICLE

Elbow-Height Handle and Staggered Stance Exhibited Greatest Force in Pushing and Pulling: A Study among Malaysian Adults

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ABSTRACT

Introduction: Pushing and pulling activities are common in daily life and industrial workplaces. These activities are potentially contributing to muscle fatigue in the back and shoulder if not managed ergonomically. Therefore, this study aimed to quantify the maximum strength of Malaysian adults in horizontal symmetrical two-handed pushing and pulling with different handle heights and stances. **Methods:** Forty-seven participants of 24 males and 23 females were recruited in pushing and pulling experiments. The participants were assistant engineers and postgraduate students of a technical university. The dependent variable was the magnitude of push/ pull force. The independent variables consisted of action, handle height and stances. The experimental design was set for 2 actions, 3 handle heights and 2 stances, yielding 12 variables combinations. **Results:** Key findings of this study revealed that combination of pull action, handle height at elbow level and staggered stance exhibited greatest force. On the contrary, combination of push action, handle height at knuckle level and parallel stance resulted in lowest force. In pushing test, both male and female participants obtained greatest force of 233.3 N and 121.7 N, respectively, when the handle height was at elbow level and staggered stance. Similarly, in pulling test, males and females obtained highest force of 242.9 N and 152.4 N, respectively. **Conclusion:** This study concluded that handle height at elbow level and staggered stance exhibited greatest force in pushing and pulling activities. This study provides information to individuals who involved in pushing and pulling tasks with least force exertion to minimize muscle fatigue in the back and shoulder. Future studies should consider the following recommendations: 1) Participants of study should involve manufacturing industry workers. 2) To study the effect of pushing and pulling tasks on muscle activity.
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Keywords: Ergonomics, Manual materials handling, Push and pull strength, Two-handed push and pull, Symmetrical pushing and pulling

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INTRODUCTION

Ergonomics is a scientific study focusing on the interaction of humans and tasks (including machine, tool and process) to improve overall work performance. The application of ergonomics for enhancing occupational health and human well-being is well established in many areas such as manufacturing industry, healthcare sector [1], agriculture [2], and motorcycle design [3]. One of the issues that require attention from the ergonomics experts is manual materials handling (MMH). In relation to MMH, pushing and pulling actions are commonly found in activities of daily living and work processes such as in the houses, offices, shopping malls, health care premises, construction sites and manufacturing industries. Even though automation system is widely applied in the public amenities and industries, manual pushing and pulling actions are still relevant and regularly practiced by human, especially workers at production lines [4]. Pushing and pulling is defined as the exertion of the hand force by a person on a static or moveable object, provided that the direction of the major component of the resultant force is horizontal [5]. In pulling, the hand force is directed towards the body. Inversely, in pushing, the force of hand is directed away from the body [6]. The push and pull forces are also known as compression and tension forces, respectively.

Garg [7] listed factors affecting push and pull forces include friction, slope or angle of ramp, wheel design and its maintenance, condition of carts and floors, weight of the cart, body posture, foot placement, frequency and distance of pushing and pulling, and handle height. Handle is one of important components in materials handling equipment used for manual pushing and pulling tasks. A recent study pointed that the orientation of the handle influences the maximum forces that can be exerted by the hand, for example, a handle located perpendicular to the direction of force can provide the greatest strength [8].

Improper design of materials handling equipment such as trolleys is the most common cause of occupational injuries and muscle sprain experienced by industrial workers. The trolley's substandard design, such as inappropriate handle height and poor wheel design, can lead to excessive muscular loads during pushing and pulling tasks. Research in ergonomics has identified pushing and pulling tasks as the main contributors to shoulder complaints [9]. In Netherlands, a survey on musculoskeletal symptoms reported that industrial workers experienced pain in the back and shoulder due to pushing and pulling tasks [10]. The Australian Workers' Compensation Statistics reported that from 2017 to 2018, workers suffered more than 16,000 musculoskeletal injuries associated with manual handling tasks. The median cost for treating these injuries is $13,100, with 6.4 weeks lost [11].

In Malaysia, many ergonomists reported that workers from multi-industries (e.g. manufacturing, grocery retail and hotel) suffered from musculoskeletal symptoms such as pain in the back and shoulder due to MMH associated with pushing and pulling tasks [12-15]. The Social Security Organisation (SOCSO) of Malaysia reported 1154 accidents cases related to over-exertion in pushing or pulling tasks from the year 2016 to 2018. These accidents resulted in paid temporary disability of RM 980 [16-18]. Although pushing and pulling tasks are very common in Malaysian industrial settings and their association to musculoskeletal symptoms are frequently reported nonetheless, these kinds of MMH are less studied quantitatively than lifting tasks [19-20]. Based on the literature, quantitative data and statistical analysis on push and pull forces among Malaysian industrial workers is nearly inaccessible. Hashim [21] quantified the push and pulled forces through a computer simulation; however, as per the author's knowledge, very minimal empirical studies have been conducted to provide the absolute magnitude of push and pull forces among Malaysian young adults.

This study aimed to measure the maximum strength in horizontal two-handed symmetrical pushing and pulling actions with different handle heights and stances among male and female Malaysian young adults. This study fills a gap in the current ergonomics knowledge by providing quantitative data and analysis of push and pull forces regarding the physical strength of Malaysian young adults. The outcomes of this study will certainly help industrial workers to apply an appropriate action (either push or pull), handle height and stance that can produce the greatest force magnitude to execute manual materials handling tasks such as pushing or pulling a manual operated trolley. The benefit of knowing this configuration is that the engineers and ergonomists can design the pushing and pulling tasks with less effort of muscle activation to prevent body fatigue. Furthermore, occupational therapists can refer to this quantitative push and pull forces data to screen healthy and symptomatic workers concerning pushing and pulling capability.

MATERIALS AND METHODS

This study consisted of two experiments of pushing and pulling tests. The experiments were conducted at the Ergonomics Laboratory of Universiti Teknikal Malaysia Melaka, Malaysia.

Participants

Participants were healthy Malaysians aged between 25 to 27 years old. The participants were assistant engineers and postgraduate students of a technical university. These participants represent the major age group of labor force actively working at multi-industries in Malaysia [22]. The participants were invited through personal invitation and social networking mediums such as WhatsApp's group, FaceBook, Instagram and Twitter. Participants were screened through a self-reporting interview, and they will be qualified if no history of low back pain, shoulder and arm pain, neurological disorders and physical injury. Information provided to the participants, including the experiment's benefit and risk, confidentiality, voluntarily of participation, and operational procedure of the experiment. Once the participant is well informed and agreed to participate in the experiment, they have to sign the consent form. Forty-seven university students of 24 male (age: 25.7±1.3 years) and 23 female (age: 25.1±1.2 years) were recruited in this study. This sample size was found to be sufficient to detect a moderate effect size in variables of interest with a power of 0.85 and a significance level (α) of 0.05. Each participant was assigned a unique number for future reference if he or she has to continue the experiment in the next day. The participant number, age, and gender were recorded in the participant form.

Shoe-floor friction

The participants wore anti-slip shoes such as safety boots or sports shoes as these footwears provide a high value of static coefficient of friction between the shoe sole and floor. Slippery footwear such as slippers or sandals was not allowed. This is important to avoid slip during pushing and pulling experiments. The magnitude of pushing and pulling forces is significantly affected when performed on surfaces with a low static coefficient of friction [23]. The static coefficient of friction, denoted by μs can be obtained by dividing the frictional force with the normal reaction force. Greater static coefficient of friction and normal reaction force can generate greater frictional force and higher anti-slip property. Hence, a high value of static coefficient of friction is recommended to provide enough grips between the shoe sole and floor to allow participants to generate maximum pushing and pulling forces.

Ambient temperature

Environmental temperature significantly affects skeletal muscle contractility and consequently influences muscular strength [24-26]. At very low temperature, the muscles produce lower rate of force generation. On the other hand, hot temperature reduced the voluntary isometric force production and activation of the muscle [27]. As a consequence of hot ambient temperature, the work capability was reduced by 16% in pushing [23]. In this study, the ambient temperature was around 20 – 24 ^{o}C.

Instrument

A hand-held digital force gauge manufactured by Mark-10 Series 5 (Copiague, New York, USA) was used to measure the compression (push) and tension (pull) forces. In compression (push), the attachment consisted of a rectangular pad designed for pushing against a rigid surface. In the experimental work, the gauge was attached with two handles to measure push and pull forces exerted by both hands. This hand-held dynamometer is incorporated with a load cell and has a digital display of force magnitude both compression and tension. Before the experiments began, this force gauge was checked and calibrated. This force gauge was calibrated and certified according to the National Institute of Standards & Technology (NIST), USA. The measurement unit was set in Newton (N). The display modes are real-time (RT), peak compression (PC) and peak tension (PT). In addition, the researchers performed cross-calibrated with reference weights to ensure the force gauge was reading the same weight (force). The force gauge was set '0' before the measurement began.

Measurement of Relevant Anthropometry

Eight relevant anthropometric parameters of the participants were measured. Participant's body mass and height were measured without shoe. Then, the forearm length, forearm circumference and upper arm circumference were measured. The forearm and upper arm circumference were measured at the distance of two fingers from the elbow crease (i.e., placing the measuring tape about two fingers from the elbow crease). Additionally, shoulder height, elbow height and knuckle height were measured based on the reference points suggested by Pheasant [28]. The relevant anthropometric parameters of the participants are provided in Table I.

Table I: Eight anthropometric parameters of participants

	Male (n = 24)		Female (n = 23)	
	Mean	SD	Mean	SD
1) Body weight (kg)	73.3	3.5	60.0	3.0
2) Body height or stature (cm)	170.0	1.1	160.0	2.0
3) Shoulder height (cm)	137.3	1.0	126.0	1.0
4) Elbow height (cm)	106.9	1.1	100.0	1.3
5) Knuckle height (cm)	78.75	1.3	72.6	1.5
6) Forearm length (cm)	26.6	0.3	25.5	0.3
7) Forearm circumference (cm)	27.2	0.6	23.5	0.5
8) Upper arm circumference (cm)	29.7	0.9	26.4	0.9

Push-Pull Forces Measurement Procedures

The measurement procedures were reviewed and approved by the Research Ethics Committee of Universiti Teknikal Malaysia Melaka (Approval reference no.: UTeM,11.02/500-25/1/4-22). All positions during the measurement of push and pull forces were in standing posture. The participants looked straight forward and paid their attention in experiments.

Measurement of Push Force

Step 1: Participant was in standing position with both hands were in pronation (palms directed vertically downwards). This hand posture is suggested in pushing experiment as the increase in the elbow extension causes pronation posture to produce higher force than supination [29]. The participant holds the handle of Mark 10 Force Gauge at the specified handle height (e.g., shoulder level). A fixed and flat concrete wall was used to resist the movement of push force.

Step 2: The participant was allowed to set the distance between their body and the handle at their own preference. Additionally, the participant was asked to adjust his or her upper extremity postures. The posture adjustment will allow the participant to increase the pushing effort by engaging the torso through forward-leaning [30]. Then, the participant was instructed to apply the strength of the upper extremities, torso, and legs to push the handle. They were required to increase the exertion gradually until the maximum level (without jerking the handle) within the first two seconds, maintain this effort at four seconds [31] and then relax. Two repeated trials were recorded for each test combination. However, the experimenters took the maximum value between the two trials because the maximum value represents the maximum strength. A rest break of more than 5 minutes was provided between the trials to diminish the effect of muscle fatigue from the first trial.
Step 3: Repeat step 1 and step 2 for other handle heights and stances.

Measurement of Pull Force

Step 1: Participant was in standing position with both hands were in supination (palms directed vertically upwards). Supination posture was used to maintain the forearm in neutral posture – no twist in the pronator teres and pronator quadratus muscles during the pulling action. This posture can reduce the risk of muscle strain and sprain. Also, supination is stronger than pronation for the mid-range of elbow flexion in pulling [29], [32]. The participant holds the handle of Mark-10 Force Gauge at the specified handle height (e.g., elbow level).

A fixed and rigid post was used to withstand the pulling force.
Step 2: The participant was allowed to decide the distance between his/ her body and the handle at their own preference. Moreover, the participant was asked to adjust his or her upper extremity postures. The posture adjustment will allow the participant to increase the pulling effort by applying the torso weight through backward leaning [30]. Then, the participant was instructed to apply strength of the upper extremities, torso and legs to pull the handle. He or she was required to increase the exertion gradually until the maximum level (without jerking the handle) within the first two seconds, maintain this effort at four seconds [31] and then relax. Two repeated trials were recorded for each test combination (however, the experimenters took the maximum value between the two trials). A rest break of more than 5 minutes was provided between the trials to diminish the effect of muscle fatigue from the first trial.
Step 3: Repeat step 1 and step 2 for other handle heights and stances.

Experimental Design
The dependent variable was the magnitude of force, measured in Newton (N). The independent variables consisted of 'action', 'handle height' and 'stance'. The action denotes the participant's exertion type, effort, or activity while applying the force, either pushing or pulling the handle gauge. The handle height is the vertical dimension of the handle measured from the floor. The handle heights were shoulder level, elbow level and knuckle level. The parallel stance refers to the position of the legs side by side, the feet are apart about the shoulder inter distance with the knees and toes pointing forward. Meanwhile, the staggered stance is defined as staggered feet - one foot was placed forward with the leg in an inclined position, and then the another foot was placed backward, and the leg is slightly bent at the knee, as per the participant's preference for a stable and flexible posture. The experimental design consisted of 12 combinations of 2 actions (push and pull), 3 handle heights (shoulder level, elbow level, knuckle level) and 2 stances (parallel and staggered). Fig. 1 shows an example of two-handed symmetrical pushing action with shoulder handle-height and staggered stance.

Demonstration of Procedures and Light Trial
Participants were trained at a submaximal intensity for the required procedures before the experiment began.

Figure 1: Action: Push; Handle height: Shoulder level; Stance: Staggered

They were given instructions and a demonstration on how to hold, push and pull the handle of Mark-10 Digital Force Gauge, the legs position and the trunk posture. All participants were given a chance to do a light trial of the pushing and pulling procedures for familiarization. After performing the first trial, the participant was provided a rest period of at least 5 minutes before taking the next test. The time interval is expected to wash out the effect of muscle fatigue due to the former test.

Participants Counterbalance
The counterbalance and arrangement of the tests are important to minimize the effects of trials orders and muscle fatigue [33]. Three handle heights (shoulder level, elbow level and knuckle level) were tested, yielding six arrangements from the two trials (3! = 6). The arrangement sequences were repeated for every six participants. For example, the first participant followed the sequence of handle height in the first arrangement: started with 2 trials for the shoulder level, continued by 2 trials for the elbow level, and ended with the 2 trials for the knuckle level. The maximum value of push and pull forces from these 2 trials was chosen for statistical analysis.

Statistical Analysis
Statistical analysis associated with descriptive statistics, analysis of variance, correlation, and linear regression were performed using Microsoft Excel 2010 and Minitab. The significance level was set at $\alpha = 0.05$ for all the statistical tests.

RESULTS

Push and Pull Forces of Participants
Results of descriptive statistics (minimum, mean, maximum and standard deviation) of symmetrical two-handed push and pull forces for each combination of action, handle height and stance among male and

female participants are presented in Table II. Apparently, push and pull forces of male participants are greater than females for all combinations. Additionally, this study observed that combination of pull action, handle height at elbow level and staggered stance generated the greatest force. In contrast, combination of push action, handle height at knuckle level and parallel stance resulted in lowest force. These trends applied to both male and female participants. For pushing, both male and female participants obtained greater force (233.3 N and 121.7 N, respectively) when the handle height was at elbow level and staggered stance. Similarly, in pulling test, male and female participants obtained greater force when the handle height at elbow level and staggered stance (242.9 N and 152.4 N respectively). These results summarized that handle height at elbow level and staggered stance were good for obtaining a greater force in performing pushing and pulling tasks.

Analysis of variance (Table III) was used to determine which variables and combinations having a significant influence to the push/ pull force. Four variables were included in the analysis: gender, action, stance and handle height. The analysis of variance showed that the effect of gender, action, and handle height on push/ pull force was significant ($p < 0.01$). However, the stance was non-significant ($p > 0.05$). Two combinations of variables: stance and handle height; and gender, stance, and handle height were found significant to the force ($p < 0.01$).

Prediction Model of Force

A multiple linear regression was calculated to predict the magnitude of push/ pull force based on the gender, action, handle height, and stance. A significant regression equation was found ($F(4, 571) = 126.41$, $p < 0.01$), with an R Square of 0.47. The predicted force based on Table

Table II: Descriptive statistics results for each combination, unit in Newton (N)

	Male participant (n = 24)				*Female participant (n = 23)*			
Combinations	*Min*	*Mean*	*Max*	*StDev*	*Min*	*Mean*	*Max*	*StDev*
Push*Shoulder level*Parallel stance	108.4	178.3	313	51.8	48.9	92.1	118.7	21
Push*Shoulder level*Staggered stance	134.9	225	360.3	62.7	50.8	109.7	168.4	27.9
Push*Elbow level*Parallel stance	106.9	177.7	257.3	49.8	51.8	104.2	169.5	27
Push*Elbow level*Staggered stance	145.2	233.3	356.6	57.3	67.7	121.7	196.7	32.6
Push*Knuckle level*Parallel stance	103.6	137.3	206	33.5	51	87	143.4	21.3
Push* Knuckle level*Staggered stance	99.1	170.7	265.2	48.3	40.2	99.9	170.5	29.1
Pull*Shoulder level*Parallel stance	141.3	190	267.6	35.8	55.9	115.6	151.8	2.12
Pull*Shoulder level*Staggered stance	133	234.7	356.8	56.8	99.3	146.7	223.7	20.8
Pull*Elbow level*Parallel stance	118	196.5	293.8	4.67	73.1	116.2	181	25.9
Pull*Elbow level*Staggered stance	128.3	242.9	338.9	45.8	101.5	152.4	245	40
Pull*Knuckle level*Parallel stance	104	180.1	335	57.6	50.5	109.4	161.4	29.4
Pull*Knuckle level*Staggered stance	133.2	229.8	383.6	61.1	70.9	128.7	241.8	40.7

Table III: Analysis of Variance

Variables and Combinations	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P-value*
Gender	1	1012427	1012427	1012427	565.49	0.000
Action	1	94603	94603	94603	52.84	0.000
Stance	1	55	55	55	0.03	0.861
Handle height	2	20366	20366	10183	5.69	0.004
Gender*Action	1	18	18	18	0.01	0.920
Gender*Stance	1	564	564	564	0.31	0.575
Gender*Handle height	2	2625	2625	1313	0.73	0.481
Action*Stance	1	6606	6606	6606	3.69	0.055
Action * Handle height	2	3462	3462	1731	0.97	0.381
Stance* Handle height	2	216347	216347	108173	60.42	0.000
Gender*Action*Stance	1	3733	3733	3733	2.08	0.149
Gender*Action*Handle height	2	7061	7061	3530	1.97	0.140
Gender*Stance*Handle height	2	26533	26533	13267	7.41	0.001
Action*Stance*Handle height	2	4301	4301	2150	1.20	0.302
Gender*Action*Stance* Handle height	2	4680	4680	2340	1.31	0.271
Error	552	988276	988276	1790		
Total	575	2391656				

S = 42.31   R-Sq = 58.68%   R-Sq(adj) = 56.96%

IV is expressed in Eqn. 1:
FORCE = 257.12 – 83.85 (GENDER) + 25.63 (ACTION) – 6.48 (HANDLE HEIGHT) + 0.62 (STANCE) …… (Eqn. 1)
Where the independent variables are coded as: Gender: Male = 1 and Female = 2; Action: Push = 1 and Pull = 2; Stance = Parallel: 1 and Staggered: 2; Handle height: Shoulder level = 1, Elbow level = 2 and Knuckle level = 3.

Based on Eqn. 1, it was identified that gender is the most significant predictor to the pushing and pulling forces as represented by its coefficient of -83.85 (inverse proportional). It denotes that lower level of gender (level 1 = male) contributing greatest pushing and pulling forces. In addition to that, the action (coefficient of 25.63) and stance (coefficient of 0.62) have a positive correlation with the pushing and pulling forces. The interpretation is that, higher level of action (level 2 = pull) and stance (level 2 = staggered) contributing utmost force. On the other hand, the handle height has a negative correlation (coefficient of -6.48) with the pushing and pulling forces. It simplifies that lower level of handle height (level 1 = shoulder level) contributing higher force. Additionally, this study found that gender, action, and handle height were significant predictors to the pushing and pulling forces (P-value < 0.01), as shown in Table IV.

The regression model developed by this study is useful to predict the magnitude of force generated by individuals involved in pushing and pulling tasks/ activities. The model can be applied to anyone as long as the samples taken from the same population (Malaysian).

Relationship of Anthropometric Parameters and Force

Further statistical analysis, Pearson correlation was computed to assess the relationship between anthropometric parameters and force generated by the participants. The force is obtained from the combination of independent variables that exhibited the greatest magnitude. In this case, the combination was pull action, handle height at elbow level and staggered stance, as verified by the descriptive statistics in earlier section. In male participants, a strong positive relationship ($r = 0.60$) existed between the body weight and the force, as tabulated in Table V. This relationship was significant ($p < 0.01$). This finding indicated that increases in body weight were correlated with increases in force. The same trends were observed for knuckle height, forearm circumference, and upper arm circumference.

Similarly, a strong positive relationship ($r = 0.57$) existed between the shoulder height and the force among female participants (Table V). Also, this relationship was significant ($p < 0.01$). This result indicated that rises in handle height (shoulder level) were correlated with increases in force. The same patterns were observed for elbow height, and knuckle height.

DISCUSSION

Effects of Individual Factors

Table VI tabulates the mean values of push and pull forces compiled from several studies on pushing and pulling strength. Note that the experimental design of each study was matched as close as possible for a fair comparison. Referring to Table VI, it is clearly identified that individual factors associated with gender influenced the strength during symmetrical two-handed pushing and pulling experiments. Consistent with previous research, mean values for push and pull forces of male participants quantified by this study were

Table IV: Regression statistics, ANOVA, and coefficients values of variables

Regression Statistics	
Multiple R	0.69
R Square	0.47
Adjusted R Square	0.47
Standard Error	47.13
Observations	576

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	4	1123235	280808.8	126.41	3.118E-77
Residual	571	1268421	2221.402		
Total	575	2391656			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	257.12	11.45	22.45	1.64E-80	234.63	279.62	234.64	279.62
Gender	-83.85	3.93	-21.35	8.79E-75	-91.56	-76.13	-91.56	-76.14
Action	25.63	3.93	6.53	1.49E-10	17.92	33.35	17.92	33.35
Stance	0.62	3.93	0.17	0.87	-7.09	8.33	-7.09	8.33
Handle height	-6.48	2.41	-2.70	0.007	-11.20	-1.76	-11.21	-1.76

Table V: Correlation coefficient, *r* of anthropometric parameters and force

Anthropometric measurements	*Male*	*Female*
1) Body weight	0.60**	-0.12
2) Body height or stature	0.04	0.14
3) Shoulder height	0.11	0.57**
4) Elbow height	0.35	0.47*
5) Knuckle height	0.49*	0.43*
6) Forearm length	-0.05	0.22
7) Forearm circumference	0.57**	-0.04
8) Upper arm circumference	0.52*	0.10

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

observed higher than female participants. In general, males are stronger than females. The reason is males have bigger physical dimensions and muscle mass than females. Having a big body size and muscle mass gives a mechanical advantage to males as bigger muscle mass generates higher force. Additionally, the heavy body mass of males can also increase the coefficient of friction between the feet/ shoes and the floor [34], thus preventing males from slipping during the pushing and pulling experiments. Another reason determines the push and pull strength is the population factor. As shown in Table VI, the mean values of push and pull forces vary amongst participants' countries. For example, the push and pull forces of the study participants from the USA and Canada were higher than Asian populations such as Indian, Taiwanese and Malaysian, which have smaller anthropometric body sizes.

Effects of Handle Height

Handle height is essential because it influences the posture of the hand and back while performing pushing and pulling tasks. Consequently, posture of the hand and back determines the ability of a person to generate push and pull forces. Inappropriate handle height such as too low causes a person bends their trunk to push or pull the handle. Consequently, high peak compression forces may occur on the spinal column [43] and trigger back pain. This study revealed that both male and female participants generated high push and pull forces when the handle height is at higher position (shoulder and elbow levels) than lower level (knuckle height). Chow [34] suggested that the handle height for pulling and pushing tasks should be at waist level and shoulder level, respectively. Weston [33] proposed that higher handle heights are needed for both pushing and pulling exertions in a recent study. There are two reasons why a higher handle height is recommended for pushing and pulling tasks. Firstly, a study proved that the hands exert a lower push force at higher handle height when pushing heavy objects [44]. Secondly, from biomechanics point of view (especially the moment at the shoulder joint), this mechanical load is lower when pushing and pulling exertions are performed at shoulder level [45]. Based on these two solid reasons, the hands are in a good possession to generate more force when the handle is located at a high level.

Effects of Stance

This study revealed that both male and female participants obtained greatest push and pull forces when their feet in staggered stance. It was observed from the pushing experiment, both male and female participants tended to lean forward, pivoting about the rear foot to boost their pushing strength. Meanwhile, all participants tried to lean backward in the pulling experiment, pivoting about the front foot to maximize their pulling strength. The same observation was reported by Lee [46]. Furthermore, this finding can be explained by the advantage of body posture flexibility and stability. Standing with feet in staggered stance provides a wider foot stance, stabilizes the posture by leveraging the body mass and stature which consequently generate more force [34]. This finding shows a good agreement with a previous study which pointed that foot positions

Table VI: Mean value of push/ pull forces in previous studies, unit in Newton (N)

Studies	*Study population, (Sample size)*	*Conditions of push/ pull tests*	*Push (male)*	*Pull (male)*	*Push (female)*	*Pull (female)*
[35]	USA, (40)	Handle height at waist level and feet in parallel stance.	266	387	207	275
[36]	Canada, (24)	Handle height was 100 cm above the floor.	453.9	326.4	290.3	243.5
[37]	India, (920)	Horizontal handle at shoulder level, staggered stance.	253.8	234.2	183.1	185.1
[38]	India, (1701)	Exerts force in horizontal plane on the handle bar without jerks.	277	202.7	180.8	121.7
[39]	India, (200)	Pulling in the frontal direction with handle at waist level.	NA	198.9	NA	187.2
[40]	Taiwan, (60)	Isometric horizontal pulling strengths at 120 cm from the floor.	NA	291	NA	184.6
[41]	Taiwan, (10)	Pushing and pulling forces at 88 cm handle height.	305	385	NA	NA
[42]	Pakistan, (20)	Isometric horizontal pulling force in standing posture.	NA	490.5	NA	NA
This study	Malaysia, (47)	Handle height at elbow level and staggered stance.	233.3	242.9	121.7	152.4

significantly influence the push and pull strengths [47].

Effects of Push and Pull Actions
It was observed that the pull forces were invariably higher than push forces for both male and female participants of this study. This finding is in line with the study by Kumar [35]. One of the reasons is that pulling actions promotes safe handling as it creates a smaller compressive force and moment in the lower back than pushing under the same conditions [48]. In contrary to findings by Kumar [35], Agrawal [49] found that the push force is greater than pull force in pushing and pulling tasks.

CONCLUSION

The significant findings of this study are about the combination of action, handle height and stance in performing two-handed symmetrical pushing and pulling tasks in standing body posture. Based on the experimental results, this study quantified that the maximum magnitude of forces in pushing test were 233.3 N and 121.7 N for male and female participants, respectively. In pulling test, male and female participants recorded greatest forces of 242.9 N and 152.4 N, respectively. Specifically, pull action with handle height at elbow level and staggered stance generated greatest force for both male and female participants. This combination provides least muscle activation and may help to reduce discomfort and fatigue in the back and shoulder. However, push action with handle height at knuckle level and parallel stance should be avoided because this combination resulted in the lowest force, which requires people to exert higher muscle effort and trigger quicker physical fatigue. This study recommends the handle height of materials handling equipment (e.g. trolley, cart and hand pallet jack) is designed between the elbow to shoulder levels as this height provides greater force than low handle height. Additionally, staggered stance could be applied for acquiring high initial force in pushing and pulling tasks.

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