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Development of an Ergonomics Risk Assessment Tool for Pushing and Pulling (PUSHPULL) Activities at the Workplace

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ABSTRACT

The observational method remains the most widely utilized for assessing the risk factor of Work-related Musculoskeletal Disorders (WMSDs) as it is inexpensive, quick and practical in field data collection. However, there is some limitation with the current risk assessment on Pushing and Pulling (PP), such as the need to use expensive force measuring equipment, limited coverage of critical variables for assessing the risk and psychometric properties for the method, which is not adequately established. This study aims to develop a new method for assessing the PP of wheeled equipment called the PUSHPULL method and establish the reliability and validity of the PUSHPULL method. Two stages are involved in developing the PUSHPULL method: i) development of PUSHPULL specification and ii) psychometric properties evaluation. Selection of variables for inclusion in the PUSHPULL method employed three strategies: i) literature review, ii) expert panel review, and iii) survey among Occupational Safety and Health (OSH) practitioners. Current assessment methods were also reviewed to assist in assigning rating scores. Psychometric properties evaluation was performed for content validity (representative, relevance and clarity) and inter and intra-rater reliability testing. Consequently, content validity was performed by six experts. The results of content validity (S-CVI/Ave) were discovered to be in the acceptable range of 0.97, 0.98 and 0.82, respectively, for representativeness, relevance and clarity. Based on the inputs from the expert panel, improvements were made, and prototype 2 was generated. Prototype 2 underwent reliability testing, and Gwet AC_1 was discovered to be 0.596 (moderate) and 0.77 (good), respectively, for inter and intra-rater reliability. The PUSHPULL method was developed based on empirical data from a literature review, expert panel review and inputs from OSH practitioners. The method covers all the significant variables related to the risk of PP. Moreover, the reliability and validity of the PUSHPULL method were clarified during the development stage. The tool can determine the risk level and prioritize the intervention.

Keywords:
Risk assessment method; Pushing and pulling; Ergonomics tools and methods

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1. Introduction

Nowadays, employers are increasingly concerned about ergonomics because of its effects on both the performance, safety and health of workers [1]. Lifting, lowering, and carrying have been major activities of manual handling [2], which resulted in ergonomics risk [3]. Thus, Pushing and Pulling (PP) has been introduced to mitigate the risk of other manual handling activities [3]. Marras *et al.,* [4] highlighted that PP is not as simple once it has been accepted since they involve complex biomechanics compared to lifting and lowering.

Kuijer *et al.,* [5], Frost *et al.,* [6], and Hoozeman *et al.,* [7] reported that PP increases the risks of a shoulder injury. However, it does not necessarily lower back pain and is a major cause of musculoskeletal injuries at the workplace [8].

One of the key elements for managing Musculoskeletal Disorders (MSDs) at the workplace is ergonomics management, which can be accessed via ergonomics risk assessment [8-12]. As per David [12], there are three ergonomics risk assessment categories: self-report, observation methods (simple and advanced techniques), and direct measurement. Nevertheless, safety and health practitioners always prefer the simple observational method for assessment [4,13-15]. Health and Safety Laboratory [14] suggested that the assessment tool for PP operation should be user-friendly, reduces or eliminates the need for force measurement, requires minimal expert knowledge to apply, identifies high-risk operations, and intuitively indicates good practice.

Assessment for PP tasks can be performed using Revised Tables of Maximum Acceptable Weights and Forces [16], Mital Table [17], Key Indicator Method (PP) [18], PP Operations Assessment Charts Tool (PPAC) [19], ISO 11228-2: 2007 Ergonomics – Manual handling – Part 2: PP [20], AORN Ergonomics Tool 7: Pushing, Pulling and Moving Equipment on Wheel [21], Risk Assessment of Pushing and Pulling (RAPP) tool [22], PP: An assessment tool for OHS practitioners [23] and DUTCH: A New Tool for Practitioners for Risk Assessment of Push and Pull [24]. Most of the abovementioned tools used force exertion as one of the assessment criteria, which required the usage of a force gauge, which is very limited among safety and health practitioner. Nevertheless, most assessment tools only cover certain aspects of the risk factors and do not cover all the risk factors for PP activities. Furthermore, most tools do not undergo reliability and validity tests during development. However, these psychometric properties are essential for the assessment tool [13,25,26]. Therefore, an attempt has been made to address the limitation mentioned above by developing a new assessment tool for PP of wheeled equipment in the workplace called PP risk assessment (PUSHPULL). The PP activities in the context of the article is concerning on wheeled equipment such as trolley, cart and pallet jack and using hand forces.

2. Methodology

There are two stages involved in developing the PUSHPULL method

i. development of PUSHPULL specification
ii. psychometric properties evaluation

Figure 1 displays the stages in the development process.

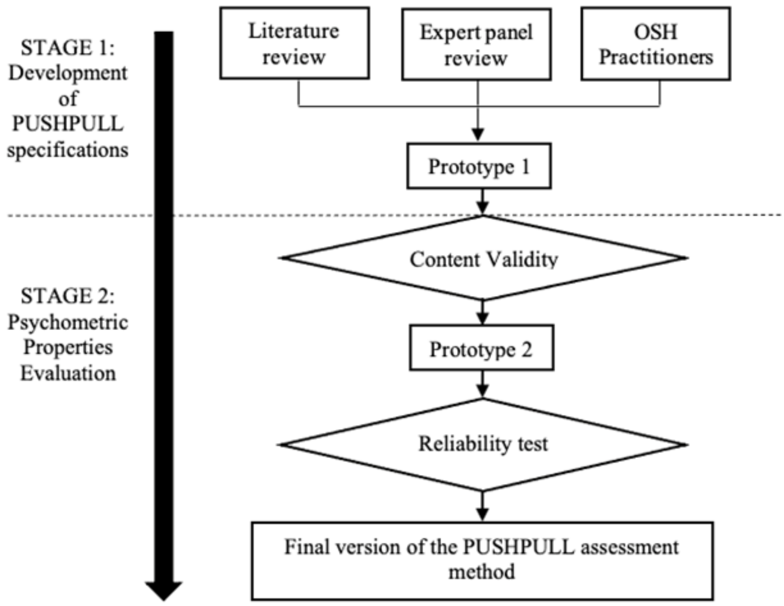

Fig. 1. PUSHPULL development process

2.1 Stage 1: Development of PUSHPULL Specifications

Selection of variables for inclusion in the PUSHPULL method employed three strategies:

i. literature review
ii. expert panel review [27]
iii. survey among Occupational Safety and Health (OSH) practitioners [28].

Based on the three strategies, the most critical variables for PP activities were selected. A detailed explanation of methods and result from the expert panel review and survey among OSH practitioners were reported elsewhere [27,28]. Moreover, current assessment methods were also reviewed to assist in assigning rating scores.

2.2 Stage 2A: Psychometric Properties Evaluation – Content Validity Testing

Content validity testing was conducted for prototype 1. Thus, an invitation for participation in the content validity study was sent out to 20 experts from around the world through e-mail to ensure enough experts' responses for statistical significance. Note that a content validity form was prepared based on each item in the PUSHPULL method. The aspect of the measured content validity was representative, relevance and clarity with a 4-point ordinal Likert scale. Lynn [29] pointed out that 4 points scale is preferred to avoid having a neutral rating and produce a meaningful Content Validity Index (CVI) during data analysis. The content validity evidence can be represented by the CVI, in which CVI for the item (I-CVI) and CVI for scale (S-CVI) [30]. Subsequently, the rating score by the experts should be transformed into 1 (for scores 3 or 4) or 0 (for scores 1 or 2) [29-31]. Note that scores 1 and 2 are considered content invalid, and scores 3 and 4 are considered content valid [32]. S-CVI/Ave is more liberal and is preferred by Polit and Beck [31], with an acceptable standard for S-CVI/Ave of 0.8. Prototype 1 was improved based on the content validity results, the experts' comments and suggestions, and prototype 2 was created.

2.3 Stage 2B: Psychometric Properties Evaluation – Reliability Testing

The potential user of the tool was recruited, and proper training on the usage of the PUSHPULL method was presented to 33 participants via an online platform. Correspondingly, they were provided three case studies for assessment using the PUSHPULL method. Case study 1 is about pulling at the bakery factory, case study 2 is pulling trolley at chemical processing and case study 3 is pushing done by the storekeeper. One reviewing the case study, they need to submit the filled-up PUSHPULL form to the researcher. Intra-rater reliability was conducted after intervals of one week, where the participants assessed the same case study. In this research, Gwet's AC_1 was reported, replacing Cohen's Kappa to minimize the effect of the Kappa Paradox [33].

3. Results

3.1 Stage 1: Development of PUSHPULL Specifications

Based on the literature review, expert panel review [27] and a survey among OSH practitioners [28], twelve variables (type of device, load weight, gender, wheel diameter, handle height, hand grip, frequency, distance, posture, floor condition, congestion and task duration) were revealed to be critical in the assessment of PP. Thus, the PUSHPULL method employed these twelve variables as assessment criteria.

3.1.1 Type of device, load weight and gender

It is common to combine the type of device and load weight to assess PP [34,35]. On the other hand, the suggested force or weight during the PP task will be based on gender characteristics when using methods such as International Organization for Standardization (ISO) [20], Snook and Ciriello [16], and DUTCH [24].

Additionally, in the PUSHPULL method, the variables of device type, load weight and gender are combined, considering that the three variables are interconnected. Past literature has demonstrated that the type of devices can be a risk factor in PP activities and the development of musculoskeletal injuries, higher heart rate, oxygen intake and required hand forces [36-41]. Another vital variable related to biomechanics during PP activities and a significant risk factor for MSD among workers is load weight [2-4,38,40,42-59]. Consequently, the factor influencing PP activities is gender due to evidence that males exert greater forces compared to females [45,50,51,54,60-65]. Female to male strength ranged from 67% to 70% [61,65,66].

Thus, for the PUSHPULL method, the criteria rating was developed based on the adjustment of dynamic strength and separated based on gender. The data from RAPP [35] and KIM-PP [34] were adjusted for gender based on 70% strength [61,65,66]. This is to create the rating score for the type of device, gender and load weight for PUSHPULL.

3.1.2 Wheel diameter

Although wheel diameter is one of the important factors during PP, it is always discounted during the assessment [67]. A larger wheel requires less force while manoeuvring the cart [38,39,55,68-71]. Drury *et al.,* [72] reported that the staff could push carts 16% faster when the wheel size is 25 cm compared to the 7.5 cm wheel size. Das *et al.,* [73] recommended using a 20 cm wheel for a hospital cart to reduce the pushing force. Al Eisawi *et al.,* [55] studied the effect of wheel diameter (51 mm, 102 mm and 153 mm) on PP force and discovered that the wheel diameter is inversely proportional to push/pull force. Correspondingly, the wheel diameter in PUSHPULL has been categorized into three divisions; equal or more than 15 cm (low), 7.5 cm to 14.9 cm (medium) and less than 7.5 cm.

3.1.3 Handle height

Handle height has been an important topic of study in the literature for many years. Studies have demonstrated a strong and consistent link between handle height and biomechanics during PP, which could directly contribute to the development of musculoskeletal injuries [4,38,42,44,45,53,59,61,62, 64,70,71,74-81,82-88]. In the PUSHPULL assessment method, the reference of handle height is based on the physical anatomy reference rather than dimension since the cost of biomechanics depends on individual anthropometry and is not based on standardized dimension.

In the PUSHPULL method, the height is further divided into two categories, PP, as the implication of height towards the biomechanical loading depends on the type of motion (pushing or pulling). Thus, during pushing, the handle height between shoulder to elbow is considered a low risk, elbow to knuckle height is medium risk, whereas below knuckle or above shoulder height is considered a high risk. As for the pulling, low risk is when the handle height is between elbow and knuckle height, and the medium risk is between elbow and shoulder. Meanwhile, high risk is when the handle height is below knuckling height or above shoulder height.

3.1.4 Hand grip

Power grip is always preferred because it produces the highest degree of contact between the hand and handles [81] regarding the high push and pull forces required [89]. Pressure force during hand grip could lead to musculoskeletal injuries with time exposure [90-94]. Moreover, awkward wrist posture has been indicated to be a contributing factor to wrist injuries [92,95,96]. Three rating scores were assigned for hand grip categories; low risk if one can exert a power grip, medium risk for partial contact with the handle, and high risk if no proper handle is observed.

3.1.5 Frequency

Frequency as a strong determinant for the occurrence of musculoskeletal injuries has been well-studied [68,77,97-99]. A few researchers in the past reported that frequency should be considered during the assessment of PP due to the impact on biomechanical load [53,100,101]. Furthermore, the frequency of PP is well studied, and it is reported that it is inversely proportional to force during PP [16,17,62,82,102]. In the PUSHPULL method, there are three categories for frequency and all the frequency is based on per hour. The categories are; 1 to 12 push/pull per hour (score 1), [14-31] push/pull per hour (score 2) and 31 to 240 push/pull per hour (score 3), adapted from Lind [23] with only three categories.

3.1.6 Distance

Previous evidence on PP distance revealed that it is inversely proportional to force exertion during PP activities [16,17,62,82,103]. Mital *et al.,* [17] concluded that the capacity is significantly reduced if the PP distance exceeds 10 m. Once the distance increases, the risk factor also proportionally increases [14,16,17,100,104]. The distance category in the PUSHPULL method is further divided into three risk categories: 8 m or less (score 1), more than 8 m and below 30 m (score 2) and more than 30 m (score 3).

3.1.7 Posture

Poor PP posture, such as bending and forward inclination, has a high biomechanical impact on the body [43,50,59,80,83,86,105-108]. In the PUSHPULL method, there are three categories for risk rating, as provided below:

i. Green (low risk) – Back is almost neutral most of the time (0°)
ii. Yellow (medium risk) – moderately flexed or twisted or side bent; Flexion (0° – 20°) or back extension (0° – 20°)
iii. Red (high risk) – excessively flexed or twisted or side bent; Flexion (more than 20°) or back extension (more than 20°)

3.1.8 Floor condition and obstacles

Different types of surface conditions have the potential to impact the performance and musculoskeletal system in various ways, which could increase the likelihood of injuries [38,40,43,52,54,57,64,109-111]. The research examined the inclination, ramp and curb and established a strong association between the variables and human biomechanics, musculoskeletal demand and perceived exertion [46,47,54,56,79,88,107,111-115]. In the PUSHPULL method, a score of 1 (low; green) is given to "Dry clean, No obstacles, Good conditions" score of 2 (medium; yellow) for "Mostly dry, Slight inclines 2°, One type of obstacles, Trip/collision hazards" and finally score 3 (high, red) for "Contaminated, Inclines surface more than 2°, Ramp, unpaved/rough surface, More than 2 type obstacles, Wet, soft, uneven/unstable, Carpeted floor."

3.1.9 Congestion and space constraint

Although congestion or space constraints have limited publication, the available research established a strong association between force exertion during the PP tasks and impact on to shoulder [54,83,109,116,117]. For example, Zhang *et al.,* [54] recommended that it should be included during the assessment of PP and excluded that it could miscalculate the risk of musculoskeletal injuries. In the PUSHPULL method, congestion was categorized into three different risk levels such as "no congestion, posture and movement unhindered" for the low-risk level, "restricted movement" for medium risk level and "severely restricted movement" for the high-risk level.

3.1.10 Task duration

The association of task duration and MSD during PP activities has been reported by Chinichian et *al.,* [118]. Muscle fatigue and decreased strength were reported due to increased task duration [90,99]. In addition, there has been a constant recommendation by the experts for the inclusion of task duration as a criterion during the assessment of PP [53,70,77,101]. In prototype 1, the task duration is calculated based on the function of the multiplier. Nonetheless, after the content validity testing, a matrix table was created based on the task duration and score to determine the risk level and priority.

Therefore, the task duration score (prototype 2) was categorized into four different risk levels: low for less than 2 hours, medium for 2-4 hours, high for 4-8 hours and very high for 8-10 hours.

3.1.11 PUSHPULL scoring system (prototype 2)

Quick Exposure Checklist (QEC) [13], Manual Handling Assessment Chart (MAC) [14], KIM-PP [119], Rapid Entire Body Assessment (REBA) [120], Rapid Upper Limb Assessment (RULA) [121] Entire Body Risk Assessment (ENBORA) [122] used a sum score of weighted items. A similar approach was used in the PUSHPULL development due to the visual representation and mathematical scoring system, which utilized the addition principle. The rating for each variable divided into Low (1), Medium (2) and High (3) based on the descriptions in each category. Only for the "Type of device, load weight and gender" there is additional score, Very High (4). The calculation for the total score as below:

For example, if 5 of the categories scored Score 1 (Low) while 4 of the categories in the PUSHPULL form scored Score 2 (Medium), thus the calculation score for that pushing and pulling activity is (5X1)+(4X2)=13 which indicate risk level of Low.

Subsequently, a matrix table with score and duration was developed to determine the overall risk level and indicate the priorities. Table 1 summarizes the combination of score, total score and risk level.

Table 1
Combination of the score, total score and risk level

Score 1 (Low)	Score 2 (Medium)	Score 3 (High)	Score 4 (Very High)	Total score	Risk Level
9	0	0	0	9	Low
8	1	0	0	10	Low
7	2	0	0	11	Low
6	3	0	0	12	Low
5	4	0	0	13	Low
4	5	0	0	14	Medium
3	6	0	0	15	Medium
2	7	0	0	16	Medium
1	8	0	0	17	Medium
0	9	0	0	18	Medium
0	8	1	0	19	Medium
0	7	2	0	20	Medium
0	6	3	0	21	Medium
0	5	4	0	22	Medium
0	4	5	0	23	High
0	3	6	0	24	High
0	2	7	0	25	High
0	1	8	0	26	High
0	0	9	0	27	High
0	0	8	1	28	Very High

Figures 2 and 3 illustrate the PUSHPULL form (prototype 2).

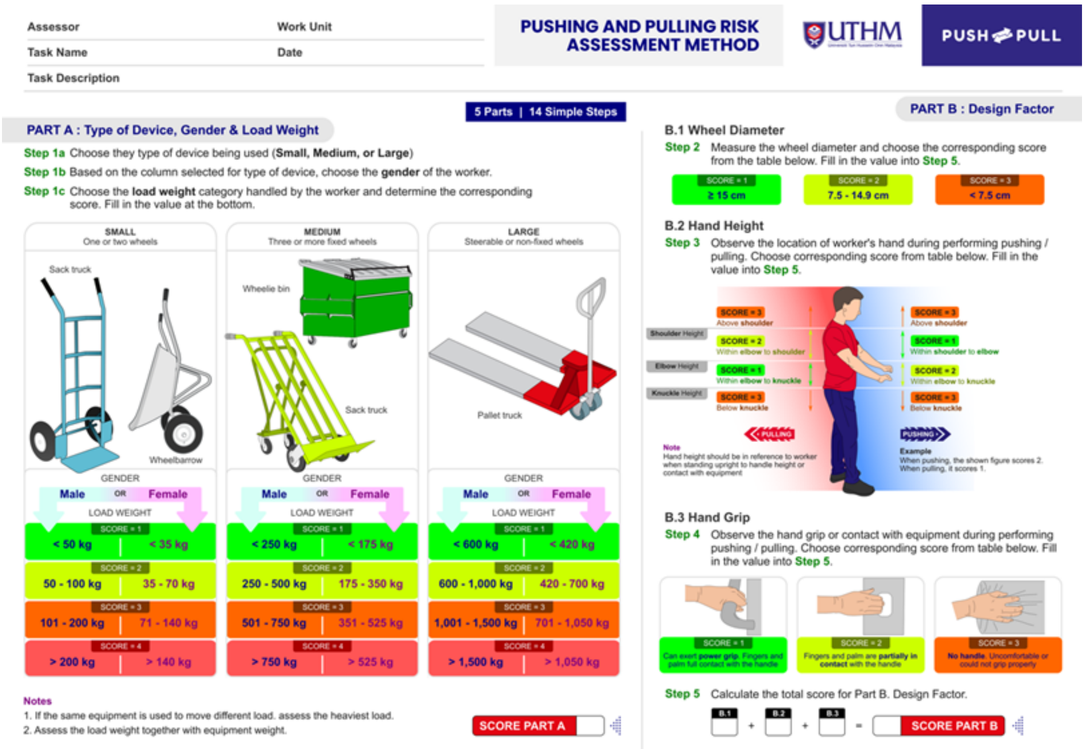

Fig. 2. PUSHPULL form-page 1 (prototype 2)

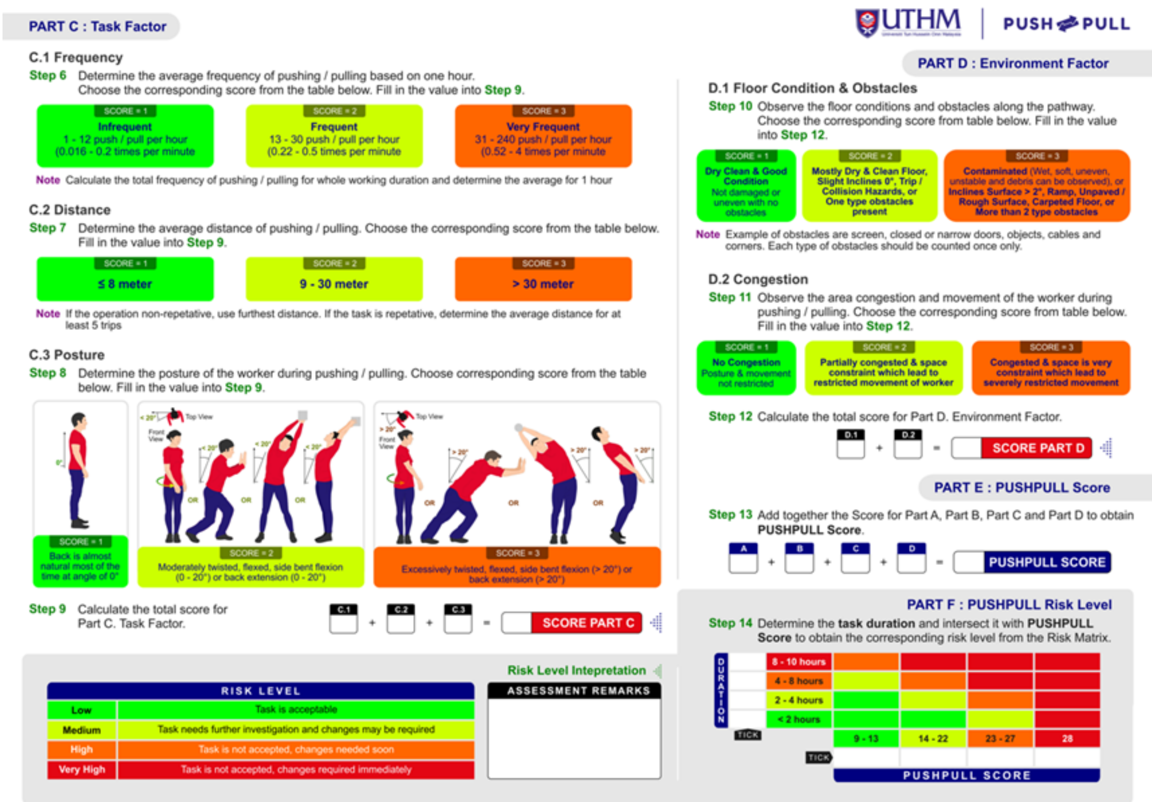

Fig. 3. PUSHPULL form-page 2 (prototype 2)

3.2 Main Findings
3.2.1 Psychometric properties evaluation – content validity testing

Lynn [29] has mentioned that a minimum of five experts is sufficient, while Yusof [30] reported that content validation should be at least six and not more than ten. The reviewer's experience ranges from 7 to 20 years in Ergonomics and Human Factor Engineering. Other than that, three reviewers were from Malaysia, two from India and one from Japan. Demographic representation of the expert panel for content validity study as presented in Table 2.

Table 2
Demographic representation of the expert panel for content validity

No	Reviewer	Age	Occupation	Working experience in Ergonomics field/ Human Factor Engineering (years)	Country
1	Panel 1	42	Researcher	18	India
2	Panel 2	49	Professor	20+	Malaysia
3	Panel 3	39	Associate Professor	12	Malaysia
4	Panel 4	34	Senior researcher	7	Japan
5	Panel 5	49	Technical Expert	21	Malaysia
6	Panel 6	40	Senior Assistant Professor	11	India

3.2.1.1 Representativeness

The acceptable CVI value for at least six experts is 0.83 [29,31]. Eight out of ten variables in the PUHSPULL method achieved a value of I-CVI of 1.00, while another two variables achieved a value of 0.83, an acceptable value [29,31]. This indicates that all the items in the PUSHPULL method represent assessing the overall PP activities. The S-CVI/Ave value is 0.97, more than the acceptable value of 0.8 [31].

3.2.1.2 Relevance

Nine variables reported a value of 1 for I-CVI, while one variable (task duration multiplier) exhibited a value of 0.83. Thus, all the items achieved the minimum requirement [29,31]. The values of S-CVI/Ave are 0.98 for the content validity of relevance and more than 0.8, which suggests acceptability [31].

3.2.1.3 Clarity

The value of S-CVI/Ave is 0.82. Three items scored less than 0.83 for I-CVI: the type of device, gender and load weight, frequency and task duration multiplier. Since clarity is the only issue here, thus, the variable is not eliminated but is improvised.

3.2.2 Psychometric properties evaluation – reliability testing

Thirty-three participants participated in the inter-reliability study conducted. Table 3 provides the years of experience conducting ergonomics risk assessment and working experiences in the OSH or ergonomics field. The total mean experience in conducting ergonomics risk assessment (ERA) was 2.06 (SD = 2.44) in the range of 0 to 8 years, while the mean of working experience in OSH or Ergonomics field was 5.55 (SD = 5.06) in the range of 0 to 20 years.

Table 3
Demographics characteristic for experience in ERA and working experience

Group of participants	Mean	Std. Deviation	Range	Minimum	Maximum
Experience in conducting ERA (years)	2.06	2.44	8	0	8
Working Experience in OSH/Ergonomics (years)	5.55	5.06	20	0	20

Based on Gwet [123], the value of Gwet AC_1 less than 0.2 demonstrates poor agreement; 0.2 to 0.4 is a fair agreement, 0.4 to 0.6 is a moderate agreement, 0.6 to 0.8 is a good agreement, and 0.8 to 1.0 is a very good agreement. Overall, Gwet AC_1 for all three tasks was 0.596 (moderate). The fair and poor agreement for the floor condition and congestion, respectively, could be explained by the assessment conducted using video observation. Thus, the potential loss of the larger environmental context outside the view of the lens [124]. Hence, it may affect the judgment of the rater. Meanwhile, the poor agreement between the rater for the posture could be explained with observation in the video, where they could not have the right direction for determining the trunk posture angle. Furthermore, it is difficult to determine the angle only via observation [13,15,25].

Overall, the inter-rater reliability of the PUSHPULL was demonstrated better than QEC, where the agreement for each item was a poor level agreement to a fair level of agreement (12). Table 4 summarizes the inter-rater reliability results.

Table 4
Inter-rater reliability

PUSHPULL Items	Case Study 1		Case Study 2		Case Study 3	
	Percentage of Agreement (%)	AC_1	Percentage of Agreement (%)	AC_1	Percentage of Agreement (%)	AC_1
Type of device, Gender and Load Weight	87.50	0.870	68.75	0.656	75.00	0.730
Wheel Diameter	93.75	0.936	68.80	0.638	87.50	0.867
Hand Height	50.00	0.331	62.50	0.466	56.20	0.465
Hand Grip	62.50	0.469	81.25	0.795	87.50	0.867
Frequency	50.00	0.343	87.50	0.859	75.00	0.719
Distance	75.00	0.718	93.75	0.936	75.00	0.718
Posture	75.00	0.661	50.00	0.367	37.50	0.180
Floor Condition & Obstacles	43.80	0.274	62.50	0.466	87.50	0.832
Congestion	87.50	0.834	43.80	0.181	50.00	0.356
Duration	56.25	0.493	56.20	0.502	62.50	0.580
Risk Level	62.50	0.572	50.00	0.421	62.50	0.580

Intra-rater reliability test is also known as test and retest reliability. The same rater will evaluate the same condition after one week. The total rater who joined during the second round of data collection was 32, and 1 dropped out. The analysis for intra-rater reliability was performed for 32 raters. Overall, the average Gwet AC_1 for all three tasks was 0.770 (good), higher than the inter-reliability test, 0.596 (moderate). Table 5 provides the intra-rater reliability results.

Table 5
Intra-rater reliability

PUSHPULL Items	Case Study 1		Case Study 2		Case Study 3	
	Percentage of Agreement (%)	AC_1	Percentage of Agreement (%)	AC_1	Percentage of Agreement (%)	AC_1
Type of device, Gender and Load Weight	93.80	0.936	87.90	0.867	90.60	0.900
Wheel Diameter	90.62	0.902	90.60	0.896	87.50	0.867
Hand Height	62.50	0.497	71.90	0.605	87.50	0.849
Hand Grip	78.10	0.687	93.80	0.932	100.00	1.000
Frequency	84.40	0.802	90.60	0.893	93.80	0.932
Distance	84.40	0.820	96.88	0.968	84.38	0.831
Posture	68.80	0.580	81.20	0.758	68.80	0.591
Floor Condition & Obstacles	81.20	0.755	59.40	0.419	75.00	0.659
Congestion	78.10	0.700	87.50	0.821	84.40	0.797
Duration	81.20	0.790	75.00	0.708	68.80	0.631
Risk Level	78.10	0.757	68.80	0.635	71.90	0.671

Generally, the average level of agreement for all three case studies for the intra-observer (AC_1 = 0.748 – 0.794) was higher than the inter-observer (AC_1 = 0.571 – 0.627) and concorded with past studies [13,125].

4. Discussion and Conclusion

The PUSHPULL method has been developed to assess the PP of wheeled equipment in the workplace. A rigorous process has been employed for selecting variables for inclusion in the PUSHPULL method, mainly literature review, expert panel guidance, and safety and health practitioners' input. This research is unique in the sense of utilizing 3 strategies for selection of critical variables for the PUSHPULL method.

Psychometric evaluation for the PUSHPULL method is conducted at the development stage itself to determine any short coming if any [126]. Two psychometric studies conducted were content validity and reliability study (inter-rater and intra-rater). Content validity denotes the extent to which an instrument represents the measured construct. This process, which provides concrete evidence to support the measurement tool's authenticity, uses experts for validation [29,30]. Instrument representativeness and relevance are used to examine content validity [30]. In this study, item clarity was also included as the research subject [32]. The first prototype of PUSHPULL was tested for content validity, and the results revealed S-CVI/Ave for representative, relevance and clarity to be 0.97, 0.98 and 0.82, respectively and exceeded the standard value of 0.8 [31].

Based on the feedback and recommendation by the experts, some modifications were made to prototype one and prototype two were generated. Moreover, the inter and intra-rater reliability was established for the PUSHPULL prototype two through a training session, and the value of Gwet AC was calculated for the agreement analysis. To ensure the understanding of using the PUSHPULL method is well received, each step explained in detail using example of a case study in which the raters follow through until the end results. Once the knowledge and experience of using it established, they were given the three case studies. As a result, the average Gwet AC value for inter-rater reliability for all three tasks was 0.596 (moderate), while intra-rater reliability was discovered to be 0.77 (good).

5. Recommendations

In the future, the PUSHPULL method can be tested for usability and construct validity in relation to other established methods. Furthermore, a user guide for the PUSHPULL method should be developed for reference by the users. The user guide should provide basic information about the method and the step-by-step using the method.

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