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Effects of the maximum acceptable level of physical activity on physiological and psychological strains for Taiwanese females of different age groups

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ABSTRACT

The prevalence of musculoskeletal disorders (MSDs) across different countries, with resulting DAFW and WC claims, indicates that MSDs are significant health problems in the work environment. As the global labor force ages, maintaining regular and adequate levels of physical activity (PA) has been recommended by the World Health Organization (WHO) as one of the protective and proactive strategies to reduce the risk of musculoskeletal disorders, especially for mid-life and older adults. Currently, inconsistent findings have been reported regarding the effectiveness of PA interventions on reducing musculoskeletal symptoms. The inconsistent effects may come from different levels of PA intervention administered across studies or the scarcity of studies that fully complied with the WHO's recommended PA guideline. Accordingly, this study adopts a psychophysical approach for Taiwanese females of three age groups to determine the maximum acceptable level of physical activity (MAL-PA) using laboratory-owned shoulder-upper extremity and low back-pelvis fitness training equipment. In addition, the strain levels associated with the MAL-PA determined were assessed objectively and subjectively to be further examined for their differences with existing or future studies. The results show that the determined MAL-PA decreased with age while performing functional strengthening exercise using shoulder-upper extremity fitness training equipment and increased with age while performing functional strengthening exercise using low back-pelvis fitness training equipment. The mean heart rates measured associated with MAL-PA showed that the participants are pacing themselves appropriately during each MAL-PA simulation. Subsequently, MAL-PA intervention could be adopted in future studies to make a comparative evaluation of the effects on reducing musculoskeletal symptoms to preserve the worker's health and safety when achieving and maintaining an active, productive, and prolonged working life.

Keywords: Musculoskeletal disorders, Maximum acceptable level of physical activity, Physiological strain, Subjective strain, Wearable sensing device.

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1. INTRODUCTION

Work-related musculoskeletal disorders (WRMSDs) accounted for 32% of all work-related illness cases and 26% of total lost workdays in 2023/2024, as reported by the Health and Safety Executive (HSE) of Great Britain (HSE, 2024). The percentages of body parts affected by WRMSDs are the back (43%), the upper limb or neck (37%), or the lower limbs (20%). Among the total non-fatal occupational injuries and illness cases for all workers in the US (counted in 2015), the US Bureau of Labor Statistics showed that 32% were musculoskeletal disorders (MSDs) cases (USBLS, 2016). In addition, 30% of the total days away from work (DAFW) cases reported in 2018 are MSDs cases in the US private sector (USBLS, 2020). In the European Union, 38% of the total occupational injuries/injuries were MSDs in twelve Member States (EUMUSC, 2013).

Among 18815 workers surveyed in Taiwan during 2010, the most commonly affected MSDs regions are the neck, shoulders, lower back, and upper extremities for around 40%–60% of workers (ILOSH, 2011). The Bureau of Labor Insurance (BLI) of Taiwan also showed that the ratios of workers' compensation (WC) claim of WRMSDs to total WC claims (all occupational injuries/illnesses) were 83.2%, 78.9%, 84.9%, 55.2%, and 84.3% for 2017 to the Jan.–Sept. of 2021 (TWBLI, 2021). The prevalence of MSDs across different countries, with resulting DAFW and WC claims, indicates that MSDs are significant health problems in the work environment. Follow-up intervention strategies should also be provided/adopted to reduce the occurrences of WRMSDs.

Sowah et al. (2018) performed an overview of systematic reviews of low back pain (LBP) prevention interventions with the potential to be implemented in workplace settings. Among 28 eligible review articles included published between 1994 and 2016, the reported interventions were categorized under three broad groups: (1) devices, technologies, or workplace modifications; (2) educational and behavioral interventions; and (3) exercise/physical activity. Category 1 interventions included lumbar supports and other assistive devices (back belts, braces, corsets) (15 reviews, 18 studies), shoe insoles (4 reviews, 6 studies), and workplace/risk factor modifications (6 reviews, 10 studies). Category 2 interventions comprised educational programs such as back schools (10 reviews, 30 studies), MMH techniques or advice (6 reviews, 24 studies), and other types of instruction (4 reviews, 14 studies) including pamphlets, booklets, videos, and e-mail discussions aimed at providing knowledge on how to prevent LBP at the workplace. Category 3 interventions were reported in 12 reviews (35 studies) consisted of strengthening and endurance (abdominal and back extensor muscles), stability and flexibility, calisthenics (exercises without the use of equipment), stretching, and cardiovascular fitness exercises with duration and frequency varied considerably from 3 months follow-up to 18 months follow-up (5 min to 60 min per session). Their overview results found evidence of effectiveness for exercise interventions and suggested that physical activity and exercise programs can be prescribed to workers with the potential to prevent/reduce LBP. No other type of intervention was found consistently effective in the prevention of LBP.

Published articles regarding upper extremity musculoskeletal disorders (UEMSDs) prevention interventions with the potential to be implemented in workplace settings had been systematically reviewed by Van Eerd et al. (2016). Among the 9909 references searched from 6 electronic databases between January 2003 and April 2013, 30 different intervention categories were grouped by the authors from 61 high-quality and medium-quality studies. Van Eerd et al. (2016) further evaluated these 30 intervention categories and recommended "workplace-based resistance training exercise" with strong evidence to be implemented for preventing and managing UEMSDs and symptoms. Moderate evidences for UEMSDs and symptoms prevention were also reported while prescribing "stretching programme", "mouse use feedback" and "forearm supports" interventions. Recently, Tersa-Miralles et al. (2022) surveyed 276 articles published from January 2010 to December 2020 in a systematic review article. Seven studies with a total of 967 participants met their inclusion criteria and suggested that exercise interventions (with a wide variety of exercise routines) have shown effects for reducing MSDs on the lower back, neck, and general regions of the body.

Physical activity (PA), including the "exercise" subcategory, is defined by WHO (2024) as "any bodily movement produced by skeletal muscles that requires energy expenditure," which includes walking, cycling, wheeling, sports, active recreation, play, etc. WHO stated that regular PA provides significant physical and mental health benefits, contributes to the prevention and management of noncommunicable diseases such as cardiovascular diseases, cancer, and diabetes, reduces symptoms of depression and anxiety, enhances brain health, and can improve overall well-being. However, WHO had not indicated the benefits of regular PA on lowering the risk of MSDs for adults. In addition, not enough evidence of PA interventions (e.g., aerobic, postural, or specialized exercise programs, etc.) on MSDs was also reported in Van Eerd et al.'s (2016) review study for self-employed persons, computer operators, visual display unit workers, etc. Sung et al. (2024) also indicated that no statistically significant differences were found after 12 weeks PA intervention in the reductions of pain intensity for females of young adults (ages 20–35 years), middle-aged adults (ages 36–55 years), and older adults (aged older than 55 years). Though the PA effect on cardiovascular function improvements and lesser magnitudes of muscular demands were reported. Moreira et al. (2021) and Dalager et al. (2023) stated that the inconsistent findings were obtained since the degree of adherence of PA interventions with WHO guidelines (e.g., 150–300 minutes of moderate-intensity activity per week) is scarce in the literature. In addition, Machado-Matos and Arezes (2016) indicated that the inconsistent PA effects may come from different levels of PA intervention administered in different studies. Andersen et al. (2012) also stated that the optimal combination of exercise frequency and duration to be implemented for reducing upper extremity symptoms remains unknown.

As stated above, there is a lack of articles discussing the PA intervention levels for MSDs prevention when the degree of adherence to WHO guidelines is met. To make the administered PA interventions comparable to existing or future studies, a psychophysical approach was adopted to assess the maximum acceptable level of PA (MAL-PA) interventions for Taiwanese female adults of three age groups. In addition, this study used wearable sensing devices and subjective assessment tools to measure various physiological and psychological strain levels associated with the determined MAL-PA interventions. Then, the

MAL-PA intervention could be adopted subsequently in future studies to make a comparative evaluation of the effects on musculoskeletal symptom reduction to preserve the worker's health and safety when achieving and maintaining an active, productive, and prolonged working life.

2. METHODOLOGY

2.1 Subjects

Twenty-six females categorized by age (Petry, 2002) into young adults (ten subjects aged 20–35 years), middle-aged adults (eight subjects aged 36–55 years), and older adults (eight subjects aged older than 55 years) participated in this study. Free of WRMSDs in the upper extremities and lower back within the prior three months was self-reported by each subject during the recruiting process. Anthropometric data of each subject, such as height, weight, maximum voluntary contraction (MVC) grip and palm pinch strength, as shown in the previous research (Sung et al., 2024), were measured using a scale, a tape measure, a Jamar grip dynamometer, and a Jamar pinch gauge, respectively. A steady exertion sustained for five seconds and at least ten-minute rest periods between exertions, with testing postures recommended by Sung (2022), was followed. In addition, two replications within 10% tolerance of the mean score were recorded. The mean age, height, and BMI of young adults, middle-aged adults, and older adults are 23.5 ± 1.4 years, 47.9 ± 3.6 years and 58.0 ± 2.9 years, 159.5 ± 6.7 cm, 157.7 ± 4.4 cm, and 156.9 ± 4.1 cm, and 22.8 ± 4.2 kg/m^2, 26.1 ± 2.9 kg/m^2, and 23.7 ± 2.2 kg/m^2, respectively. This study has been approved by the Institutional Review Board of Dali Jen-Ai Hospital (Taichung, Taiwan).

2.2 MAL-PA Determination

Laboratory-owned shoulder-upper extremity fitness training equipment (Fig. 1) and low back-pelvis fitness training equipment (Fig. 2) were used to determine the maximum acceptable level of physical activity (MAL-PA). Each subject attended five one-hour experiments on five different days, separated by at least 24 hrs for each equipment. In each one-hour experiment, two 15-minute functional strengthening exercises were performed with one randomly selected resistance level (L12, L11, L10, L9, or L8), where L10 is the default resistance level (Sung et al., 2024), separated by a 15-minute break. The default target speed (degrees/s) and range of movement (degrees) training parameters for shoulder-upper extremity fitness training equipment (30 degrees and 110 degrees) and low back-pelvis fitness training equipment (30 degrees and 80 degrees) were also adopted in this experiment. Since the target speed and range of movement of functional strengthening exercise are smaller or equal to the other two training exercises (stretching exercise and rhythmic coordination exercise), this study only adjusts the resistance level for functional strengthening exercise for each subject to make the determined MAL-PA comparable across different age groups.

During the MAL-PA determining process, each participant was verbally instructed to imagine that she is working as hard as she could without straining herself (Fredericks et al., 2008; Lee, 2003) during this 15-minute exercise session and still be able to complete a 50-minute intervention. The detailed procedure for performing each exercise (e.g., starting and ending instructions, starting and stopping angles, etc.) can be found in the author's previous study (Sung et al., 2024). In addition, the subject was informed that she could stop this 15-minute exercise anytime if she felt uncomfortable. At the end of the five one hr experiments, the highest resistance level that the subject can complete the two 15-minute sessions without discomfort will be adopted as the maximum acceptable level of PA intervention to be administered for that subject.

Fig.1. Determination of MAL-PA for shoulder-upper extremity fitness training equipment

2.3 Physiological Strains/Subjective Strains Evaluation of the MAL-PA Simulation Session

After the MAL-PA was determined, each subject will attend two additional 1.5-hour sessions to perform functional strengthening exercise using shoulder-upper extremity fitness training equipment and low back-pelvis fitness training equipment on two different days separated by at least 24 hours. In the first 0.5 hour of the 1.5-hour session, a wearable real-time physiological data measuring system (Sung, 2022) designed in-house was worn to record heart rate and tympanic temperature of the subject while performing MAL-PA simulations with a 1 Hz sampling rate.

In addition, each subject was asked to provide an evaluation of subjective demands pre-intervention using the Borg rating of perceived exertion (Borg RPE) scale, ranging between 6 (no exertion at all) and 20 (maximal exertion) (Borg, 1998), to estimate the pre-intervention strain levels subjectively.

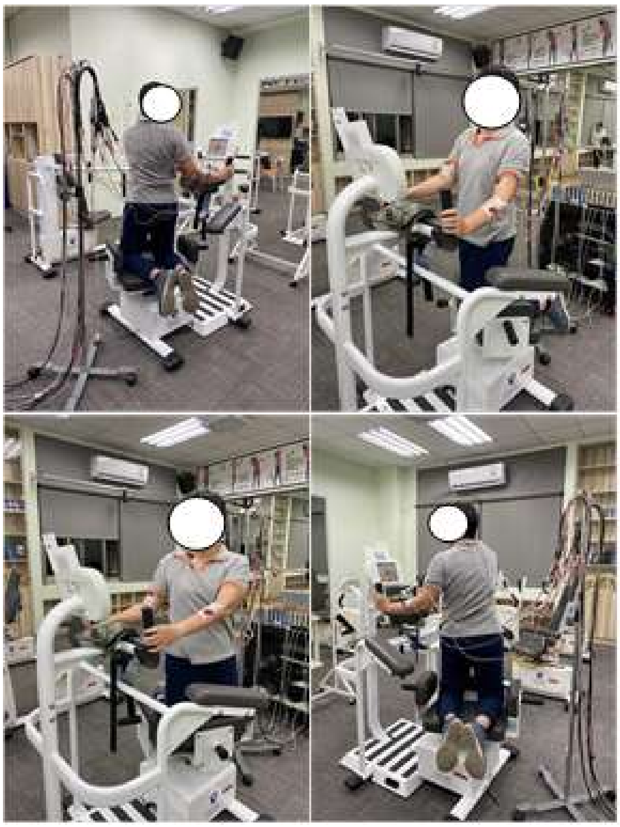

Fig. 2. Determination of MAL-PA for low back-pelvis fitness training equipment

In the last hour of the 1.5-hour session, the subject will perform a 50-minute AL-PA simulation. During this 1-hour session, the physiological strains were recorded 5 minutes before and 5 minutes after each 50-minute MAL-PA simulation. At the end of this session, the subject was asked to fill out the Borg RPE questionnaire to estimate subjective strain level for the MAL-PA simulation session.

2.4 Statistical Analysis

Age is the only independent variable included in this study. The dependent variables are MAL-PA, physiological strains (heart rate and tympanic temperature), and subjective strains (Borg RPE score).

The descriptive statistics were used to compute the mean and standard deviation of the dependent variables and anthropometry data. Repeated measures ANOVAs were used to determine whether there was a statistically significant age effect on dependent variables. In addition, Fisher's Least Significant Difference (LSD) analysis was then performed to determine which pairs of means are significantly different. All data were analyzed for statistical significance at $p \leq 0.05$ using the IBM SPSS V.21 (IBM Corp.) statistical software.

3. RESULTS AND DISCUSSION

The MVC grip strength and palmar pinch strength (mean ± SD) estimated for 26 females categorized as young adults, middle-aged adults, and older adults are shown in Table 1. The strength data measured for these three age categories all fall within the normative data range reported by Mathiowetz et al. (1985) for Milwaukee, United States females and by Mohammadian et al. (2014) for Iranian females. The repeated-measured ANOVA analysis results show statistically significant age effect on the MVC grip strength ($F = 3.774$, $p < 0.05$) and the MVC palmar pinch strength ($F = 4.146$, $p < 0.05$). LSD pairwise comparisons indicate that the grip and palmar pinch strength estimated for young adults are 34.9 N ($p < 0.05$) and 34.8 N ($p < 0.05$) higher than middle-aged adult females and older female adults, respectively. Higher muscular demands will be expected for middle-aged females and older females when performing tasks with the same load since weaker hand strengths were observed in this study (Sung et al., 2024).

Table 2 shows the MAL-PA of functional strengthening exercise determined for 26 females of three age categories and for two fitness training equipment. The MAL-PA determined ranged from 10.5 ± 1.3 (L) to 11.3 ± 0.9 (L) and 10.3 ± 0.8 (L) to 11.3 ± 0.9 (L) for shoulder-upper extremity equipment and low back-pelvis fitness training equipment, respectively. No statistically significant effects of age and fitness training equipment on the MAL-PA are found in this study. Fig. 3 shows the plot of the significant interaction effect between age group and the fitness training equipment ($F = 8.043$, $p < 0.005$). The determined resistance levels decreased with age while performing functional strengthening exercise using shoulder-upper extremity fitness training equipment and increased with age while performing functional strengthening exercise using low back-pelvis fitness training equipment.

The mean baseline heart rates of young females, middle-aged females, and older females are 81.7 ± 8.6, 71.5 ± 8.4, 70.9 ± 10.2 bpm, respectively. The baseline heart rates of these 26 Taiwanese females measured are within 25th to 75th percentile of the reference data determined for U.S. females aged 20–65 years old (Ostchega et al., 2011). Table 3 contains the means and standard deviations of heart rate and tympanic temperature measured from 26 female subjects of three age categories while performing functional strengthening exercise with MAL-PA. The heart rates measured during MAL-PA simulation sessions ranged from 76.3 ± 8.8 beats per min (bpm) to 101.3 ± 11.2 bpm and 83.1 ± 8.1 bpm to 94.5 ± 20.1 bpm for shoulder-upper extremity equipment and low back-pelvis fitness training equipment, respectively. The mean heart rates measured in this study are classified as "light works (< 90 bpm)" to "moderate works (90–110 bpm)" categories suggested by Hwang et al. (2016) showing that the participants are pacing themselves appropriately for each 50 min MAL-PA simulation. In addition, tympanic temperatures measured during MAP-PA simulation sessions ranged from 36.77 ± 0.06°C to 36.81 ± 0.08°C and 36.79 ± 0.04°C to 36.80 ± 0.04°C for shoulder-upper extremity equipment and low back-pelvis fitness training equipment, respectively.

The repeated measures ANOVA results (Table 4) indicate that there are slightly significant differences among age groups on heart rate (F = 3.407, p = 0.056). In addition, statistically significant fitness training equipment effect on heart rate was found in this study (F = 12.736, p < 0.01). No statistically significant age and fitness training equipment effects were found on tympanic temperature in this study. LSD pairwise comparisons show that the heart rate estimated for young females is 11.1 bpm higher than older adults (p < 0.01). The plausible explanations are that the mean baseline heart rates of young participants observed in this study are 10.3 bpm (p < 0.05) and 10.8 bpm (p < 0.005) higher than those of middle-aged and older participants, respectively. The heart rates estimated for females performing functional strengthening exercises using shoulder-upper extremity equipment are 8.0 bpm higher than those using low back-pelvis fitness training equipment.

Table 1. The MVC grip strength and palm pinch strength estimated for 26 females of three age categories

Age group	MVC grip (in Newton)	MVC palmar pinch (in Newton)
Young adult (10 subjects)	262.7 ± 49.3	123.8 ± 42.3
Middle-aged adults (8 subjects)	227.9 ± 43.7	93.5 ± 28.1
Older adults (8 subjects)	249.4 ± 38.8	88.9 ± 22.8

Table 2. The MAL-PA determined for 26 females of three age categories

Age group	Shoulder-upper extremity (L)	Low back-pelvis (L)
Young adult (10 subjects)	11.3 ± 0.9	10.3 ± 0.8
Middle-aged adults (8 subjects)	10.9 ± 0.8	11.3 ± 0.9
Older adults (8 subjects)	10.5 ± 1.3	11.3 ± 0.7

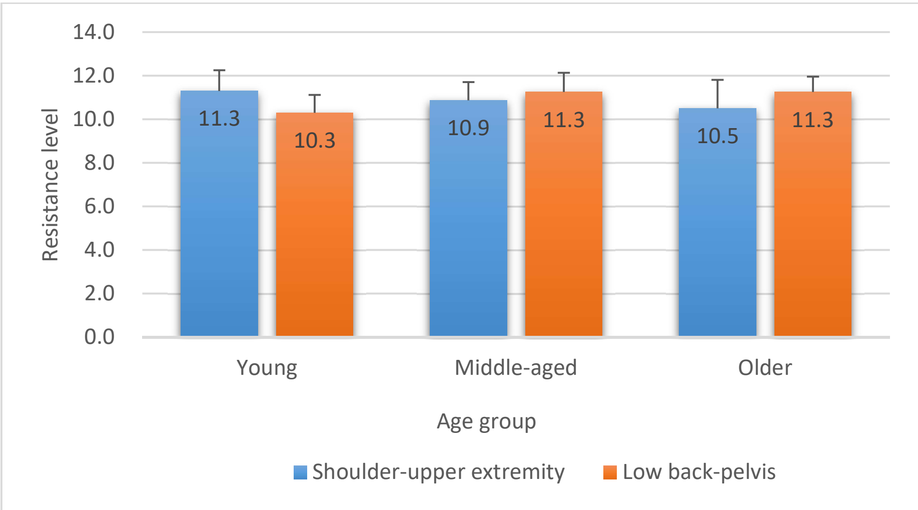

Fig. 3. The significant interaction effect between age group and fitness training equipment on resistance levels for 26 Taiwanese female subjects

Table 3. Means and standard deviations of heart rate and tympanic temperature of 26 females of three age categories measured during MAL-PA simulation sessions

Age group	Fitness training equipment	Heart rate (bpm)		Tympanic temperature (°C)	
		Mean	SD	Mean	SD
Young	Shoulder-upper extremity	107.3	11.2	36.77	0.06
	Low back-pelvis	93.7	4.47	36.82	0.04
Middle-aged	Shoulder-upper extremity	92.6	14.0	36.81	0.04
	Low back-pelvis	94.5	20.1	36.79	0.04
Older	Shoulder-upper extremity	76.3	8.8	36.81	0.08
	Low back-pelvis	83.1	8.1	36.79	0.06

Table 4. The repeated-measure ANOVA results on heart rate and tympanic temperature

Independent/Dependent Variables	Heart rate		Tympanic temperature	
Source of variance	*F*	Sig	*F*	Sig
Age	3.407	0.056	0.083	0.921
Fitness training equipment	12.736	0.006	0.603	0.457

Table 5. The means and standard deviations of Borg RPE score reported right after the MAL-PA simulation sessions for the three age group females

Age group	Shoulder-upper extremity (score)	Low back-pelvis (score)
Young adult (10 subjects)	14.2 ± 2.5	12.0 ± 2.8
Middle-aged adults (8 subjects)	11.9 ± 1.6	10.6 ± 2.0
Older adults (8 subjects)	12.1 ± 1.1	10.0 ± 1.8

The subjective reported Borg RPE scores are shown in Table 5 for 26 females of three age categories and for two fitness training equipment's. The reported Borg RPE score ranged from 11.9 ± 1.6 to 14.2 ± 2.5 and 10.0 ± 1.8 to the 12.0 ± 2.8 for shoulder-upper extremity equipment and low back-pelvis fitness training equipment, respectively. The repeated measures ANOVA results indicate that there are significant differences among the age groups (F = 4.479, $p = 0.062$) and fitness training equipment (F = 18.393, $p = 0.002$) on Borg RPE score. LSD pairwise comparisons show that the Borg RPE score reported for young females is 2.0 higher than older adults ($p < 0.05$). The Borg RPE score reported for subjects performing functional strengthening exercises using shoulder-upper extremity equipment is 1.9 higher than using the low back-pelvis fitness training equipment ($p < 0.005$). No statistically significant interaction effect of age group and fitness training equipment is found.

To measure physical strain subjectively, DiDomenicoa and Nussbaum (2008) recommended the Borg Rating of Perceived Exertion (Borg-RPE) scale for a fair estimation of physical exertion during operations. For the 16 middle-aged and older participants, the Borg-RPE ratings are all reported below or as "moderate" levels (score 14), indicating the MAL-PA exercising operations are performed with appropriate exertions or workload. However, since 4 out of 10 young females rated MAL-PA exercise operations with 14 or higher Borg-RPE scores performed with shoulder-upper extremity equipment, further evaluation of the MAL-PA for young females is needed beyond the initial assessment. NASA-TLX (Task Load Index) technique reported as one of the systematic assessment tools for measuring both mental and physical strains with sensitivity to changing demands (Hart and Staveland, 1988; Liu et al., 2022) or relative intensity on a scale of 0 (effort required to sit) to 10 (maximal effort) recommended by CDC (2023) to rate physical activity intensity could be adopted in future studies for subjective strain level assessments.

The MAL-PA of functional strengthening exercise of two fitness training equipment's determined in current study were recommended to be applied for future PA intervention studies and the associated strain levels were also assessed objectively and subjectively to make a comparative effects evaluation on reducing musculoskeletal symptoms across related studies. Although the hand strength measured for 26 Taiwanese females of three age categories in this study were comparable to United States females and Iranian females, incorporating different races and ethnic groups into evaluation are deserving of further study and discussion to adequately represent the diversity of the study population. In addition, the optimal combination of frequency and duration for MAL-PA intervention to be implemented could also be evaluated in future studies to better the effects on MSDs symptoms reductions.

5. CONCLUSION

This study adopts a psychophysical approach to determine the maximum acceptable level of physical activity (MAL-PA) using laboratory-owned fitness training equipment's. The MAL-PA of functional strengthening exercise determined for 26 females of three age categories and ranged from the 10.5 ± 1.3 (L) to 11.3 ± 0.9 (L) and 10.3 ± 0.8 (L) to 11.3 ± 0.9 (L) for shoulder-upper extremity equipment and low back-pelvis fitness training equipment, respectively. The determined MAL-PA decreased with age while performing functional strengthening exercise using shoulder-upper extremity fitness training equipment and increased with age while performing functional strengthening exercise using low back-pelvis fitness training equipment. In addition, the strain levels associated with the MAL-PA determined were assessed objectively and subjectively to be further examined for their differences with existing or future studies. The mean heart rates measured associated with MAL-PA showing that the participants are pacing themselves appropriately during each MAL-PA simulation. Subsequently, MAL-PA intervention could be adopted in future studies to make a comparative effects evaluation on musculoskeletal symptoms reductions to preserve the worker's health and safety when achieving and maintaining an active, productive, and prolonged working life.

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