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Differences and Relationships in Delayed Onset Muscle Soreness (DOMS) and Muscle Strength between Dynamic Warm-Up Alone and Dynamic Warm-Up with Static Stretching among Untrained Female University Agriculture Students

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Abstract **Problem Statement:** DOMS has been primarily studied in trained athletes, leaving a significant gap in knowledge about untrained populations. **Objectives:** This study aimed to examine the relationships and differences in delayed onset muscle soreness and muscle strength between dynamic warm-up alone and dynamic warm-up with static stretching among untrained female agriculture students. **Methods:** Thirty-nine out of 76 qualified university students from a state university in the Philippines completed the interventions. The students consist of females enrolled in Physical Activity Towards Health and Fitness from two blocks, supervised by the researchers. The study utilized a mixed model design with two groups; each group underwent five series of similar field tests following the intervention. **Results:** The study found significant reductions in DOMS for both dynamic warm-up (DWG) and dynamic warm-up with static stretching (DSWG) across various time intervals, with the most notable effects observed from 1 to 12 hours and 48 to 72 hours. Muscle strength recovery showed no significant differences in the first 24 hours for DWG, but improvements were significant from 24 to 72 hours, while no significant changes were observed for DSWG. Additionally, a significant relationship between muscle strength and DOMS emerged in the DWG group from 48 to 72 hours, but no such relationship was found in DSWG. **Conclusions:** Dynamic warm-up effectively reduces DOMS and promotes muscle strength recovery, particularly between 24 and 72 hours post-exercise, while static stretching does not offer additional benefits for muscle strength recovery.

Keywords Muscle Recovery, Pain Management, Muscle Adaptation, Warm-up Protocols, Soreness

1. Introduction

Muscle soreness is a common physiological response during the recovery phase of muscle adaptation following intense physical activity or exercise. This condition, known as delayed-onset muscle soreness (DOMS), typically arises 24 to 78 hours post-exercise and is characterized by muscle pain and stiffness [1-3]. Although muscle soreness is a natural response, improper form or excessive exertion during training can lead to more serious issues such as muscle strain, sprains, and exhaustion. It was historically believed to be caused by the accumulation of lactic acid, a by-product of the circulatory system that helps maintain hydration, regulate blood glucose levels, and inhibit bacteria [4,5]. However, during the exercise, the lactic acid is produced faster than what the body can metabolize [6]. This results in acidosis that may cause acute muscle pain [7]. This pain typically subsides within minutes of rest as the body restores homeostasis, and lactic acid is absorbed into the bloodstream, returning to normal levels.

Sex-based differences in muscle physiology, pain perception, and recovery patterns justify the exclusive focus on female participants in this study. Women tend to exhibit lower absolute muscle mass, strength, and power output compared to men [8,9], which may influence their susceptibility to muscle damage and delay onset muscle soreness following unfamiliar or intense exercise. Additionally, hormonal fluctuations, particularly variations in estrogen levels, have been shown to modulate inflammatory responses and muscle repair mechanisms, potentially affecting the onset, duration, and intensity of DOMS [10,11]. Female university students, especially those who are untrained, may also report greater sensitivity to discomfort and fatigue, which can discourage regular physical activity if not properly managed [12]. Therefore, understanding the effectiveness of warm-up strategies, such as dynamic warm-up and static stretching, in this specific population is essential to design inclusive and responsive exercise programs that cater to women's unique physiological and perceptual characteristics.

Numerous treatment strategies have been proposed to alleviate DOMS symptoms, including light muscle activity, nutritional supplements, compression, acupuncture, transcutaneous electrical nerve stimulation (TENS), laser therapy, hyperbaric oxygen therapy (HBOT), and combination therapies [13]. Clinical manifestations of DOMS are generally consistent and include muscle swelling, reduced active range of motion (ROM), decreased peak active force potential, and alterations in electromyographic (EMG) activity [14].

Warm-up techniques, such as static stretching and dynamic warm-up, have been shown to reduce DOMS [15] and improve muscle performance [16]. These warm-up exercises are particularly beneficial in preventing age-related declines in muscle strength and improving physical performance. It also reduces the risk of sports-related injuries. Competitive and recreational athletes regularly perform warm-up and stretching routines to prepare their bodies for strenuous physical activity [17,18]. Despite this, DOMS remains one of the most common and persistent musculoskeletal issues in modern society, with a lack of effective prevention or treatment strategies.

Untrained individuals, such as university students, are particularly susceptible to DOMS, which can deter them from engaging in physical exercise and hinder long-term health and fitness development [19,20]. Agricultural students, with limited experience in exercise, may experience DOMS more severely due to the physical demands of their academic programs [21]. Therefore, understanding how different warm-up strategies affect the intensity and duration of DOMS is important for promoting physical activity and overall health in this vulnerable population.

Research on DOMS has largely focused on trained athletes [22], leaving a significant gap in knowledge about untrained populations. Given that agricultural students have limited exposure to intense physical activity, their experience with DOMS may differ from that of athletes. Thus, warm-up strategies that are effective for athletes may not be directly applicable to less active groups [13,23]. Furthermore, while static stretching and dynamic warm-up are widely used to alleviate DOMS, their comparative effectiveness remains inconclusive. This research aimed to provide evidence-based recommendations for reducing muscle soreness and improving recovery, which may support long-term participation in physical activity and promote better health outcomes for agricultural students.

2. Materials and Methods

2.1. Participants

Thirty-nine out of 76 qualified university students from one state university in the Philippines completed the interventions. The students consist of females enrolled in Physical Activity Towards Health and Fitness from two blocks, supervised by the researchers. Three (3) specific criteria were used to recruit qualified students (Figure 1): (1) Failure to meet the WHO's recommendations regarding physical activity for health; (2) Not engaged in fitness programs or sports activities, either within or outside the university, within the past 6 months; (3) Absence of severe medical conditions.

Qualified students were grouped according to their blocks. Each block was assigned a specific warm-up: dynamic group (DG), and dynamic with static stretching warm-up group (DSG). Informed consent forms were collected from the participants. Furthermore, groups' anthropometrics and pain tolerance were analyzed using a test for normality and a t-test to ensure no bias in grouping the students (Table 1).

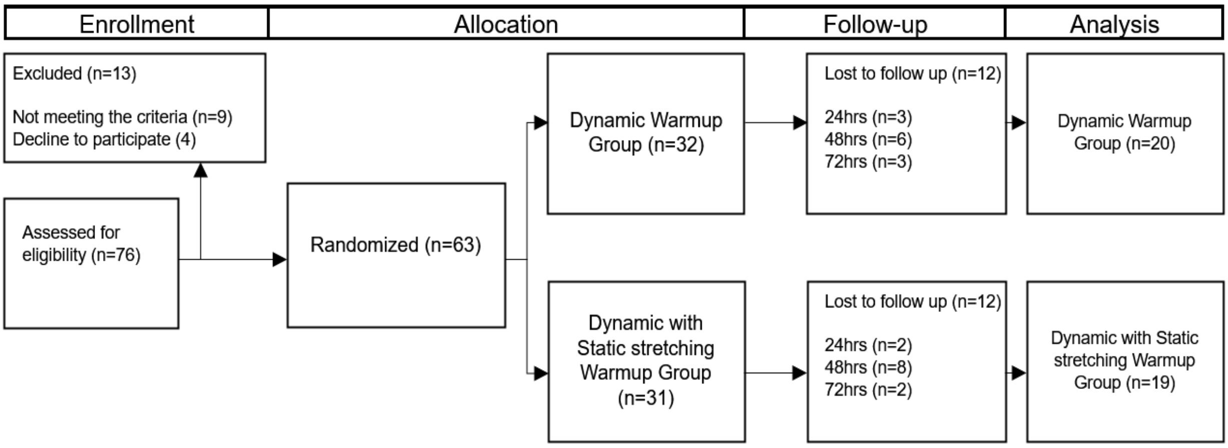


Figure 1. Flow chart of the participants' selection process

Table 1. Participants' anthropometrics and baseline data

	DG (n = 20)	DSG (n = 19)	*p*
Age	19.00 ±0.92	20.11 ±0.99	0.081
Height	157.05 ±6.55	151.21 ±2.43	0.067
Weight	48.20 ±7.56	48.63 ±7.48	0.536
Pain tolerance	605.75 ±5.25	542.37 ±3.23	0.053
Muscle strength	54.13 ±4.21	52.84 ±3.98	0.072

2.2. Study Design

The study utilized a mixed model design with two groups; each underwent five series of similar field tests following the intervention. The study consists of seven phases: one day for baseline data collection and participant characteristics assessment, followed by the intervention day. Field tests were conducted at intervals of 1 hour, 12 hours, 24 hours, 48 hours, and 72 hours post-intervention. The same set of field tests was employed at each time point to ensure consistency.

2.3. Test Procedure

To assess the initial pain tolerance of the participants and ensure normality before the intervention, the researchers used the cold pressure pain assessment. This test involves immersing the participant's thigh region using an ice pouch at around 4 ℃ to 5 ℃. The time, measured in seconds, that participants endured the cold exposure without withdrawing their hand or foot was recorded as an indicator of their pain tolerance. This test is valid and reliable [24].

The pain assessment was conducted using the 10-point pain rating scale, a commonly used subjective measure to evaluate pain intensity [19]. Participants were instructed to rate their pain level on a scale from 0 to 10, where 0 represents no pain and 10 signifies the worst pain imaginable. Before starting the test, participants were briefed on the scale and its purpose to ensure they understood how to assess their pain level accurately. The assessment began with a baseline pain measurement to record the participant's normal pain threshold before the intervention. After the intervention, participants underwent the pain tolerance test at specified intervals (e.g., 1 hour, 12 hours, 24 hours, 48 hours, and 72 hours) following the exercise or warm-up interventions. During each testing phase, participants were asked to rate the intensity of pain experienced in a specific muscle group or body part using the 10-point scale. The recorded pain scores were then used to evaluate changes in pain tolerance over time and the effectiveness of the intervention in reducing muscle soreness. This test is valid and reliable [25].

The single-leg glute bridge test is designed to assess thigh strength, particularly on the gluteal and hip extensor muscles. To begin the test, participants lay on their backs with their knees bent and feet flat on the floor, ensuring their arms are positioned comfortably at their sides. One leg was lifted off the floor while the participant engaged their core and glute muscles to raise their hips, creating a straight line from the shoulders to the knee of the elevated leg. The participants were instructed to hold this position for as long as they could while maintaining proper form, without letting the hips sag or the foot of the elevated leg touch the ground. The test was timed, and the number of seconds that the participant could hold the glute bridge position was recorded for each leg. The final score was the average of the times recorded for both thighs, providing a measure of the participant's lower body strength and endurance, particularly in the glutes and thighs. This procedure was repeated for both legs to ensure a balanced assessment of strength between the two sides. The single-leg glute bridge test was used because it focused on the gluteal and hamstring muscles while also challenging core stability and unilateral control.

2.4. Intervention

Qualified students were grouped based on their blocks assigned to warm-up interventions: the DG and, DSG. The DG focused on dynamic stretches such as leg swings, walking lunges, high knees, and butt kicks to increase muscle temperature, activate muscle groups, and improve range of motion. The DSG combined both static stretching and dynamic warm-up exercises to provide a comprehensive preparation (Table 2). After the warm-up, all groups were engaged in a main set of exercises designed to improve strength and endurance, including jump squats, Bulgarian split squats, reverse lunges, squat pulses, and high knees. The session concluded with a cool-down period that included gentle walking and stretching exercises to promote recovery and flexibility.

2.5. Data Analysis

The mean ±standard deviation and the Shapiro-Wilk test were used to assess the normality of the data, specifically the baseline performance. The median was used to describe non-normal data after the interventions. The Durbin-Conover paired test was used to assess interval performance differences within groups, while the Mann-Whitney U test was used to assess differences between groups. Statistical significance was set at $p \leq 0.05$. Cohen's d effect size (ES) was computed to display the magnitude of differences between intervals. Spearman's correlation was then used to assess the relationship between pain and muscle strength.

Table 2. Interventions

Static Stretching Warm up	**Duration**		
Standing Quad Stretch	30 sec. per leg		
Hamstring Stretch	30 sec. per leg		
Hip Flexor Stretch (Lunge Stretch)	30 sec. per side		
Calf Stretch	30 sec. per leg		
Inner Thigh Stretch (Standing)	30 sec. per side		
Pigeon Pose (for Glutes and Hips)	30 sec. per leg		
Gentle walking with deep breathing	2 min.		
Dynamic Warm Up	**Duration**		
Leg Swings (Front to Back)	30 sec. per leg		
Leg Swings (Side to Side)	30 sec. per leg		
Walking Lunges	1 min.		
High Knees	1 min.		
Butt Kicks	1 min.		
Walking Leg Cradles	1 min.		
Lateral Leg Swings (Criss-Cross)	30 sec. per leg		
Main set	**Variables**		
	Intensity	**Rest**	**Tempo**
Jump Squats	20 sec.	10 sec.	1:2
Bulgarian Split Squats (LLeg)	20 sec.	10 sec.	1:3
Bulgarian Split Squats (RLeg)	20 sec.	10 sec.	1:3
Reverse Lunges	20 sec.	10 sec.	1:3
Squat Pulses	20 sec.	10 sec.	1:1
High Knees (Quick)	20 sec.	10 sec.	2:1

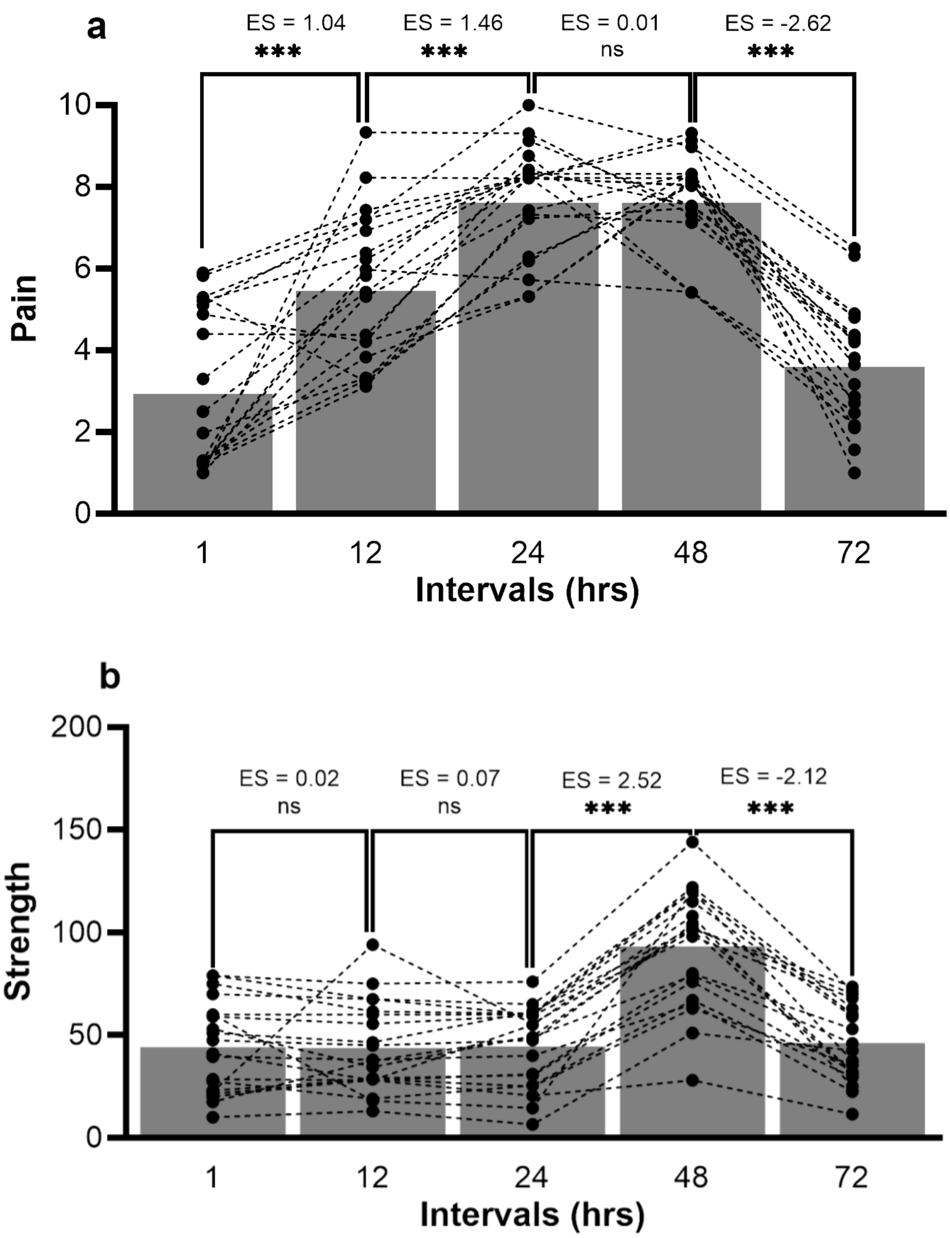
3. Results

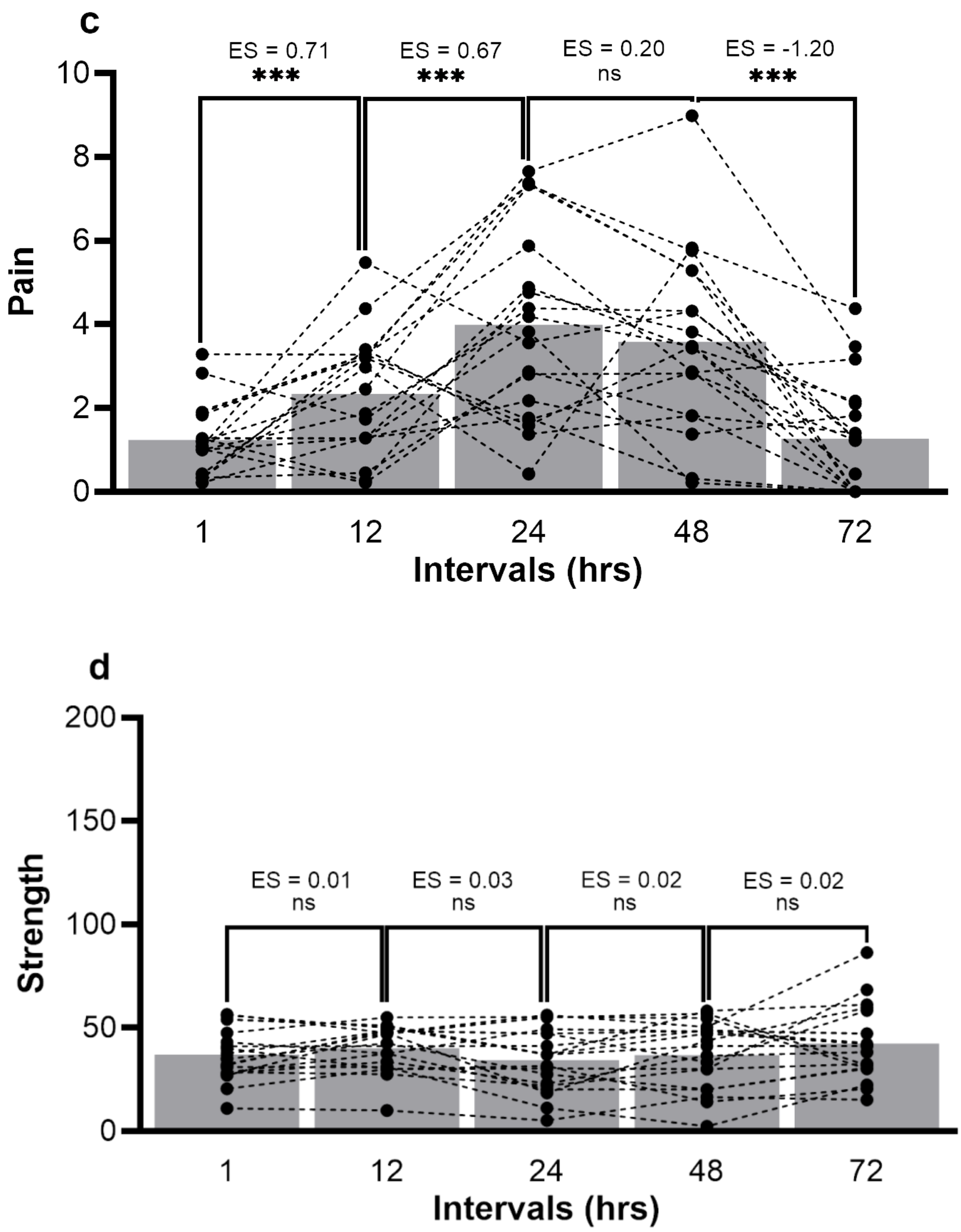
A significant difference in pain was found in DG in 1 to 12 [ES=1.04], 12 to 24 [ES=1.46], and 48 to 72 [ES=-2.62]-hour intervals at $p \leq .001$. In contrast, no significant difference was observed between 24 and 48 [ES=0.01]-hour intervals at $p = 0.405$. A significant difference was also found in DSG at 1 to 12 [ES=0.71], 12 to 24 [ES=0.67], and 48 to 72 [ES=-1.20]-hour intervals with $p = 0.037$, 0.009, and 0.001, respectively. In contrast, no significant difference was observed between 24 and 48 [ES=0.20]-hour intervals at $p = 0.456$ (Figure 2).

No significant difference was observed in muscle strength during the first 24 hours for DG at $p < 0.01$ [ES=0.02] and 0.333 [ES=0.07], respectively. However, a significant difference was then observed from 24 to 72 hours at $p < .001$ [ES=2.52; ES=-2.12]. Moreover, no significant differences across intervals were observed for DSG at $p = 0.562$ [ES=0.03], 0.173 [ES=-0.57], 0.371 [ES=0.23], and 0.293 [ES=0.33] (Figure 2).

No significant relationship was observed between muscle strength and DOMS of DG during the first 48 hours after the workout at $p \leq 0.05$. In contrast, a significant relationship was observed from 48 to 72 hours at $p < 0.037$. Moreover, no significant relationship was observed for DSG [ES = 0.01; 0.03; 0.02;0.02], across intervals (Figure 3).

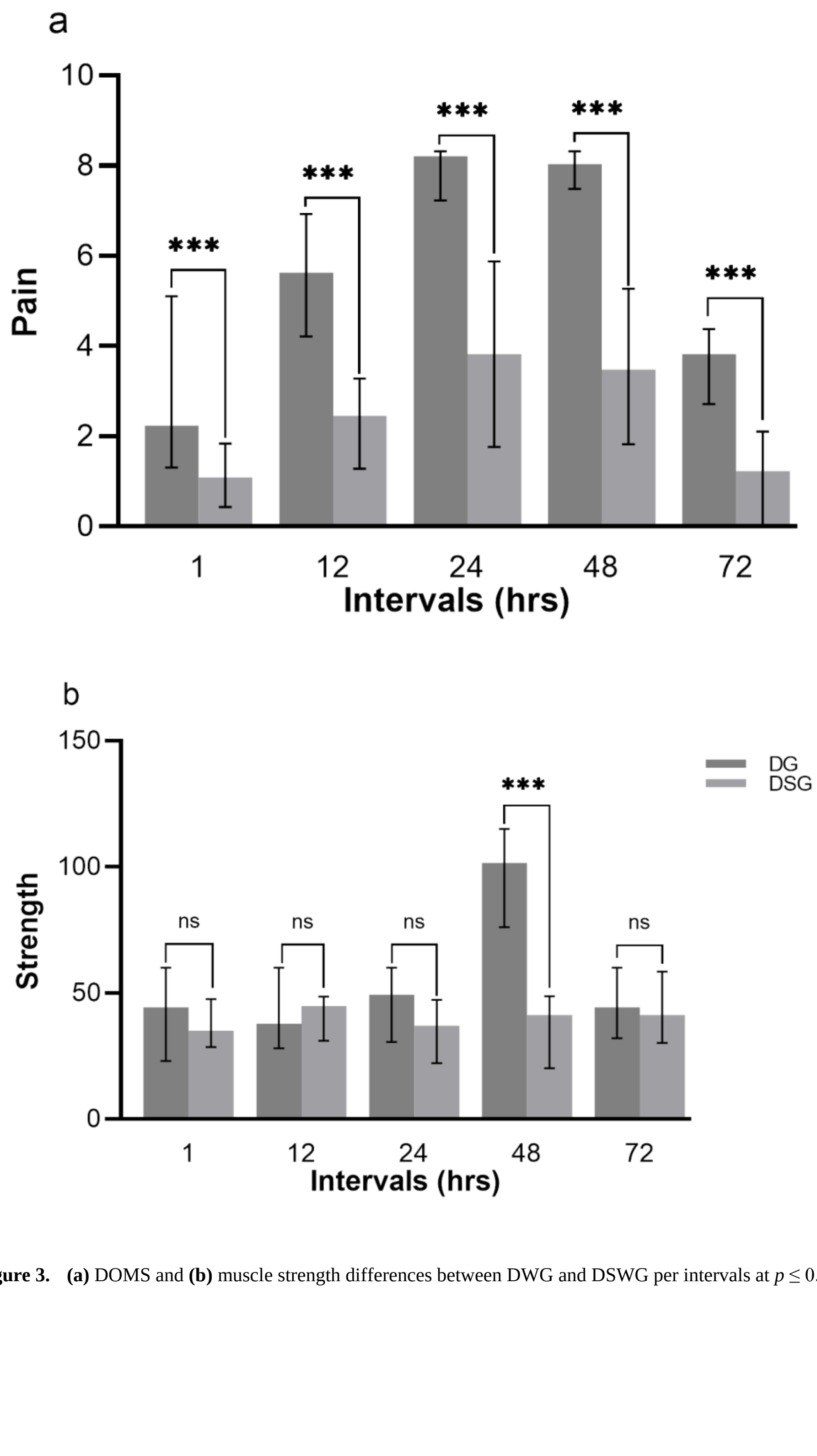
There is a significant difference across pain intervals between groups, favoring DWG at $p \leq 0.001$. In contrast, no significant relationship was found in muscle strength intervals, except for 48 hours, in favor of DG at $p \leq 0.001$ (Figure 4).





No significance, NS; $p < 0.001$, ***

Figure 2. DOMS and muscle strength performance intervals after the workout between **(a & b)** DG and **(c & d)** DSG, at $p \leq 0.05$



Note: p <0.001, ***

Figure 3. (a) DOMS and **(b)** muscle strength differences between DWG and DSWG per intervals at $p \leq 0.05$.

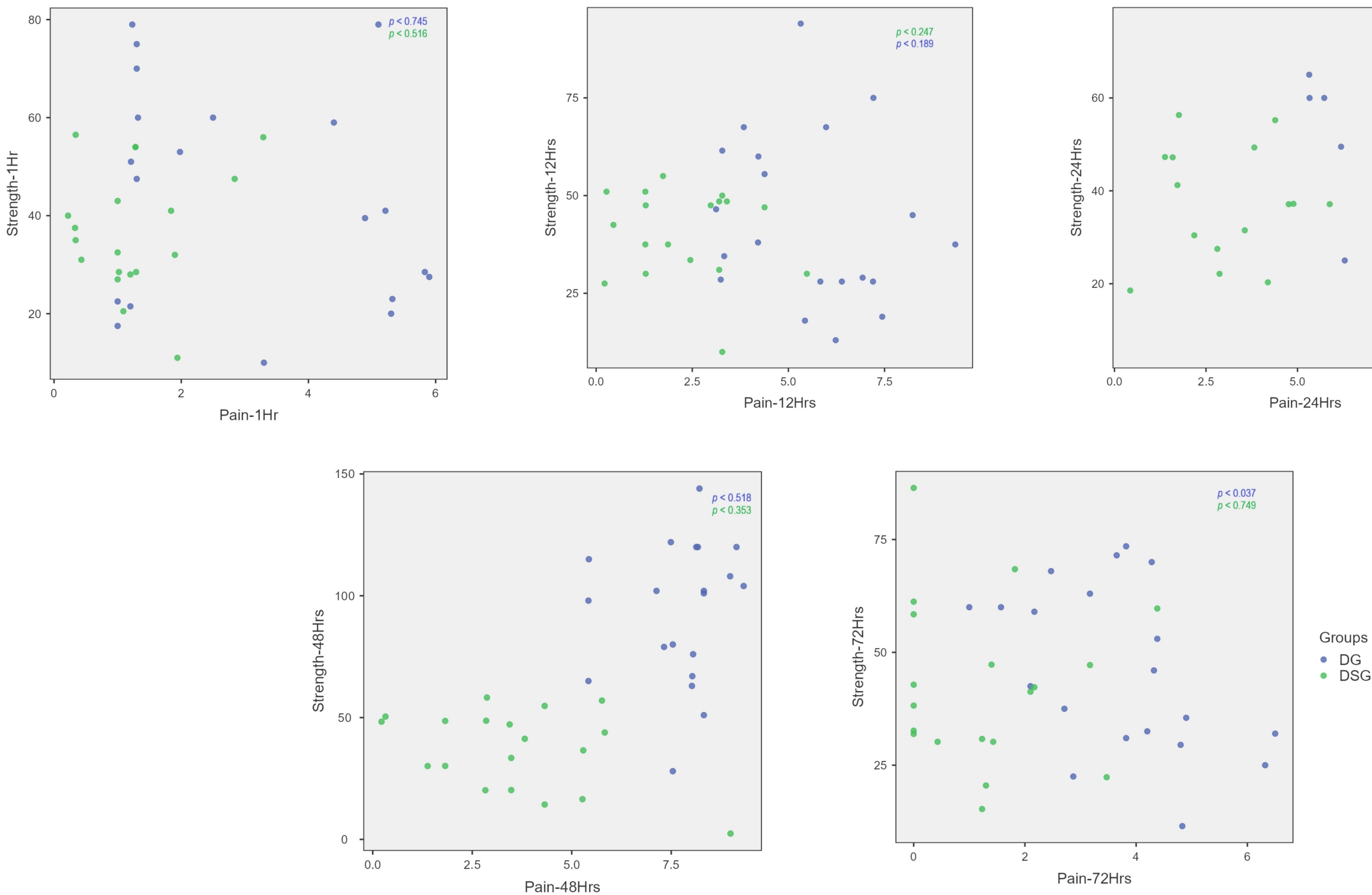


Figure 4. Comparison of DOMS and muscle strength performance intervals between DG and DSG

4. Discussions

Our present study investigated the effects of DG and DSG on delayed onset muscle soreness (DOMS) and muscle strength recovery in untrained female agricultural students. Our findings reveal significant progressive differences in DOMS levels within both groups, with greater pain reported at specific post-exercise intervals. Strength recovery exhibited distinct patterns between the interventions.

The decrease in DOMS across the 1 to 12, 12 to 24, and 48 to 72-hour intervals for DG (ES=1.04 to 1.46) implies the immediate and medium-term benefits of dynamic warm-up alone in easing post-exercise muscle soreness. Notably, no significant difference was found between the 24 and 48-hour interval (ES=0.01). This suggests that the benefits of a dynamic warm-up may increase after the first 24 hours. This claim was similar to the recent study, which found that the effect of warm-up exercises in ameliorating the symptoms of DOMS is seen 24 h later [26]. Additionally, while a dynamic warm-up can effectively reduce soreness shortly after exercise, its benefits diminish as the recovery period extends beyond a day. In contrast, DSG showed significant differences in DOMS reduction at similar intervals (1 to 12, 12 to 24, and 48 to 72 hours), (0.71, 0.67, and -1.20). The combination of dynamic warm-up and static stretching provides a more sustained reduction in DOMS over a longer period. The negative effect size observed in the 48- to 72-hour interval (ES = -1.20) also suggests that the addition of static stretching may have a cumulative benefit that further enhances muscle recovery as time progresses. On the other hand, static stretching is not effective in reducing DOMS when only a single bout of stretching is used [27]. A recent study also found that while the dynamic stretching group showed a significant increase in pain pressure threshold at some points, the general effect on relieving DOMS was insignificant [28].

Regarding muscle strength, our findings suggest that dynamic warm-up alone (DG) did not show an immediate impact on strength recovery within the first 24 hours ($p < 0.01$, ES = 0.02). However, significant differences were observed from 24 to 72 hours ($p < 0.001$, ES=2.52 and ES=-2.12). This points to a delayed effect of dynamic warm-up on muscle strength recovery. Dynamic warm-up facilitates the restoration of muscle strength beyond the immediate post-exercise phase [29]. This may potentially be achieved through mechanisms such as improved circulation, oxygen delivery, and muscle perfusion. It may support the recovery of muscle fibers and the re-establishment of homeostasis. On the other hand, no significant differences were found for muscle strength across any time intervals in the DSG group. This suggests that static stretching, when added to the dynamic warm-up, does not provide a noticeable advantage in muscle strength recovery. Another study mentioned that slight static stretches cause only trivial negative effects on subsequent strength and power performances [30]. Similarly, research also shows that dynamic stretching has a limited effect on DOMS; therefore, more evidence is needed [31].

The differences in pain experienced across intervals (ES=1.18 to 2.45) indicate that dynamic warm-up, whether done alone (DG) or with static stretching (DSG), leads to a significant pain reduction at different time points after exercise, especially during the early recovery phase. The higher effect was observed during the 12-24- and 48-72-hour intervals. These interventions have a strong and sustained effect on reducing pain as time progresses. This emphasizes the importance of warm-up strategies in managing the DOMS recovery period [32]. Incorporating dynamic warm-ups and static stretching could help alleviate pain during the post-exercise period, even beyond the immediate recovery phase.

Individuals engaged in physical activity, particularly those who are untrained, dynamic warm-up alone (DG) can be recommended to reduce DOMS and enhance muscle strength recovery in the short to medium term, particularly within the first 24 hours after exercise. However, for longer-term DOMS management, incorporating static stretching (DSG) into the warm-up routine may offer additional benefits, particularly in mitigating muscle soreness up to 72 hours post-exercise. These findings were useful for designing effective recovery protocols tailored to untrained populations. Managing DOMS and optimizing recovery are critical to maintaining exercise adherence and reducing injury risk [33,34].

Our findings suggest that dynamic warm-up alone may not substantially influence the immediate interplay between muscle strength and DOMS, but the relationship becomes evident from 48 to 72 hours in the DWG group. This delayed effect highlights the need to consider longer recovery windows when evaluating the effectiveness of dynamic warm-up routines in exercise protocols [17,35].

4.1. Limitations

The limited sample of 39 participants, despite being justified by strict inclusion criteria, reduces the statistical power of the findings and restricts their applicability to a broader population. This limitation should be explicitly acknowledged to clarify the scope and generalizability of the study's conclusions. For educators and exercise professionals, these results support the use of warm-up protocols for pain reduction and performance recovery. Particularly in female populations, who may exhibit heightened pain sensitivity and different fatigue recovery kinetics, adopting warm-up strategies that account for these physiological nuances may enhance both safety and performance.

5. Conclusions

Our findings suggest that dynamic warm-up is effective in reducing DOMS and supporting muscle strength recovery within the short to medium-term recovery phase. The dynamic warm-up alone appears to have a beneficial impact on reducing DOMS and facilitating muscle recovery, potentially through mechanisms like increased circulation and muscle perfusion. The combination of dynamic warm-up with static stretching further enhances the reduction of DOMS over a prolonged recovery period, highlighting the potential cumulative benefits of adding static stretching to a warm-up routine. However, static stretching did not seem to provide additional advantages in muscle strength recovery. Its role may be more significant in flexibility and soreness management rather than strength restoration. A dynamic warm-up optimizes recovery for untrained individuals prone to DOMS and slower recovery. The efficacy of dynamic warm-ups may be context-dependent, with specific benefits depending on the timing of the recovery phase and the nature of the exercise performed. It would be valuable to explore the underlying physiological mechanisms in untrained populations that explain the delayed effects of dynamic warm-up on muscle strength recovery. Additionally, examining the impact of various warm-up and recovery protocols on different types of exercise and across levels of training experience could provide deeper insights into effective recovery strategies for athletes and physically active individuals. Future research could investigate the long-term effects of combining dynamic warm-up and static stretching on performance outcomes and injury prevention.

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