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Human Kinetics
ORIGINAL INVESTIGATION

Does a Loaded Warm-Up Influence Jump Asymmetry and Badminton-Specific Change of Direction Performance?

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Purpose: Previously, it has been shown that loaded warm-up (LWU) can improve change-of-direction speed (CODS) in professional badminton players. However, the effect of asymmetry on CODS in badminton players and the influence of LWU on asymmetry has not been examined. ***Methods:*** A total of 21 amateur badminton players (age 29.5 [8.4] y, playing experience 8.4 [4.2] y) completed 2 trials. In the first, they performed a control warm-up. In the second, they performed the same warm-up but with 3 exercises loaded with a weight vest (LWU). Following both warm-ups, players completed single-leg countermovement jump and badminton-specific CODS tests. ***Results:*** No significant differences between control warm-up and LWU were observed for CODS, single-leg countermovement jump, or single-leg countermovement jump asymmetry. However, small effect sizes suggested faster CODS (mean difference: –5%; $d = -0.32$) and lower asymmetries (mean difference: –3%; $d = -0.39$) following LWU. Five players (24%) experienced CODS improvements greater than the minimum detectable change while 2 (10%) responded negatively. Asymmetry was not correlated with CODS following control warm-up ($\rho = .079$; $P = .733$) but was negatively associated with CODS after LWU ($\rho = -.491$; $P = .035$). ***Conclusion:*** LWU may prove a strategy to trial on an individual basis, but generic recommendations should not be applied.

Keywords: agility, imbalance, postactivation potentiation, multidirectional, speed

A dynamic warm-up has been widely demonstrated to elicit acute improvements in speed/power performance.[1] However, the addition of specific "preconditioning" activities to a warm-up may further augment improvements in performance. Previously reported as the postactivation potentiation phenomenon, this is perhaps more correctly termed as postactivation performance enhancement as electrically evoked contractile properties are not typically assessed.[2,3] As the performance of heavy resistance exercise is likely to be contraindicated prior to competition in most instances, the performance of certain ballistic activities may provide coaches with a method by which to induce postactivation performance enhancement, which can be easily applied.[4]

In the sport of badminton, the ability to quickly change direction is an important determinant of performance.[5] For example, Tiwari et al[6] noted a significant relationship ($r = -.83$; $P < .05$) between change of direction speed (CODS) and winning percentage in Indian state-level players. As such, the acute augmentation CODS is likely to be advantageous to performance. Zois et al[7] demonstrated that a heavy (5-repetition maximum) leg press stimulus improved reactive agility performance by 5% (effect size [ES] = 1.1 [0.7]) in soccer players. As these were observed alongside improvements in jump and sprint performance,[7] it is likely that changes in physical capacities underpin such augmentations. However, as previously noted, this form of preconditioning activity is unlikely to be possible prior to on-court competition in badminton.

In their review article, Maloney et al[4] concluded that performing ballistic activities (such as jumps and changes of direction) with additional load may increase the potential postactivation performance enhancement response. This is most commonly achieved through the performance of exercises while wearing a weighted vest. Several studies have reported performance improvements following a loaded warm-up (LWU),[8–12] although such augmentations have not always been observed.[13] Importantly, Simperingham et al[12] noted that loading the specific movement patterns in which augmentations are desired—for example, loaded acceleration to improve subsequent acceleration performance, is likely to be more effective than loading more generic movements such as jumps. This strategy will facilitate the rehearsal of specific patterns and provide overload within specific force vectors.[12]

To the authors' knowledge, 2 investigations have sought to determine the efficacy of a weight vest LWU on CODS. In a population of 8 professional badminton players, Maloney et al[14] reported that additional loads of 5% and 10% of body mass significantly improved the performance of a badminton-specific CODS task over an unloaded control (5%: ES = 0.39; 10%: ES = 0.83), but did not report an effect on jump performance. Turki et al[15] examined the effect of loadings equivalent to 5%, 10%, and 15% body mass on a repeated CODS task in young (age = 18 [0.88] y) soccer players. The authors reported that all 3 loading conditions improved fastest (1.31%–1.58%) and total (1.89%–1.98%) CODS times compared with an unloaded control with no difference between loadings.

Currently, the relationship between asymmetry and athletic performance is not clear.[16] Specifically, asymmetries in single-leg countermovement jump (SLCMJ) height have been correlated with impaired CODS in youth tennis players,[17] and academy soccer players,[18] but not in youth handball players,[19,20] female soccer players,[21] or in a mixed cohort of professional soccer and cricket players.[22] However, the influence of asymmetry on CODS performance in badminton players has not been evaluated. Badminton is a highly unilateral-biased sport where asymmetry is to be expected given long-standing participation in the sport.[23] While it may be reasonable to hypothesize that asymmetries would not be associated with deleterious performance effects in this population, such assertions require empirical support. Moreover, the influence of acute interventions on asymmetry has not been explored.

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The current study aimed to evaluate the acute effects of dynamic warm-up with a weighted vest on CODS, and SLCMJ asymmetry in badminton players. It was hypothesized that the LWU would significantly improve CODS, but not SLCMJ performance or asymmetry.

Method

Subjects

A total of 21 amateur badminton players (18 males and 3 females; age = 29.5 [8.4] y; stature = 1.75 [0.12] m; body mass = 74.0 [13.7] kg; self-reported playing history = 8.4 [4.2] y) provided written informed consent to participate in the study. A minimum of 21 participants were required according to *a priori* power analyses (G*Power [version 3.1, Heinrich-Heine-Universität, Düsseldorf, Germany]), based on ES of 0.5[14] and power of 0.8.[24] In order to minimize the possibility of any learning effect during the investigation, all participants were required to have >3 years' competitive playing experience (competing in Badminton England sanctioned events) to ensure they were adequately skilled in badminton footwork/movement patterns and have been free from injury for >3 months preceding the study. All players had previously performed the SLCMJ and CODS tests employed in the study. All procedures were approved by the Middlesex University ethics committee.

Design

The current study employed a repeated-measures design to determine the effect of a LWU on CODS and asymmetry in amateur badminton players. All data were collected across 2 testing sessions: first, a control warm-up (CWU) session, and second, and LWU session. These were performed on 2 separate days separated by 1 week. The same dynamic warm-up protocol (Table 1) was performed in both conditions; however, the final exercises (exercises 20–22) in the LWU condition were performed with a weight vest (10% body mass); this loading has been shown to improve CODS performance in elite badminton players.[14] Post warm-up, players sequentially performed SLCMJ, then badminton-specific CODS tests.

Procedures

The investigation consisted of 2 testing sessions, a control condition (normal dynamic warm-up; CWU) and an experimental condition (LWU). An overview of the study is shown in Figure 1. In both sessions, participants performed the same warm-up protocol (detailed below) and performance assessments. All testing sessions were executed on the same indoor badminton courts. Participants were requested not to engage in any vigorous exercise for 48 hours prior to testing and to avoid caffeine intake for 2 hours before each session. Despite the intention to counterbalance the order of conditions, this was not possible as the weight vests were not available during the first testing session.

All participants performed a badminton-focused dynamic warm-up (Table 1) previously outlined by Maloney et al[14] The warm-up protocol consisted of 22 exercises, progressing from low- to high-intensity movements. During exercises 1 to 19, participants jogged one width of a full-size badminton court (equivalent to 6.1 m), performed the specific exercise over another court, and then jogged across a third court (~20-m total owing to the space between courts). Participants turned around and repeated this for the following exercise. In LWU, the weight vest was worn for the performance of exercises 20 to 22. The weight vest (Surreal UK, United Kingdom) was loaded with an equivalent of 10% of participants' body mass (mean [SD]: 7.4 [1.4] kg) to the nearest 0.2 kg based upon previous investigations.[14,15] No vest was worn in the control condition.

Table 1 The Dynamic Warm-Up Protocol Completed by Players in Both Conditions

Component	Exercise no	Exercise
Dynamic stretches	1	Walking on toes
	2	Walking on heels
	3	Walking knee to chest
	4	Walking knee to chest with internal rotation
	5	Walking hip circles—medial to lateral
	6	Walking hip circles—lateral to medial
	7	Walking lunge and rotate
	8	Walking deep lunge
	9	Walking sumo squats
Pulse raiser	10	Jogging with high knees
	11	Jogging with butt kicks
	12	Fast feet running
	13, 14, 15	Repeat 10, 11, 12 backward
	16, 17	Side steps (× 2 – alternate lead foot)
	18, 19	Carioca steps (× 2 – alternate lead foot)
Speed and power priming	20[a]	Bilateral countermovement jumps (× 5 repetitions)
	21[a]	Alternating split squat jumps (× 5 repetitions each leg)
	22[a]	4-corners shadow play drill (× 2 circuits)

[a] The 3 "experimental" exercises—these were performed without additional load in the control warm-up condition and loaded with a weighted vest in the experimental loaded warm-up condition.

Following the warm-up, participants performed up to 3 familiarization trials for SLCMJ and CODS assessments (outlined below) at ~80% effort. A 3-minute recovery period was provided following the last familiarization trial and first assessment trial. Each assessment was performed 3 times, each separated by a 60-second recovery period to minimize fatigue.

SLCMJ Assessment

Unilateral countermovement jump height was measured employing a SLCMJ protocol, which was standardized with a study investigated jumping asymmetries on academy junior soccer players.[18,20] Participants began the test standing in the center of a contact mat (Jump Mat; FSL Scoreboards Ltd, Cookstown, United Kingdom) with hands on hips. The foot of the nontesting leg was instructed to be positioned at mid-shin height of the testing leg. Participants were instructed to jump as high as possible during each assessment trial but permitted to use a self-selected depth and velocity in the countermovement. Hands were required to remain

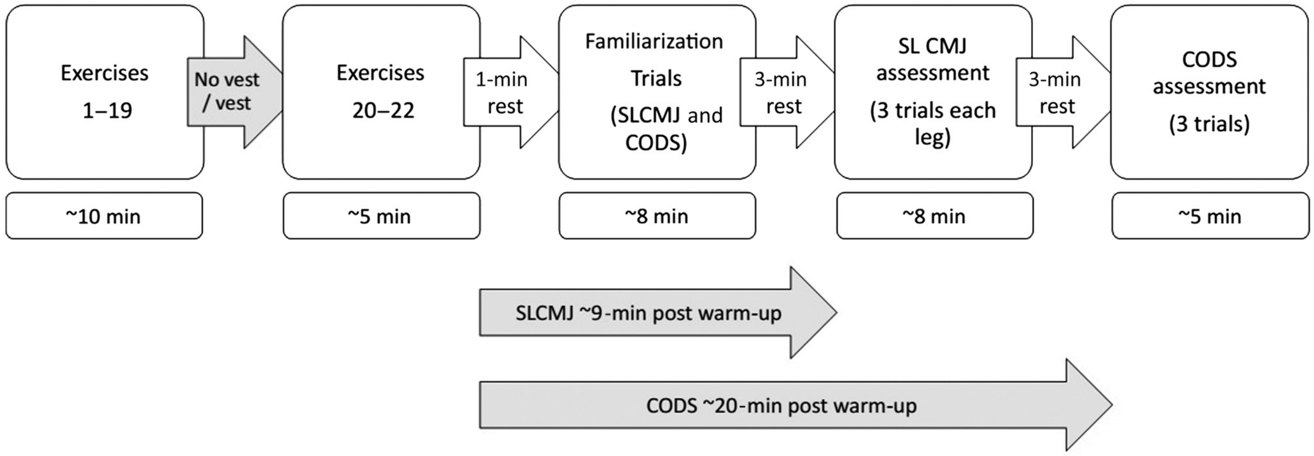

Figure 1 — A schematic of the study design. CODS indicates change-of-direction speed; SLCMJ, single-leg countermovement jump.

on hips throughout. Landings were performed on the same limb, but participants were not required to "stick" the landing and hold the position. All participants started testing on their left side with trials alternating between left and right limbs thereafter.

CODS Assessment

The CODS was evaluated using a badminton-specific protocol proposed by Paterson et al.[25] The test (shown in Figure 2) required participants to move from a rectangle positioned in center court to 8 consecutive perimeter locations with self-selected footwork, touch the marked point with their racket, and then return to center court between each location. The testing setup was reversed for the left-handed participant (n = 1). The time started when one foot left the center court rectangle and stopped when one foot returned to the rectangle after the eighth movement. As a contact mat permitting time measurements was unavailable for use in the current study, the CODS test was timed using a handheld stopwatch. Given the relatively long duration of the test (group mean: 16–17 s), this was deemed acceptable. Handheld timing was also employed in a similar CODS test and demonstrated strong intrasession and intersession reliability (intraclass correlation coefficients [ICC] = .88 and .94, respectively).[14]

Statistical Analyses

Asymmetry was determined from the SLCMJ test using mean jump heights from the dominant (D) and nondominant (ND) limbs with dominance defined by racket hand. For all participants this represented their lunging leg. The asymmetry index (in percentage) was calculated as outlined by Bishop et al[26]: (max value − min value)/max value × 100. To determine "performance" for each test within each condition, the best score was used.

All data were initially recorded in Microsoft Excel (version 16.16, Mac OSX; Microsoft Corp, Redmond, WA) and later transferred to SPSS (version 25.0; IBM Corp, Armonk, NY) for further statistical analyses. Statistical significance for all tests was set at an alpha level of $P \leq .05$. Shapiro–Wilk tests were applied to assess for normality of each variable.

The intrasession reliability of each measurement was determined in both the control and experimental conditions using 3 measures. First, 2-way random ICC with absolute agreement were calculated and interpreted using the thresholds outlined by Koo and Li[27] where >.9 = "excellent". Second, the coefficient of variation (CV) [(SD/mean) × 100] was determined. The CV was considered acceptable if <10%.[28] Finally, the SEM [SD × $\sqrt{(1 - \text{ICC})}$] was calculated.

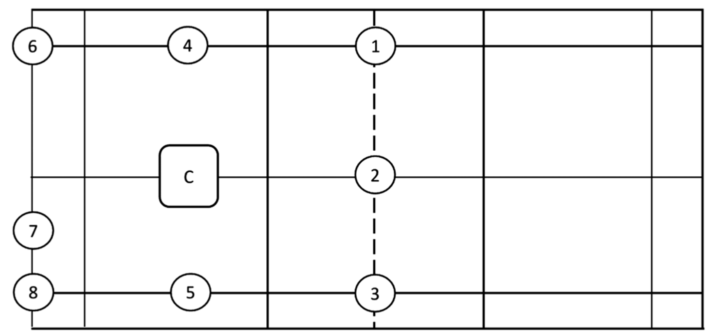

Figure 2 — The half-court setup for badminton-specific change-of-direction test performed by the participants.

To evaluate differences in variables between CWU and LWU conditions, either paired sample *t* tests or Wilcoxon signed-ranks tests were applied to variables with normal and nonnormal distributions, respectively. Furthermore, ESs (Cohen *d*) were calculated[29] and interpreted as: < 0.25 = trivial, 0.25 to 0.50 = small, 0.50 to 1.0 = moderate, and > 1.0 = large, given participants' long-standing participation in the sport.[30] To evaluate individual responses, players exhibiting changes in excess of the minimal detectable change (MDC)—calculated as [(1.96 × SEM) × $\sqrt{2}$][31]—were classified as "positive" or "negative" responders (dependent on the direction of change). Changes < MDC were classified as "neutral" responses. Correlations between asymmetry and performance in both the control and LWU conditions were examined using Spearman ρ and interpreted as: small = 0 to .3, moderate = .31 to .49, large = .50 to .69, very large = .70 to .89, and near perfect = .90 to 1.00.[32] The consistency of the asymmetry direction following the CWU and LWU conditions was evaluated using the kappa statistic and interpreted using thresholds outlined by Viera and Garrett[33] where: < 0 = poor, 0.01 to 0.20 = slight, 0.21 to 0.40 = fair, 0.41 to 0.60 = moderate, 0.61 to 0.80 = substantial, and 0.81 to 0.99 = almost perfect.

Results

While CODS and SLCMJ performances were normally distributed, asymmetry values were not. As shown in Table 2, ICCs for all test measurements were "excellent" and CV values "acceptable."

No significant differences between the CWU and LWU were observed for any variable (Table 3). "Small" ESs suggested faster CODS times (Figure 3) and lower asymmetries following LWU. Individual responses to the LWU are shown in Table 4.

Following CWU, SLCMJ asymmetry was not associated with CODS time or SLCMJ height (Table 5). However, following LWU, CODS and SLCMJ D were significantly correlated with asymmetry such that better performances were associated with larger asymmetries. Higher SLCMJ heights on both limbs were associated with faster CODS times following both warm-ups, but correlations were larger following LWU. There was "substantial" agreement for the direction of asymmetry following CWU versus LWU ($\kappa = 0.741$; $P < .001$; Figure 4). Four players exhibited larger SLCMJ heights on the ND limb following both conditions while 15 exhibited larger D limb performances. The remaining 2 players saw a change from ND dominance or parity in CWU to D dominance in LWU.

Discussion

The aim of the current study was to examine the effects of a LWU (10% body mass) on sport-specific CODS, SLCMJ performance, and asymmetry in badminton players in comparison with a "traditional" dynamic warm-up. The current study reports that the LWU did not yield any significant effect on performance or asymmetry in contrast to the experimental hypothesis. However, "small" ESs suggested faster CODS performances and lower asymmetries following LWU. Subsequent individual analysis revealed that the LWU induced CODS improvements greater than the MDC for almost a quarter of the cohort, but negatively impacted 2 players. As such, LWU may prove a strategy to trial on an individual basis but should not be more globally implemented given the potential for some athletes to respond negatively.

Across the cohort, players' fastest CODS performances were not significantly faster following LWU versus CWU (4.89%; $P = .075$), although the observed variance within the test (CWU CV = 4.08% and LWU CV = 5.76%) increases the likelihood of

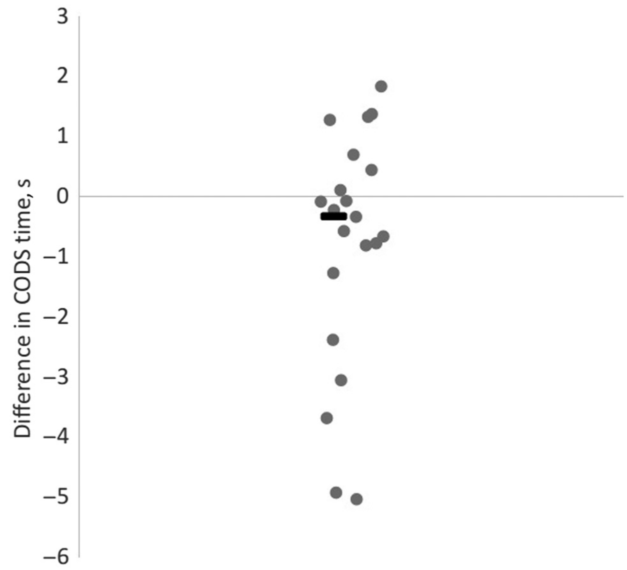

Figure 3 — The mean (bold black line) and individual differences in CODS test time between control and loaded warm-up conditions. Negative values indicate a faster time in the loaded condition. CODS indicates change-of-direction speed test.

Table 4 Individual Responses to the Loaded Warm-up Condition in Comparison With the Control Warm-up

Variable	Positive (n)	Neutral (n)	Negative (n)
CODS	5	14	2
SLCMJ D	2	19	0
SLCMJ ND	5	15	1

Abbreviations: CODS, change-of-direction speed test; D, dominant limb; ND, nondominant limb; SLCMJ, single-leg countermovement jump. Notes: Positive and negative response defined as a change greater than the minimal detectable difference.

Table 2 Reliability of Performance Outcomes in Both Warm-up Conditions

	Control warm-up condition			Loaded warm-up condition		
Variable	ICC (95% CI)	SEM	CV, %	ICC (95% CI)	SEM	CV, %
Change-of-direction speed, s	.969 (.922 to .987)	0.49	4.08	.924 (.739 to .973)	0.70	5.76
SLCMJ dominant limb, cm	.972 (.943 to .988)	0.63	6.42	.969 (.936 to .986)	0.64	4.84
SLCMJ nondominant limb, cm	.974 (.948 to .989)	0.56	6.68	.967 (.933 to .986)	0.59	6.22

Abbreviations: CI, confidence interval; CV, coefficient of variation; ICC, intraclass correlation coefficient; SLCMJ, single-leg countermovement jump.

Table 3 Differences in Group Mean Performances and SLCMJ Jump ASYM Between CWU and LWU Conditions

Variable	Post-CWU	Post-LWU	*P*	ES (95% CI)
Change-of-direction speed, s	16.58 (2.80)	15.77 (2.16)	.075	−0.32 (−0.93 to 0.29)
SLCMJ dominant limb, cm	16.30 (3.88)	16.55 (3.78)	.345	0.06 (−0.54 to 0.67)
SLCMJ nondominant limb, cm	14.85 (3.45)	15.50 (3.24)	.067	0.20 (−0.42 to 0.80)
SLCMJ asymmetry, %	12.98 (7.66)	9.96 (7.75)	.140	−0.39 (−0.99 to 0.23)

Abbreviations: CI, confidence interval; CWU, control warm-up condition; ES, effect size; LWU, loaded warm-up condition; SLCMJ, single-leg countermovement jump.

Table 5 Correlations (Spearman ρ) Between Selected Variables Following the CWU and LWU Conditions

		Asymmetry vs			CODS vs	
Condition		**CODS**	**SLCMJ D**	**SLCMJ ND**	**SLCMJ D**	**SLCMJ ND**
Post-CWU	ρ	.079	.098	−.144	−.600**	−.535*
	P	.733	.672	.533	.004	.012
Post-LWU	ρ	−.491*	.497*	.174	−.730**	−.654**
	P	.035	.022	.450	< .001	.001

Abbreviations: ASYM, asymmetry, CODS, change-of-direction speed test, CWU, control warm-up condition; D, dominant limb, LWU, loaded warm-up condition, ND, nondominant limb, SLCMJ, single-leg countermovement jump.
*Significant ($P \le .05$) of the correlation. **Significant ($P \le .01$) of the correlation.

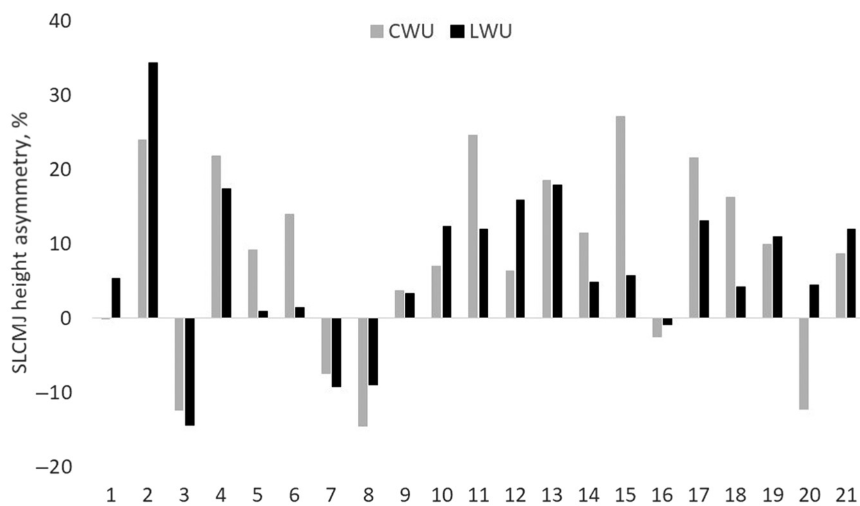

Figure 4 — The magnitude and direction of individual athletes' SLCMJ height asymmetries following the CWU and LWU. Positive values indicate a higher jump on the dominant limb; negative values indicate a higher jump on the nondominant limb. CWU indicates control warm-up condition; LWU, loaded warm-up condition; SLCMJ, single-leg countermovement jump.

type II error. The LWU protocol in the current study was based upon a previously used methodology. Maloney et al[14] reported that LWU with the same loading as the current study (10% body mass) resulted in a similar magnitude of improvement in badminton-specific CODS (5%; ES = 0.83) in professional players. It is likely that Maloney et al[14] observed significant improvements and a larger ES in comparison with the current study as a result of less variance in the CODS test (SEM of 0.40 s in a shorter [~12 s] test). Moreover, players in this investigation performed the CODS test ~20 minutes after the last warm-up exercise, far longer than the 6 to 8 minutes previously employed.[14,15] This length of recovery has been demonstrated to elicit improvements following heavy resistance exercise but is longer than has been evaluated in regards to ballistic preconditioning interventions.[4] The kinetics of fatigue-potentiation responses beyond 8 minutes[15] are yet to be well examined following LWU and require direct investigation.

The worse reliability reported in the current study could be explained by the use of amateur players in comparison with professionals, or that the modified CODS test protocol is a less reliable test. The CODS assessment employed here was proposed by Paterson et al[25] in an attempt to cover a more complete array of sport-specific movements. However, the reliability of this test versus the Hughes[34] assessment utilized by Maloney et al[14] has not been established. It is therefore not clear which test may prove a more sensitive measure of CODS performance for the badminton player and may prove a topic for future investigation. Turki et al[15] also examined the effect of LWU on CODS performance (20-m zigzag test). The investigators reported that all LWU conditions (5%, 10%, and 15% BW) improved fastest (1.31%–1.58%) and total (1.89%–1.98%) CODS versus CWU, with no difference between loadings. While the magnitude of change is lower than reported in the current study, so too were the CV values for the zigzag test (1.04%–1.49%) and likely explain the significance of the effect.

To the authors' knowledge, this is the first investigation to report the effect of an acute exercise intervention on asymmetry. The LWU in the current study did not influence SLCMJ asymmetry in comparison with CWU. This is perhaps not surprising as the preconditioning activity did not attempt to replicate kinetics or kinematics of the SLCMJ and performance improvements within the test that may not be anticipated. However, one interesting finding was revealed. Whereas asymmetry was not associated with performance following CWU, correlations for both CODS and SLCMJ D with asymmetry were reported after LWU such that better performances were associated with larger asymmetries. This is the first study to show a significant relationship in this direction for CODS, although larger pedal force asymmetries have been associated with improved cycling performance in one instance.[35] Previously, SLCMJ asymmetries have been associated with impaired CODS in youth tennis players[17] and academy soccer players,[18] although other investigations have observed no relationship in team-sport athletes.[19–22]

It is not clear why asymmetry should directly influence performance in a positive or negative manner; aside from serving as a potential proxy for a neuromuscular deficiency.[16] Longstanding participation in a highly unilaterally biased sport such as badminton is to be expected to result in asymmetric adaptations. For example, thicker and wider Achilles and patellar tendons in the racket leg.[36] As the magnitude of asymmetry would be anticipated to increase with playing age,[23] it may be expected that performance in sport-related tasks would too. This may explain why larger SLCMJ asymmetries were associated with better performances in the CODS test (representing sport-specific movement patterns) and the SLCMJ D (representative of neuromuscular capacity on the lunging leg); badminton players have adapted to perform these types of task. However, asymmetry was not associated with performance in the SLCMJ ND. As such, it is likely that badminton players have developed asymmetries which may be deemed "functional" as they underpin performance within movement patterns associated with their sport. Nonetheless, the marked difference in the strength of the relationship (or lack thereof) in the CWU versus the LWU is hard to explain. The likelihood of a type I error should therefore not be discounted. Moreover, it is hard to explain why a small percentage ($n = 4$) of the cohort exhibited superior SLCMJ performance on their nondominant limb.

It is important to note that the order of CWU and LWU was not counterbalanced in this investigation due to logistical constraints, this is a clear limitation. Given players' familiarity with the movement patterns assessed by the CODS and SLCMJ tests, learning or practice effects are perhaps unlikely but, again, should not be discounted. In addition, the study was unable to control for individual differences between participants such as strength, badminton ability/training age, or discipline (singles, same-sex doubles, and mixed doubles).

Practical Applications

While a significant effect of the LWU was not observed, several individuals responded in a positive manner and a "small" positive effect was reported. As such, LWU may prove a strategy to trial on an individual basis. However, given the potential for some athletes to respond negatively to LWU, generic recommendations should not be applied across groups of athletes. Moreover, it is important to consider that CODS was tested ~20 minutes following the LWU, which is unlikely to be representative of a typical post warm-up recovery duration. It was further observed that larger asymmetries were associated with faster CODS performances following LWU. For this reason, typical recommendations to reduce asymmetries with a view to enhancing performance do not appear to be justified in badminton players.

Conclusions

The current study reported no significant effect of a LWU (10% BW) on CODS performance or SLCMJ asymmetry versus a CWU in amateur badminton players. Nonetheless, a "small" ES suggested faster CODS following LWU and several individuals responded in a positive manner. In addition, it was also observed that larger asymmetries were associated with faster CODS performances following LWU. This is the first investigation to examine the association between asymmetry and CODS in badminton, a highly asymmetric sport.

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