Beneficial effects of small-sided games as a conclusive part of warm-up routines in young elite handball players

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ABSTRACT

The aim of this study was to compare the effects of small sided games (SSG) and traditional warm-up strategies on the mechanical, physiological, and perceptional responses of handball players. Using a randomized and counterbalanced design, 12 elite male handball players completed a general 8 min warm-up which was concluded with an 8 min section of either specific handball shooting drills or 3 × 2 min of 3 vs. 3 SSG with a passive recovery of 1 min between bouts. Countermovement jumps and plyometric press-ups were assessed before and immediately after the warm-up regimens using a force plate. Heart rate (HR) was assessed during the warm up regimens, and rating of perceived effort (RPE) was assessed after the regimens. Meaningful differences favoring SSG were observed in most of the kinetic variables in the countermovement jumps and plyometric press-ups (|Hedges' g| = 0.26–1.42). Conversely, no meaningful differences were found between warm up regimens in RPE or HR responses (z-scores = 0.45 and 1.88, respectively). These results indicate that concluding warm-ups with SSGs offer greater benefits compared to a more traditional warm-up routine, despite similar HR and RPE responses even when matched for duration among elite level handball players.

Keywords: Assessment; competition; musculoskeletal; team sport; training

INTRODUCTION

Warm-up routines are widely implemented prior to athletic competition as means to optimize performance. A recent meta-analysis reported that 79% of the analyzed studies observed performance enhancing effects following various warm-up protocols (12). The proposed mechanisms accounting for the benefits of warm-ups are physiological, mechanical, and psychological in nature (23). **These mechanisms have been attributed to temperature- and non-temperature-related processes, which facilitate and potentiate the effects of the warm up (3). The temperature-related mechanisms include decreases in muscle stiffness, increases in nerve-conduction rate, anaerobic energy provision, and altered force-velocity relationships. The non-temperature-related mechanisms include increases in oxygen delivery, post activation potentiation (PAP) (3) (23), and enhanced oxygen kinetics.** While the **underpinning mechanisms and** practical benefits of warm-ups are generally agreed upon, the implementation strategies are still debated (23). In team sports, warm-ups may last up to 40 min (26) and are traditionally **include** sequences of moderate- to high-intensity and generic to specific activities (23). However, evidence suggests that shorter-duration (10-15 min) activities, completed at 40-70% of maximal rate of oxygen consumption, may be sufficient to improve short, intermediate, and long-term performance (4). Reviewing the warm-up literature, McGowan et al. (23) concluded that pre-match warm-up strategies for team sports that aim to optimize subsequent performances should employ sport-specific activities, while keeping the total effective duration of less than 16 min. As such, shortening the duration of the warm-up and making it more sport-specific may further improve its benefits, both of which can be achieved by implementing small-sided games (SSG) as a warm-up strategy.

SSG can be defined as team-sport games, performed in small playing areas with a reduced number of players, variable rules, and technical constraints (5, 8, 17). These games are designed to simulate both the technical/tactical and physical/physiological demands of a particular discipline (15). **By replicating real game scenarios, SSG targets not only physiological aspects of training, but also forces players to make decisions under pressure and in constrained conditions. In view of this, SSG may offer additional benefits if implemented as a warm-up strategy in comparison to traditional warm-up activities. Most investigations of SSG examined the long-term training effects, with only two studies examined SSG as a warm-up regimen reporting mixed results.**

Gabbett et al. (14) investigated the effects of open-skill activities as a warm-up strategy for basketball players and observed no differences in comparison to a traditional warm-up, as measured by reactive agility, vertical jump, and sprint performance. The open-skill activities included a variety of technical high-intensity actions performed individually, which progressed into 4 vs. 4 SSG. Conversely, Zois et al. (34) found that using 3 vs. 3 SSG improved countermovement jump (CMJ), repeated sprint, reactive agility, and 40 m sprint performance among soccer players compared to a traditional warm-up. These conflicting effects could stem from the different durations of the warm-up periods. Whereas the overall duration of the warm-up in Gabbett’s study was 22 min, **with** the SSG part **lasting** 15 min, the warm-up duration in Zois`s study lasted approximately 12 min in total, with only 6 min dedicated for the SSG. The long duration of high-intensity warm-ups in Gabbett’s study may have compromised the enhancement of subsequent performance (14).

Considering the potential SSG have as a warm-up strategy and the dearth of studies on this topic, there is a need to further explore and compare the inclusion of SSG in warm-up regimens to traditional warm-ups. Accordingly, the aim of this study was to compare the acute effects of SSG-based warm-up and a traditional warm-up on upper and lower body athletic performances and the associated mechanical, physiological, and perceptional outcomes in elite handball players.

METHODS

Experimental Approach to the Problem

A randomized, crossover study design was **used**, in which mechanical, physiological, and perceptual responses (11) were monitored before and immediately after either traditional or SSG-based warm-up protocols. Athletes completed two experimental trials five days apart in a random order. The first half of the warm-up protocol was similar in both conditions and was composed of standardized handball pre-match warm-ups lasting roughly 8 min. Subsequently, athletes completed a baseline CMJ and PP assessment, followed by either handball-specific shooting drills or **3 vs. 3** handball SSG for 8 min. The same CMJ and PP tests were then repeated 7 min **after the completion of** the warm-up regimens (4), during which the athletes stood or walked. The order in which the tests were completed was counterbalanced for each participant and the order of conditions was determined by block randomization (27) using an online randomization tool. Two weeks prior to the study, participants performed two familiarization sessions 5 days apart. On these occasions, the exact experimental sequences, including baseline assessment, either traditional or handball specific SSG-based warm-up protocols, and post warm-up assessment were followed.

Subjects

A convenience sample of twelve elite male handball players belonging to a U-21 national handball team (age 19.3 ± 0.4 years; height 186.5 ± 8.4 cm; weight 86.8 ± 8.4 kg) participated in the study. The participants had 8.2 ± 1.5 years of training experience, and practiced 8 times per week for a total of 11.5 ± 1.1 hours of weekly handball activities. **Athletes who suffered from an upper and/or lower limb injury in the last six months in any were excluded.** This study was carried out in accordance with the recommendations of the Declaration of Helsinki after being approved by the ethical committee for human research of the Academic College at Wingate, Israel. Written informed consent was obtained from each participant after receiving an explanation of the purpose, benefits, and potential risks of the study.

Procedures

Five days prior to the first experimental trial, measurements of height and body mass (SECA model 284, Germany) were taken. On the same day, the Yo-Yo intermittent recovery test level 1 (YYIRTL1) (28) was performed to determine the maximum heart rate (HR_{max}) values, which were used for the calculation of exercise intensity during the two experimental warm-up sessions. All testing sessions were performed on a regular indoor court and completed at the same time of the day (11:00 a.m. - 13:00 p.m.) and in similar ambient conditions of temperature (20.5 ± 0.5°C) and relative humidity (60 ± 4.5%). In order to prevent unnecessary fatigue, players and coaches were instructed to avoid intense training 24 h prior to each testing day. Additionally, participants were also asked to avoid eating 2 h before each testing sessions.

Lower body mechanical assessment

Lower body mechanical capabilities were assessed by a CMJ test according to the protocol previously described by Dello Iacono et al. (9). Each subject performed a bilateral CMJ on a force plate (Kistler Biomechanics, Winterthur, Switzerland) starting from a stationary position with their hands on the waist and knees fully extended, squatting down to ~90° of knee flexion before starting an explosive, upward motion, with the intent to jump as high as possible. Knowledge of jump performance was provided to the athletes after each jump, and verbal encouragement was provided prior to each trial by two research assistants, who were blinded to which group each subject was assigned. Subjects carried out three maximal CMJ with 30–45 s rest between each jump to avoid fatigue.

The vertical ground reaction force signal (F_z) was acquired from the Kistler amplifier to a 12-bit A/D converter at 1000 Hz sampling rate and stored on a PC (Dell Inspiron 9100, Dell, United Kingdom). Data were filtered through a fourth-order, low-pass Butterworth digital filter, with a cutoff frequency of 100 Hz. The F_z signal was later analyzed according to the methods described by Caserotti et al. (6), and the following parameters were calculated: peak eccentric force ($F_{peak\text{-}ecc}$), peak concentric force ($F_{peak\text{-}con}$), peak concentric power ($P_{peak\text{-}con}$), jump height (JH), and displacement of the body center of mass during the eccentric (S_{ecc}) phase. Specifically, jump power was calculated as the instantaneous product between the F_z and the vertical velocity (v) of the center of mass; force and velocity in other planes were assumed to be negligible. The latter was obtained by time integration of the instantaneous acceleration:

$$v(t) = \int_0^T a_{net}(t)dt = \int_0^T [F_z(t)/m - g]dt$$

where a_{net} is the vertical acceleration, F_z is the vertical force measured by the platform, m is the body mass of the subject, and g is the acceleration due to the gravity (9.81 m/s^2). Center of mass position was plotted throughout the whole movement by time integration of the velocity signal. Finally, jump height was measured from the value of vertical velocity at take-off point ($v_{takeoff}$):

$$jump\ height = \frac{v_{takeoff}^2}{2g}$$

Upper body mechanical assessment

Upper body mechanical capabilities were assessed by PP according to the protocol of Johnston et al. (18). Players were asked to start in a press-up position with their hands on the force platform in a self-selected position and arms extended. On the experimenter's signal, the players lowered their body by flexing their elbows to a self-selected depth before extending the elbows as quickly as possible so that their hands left the platform. Subjects performed two self-chosen trials without data being recorded before completing three PP with 30–45 s of rest between them. The same procedural methods described above for the lower body mechanical responses assessment were applied (9). All PP trials were analyzed for the eccentric and the concentric phases and the kinetic parameters selected for further analysis were: peak eccentric force ($F_{peak\text{-}ecc}$), peak concentric force ($F_{peak\text{-}con}$), and peak concentric power ($P_{peak\text{-}con}$).

Warm-up protocols

Proceeding each experimental session, participants underwent an 8 min standardized warm-up: 3 min of locomotor activities including jogging, running, and multidirectional changes of direction (COD); 3 min of dynamic stretching exercises for the upper and lower extremities; and 2 min of jumping drills and press-up exercises, accelerations, and short-sprint drills over a distance of 20 m. Shortly after an active recovery (~2 min), participants completed baseline assessment including the CMJ and PP **(~3 min)**. Immediately after, the players completed either handball-specific shooting warm-up drills or SSG for additional 8 min. The handball-specific shooting warm-up was composed of:

- Short (5 m) to long distance (20 m) passes (both with one and two arms performed as overhead or side ones), completed in couples;
- Five free shots performed from the 9 m line with increasing intensity up to maximal shooting effort.
- Five jump shots performed from the players' own position and preceded by a run-in of about 5 m (32).

Finally, about 7 min following the shooting warm-up, the assessment procedures were repeated.

The SSG warm-up was composed of: regular small-sided handball matches and were organized in 3-a-side teams including goalkeepers (8-10, 17). The SSG warm-up consisted of 3 × 2 min bouts with a passive recovery of 1 min between bouts played on a regular handball court (40 m × 20 m). Some playing rules were created in order to avoid game breaks ensuring continuity and high exercise intensity. For instance, standing and dribbling were not allowed, defense stops due to regular fouls were sanctioned with ball turnover, **and** the maxim**um** time to complete an attack before losing ball possession was **constrained to** 20 s. Additionally, several balls were placed around the sided games area for immediate availability in order to avoid game pause. Finally, penalties were considered to be a regular goal and no free shot was given. To avoid any bias due to the players' anthropometric, physiological, and positional role characteristics, the four teams were equally matched, including one wing player, one line player/pivot, and one back player (7).

Heart rate responses

HR responses were monitored during both the traditional and the specific SSG-based warm-up to provide the mean heart rate percentage (%HR_{mean}), **which is more** indicative of what occurs over the entire warm-up as compared to HR_{max}. HR responses were recorded via a telemetry system (Hosand Technologies Srl, Verbania, Italy) at 5 s intervals throughout each SSG, and then filtered using a software-embedded proprietary algorithm (Hosand MC Software^{TM}, Verbania, Italy). The %HR_{mean} and the HR_{max} were those measured during and at the end of the YYIRTL1 test.

Rating of perceived effort (RPE)

Players indicated their rating of perceived exertion (RPE) using the category rating 10 (CR-10) scale modified by Foster et al. (11) at the end of the experimental session, using a standardized questionnaire. **All players were familiarized with this method as it was employed by the coaching staff as a load monitoring tool.**

Statistical analyses

To assess the effects of the warm-ups, all data were imported to R (version 3.4.3) for analyses (30). For data that consisted of pre- and post-testing (JH; S_{ecc} during the CMJ; $F_{peak\text{-}con}$ and $F_{peak\text{-}ecc}$ during the CMJ and PP; and $P_{peak\text{-}con}$ during the CMJ and PP), linear mixed-effects models were used (2). Using the effect of condition (i.e., the effect of SSG relative to control), Hedges' *g* effect sizes were calculated to estimate a conservative standardized mean difference (16, 21). Finally, 95% percent confidence intervals (CI) were calculated for the condition effects.

RPE and HR data were analyzed using permutation tests, which is a nonparametric testing paradigm that compares the observed effects to a simulated null distribution. By comparing the observed effects to the null distribution, a *z*-score and *p*-value could be calculated. Finally, 95% CIs were calculated around the observed effect.

To avoid dichotomous interpretations of the results, no *a priori* α-level was set. Rather than interpreting effects from a single test, or set of tests, the results were interpreted on a continuum using all statistical outcomes, in combination with theory and practical considerations (24). Due to the unconventional nature of these procedures in our field, **a more thorough description of our analyses and R code can be found on the Open Science Framework (https://osf.io/327za/).**

RESULTS

Linear mixed-effects models revealed marked improvements in JH, S_{ecc} during the CMJ, $F_{peak\text{-}ecc}$ during the CMJ, $F_{peak\text{-}con}$ force during the CMJ, CMJ $P_{peak\text{-}con}$, PP $F_{peak\text{-}ecc}$, PP $F_{peak\text{-}con}$, and PP $P_{peak\text{-}con}$ relative to the control warm-up (Table I and Figures 1 and 2). Permutation tests did not reveal any remarkable differences between SSG and warm-up conditions in RPE or mean HR (Table I).

*****Table 1 near here*****

*****Figure 1 near here*****

*****Figure 2 near here*****

DISCUSSION

The SSG warm-up **led to** superior outcomes for both upper and lower body **performance measures,** even when considering that **the** duration, intensity, and perceptional responses of the two routines were similar. To our knowledge, this is the first study to have examined mechanical responses and physiological mechanisms underlying changes in the assessed athletic performances of SSG warm-up.

Lower body

The SSG-based warm-up enhanced CMJ height by 7.1% compared to the traditional warm-up routine and was associated with greater improvements in all the kinetic measures. Specifically, S_{ecc}, $F_{peak\text{-}ecc}$, $F_{peak\text{-}con}$, and $P_{peak\text{-}con}$ increased by 8.7%, 13.8%, 10%, and 9.8% in the SSG compared to the traditional warm-up routine, respectively (Figure 1). These results are in line with some, but not all investigations. Whereas the results of the current study are in line with those reported by Zois et al. (34), which observed a similar 6% improvement in CMJ following the SSG warm-up, Gabbett et al. (14) did not observe an advantage of open skill-based warm-up including SSG over a traditional warm-up routine on **reactive agility, sprinting, COD, and jumping** performances. This discrepancy could stem from dissimilar durations of the warm-up in these studies. Whereas the duration of the warm-up in present study and the study by Zois et al. (34) lasted 12-16 min, a duration that is in line with published recommendations, Gabbett and colleagues (14) implemented a 22 min warm-up, which may have hindered subsequent performance. **That is, longer duration warm-ups may lead to excessive muscular fatigue thereby hindering physical performance.**

The enhancement of the CMJ performance following the SSG-based warm-up may in part be explained by a PAP effect (29). The frequent “one-on-one” SSG-related playing situations involve dynamic actions such as accelerations, decelerations, **COD,** and jumps. These actions are ballistic in nature, and previous research has indicated that ballistic movements produce greater muscle activation and power output than non-ballistic ones (20, 25). As a consequence, they may have induced activation of high-threshold motor units, which have been proposed to underlie PAP (31). **The improved jump ability observed following the SSG-based warm-up could stem from various biochemical and neuromuscular adaptations, such as an increase in the sensitivity of the actin-myosin myofilaments to Ca^{2+}, neural drive to the agonist muscles (1), improved intermuscular coordination (19), changes in the muscle-tendon mechanical-stiffness characteristics (13), and changes in single-fiber mechanics (1)**. Our results are also consistent with the observations of Wilson et al. (33); that is, (1) multiple sets of the potentiating activities and (2) recovery intervals of 5–7 min between the conditioning activity and the subsequent performance induce large PAP effects. Therefore, we suggest that the short duration of the SSG-based warm-up protocol (8 min) organized in a multiple-set format (3 × 2 min) and the time scheduling relative to the functional performance (7 min) have likely influenced the magnitude of the effects on muscle mechanical enhancements. The lack of differences in the HR and RPE responses between the two warm-up regimens strengthens the possibility that increases in neural activation associated with the PAP effects accounted for the superior SSG warm-up performance.

The changes in the mechanical responses following the SSG-based warm-up suggest small modifications in jumping strategy. During the eccentric phase of the CMJ, athletes reduced the downward displacement while developing greater force and power outputs during both the downward and the subsequent upward actions (Figure 1). The underlying mechanisms leading to these effects may be related to modifications in the characteristics of the joints involved and muscles recruited. Following the SSG-based warm-up, the lower limbs kinematics may have changed, resulting in increased joint velocities and improved joint coupling (19) (29). Such modifications of the jump strategy and the required motor control are presumably responsible for the reduced downward displacement during the CMJ after the SSG-based warm-up. In addition, parallel changes of muscle-related characteristics like increases in motor unit recruitment and discharge rates, changes in muscle architecture **(e.g., pennation angles)** (13) (22), and muscle stiffness (1) (31) may have contributed to the increase in strength and power outputs. However, because no direct neurophysiological measurements were collected in this study, the two assumptions accounting for the improved mechanical outputs are speculative and should be explored by future**, mechanistic** research. Additionally, the size of the effect was small, and as such, it is not clear if the identified differences in jump strategy represent a meaningful **and** replicable effect.

Upper body

The SSG-based warm-up led to greater improvements in all the mechanical measures in the PP in comparison to the traditional warm-up protocol. $F_{peak\text{-}ecc}$, $F_{peak\text{-}con}$, and $P_{peak\text{-}con}$ increased by 12.9%, 13.3%, and 22.8%, respectively, in the SSG warm-up relative to the traditional warm-up (Figures 2). To our knowledge, no other study examined and compared the effects of SSG and traditional warm-ups on explosive upper body exercises, making direct and contrasting comparisons impossible. It can be assumed that common handball-specific physical contact actions such as hitting, blocking, pushing, and holding occurring between players in the SSG warm-up, in addition to shooting and passing, could have generated a PAP effect on the PP task. This is especially the case when considering that such actions are completed against heavy resistance, as represented by the opponent's mass, a condition that was absent from the traditional warm-up routine. Accordingly, the high similarity between the upper body actions demanded during handball SSG and the assessed PP task, together with a proper mechanical overloading, may have produced PAP.

There is clear evidence of the chronic effects of contact SSG on upper body neuromuscular performance in handball players. Iacono et al. (17) observed that SSG training created a cumulative training stimulus that produced improvements in upper body strength, as measured by a 1RM bench press test over a period of 8 weeks. However, the same authors (9) recently demonstrated that a SSG lasting 15 min led to acute impairments in upper body mechanical performances during the following PP task. The performance decrements reported by Dello Iacono et al. (9) are likely due to the longer duration of the SGG in comparison to the warm-up protocol used in the current study (15 vs. 6 min). These results indicate that the presence of an adequate **number** of actions associated **with** physical contact during SSG determines ergogenic effects on upper body musculature.

These findings may have immediate implications for the implementation of SSG formats into a warm-up routine. Besides the observed positive effects on the subsequent CMJ and PP performances, the opportunity to easily schedule this warm-up protocol, using sport-specific drills, in the imminence of the competitive activity, may likely improve both players' compliance and coaches' acceptance. **Seven minutes following the completion of the SSG-based warm-up, considerable improvements in performance were noted in both upper and lower body functional tasks. These results are in line with the literature (33) reporting that the greatest**

effects in the temporal profile of PAP strategies are commonly elicited 5–9 min following the conditioning activity. Accordingly, coaches are advised to consider this guideline for effectively scheduling SSG-based warm-up strategies before daily training and before a match is expected to begin. The advantages of using sport-specific drills, like SSG as warm-up means, are several. First, SSG could be easily administered on the field without the need of weight rooms, training equipment, or individually-designed protocols. Second, the similarities between the SSG-based warm-up and the competitive activities may increase the chances to achieve greater transfer effects and mechanical adaptations. Finally, besides the positive physiological changes and the methodological rationale supporting the use of SSG-based warm-up strategies, it is possible that psychological mechanisms, associated with the players' and coaches' compliance and motivation, may contribute to greater improvements in the subsequent performances.

There are a number of limitations in this study **worth noting**. First, due to logistical constraints, only two outcome measures were collected, both of which are indirectly related to handball performance. Future studies should also measure more sport-specific tests, such as agility tests and ball-throwing velocities. Second, the 7 min delay between the end of the warm-up routines and the initiation of the testing procedures may have washed out some of the warm-up effects. Despite this limitation, this testing procedure has a higher degree of ecological validity as it mimics the common behaviors of team sport associated with 5-10 minutes delay between the end of the warm-up and beginning of a game (23). Finally, we did not conduct a power analysis to determine the **sample** size. This is because the population from which well-trained handball players can be drawn, belonging to the same team and with a common training background is limited. To overcome this problem, we conducted a within-subject design, and attempted to reduce learning curves by including familiarization sessions.

PRACTICAL APPLICATION

Coaches should consider implementing SSG not only as a training strategy, but also as part of a warm-up strategy. **Practically, we suggest using 3 vs. 3 SSG, played in 3 bouts of 2 min and 1 min of passive recovery, as the conclusive part of a pre-competition warm-up. To observe the greatest PAP effects, attempt to complete the SSG warm up ~7 minutes prior to the match/training session. Finally, in order to optimize the PAP effects, practitioners should consider developing adequate strength levels, since stronger individuals are more likely to express greater PAP responses.**

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FIGURE LEGENDS

Figure 1: Plot of the CMJ mechanical responses changes following the traditional (CON) and SSG-based (SSG) warm-up protocols

Figure 2: Plot of the PP mechanical responses changes following the traditional (CON) and SSG-based (SSG) warm-up protocols