Effects of Warming-up on Physical Performance: A Systematic Review With Meta-Analysis

Andrea J. Fradkin,[1] Tsharni R. Zazryn,[2] and James M. Smoliga[3]

[1]Department of Exercise Science, Bloomsburg University, Bloomsburg, Pennsylvania; [2]Department of Health Science, Monash University, Frankston, Australia; and [3]Department of Health and Physical Education, Marywood University, Scranton, Pennsylvania

Abstract

Fradkin, AJ, Zazryn, TR, and Smoliga, JM. Effects of warming-up on physical performance: a systematic review with meta-analysis. *J Strength Cond Res* 24(1): 140–148, 2010—The value of warming-up is a worthy research problem because it is not known whether warming-up benefits, harms, or has no effect on individuals. The purpose of this study was to review the evidence relating to performance improvement using a warm-up. A systematic review and meta-analysis were undertaken. Relevant studies were identified by searching Medline, SPORTDiscus, and PubMed (1966–April 2008). Studies investigating the effects of warming-up on performance improvement in physical activities were included. Studies were included only if the subjects were human and only if the warm-up included activities other than stretching. The quality of included studies was assessed independently by 2 assessors using the Physiotherapy Evidence Database scale. Thirty-two studies, all of high quality (6.5–9 [mean = 7.6] of 10) reported sufficient data (quality score >6) on the effects of warming-up on performance improvement. Warm-up was shown to improve performance in 79% of the criterions examined. This analysis has shown that performance improvements can be demonstrated after completion of adequate warm-up activities, and there is little evidence to suggest that warming-up is detrimental to sports participants. Because there were few well-conducted, randomized, controlled trials undertaken, more of these are needed to further determine the role of warming-up in relation to performance improvement.

Key Words review of evidence, effect size, warm-up, performance improvement, physical activity

Address correspondence to Andrea J. Fradkin, afradkin@bloomu.edu.

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Introduction

The term warm-up in sport is defined as a period of preparatory exercise to enhance subsequent competition or training performance (18). Performance improvement is the concept of measuring the output of a particular process or procedure, then modifying this to increase the effectiveness of the initial process or procedure (3). This performance can relate to either competition or a training performance.

The traditional warm-up paradigm typically includes a brief period of low-intensity aerobic exercise followed by stretching and sports specific exercise (33). However, many sports participants only participate in 1 or 2 of the recommended activities and assume that they are performing an appropriate warm-up (14,15). Smith (37) indicated that the general purpose of a preexercise warm-up is to increase muscle and tendon suppleness, to stimulate blood flow to the periphery, to increase muscle temperature, and to enhance free, coordinated movement. Therefore, not undertaking all 3 recommended warm-up components may not meet the minimum demands required for the muscle warming.

Given the amount of focus and importance that professional athletes place on warm-up, there is a surprisingly limited amount of "good" research evaluating whether a warm-up improves performance (6). As a result, warm-up procedures are usually based on the trial and error experience of the athlete or coach, rather than on scientific study. Amateur and recreational sports participants do not seem to rely as heavily on warming-up as professional athletes do (3,13,15); however, both groups of participants may potentially benefit from warm-up exercises.

Although the practice of some of the recommended warm-up components is widely undertaken, the value of warm-up has become a worthy research issue as it is not known whether warming-up is of benefit, of potential harm, or having no effect on an individual's performance. Perhaps more importantly, comparisons of different types and structures of warm-up are being made in controlled studies to determine the effects, if any, of warming-up (25,38). Although the optimum warm-up cannot be defined at this

time, the influence of warm-up on subsequent performance has been investigated since the 1930s (35).

Summarizing the findings of the many warm-up studies conducted over the years is difficult. Many of the earlier studies were poorly controlled, contained few study participants and often omitted statistical analyses. Furthermore, over the years, warm-up protocols consisting of different types (e.g., active, passive, and specific) and structures (e.g., varied intensity, duration, and recovery) have been used. Finally, although many studies have investigated the physiological or psychological responses to warm-up, relatively few studies have reported changes in actual training or competition performance after warm-up.

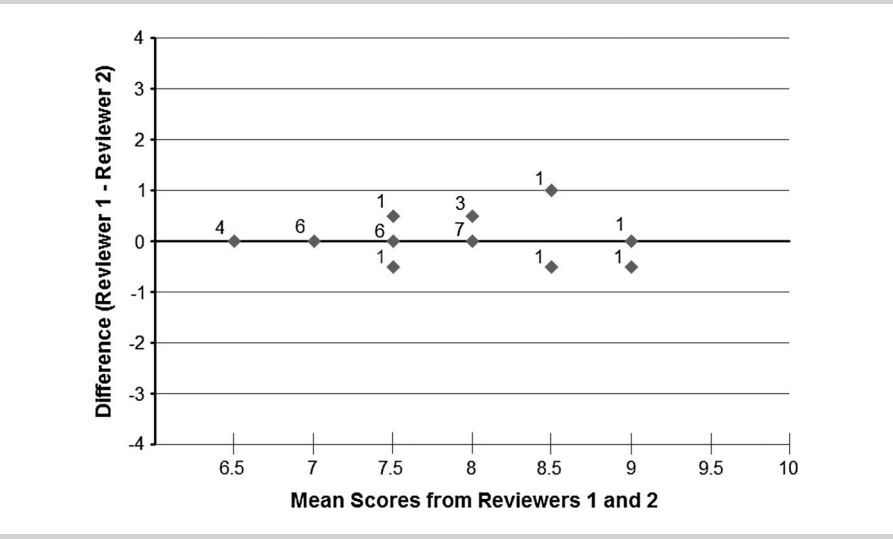

Figure 1. Bland and Altman plot highlighting the agreement between the 2 reviewers.

This systematic review and meta-analysis synthesizes research findings on the effects of warm-up on performance during physical activity.

Methods

Inclusion and Exclusion Criteria

This review integrated studies that examined the results of warming-up on performance during physical activities. Studies were included only if the subjects were human, the outcome measure was an actual sporting or physical activity performance, and only if the study incorporated at least 2 components of a warm-up, not merely stretching. Studies reported in languages other than English were not included because translations were not accessible.

Search Strategy

Relevant studies were identified by searching Medline (1966–April 2008), SPORTDiscus (1966–April 2008), and PubMed (1966–April 2008). The databases were searched for the terms "warm-up," "warm up," "warmup," "warming-up," "warming up," "exercise," and "prior exercise." These terms were then combined with "performance improvement" and "improved performance." Reference lists of reviews and retrieved studies were checked for additional studies until no additional studies were evident.

The titles and abstracts of all reviewed articles were read, and those clearly not relevant, or those not meeting the inclusion criteria were eliminated. Full copies of all the remaining studies were obtained and scored on the PEDro (Physiotherapy Evidence Database) scale.

Assessment of Study Quality

Methodological quality was calculated with the PEDro scale, which is based on the Delphi list (41). A score of 10 is derived for every study from the number of criterion satisfied (footnote in Table 2 provides a concise explanation of criterion). The higher the score achieved, the better the quality of evidence. If the study did not clearly state that a criterion was met, it was scored as not satisfying the criterion.

The quality of included studies was calculated separately by 2 appraisers. If the 2 independent assessments varied by more than 1 point, another assessment was undertaken by a third assessor. All studies with a PEDro score of 6 or lower were excluded from final inclusion. This cutoff point is considered the minimum standard for inclusion on a 10-scale criterion (41). Figure 1 highlights the interrater agreement in a Bland and Altman plot. The numbers on the graph represent the number of studies that fell on the exact same position. For example, the number 4 next to the first point shows that there were 4 studies that had a mean rating of 6.5 with a zero difference between reviewers. Therefore, this figure shows that there was a very high level of agreement between the 2 reviewers.

Meta-analysis

The results of the included studies were all recalculated to determine the percentage increases or decreases in physical performance after each warm-up protocol was undertaken. This then allowed comparisons of different warm-up protocols over different sporting and physical activities to be undertaken.

Table 1. Summary of the methodology of studies investigating warm-up as a performance improvement measure for physical activity.*

Study	Design	Participants	Warm-up	Performance task
Andzel, 1978	Crossover	20 women	6 min jog (140 b·min^{-1}) 30 s rest†‡ 6 min jog (140 b·min^{-1}) 60 s rest†‡ 6 min jog (140 b·min^{-1}) 90 s rest†‡ 6 min jog (140 b·min^{-1}) 120 s rest†‡	Run
Andzel and Gutin, 1976	RCT	12 women	1 min bench steps (140 b·min^{-1}) no rest†‡ 1 min bench steps (140 b·min^{-1}) 30 s rest†‡ 1 min bench steps (140 b·min^{-1}) 60 s rest†‡	Stepping (bench)
Bobo, 1999	Crossover	Swimmers	Static stretch and 800 yd swim†‡§ Static stretch and 3 sets 6 reps bench press 50% RM§	100 yd swim
Bonner, 1974	RCT	60 men	Cycle†‡	Cycle
Bradley et al., 2007	Crossover	18 men	5 min cycle (120 W) and static stretch†§ 5 min cycle (120 W) and ballistic stretch†§ 5 min cycle (120 W) and PNF stretch†§	Vertical jump
Burkett et al., 2005	Crossover	29 men	5 vertical jumps‡ 5 weighted vertical jumps (10% BW)‡	Vertical jump
Burnley et al., 2005	Crossover	12 people	6 min heavy cycle†‡ 10 min moderate cycle†‡ 30 sprint cycle ‡	7 min cycle
Church et al., 2001	Crossover	40 women	Body weight circuit and static stretch†§ Body weight circuit and PNF stretch†§	Vertical jump
Faigenbaum et al., 2005	Crossover	34 girls, 36 boys	10 min callisthenics† 10 min callisthenics and 3 drop jumps†	Vertical jump, long jump, shuttle run
Faigenbaum et al., 2006	Crossover	18 girls	5 min jog and dynamic stretch†§ 5 min jog and weighted dynamic stretch (2% BW)†§	Vertical jump, long jump, medicine ball toss, 10 yd run
Fradkin et al., 2004	Case control	20 men	Aerobic exercise, static stretch, and air swings†‡§	Golf club head speed
Hajoglou et al., 2005	Crossover	31 people	15 min cycle (70% max)†‡ 15 min cycle (70% max) & 5 min 90% max†‡	3 km cycle
Koch et al., 2003	Crossover	16 men, 16 women	1 set 3 reps 50, 75, 87.5% RM squats 1 set 3 reps 20, 30, 40% RM speed squats†	Standing broad jump
Mangus et al., 2006	Crossover	10 men	Quarter squat 90% RM Half squat 90% RM	Vertical jump
Mathews and Snyder, 1959	Pre/post	50 men	440 yd jog and walk, and callisthenic exercises†‡	Run 402 m
McBride et al., 2005	Crossover	15 men	1 set 3 reps squat 90% RM 1 set 3 reps loaded jump 30% RM	40 m dash
McMillian et al., 2006	Crossover	16 men, 14 women	Calisthenics and dynamic stretch†§ Static stretch and agility run and medicine ball throw‡§	5-step jump, agility, medicine ball throw
Michael et al., 1957	Crossover	77 men	5 min Softball throw‡ 5 min callisthenics and sprint†	Softball throw
Pacheco, 1957	Crossover	10 men	3 min lunges† 3 min jog on spot† 3 min deep knee bends†	Run 55 m
Pacheco, 1959	Crossover	166 girls	3 min run†	Vertical jump
Power et al., 2004	Pre/post	12 men	5 min cycle (70 rpm) and static stretch†§	Vertical jump

(*Continued on next page*)

Richards, 1968	Crossover	80 women	2 min stool stepping (25 steps·min^{-1})† 4 min stool stepping (25 steps·min^{-1})† 6 min stool stepping (25 steps·min^{-1})†	Vertical jump
Richendollar et al., 2006	RCT	24 men	3 min jog, 3 min static stretch and 10 vertical jumps†‡§	Vertical jump, shuttle run, 40 yd run
Rochelle et al., 1960	Crossover	46 men	5 min softball throw‡	Softball throw
Romney and Nethery, 1993	Crossover	8 women, 4 men	5 min swim†‡ 5 min rope jump and 10 × 15 s callisthenics†	100 yd swim
Scott and Docherty, 2004	Crossover	19 men	5 min cycle and 5 min static stretch†§	Vertical jump, horizontal jump
Skubic and Hodgkins, 1957	Crossover	8 women	12 jumping jacks† Related warm-up‡	Cycle 160 m, softball throw, basketball free throws
Stewart and Sleivert, 1998	Crossover	9 men	15 min run 60%†‡ 15 min run 70%†‡ 15 min run 80%†‡	Run
Thompsen et al., 2007	Crossover	16 women	10 min callisthenics† 10 min weighted callisthenics (10% BW)†	Vertical jump, long jump
Thompson, 1958	Crossover	34 men	Swim†‡	30 yd swim, 5 min swim
	Crossover	26 men	Calisthenics†	30 yd swim, 5 min swim
	Pre/post	20 men	20 free throws‡	Basketball free throws
	Pre/post	56 people	1 round of bowling‡	Bowling
	Pre/post	20 men	Calisthenics†	Leg strength
Witte, 1962	Cross sectional	56 girls	10 jumping jacks and 10 lap run† 20 jumping jacks and 20 lap run† 5 jumping jacks and 5 lap run†	Softball throw
Young et al., 2004	Crossover	16 men	5 min run (10 km·hr^{-1}), 3 static stretches†§	Kick speed at impact

*RM = repetition maximum; BW = body weight; reps = repetitions; RCT = randomized controlled trial; PNF = proprioceptive neuromuscular facilitation.
†Aerobic exercise.
‡Activity similar to actual event.
§Stretching.

Results

Search Results

Initially, 2,355 studies were identified in the initial search. After reading the abstracts and titles of all of the studies, 1,841 studies were excluded. A further 47 studies were excluded because they were studies performed on animals, 295 studies were excluded because they were review articles, 62 studies were excluded because they did not deal with an actual physical performance improvement, and a further 56 studies were excluded because they only investigated stretching. Finally, 22 studies that scored 6 or below on the PEDro analysis were also eliminated. There were 32 studies remaining from the initial analysis.

Table 1 shows the characteristics of the 32 studies identified that investigated the effects of warming-up in humans on performance improvement in physical activity.

Methodological Quality of Included Studies

The methodological quality of the final included studies was high (Table 2). The range of quality scores was 6.5–9 (mean = 7.6) of 10. Not all criteria on the PEDro scale were satisfied in these studies.

Effect of Warm-up on Performance Improvement

Based on the included studies, 92 different combinations of warm-up and criterion tasks were assessed to determine the effectiveness of each in improving actual sporting performance. The majority of these showed that performance was

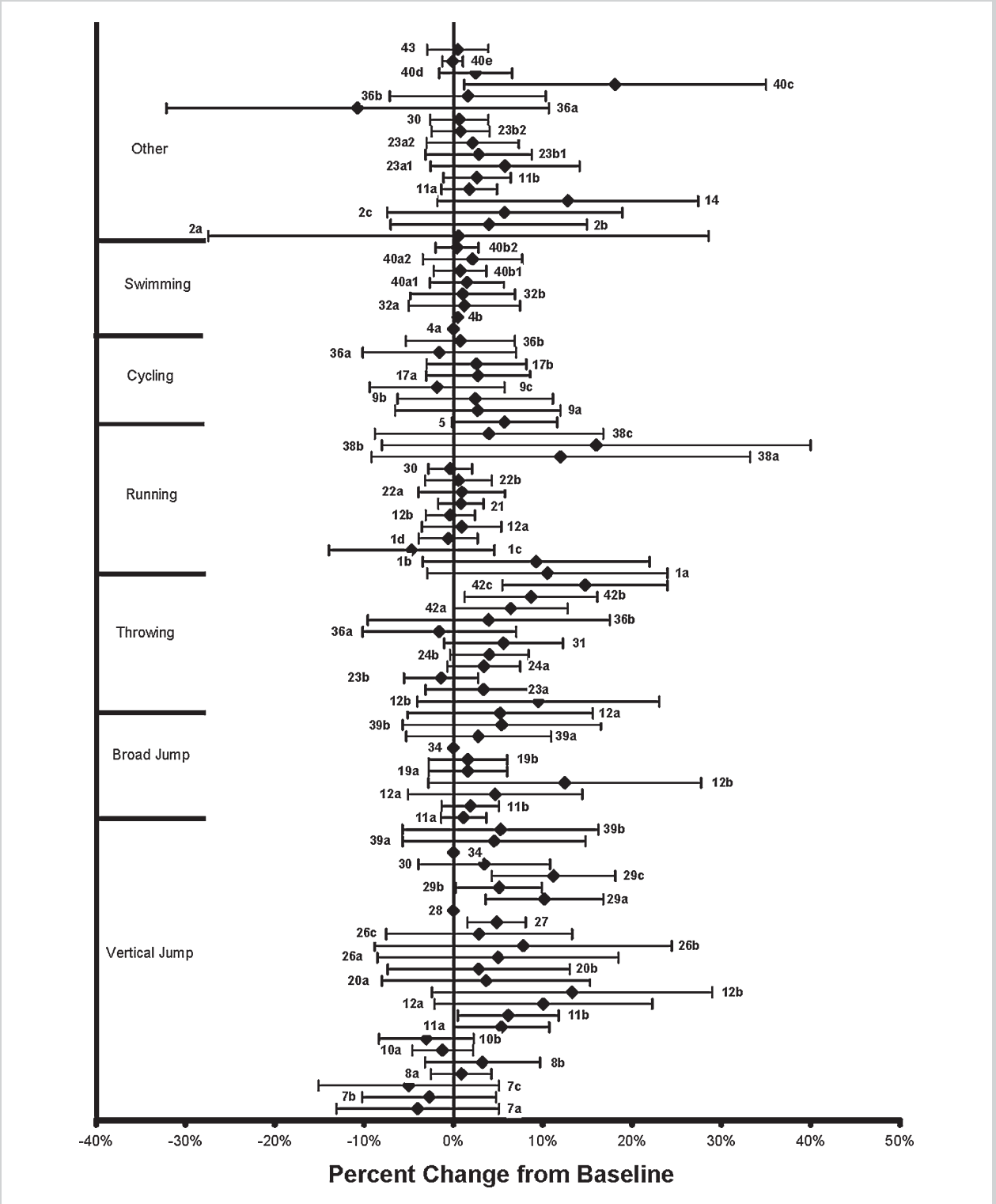

Figure 2. Meta-analysis highlighting performance changes from individual warm-up protocols (mean and 95% confidence interval shown).

Table 2. Criteria list and quality scores for methodological assessment of trials of warm-up for improving performance.

Study	Scores on PEDro Scale*										Total/10†
	1	2	3	4	5	6	7	8	9	10	
Andzel, 1978	−	+	+	−	+	+	+	+	½	+	7.5
Andzel and Gutin, 1976	−	+	+	−	+	½	+	+	½	+	7
Bobo, 1999	+	+	−	−	+	+	+	+	+	+	8
Bonner, 1974	+	+	½	½	+	+	−	+	½	+	7.5
Bradley et al., 2007	+	+	+	−	+	+	½	+	+	+	8.5
Burkett et al., 2005	+	+	+	−	+	+	+	+	+	+	9
Burnley et al., 2005	−	+	+	−	+	+	½	+	+	+	7.5
Church et al., 2001	+	+	+	−	−	+	½	+	½	½	6.5
Faigenbaum, 2005	+	+	+	−	−	+	+	+	½	+	7.5
Faigenbaum, 2006	+	+	+	−	−	+	+	+	+	+	8
Fradkin et al., 2004	−	½	+	½	+	½	+	+	+	+	7.5
Hajoglou et al., 2005	+	+	+	−	−	+	+	+	+	+	8
Koch et al., 2003	½	+	½	−	−	+	+	+	+	+	7
Mangus et al., 2006	+	+	+	−	+	½	+	+	−	+	7.5
Mathews and Snyder, 1959	½	½	+	−	+	+	+	−	+	+	7
McBride et al., 2005	+	+	+	−	+	+	−	+	+	+	8
McMillian et al., 2006	+	+	+	−	+	+	+	−	−	+	7
Michael et al., 1957	+	+	+	−	+	+	+	+	+	+	9
Pacheco, 1957	−	+	−	−	+	+	+	+	½	+	6.5
Pacheco, 1959	−	+	+	½	+	+	+	+	+	+	8
Power et al., 2004	−	+	+	−	+	+	½	+	+	+	7.5
Richards, 1968	−	−	+	½	+	+	−	+	+	+	6.5
Richendollar et al., 2006	+	+	+	−	+	+	−	+	+	+	8
Rochelle et al., 1960	½	−	+	½	+	+	+	+	½	+	7.5
Romney and Nethery, 1993	+	+	+	−	+	½	½	+	+	+	8
Scott and Docherty, 2004	+	+	+	−	−	+	−	+	+	+	7
Skubic and Hodgkins, 1957	−	+	−	½	+	+	+	+	½	+	7
Stewart and Sleivert, 1998	+	−	+	−	+	+	+	+	+	+	8
Thompsen et al., 2007	+	+	+	−	−	+	+	+	+	+	8
Thompson, 1958	+	−	+	−	+	+	+	+	½	−	6.5
Witte, 1962	−	½	+	½	+	+	+	+	+	+	8
Young et al., 2004	+	+	+	−	+	+	½	+	+	+	8.5

*Column numbers correspond to the following criteria on the PEDro scale:
1. Eligibility criteria specified.
2. Subjects randomly allocated to groups or to an order in which warm-ups administered.
3. Appropriate subjects and groups were similar at baseline.
4. Researcher and subjects were blinded.
5. Control group used.
6. Appropriate statistics used and measures of variability provided.
7. Warm-ups described in enough detail, that is, able to copy it.
8. Appropriate rest if same subjects used.
9. Tests described in enough detail to reproduce and appropriate to determine warm-up outcome.
10. Measures of key outcomes obtained for more than 85% of subjects.
†The total score is determined by counting the number of criteria that are satisfied.
+ Indicates that the criterion was clearly satisfied.
− Indicates that the criterion was not clearly satisfied.
½ Indicates that the criterion was partially satisfied.

improved after a warm-up (79%), with 3% showing no change at all in performance, and 17% finding that the warm-up had a negative impact upon the performance (Figure 2).

Discussion

This study has shown that completing a warm-up before participating in many different sports has been shown to improve the subsequent performance. Improvements have been demonstrated in aerobic and anaerobic type sports such as cycling (4,5,9,17,32,36,40), running (2,21,22,38), and swimming (4,32,40). Improvements have also been shown in the activities of vertical jumping (8,11,12,20,26,27,29,39,43), long jumps (11,12,19,39), agility (11,23,30), bench stepping (2), kicking (43), and in actual sporting performances, such as

softball (24,31,36,42), basketball (36,40), bowling (40), and golf (16). The degree of improvement varied widely, from less than 1% through nearly 20% improvement. As evidenced through studies evaluating multiple variations of similar warm-up protocols, the wide variation in results may be attributable to the specifics of the warm-up practices employed (such as the type or structure of the warm-up) (1,2,7,9,26,29,38,42). This emphasizes the need for continued research to determine which methods of warm-up are best for a given sport or activity.

Although most of the warm-ups and criterion tasks evaluated showed an improvement in performance (79%), 17% showed a decrement. When examining these in more detail, it was shown that many of these warm-ups were not suited to the performance to be performed. For example, 10–12 jumping jacks were performed before throwing, cycling, and basketball free throw performances. When compared with the best-practice theory of warm-up protocols, these warm-ups did not include aspects specific to the tasks to be performed, and completion of the warm-up was not of a long enough duration for an increase in muscle temperature to occur; thus, it would not be expected that in these circumstances that performances would improve (36). Other examples where performance was decreased after completion of a warm-up included when vigorous activity was completed before vertical jump performance (7,10), weighted warm-ups before running (12), and specific warm-ups followed by longer rest periods before the performance (1). It is important to note that not all of the warm-ups that showed a detriment in performance were inappropriate to the activity, with 36% of the warm-ups that showed a detriment in performance being a suitable warm-up to undertake before the activity (8,9,11,23,36).

Other factors not explored in this analysis may influence what role warm-up has on performance (42). The subjects' initial training status or conditioning levels may impact the results of a warm-up study because a given absolute intensity is a lower relative intensity for a trained person as opposed to an untrained person. A similar phenomenon may be evident for the subjects' age and gender because different age levels and genders may react differently to the same exercises in terms of ability to perform them and fatiguing effects. Most of the studies did not report the timeline from the end of the warm-up until beginning the actual performance, and as such, it is possible that the effect of the warm-up may have decreased. Finally, psychological factors such as self-efficacy or expectations may influence how well a subject adheres or tries in an exercise intervention program.

A number of methodological issues in the studies reviewed may also have impacted upon the results seen. Some of the studies did not have a control group or genuine control condition in the study design. Instead, many of the studies used an actual warm-up procedure as their baseline value and then compared variations in the warm-up with baseline (5,7,11,12,19,29,39,42). Although this still allowed for performance improvements and decrements to be determined, it did not reflect a true increase in performance from baseline because baseline ideally should have consisted of no prior activity. Furthermore, for each instance where warm-up was not demonstrated to improve performance, there are other studies demonstrating that warm-up does improve performance for that particular sport or physical activity. Therefore, it seems that the actual warm-up procedure employed is the major factor influencing the potential performance improvement, and there may be multiple warm-ups that improve the same performance.

Additionally, many of the studies in this review had very small sample sizes, which meant that many of the confidence intervals crossed the "zero point" (i.e., performance may have been improved or impaired). Although the conclusions from this study are based upon the mean results, it is important to note that only 8 of the studies showed an absolute improvement in performance when examining both the means and confidence intervals, with no studies showing an absolute decrement in performance. This provides further support for warming-up being advantageous for performance.

There are several weaknesses in this review, not least the relatively small number of subjects in some of the studies increasing the possible effects of chance. Also, searching for relevant studies is difficult, despite considerable efforts using electronic databases. Hand searching journals and checking of reference lists of retrieved articles increased retrieval of relevant articles. We looked for studies in electronic databases, and checked the reference lists of all included studies and many excluded studies and reviews. One hundred seventy-two articles had to be read, and their reference lists examined to ensure as complete a review as possible, with another 2,183 abstracts read. This study also only investigated the use of a warm-up on actual sporting and physical activity improvements. All studies that examined task specific movements or had physiology based outcomes were excluded. Therefore, it is possible that warming-up may be more or less beneficial for certain outcome measures.

The results of this systematic review and meta-analysis provide the best, if limited, available estimate for warm-up as a measure of performance improvement in physical activities and sporting performances. This review used a systematic review method to eliminate potential sources of bias as much as possible, but this does not guarantee the absence of bias. The PEDro scale, which was used to discriminate between studies of different quality, has not been fully validated; however, it is still one of the preferred methods for this type of study (41). The PEDro scale is, however, unlikely to have biased our conclusions because points are only awarded when a criterion is clearly satisfied and reported. If on a literal reading of a research article, it is possible that a criterion was not satisfied or reported a point is not awarded for that criterion. Because each sport has its own unique qualities, it is possible that warming-up may be a useful performance improvement tool for some sporting

activities and not others. This, however, needs further research to confirm or deny.

Practical Applications

This systematic review and meta-analysis have shown improved performance after a warm-up 79% of the time. This review included 32 articles of high quality with 92 different combinations of warm-up and criterion tasks to demonstrate this overall performance improvement. This review has also shown that there is little evidence to suggest that warming-up is detrimental to sports participants because many methodological issues exist within the studies that demonstrated such a change. Physical activity participants should therefore be encouraged to perform a period of aerobic exercise, followed by stretching, and ending with a period of activity similar to the event they are to perform before beginning any activity. These activities should focus on the body segments that will be used in the subsequent performance and should not be too intense in nature so as to fatigue the participant. Well-conducted, randomized, controlled trials are needed to further evaluate the role of warming-up before physical activity in relation to performance improvement. Based on the strong evidence that warm-up improves performance, future studies should specifically focus on how each component of warm-up can be optimized to maximize performance in specific sports and activities.

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