A systematic review of the effects of upper body warm-up on performance and injury

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ABSTRACT

Purpose This systematic review was conducted to identify the impact of upper body warm-up on performance and injury prevention outcomes.
Methods Web of Science, MEDLINE, SPORTDiscus, PsycINFO and Cochrane databases were searched using terms related to upper extremity warm-up. Inclusion criteria were English language randomised controlled trials from peer-reviewed journals in which investigation of upper body warm-up on performance and injury prevention outcomes was a primary aim. Included studies were assessed for methodological quality using the PEDro scale. A wide variety of warm-up modes and outcomes precluded meta-analysis except for one group of studies. The majority of warm-ups were assessed as having 'positive', 'neutral', 'negative' or 'specific' effects on outcomes.
Results Thirty-one studies met the inclusion criteria with 21 rated as having 'good' methodological quality. The studies investigated a total of 25 warm-up modes and 43 outcome factors that could be grouped into eight mode and performance outcome categories. No studies of upper body warm-up effects on injury prevention were discovered.
Conclusions Strong research-based evidence was found for the following: high-load dynamic warm-ups enhance power and strength performance; warm-up swings with a standard weight baseball bat are most effective for enhancing bat speed; short-duration static stretching warm-up has no effect on power outcomes; and passive heating/cooling is a largely ineffective warm-up mode. A clear knowledge gap in upper body warm-up literature is the lack of investigation of injury prevention outcomes.

INTRODUCTION

Warm-up prior to the start of physical activities is commonplace and lauded by health professionals,[1] coaches and landmark texts[2 3] for its potential for both performance enhancement and injury prevention. The exact mechanisms and outcomes of various warm-up modes, however, are still unclear. A term with broad connotations, warm-up is defined simply by Brukner and Khan[2] as being activity that "prepares the body for exercise." There is some disagreement in major sports medical texts regarding acceptable modes of these preparatory activities, especially with regard to whether static stretching is a warm-up activity.[2 3] For this review, we took a broad view of warm-up modes and defined warm-up as a "protocol specifically undertaken to prepare for the onset of subsequent physical activity."

Total body and lower extremity warm-up has the potential to both enhance performance and prevent injuries; however, no reviews have been conducted to determine whether and how these effects are replicated in the upper extremity. Considering the different injury mechanisms of common sites of upper and lower extremity injury[3 4] and differing motor pathways to upper and lower body performance, warm-up effects on the upper extremity need focused investigation. We conducted a systematic review to address questions regarding the optimum upper body warm-up modes for (1) performance enhancement and their physiological correlates across strength, power, endurance, flexibility and accuracy outcomes and (2) injury prevention.

METHODS

Search criteria are detailed in table 1, and include all relevant subject headings.

Inclusion criteria were randomised controlled trials (RCTs) published in English language peer-reviewed journals in which investigation of the effect of upper body warm-up was a primary aim. An 'upper body warm-up' was defined as "an intervention that targeted the upper extremity and/or core musculature and was designed to prepare the body for subsequent physical activity."

Relevant studies were identified through an initial screening of article titles and abstracts from database and bibliographic search results, followed by a full-text review of all articles deemed potentially relevant, and a final analysis of their adherence to inclusion criteria. All included studies were assessed according to the PEDro scale,[5] a systematic tool used to critique RCTs, by two authors (JMM and MH), with consultation from the third author (BJA) to resolve disagreements. Papers were given a score from 1 to 10 from a composite of PEDro scale items 2–11;[5] item 1 is related to external validity and is not used in the scoring, as per the published PEDro guidelines. Using this scale, studies were classified as having excellent (9–10), good (6–8), fair (4–5) or poor (<4) methodological quality.

Additionally, the primary outcome(s) of included studies were summarised and classified based on the impact of warm-up on these outcome(s). Studies were assessed as having either 'positive', 'neutral' or 'negative' outcomes according to whether the investigated warm-up enhanced, had no effect or degraded, respectively, performance outcome(s). Studies for which positive/neutral/negative designations were inappropriate (eg, comparisons of two or more modes of warm-up intervention with no control group) were assessed as reporting 'specific effects'. Meta-analysis could only be conducted for four studies that investigated the impact of baseball-specific warm-ups on baseball bat speed, using comparable warm-up conditions.

Table 1 Search criteria

Databases searched	Web of Science (1980–present) MEDLINE (1946–present) SPORTDiscus (1985–present) PsycINFO (1806–present) Cochrane (1966–present)
Search terms	"warm up" OR "warm-up" OR "warmup" AND "upper extremity" OR "upper limb" OR "back" OR "trunk" OR "neck" OR "spine" OR "shoulder" OR "elbow" OR "arm" OR "wrist" OR "hand" OR "forearm"

In the absence of consistent quantitative variables that allow for broad meta-analysis, we used the PEDro classification of primary outcomes and qualitative assessment to determine the strength of evidence present for any findings of this review.[6 7] As such, review results were considered according to four levels of scientific evidence using PEDro and outcome classifications:[7]

- *Level 1*: Strong research-based evidence: generally consistent findings in multiple high-quality RCTs.
- *Level 2*: Moderate research-based evidence: generally consistent findings in one high-quality RCT and in one or more low-quality RCTs, or generally consistent findings in multiple low-quality RCTs.
- *Level 3*: Limited research-based evidence: one RCT (either high quality or low quality) or inconsistent or contradictory evidence in multiple RCTs.
- *Level 4*: No research-based evidence: no RCTs.

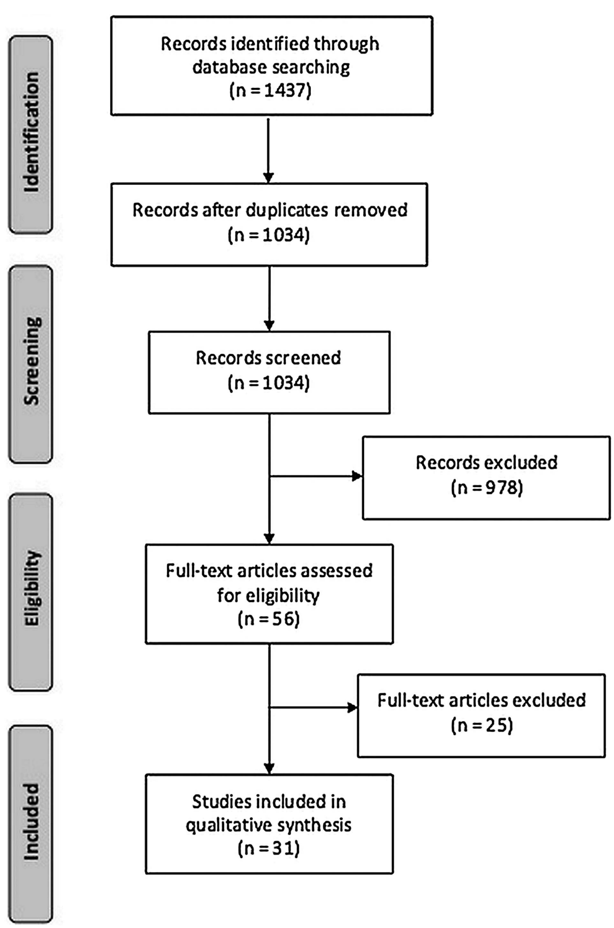

Figure 1 PRISMA flow diagram of literature screening process.

RESULTS

General systematic review statistics

See figure 1.[8] There were no included articles that investigated the effects of upper body warm-up on injury prevention; all 31 articles studied performance outcomes (see tables 2 and 3).

Included articles—sample size, demographics and population

The total sample size of all included studies was 628 participants (478 male, 124 female, 26 unreported) with an average sample size of 19±16 per study. Sixteen of the included articles investigated warm-up in a population of sport athletes (3 studies of adult athletes, 1 high school, 3 youth, 9 university), with the other 17 studies being investigations of the general population (8 adult, 9 university).

Included articles—classifications of outcomes

A detailed breakdown of study populations, warm-up modes, outcome factors and outcomes can be found in table 4. Table 5 reports the breakdown of positive/neutral/negative/specific effect outcomes from various warm-up/outcome pairings. 'Warm-up/outcome' pairing refers to the investigation of the effects of a specific warm-up mode on a single outcome measure. For example, Moran *et al*'s[9] study reported that static stretching had no effect on the golf club head speed or golf club head swing pattern, while dynamic stretching positively impacted both these outcomes. Thus, this study yielded two neutral warm-up/outcome pairings (static stretching/power and static stretching/accuracy) and two positive warm-up/outcome pairings (dynamic stretching/power and dynamic stretching/accuracy).

Included articles—meta-analysis

As seen in figure 2, bat speed is significantly decreased by 'dry swing' warm-ups with either lightweight or heavyweight bats in comparison to the increase observed when using a standard weight bat.

DISCUSSION

Our results demonstrate that there are no investigations of the effects of upper body warm-up on injury prevention outcomes. The 31 included studies investigated 25 warm-up modes using 43 outcome measures, rendering meta-analysis impractical for all modes except baseball-specific warm-up. To facilitate analysis, we used a simple classification system using 'positive', 'neutral' or 'negative' based on study outcomes in addition to meta-analysis to highlight several observable trends. These trends are summarised below according to the warm-up mode category, along with a classification of the level of evidence present to support these trends. Studies classified as having 'specific effects' on investigated outcomes, as well as a study that investigated the joint effects of two warm-up modes from different categories,[10] were not included in analyses resulting in level of evidence classifications, but are discussed where relevant.

Dynamic warm-up (levels 1, 2 and 3 evidence)

The effects of warm-up using dynamic exercises, including steady state, power, body weight and weighted exercises targeting the upper extremities, were investigated in 15 included studies and 56 warm-up/outcome pairings.[10–24] Exercises classified as being 'dynamic' can be found in table 6. Each upper body dynamic warm-up was also further distinguished with a 'high' or 'low' load classification to analyse the results in the context of the theory of postactivation potentiation, a theory

Table 2 Breakdown of populations, mode categories, outcome categories and outcome classifications of included studies

Author	Sample size (M:F)	Population	Mode category (incidence)	Outcome category (incidence)	Classification of main outcome(s) (incidence)
Bishop *et al*[14]	8 (4:4)	Young elite kayakers	Dynamic	Physiological (4); power (2)	Specific effects (6)
Bishop *et al*[15]	7 (7:0)	Elite kayak paddlers	Dynamic	Physiological (3) Power (2)	Neutral (3) Positive (2)
Brandenburg[19]	9 (9:0)	University students	Dynamic	Power	Neutral
Cé *et al*[37]	7 (2:5)	Recreationally active adults	Static stretch	Strength Physiological (4)	Negative Positive; neutral; negative (2)
Cochrane *et al*[22]	12 (12:0)	Resistance trained adults	Vibration Dynamic	Physiological; power Physiological; power	Neutral; positive Neutral; positive
Demura *et al*[18]	10 (10:0)	Right-handed university students	Passive heating/ cooling Dynamic	Strength; physiological; Endurance; power Strength; physiological; endurance	Neutral; positive; neutral; neutral Neutral; positive; neutral; neutral
DeRenne *et al*[27]	60 (60:0)	High school baseball players	Baseball specific	Power	Specific effects
Evans *et al*[13]	43 (16:27)	Untrained university students	Passive heating/ cooling Dynamic	Strength; physiological; flexibility; passive indicator; DOMS Strength; physiological; flexibility; passive indicator; DOMS	Neutral; neutral; positive; positive; Neutral Neutral; negative; neutral; neutral; neutral
Fradkin *et al*[10]	20 (20:0)	Male golfers	Dynamic Static stretch	Power	Positive *(modes not separated)*
Franco *et al*[35]	34 (34:0)	Active males	Static stretch PNF stretch	Endurance (2) Endurance (2)	Neutral (2) Negative (2)
Gelen *et al*[17]	26 (no data)	Young elite tennis players	Static stretch Dynamic	Power Power	Neutral Positive
Haag *et al*[33]	12 (12:0)	University baseball players	Static stretch	Power; accuracy	Neutral (2)
Higuchi *et al*[29]	24 (24:0)	University baseball field players	Baseball specific Isometric contraction	Power Power	Specific effects Positive
Huang *et al*[23]	16 (16:0)	University baseball players	Dynamic (2)	Power; accuracy	Specific effects (2)
Ingham *et al*[20]	10 (5:5)	Untrained university students	Dynamic	Strength (2); physiological; flexibility; DOMS	Positive (5)
Kato *et al*[21]	5 (5:0)	Healthy Japanese men	Dynamic	Physiological (2)	Positive; neutral
Khamwong *et al*[41]	28 (28:0)	Untrained male university students	Passive heating/ cooling	Strength (2) Flexibility Passive indicator (2) DOMS	Neutral (2) Positive Positive; neutral Neutral
Knudson *et al*[34]	83 (49:34)	Adult tennis players	Static stretch	Power	Neutral
Molacek *et al*[36]	15 (15:0)	Collegiate American Football players	Passive stretch PNF stretch	Strength	Neutral (2)
Montoya *et al*[28]	19 (19:0)	Adult recreational baseball players	Baseball specific	Power	Specific effects
Moran *et al*[9]	18 (18:0)	Male, right hand dominant golfers	Static stretch Dynamic stretch	Power; accuracy Power; accuracy	Neutral (2) Positive (2)
Nepocatych *et al*[24]	10 (4:6)	Adult swimmers	Vibration Dynamic	Physiological; power (2); Passive indicator Physiological; power (2); Passive indicator	Positive; neutral; neutral; neutral Neutral (4)
Nosaka and Clarkson[12]	9 (0:9)	Untrained university students	Dynamic (2)	Strength; physiological; flexibility; passive indicator; DOMS	Positive (10)
Nosaka *et al*[43]	20 (0:20)	Untrained university students	Passive heating/ cooling (2)	Strength Flexibility Passive indicator DOMS	Neutral (2) Neutral (2) Positive; neutral Neutral (2)
Otsuji *et al*[30]	8 (8:0)	Varsity university baseball/softball players	Baseball specific	Power	Specific effects
Sedgwick and Whalen[44]	20 (20:0)	Males under age 50	Passive heating/ cooling	Strength Endurance	Negative Neutral
Southard and Groomer[31]	10 (10:0)	University students with baseball experience	Baseball specific	Power	Specific effects
Symons *et al*[42]	14 (6:8)	Untrained university students	Passive heating/ cooling	Strength; physiological; flexibility; passive indicator; DOMS	Neutral (5)
Takizawa *et al*[11]	10 (10:0)	Untrained university students	Dynamic	Strength Physiological (2) DOMS	Neutral Positive; neutral Neutral
Torres *et al*[32]	11 (11:0)	University javelin, shot put, hammer and discus throwers	Static stretch Dynamic stretch	Strength; power	Neutral (16)
Wilcox *et al*[16]	12 (12:0)	University American football or baseball players	Dynamic (2)	Strength	Positive (2)

DOMS, delayed onset muscle soreness; PNF, proprioceptive neuromuscular facilitation.

Table 3 Included articles—outcome factors

Outcome category	Specific outcome factors in category	Incidence in included studies
Power	Peak power (kayak,[27] forearm flexor,[29] row,[42] 30% 1RM bench press throw,[38] isometric bench press,[38] overhead medicine ball throw,[38] lateral medicine ball throw[38])	7
	Baseball bat speed[27–31]	5
	Peak acceleration (30% of 1RM bench press throw, isometric bench press, overhead medicine ball throw, lateral medicine ball throw)[32]	4
	Peak displacement (30% of 1RM bench press throw, isometric bench press, overhead medicine ball throw, lateral medicine ball throw)[32]	4
	Average power (bench press[30]/kayak paddling[10 27])	3[14 15 19]
	Golf club head speed[10 9]	2
	Tennis serve speed[17 34]	2
	Throwing speed[23 33]	2
	Sprint performance (kayak[10], 50-yard freestyle[32])	2[14 24]
	Total	**31**
Strength	Immediate maximum isometric contraction[11 13 18 20 32 41–44]	9
	1RM[16 20 36]	3
	Peak force (30% of 1RM, overhead and lateral medicine ball throw)[32]	3
	Long-term maximum isometric contraction[12 9]	2
	Maximum eccentric muscle force[43]	1
	Maximum isokinetic contraction[42]	1
	Peak torque[37]	1
	Total	**20**
Physiological	Peak VO_2[14 15]	2
	Total VO_2[14 15]	2
	Accumulated oxygen deficit[14 15]	2
	Plasma creatine kinase levels[12 13]	2
	Muscle temperature[11 18 42]	3
	Mean EMG frequency[11 37]	2
	RMS EMG frequency[22 37]	2
	Skin temperature[20]	1
	Heart rate[24]	1
	Intracellular pH[21]	1
	Pi/PCr levels[21]	1
	Muscle fibre conduction velocity[37]	1
	1/2 contraction time[37]	1
	Total VCO_2[15]	1
	Total	**21**
Passive indicators	Upper arm circumference[12 13 42 43]	4
	Pain threshold (cold thermal, pressure)[41]	2
	Rating of perceived exertion[24]	1
	Stroke count[24]	1
	Total	**8**
DOMS[11–13 20 41–43]	Total	**7**
Flexibility	Elbow ROM[12 13 20 42 43]	5
	Wrist ROM[41]	1
	Total	**6**
Endurance	Bench press endurance[35]	1
	Maximum voluntary contraction endurance[18]	1
	Dynamic grip endurance[44]	1
	Bench press overload volume[35]	1
	Total	**4**
Accuracy	Throwing accuracy[23 33]	2
	Golf club head swing path[9]	1
	Total	**3**

DOMS, delayed onset muscle soreness; EMG, Electromyography; RMS, root mean square; ROM, range of motion.

proposing that higher load dynamic warm-ups most effectively augment performance through increased intramuscular Ca^{2+} and cross-bridge cycling.[25] Sprints, fatiguing isokinetic contractions, plyometrics, steady-state kayak ergometer warm-up at an anaerobic threshold and repeated concentric contractions at a greater than 20% maximum effort were classified as 'high-load' warm-ups. Investigated 'low–load' dynamic warm-ups were isokinetic warm-ups performed with minimum effort, a low-intensity arm ergometer exercise and repeated gripping of a sponge.

In support of the postactivation potentiation theory, the effects of high-load dynamic warm-ups were overwhelmingly positive, with 16 of 21 mode/outcome pairings reporting a positive outcome. This yielded level 1 evidence of the positive effects of high-load dynamic warm-up on strength[12 16 20] and power[15 17 19] outcomes, as well as level 2 evidence of these positive effects on flexibility[12 20] and delayed onset muscle soreness (DOMS)[12 20] outcomes. Level 3 evidence was found regarding physiological[12 15 20 21] and passive indicator[12] outcomes.

Conversely, the investigated low-load dynamic upper body warm-ups had largely no effect on performance outcomes, as 17 of 27 mode/outcome pairings reported neutral outcomes. Owing to a wide range of investigated outcome categories, no evidence of the effects of low-load dynamic warm-up could be classified as level 1; however, level 2 evidence was found regarding the neutral effects of low-load dynamic warm-up on passive indicator outcomes.[12 13 24] The neutral effects of low-load upper body dynamic warm-up on the following outcomes were classified as being level 3: power,[10 18 22 24] strength,[11–13] endurance,[18] flexibility[12 13] and physiological.[11–13 18 21–24]

Thus, consistent with the theory of postactivation potentiation and the findings of DeRenne,[26] there is strong evidence that high-load dynamic warm-up enhances upper body power and strength performance, while low-load dynamic warm-ups do not appear to be effective at enhancing any performance variables. Only one study investigated high-load dynamic warm-ups—five reps of 50%, 75% and 100% 5 repetition maximum (RM) bench press[19]—but did not report positive strength or power outcomes, suggesting that high-load dynamic warm-ups can be recommended for enhancing strength or power outcomes regardless of the specific mode used. Future investigations should focus on determining the optimum load and duration of high-load dynamic warm-up for maximum performance enhancement. Low-load upper body warm-up modes do not appear to have any effect on performance outcomes.

Baseball-specific warm-up (level 1 evidence)

A subset of dynamic warm-up, studies of warm-up via maximum effort dry swings of baseball bats of various weights have been analysed separately because their identical outcomes (baseball bat speed) enable meta-analysis. Only four of the five studies of baseball-specific warm-up included in this review could be combined for meta-analysis;[27–30] the Southard and Groomer[31] study was excluded from the meta-analysis because bat speed was measured at a different point on the bat and SDs were not reported. The meta-analysis revealed level 1 evidence that dry swing warm-up is a significantly more effective means of enhancing bat speed outcomes when performed with a standard weight bat versus heavyweight and lightweight bats; the Southard and Groomer[31] study reported similar results to the meta-analysis.

In the context of the theory of postactivation potentiation, the performance decrement resulting from warm-up swings

McCrary JM, et al. Br J Sports Med 2015;49:935–942. doi:10.1136/bjsports-2014-094228

Table 4 Included articles—methodological quality (PEDro analysis)

Study	Score	Methodological quality	PEDro item number 1*	2	3	4	5	6	7	8	9	10	11
Bishop *et al*[14]	6	Good	✓	✓		✓				✓	✓	✓	✓
Bishop *et al*[15]	6	Good	✓	✓		✓				✓	✓	✓	✓
Brandenburg[19]	6	Good	✓	✓		✓				✓	✓	✓	✓
Cé *et al*[37]	6	Good	✓	✓		✓				✓	✓	✓	✓
Cochrane *et al*[22]	6	Good	✓	✓		✓				✓	✓	✓	✓
Demura *et al*[18]	5	Fair	✓			✓				✓	✓	✓	✓
DeRenne *et al*[27]	6	Good	✓	✓		✓				✓	✓	✓	✓
Evans *et al*[13]	6	Good	✓	✓		✓				✓	✓	✓	✓
Fradkinet *al*[10]	5	Fair	✓	✓		✓				✓	✓	✓	
Franco *et al*[35]	6	Good	✓	✓		✓				✓	✓	✓	✓
Gelen *et al*[17]	6	Good	✓	✓		✓				✓	✓	✓	✓
Haag *et al*[33]	5	Fair	✓			✓				✓	✓	✓	✓
Higuchi *et al*[29]	5	Fair	✓			✓				✓	✓	✓	✓
Huang *et al*[23]	7	Good	✓	✓		✓			✓	✓	✓	✓	✓
Ingham *et al*[20]	6	Good	✓	✓		✓				✓	✓	✓	✓
Kato *et al*[21]	6	Good	✓	✓		✓				✓	✓	✓	✓
Khamwong *et al*[41]	6	Good	✓	✓		✓				✓	✓	✓	✓
Knudson *et al*[34]	4	Fair	✓							✓	✓	✓	✓
Molacek *et al*[36]	6	Good	✓	✓		✓				✓	✓	✓	✓
Montoya *et al*[28]	6	Good	✓	✓		✓				✓	✓	✓	✓
Moran *et al*[9]	5	Fair	✓			✓				✓	✓	✓	✓
Nepocatych *et al*[24]	5	Fair	✓			✓				✓	✓	✓	✓
Nosaka and Clarkson[12]	5	Fair	✓			✓				✓	✓	✓	✓
Nosaka *et al*[43]	6	Good	✓	✓		✓				✓	✓	✓	✓
Otsuji *et al*[30]	6	Good	✓			✓			✓	✓	✓	✓	✓
Sedgwick and Whalen[44]	4	Fair	✓							✓	✓	✓	✓
Southard and Groomer[31]	4	Fair	✓	✓						✓	✓	✓	
Symons *et al*[42]	7	Good	✓	✓		✓	✓			✓	✓	✓	✓
Takizawa *et al*[11]	6	Good	✓	✓		✓				✓	✓	✓	✓
Torres *et al*[32]	6	Good	✓	✓		✓				✓	✓	✓	✓
Wilcox *et al*[16]	6	Good	✓	✓		✓				✓	✓	✓	✓

*Not included in methodological quality scoring

with a lightweight bat appears consistent; however, the same result following warm-up swings with a heavyweight bat appears to be contradictory to postactivation potentiation. One possible explanation is that the use of a weighted bat during warm-up may have resulted in biomechanical adaptations that were not ideal for maximising bat speed with a normal weight bat, as supported by the Southard and Groomer[31] study. These authors noted that the weighted bat used in their study had a significantly different moment of inertia than the normal weight bat, and that the swing mechanics for the normal bat were significantly altered following a weighted bat warm-up.[31] These alterations in mechanics appear to also supersede any perceptual benefits; a separate study found that participants perceived their bat speed to be significantly faster following weighted warm-up swings, when the actual bat speed was significantly reduced.[30]

The decrease in bat speed reported following the weighted bat warm-up may also have been influenced by the extremely short duration of each bat swing or the mandated rest period between swings in each study (at least 5 s); 4–5 isolated dry swings with a heavy bat may not work the musculature enough to produce the anticipated post activation potentiation from this higher loading warm-up. The threshold of muscle activity necessary to produce a postactivation potentiation response, however, does not appear to be extremely high, given that Higuchi *et al*[29] reported that five sets of 5 s maximal isometric contractions in a batting stance, separated by a 5 s rest, significantly increased bat speed.

Further high-quality investigation is required to explain why dry swing warm-ups with a standard weight bat are most effective. Specifically, this research should include highlighted factors such as determining the minimum duration of muscle activity necessary to elicit a postactivation potentiation response, the relationships between perceived and observed performance outcomes, and the importance of task-specific equipment in warm-up to enhance performance outcomes.

Maximum isometric contraction (level 3 evidence)

Only one included study investigated the effects of maximum isometric contraction warm-up and found that 5 s of maximum isometric contraction warm-up significantly increased baseball bat speed.[29] Given that maximum isometric contraction is a high-load, albeit static, warm-up mode, this isolated result makes sense in the context of postactivation potentiation but needs to be validated by further research.

Stretching—static (levels 1 and 3 evidence)

Static stretching was found to be a largely ineffective method for performance enhancement. Despite the fact that 25 of 31

Table 5 Warm-up/outcome pairings, organised by category

Mode category	Outcome category	Warm-up/outcome pairings	Positive outcomes	Neutral outcomes	Negative outcomes	Specific effects
Dynamic	Physiological	19[11–22 24]	6[11 12 18 20 21]	8[11 15 21 22 24]	1[13]	4[14]
	Power	11[10 14 15 17–19 22–24]	5[10 15 17 22]	3[18 19 24]	–	3[14 23]
	Strength	9[11–13 16 18 20 42]	6[12 16 20]	3[11 13 18]	–	–
	DOMS	5[11–13 20]	3[12 20]	2[11 13]	–	–
	Flexibility	4[12 13 20]	3[12 20]	1[13]	–	–
	Passive indicators	5[12 13 24]	2[12]	3[13 24]	–	–
	Endurance	1[18]	–	1[18]	–	–
	Accuracy	1[23]	–	–	–	1[23]
	Total	**56**	**25**	**22**	**1**	**8**
Baseball-specific warm-up	Power	5[27–31]	–	–	–	5[27–31]
	Total	**5**	**0**	**0**	**0**	**5**
Maximum isometric contraction	Power	1[29]	1[29]	–	–	–
	Total	**1**	**1**	**0**	**0**	**0**
Static stretching	Power	17[9 10 17 32–34]	1[10]	16[9 17 32–34]	–	–
	Physiological	4[37]	1[37]	–	3[37]	–
	Strength	6[32 36 37]	–	5[32 36 37]	1[37]	–
	Endurance	2[35]	–	2[35]	–	–
	Accuracy	2[9 33]	–	2[9 33]	–	–
	Total	**31**	**2**	**25**	**4**	**0**
Dynamic stretching	Power	13[32 9]	12[9]	1[32]	–	–
	Accuracy	1[9]	1[9]	–	–	–
	Strength	4[18 32]	–	4[32]	–	–
	Total	**18**	**13**	**5**	**0**	**0**
PNF stretching	Endurance	2[35]	–	–	2[35]	–
	Strength	1[36]	–	1[36]	–	–
	Total	**3**	**0**	**1**	**2**	**0**
Passive heating/cooling	Strength	12[13 18 41–44]	–	11[13 18 41–44]	1[44]	–
	Passive indicators	6[13 41–43]	2[13 41]	4[41–43]	–	–
	DOMS	5[13 41–43]	–	5[13 41–43]	–	–
	Flexibility	5[13 41–43]	3[13 41 43]	2[42 43]	–	–
	Physiological	3[13 18 42]	1[18]	2[13 42]	–	–
	Endurance	2[18 44]	–	2[18 44]	–	–
	Power	1[18]	–	1[18]	–	–
	Total	**34**	**6**	**27**	**1**	**0**
Vibration	Power	3[22 24]	1[22]	2[24]	–	–
	Physiological	2[22 24]	1[24]	1[22]	–	–
	Passive indicators	2[24]	–	2[24]	–	–
	Total	**7**	**2**	**5**	**0**	**0**

DOMS, delayed onset muscle soreness.

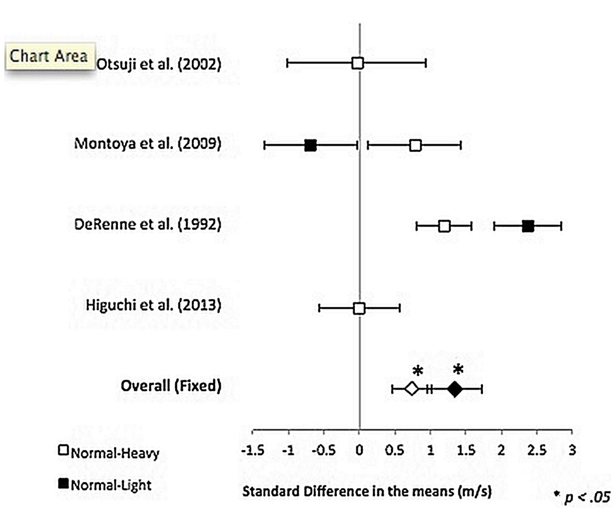

Figure 2 Bat speed.

warm-up/outcome pairings reported neutral outcomes,[9 17 32–37] the review only yielded level 1 evidence regarding the neutral effects of static stretch warm-up on power outcomes.[9 17 32–34] Level 3 evidence was discovered for the following effects: static stretch warm-up had no effect on strength,[32 36 37] accuracy[9 33] and endurance[35] outcomes; and static stretch warm-up negatively impacted physiological outcomes.[37]

Earlier reviews of total body and lower extremity static stretch warm-up proposed a 60 s[38] or 90 s[39] threshold for static stretch duration without performance decrement. As such, included investigations of upper body static stretch warm-up were grouped by stretch duration into either short (≤60 s)[17 32–35] or long (>90 s)[9 36 37] groups for further analysis; no studies investigated stretches lasting between 60 and 90 s. Even with these duration groupings, outcomes and levels of evidence for investigated outcomes remained unchanged. The notable exception was that long-duration static stretch was found to have no effect on power outcomes with only level 3 evidence due to the presence of only one investigation of this warm-up/outcome

Table 6 Included articles—warm-up mode

Mode category	Specific modes in category	Incidence in included studies
Dynamic exercises	Isokinetic contractions at minimal effort[11–13]	3
	Kayak ergometer (steady state or steady state with sprints)[14 15]	2
	Upper body plyometrics[16 17]	2
	Repeated forearm contractions around sponge[18]	1
	Isometric contractions at fatiguing effort[12]	1
	Percentage of 5RM bench press[19]	1
	Percentage of 1RM biceps curls[20]	1
	Percentage of wrist flexion MVC[21]	1
	Arm ergometer[22]	1
	Sling exercise[23]	1
	Free weights/resistive tubing[23]	1
	Medicine ball throws[16]	1
	Competition swimming warm-up[24]	1
	Body weight exercises (arm circles, windmills, trunk twists)[10]	1
	Total	18
Baseball-specific warm-up	Dry swings with weighted bat[27–31]	5
	Dry swings with unweighted bat[27–31]	5
	Dry swings with lightweight bat[27 28 31]	3
	Total	13
Passive heating/cooling	Passive heating[12 13 18 41–44]	7
	Passive cooling[43]	1
	Total	8
Static stretching	Self-administered[9 17 32–34]	5
	Passive—stretch held by researcher/ therapist[35–37]	3
Dynamic stretching	Dynamic stretching[32 9]	2
PNF stretching	PNF stretching[35 36]	2
Vibration	Vibration[22 24]	2
Maximum isometric contraction	Maximum isometric contraction[29]	1

MVC, maximum voluntary contraction; PNF, proprioceptive neuromuscular facilitation.

pairing.[9] The neutral effects of short-duration static stretching on power outcomes were classified as level 1 evidence.[17 32–34]

Thus, the only strong evidence present in the literature is that short-duration upper body static stretch warm-ups can be conducted without decreasing power,[17 32–34] a finding that is consistent with previous reviews of total and lower body static stretch warm-up.[38 39] Further investigation is necessary to confirm the level 3 finding that long-duration static stretching can also be performed without power decrement, and also to clarify the effects of both long-duration and short-duration static stretching on strength, accuracy, physiological and endurance outcomes.

Stretching—dynamic (level 3 evidence)

Only two included[32 9] studies investigated the effects of dynamic stretching warm-up on four total outcomes, with Torres *et al*[32] reporting that dynamic stretching had no effect on a variety of upper body force and power measures (see table 3), and Moran *et al*[9] finding that dynamic stretching increased golf club head speed and accuracy. Given these mixed results, the evidence is classified as level 3. The absence of reported negative outcomes suggests that upper body dynamic stretching warm-ups can most likely be performed without negative effects. The benefits of upper body dynamic stretching warm-up, however, need to be clarified with further investigation.

Stretching—proprioceptive neuromuscular facilitation (level 3 evidence)

The two included studies[35 36] of upper body proprioceptive neuromuscular facilitation (PNF) stretching warm-ups found that PNF stretching had no effect on strength outcomes[36] but negatively impacted endurance outcomes.[35] Evidence is classified as level 3. No studies investigated the effects of upper body PNF stretching warm-up on flexibility outcomes—the main reported benefit of PNF stretching[40]—so the utility of this warm-up mode in the upper body remains unclear (table 6).

Passive heating/cooling (levels 1, 2 and 3 evidence)

Passive heating and/or cooling appear to have extremely limited use as a warm-up mode, with the only positive outcome being that passive heating warm-ups positively affect flexibility outcomes for up to 8 days following fatiguing eccentric exercise (level 1 evidence).[12 13 41–43] The acute effects of passive heating warm-up were not investigated. Level 1 evidence also supported the conclusion that passive heating or cooling warm-ups do not affect DOMS,[12 13 41–43] or strength[12 13 18 41–43] outcomes. Level 2 evidence shows that passive heating warm-ups do not have any impact on endurance outcomes,[18 44] and level 3 evidence suggests that neither passive heating nor passive cooling warm-ups impact passive indicator,[13 41–43] physiological[13 18 42] or power[18] outcomes. Thus, the only notable conclusion that can be presented regarding upper body passive heating and/or cooling warm-up is that passively heating muscles before a fatiguing eccentric exercise is likely to significantly minimise losses in flexibility in the days following the fatiguing exercise. Future investigations should focus on any acute flexibility benefits from upper body passive heating warm-up; however, the benefits of this warm-up on performance outcomes seem to be limited.

Vibration (levels 2 and 3 evidence)

Upper body vibration warm-ups were investigated in two included studies and six warm-up/outcome pairings,[22 24] with limited results. Vibration warm-up was found, with level 2 evidence, to have no effect on physiological outcomes[22 24] and, supported by level 3 evidence, has no effect on passive indicator outcomes[24] and mixed effects on power outcomes.[22 24] Of note is the fact that vibration warm-up was performed with the participant lying prone on a bench in both studies of power outcomes, with prone row power experiencing significant postwarm-up improvements,[22] but not 50 yard freestyle swim time.[24] As such, there may be a level of similarity between vibration warm-up mode and activity necessary to achieve performance benefits.

Injury prevention (level 4 evidence)

We found no studies of upper body warm-up with injury prevention outcomes. Thus, while warming-up for injury prevention purposes is popular, this practice is not yet supported by evidence for upper body activities. The American Academy of Orthopaedic Surgeons notes that 5 of the 10 most common orthopaedic injuries occur in the upper extremity[45] and it recommends, along with many others,[1–3] warm-up as an important part of an injury prevention plan. Thus, there is a clear need for high-quality scientific research evidence to support these warm-up recommendations currently based only on theory, sporting experience and anecdotal evidence.

The current literature on upper body warm-up covers a wide range of warm-up modes and performance outcomes (25 modes, 43 outcomes). Several trends may guide future research and clinical practice.

- For the most part, results were consistent with findings of previous reviews of total and lower body warm-up.
- We found strong evidence that high-load dynamic upper body warm-ups enhance both strength and power outcomes. There may, however, be a minimum duration of muscle loading (exceeding 4–5 dry swings of a weighted baseball bat) for these warm-ups to have the desired effect. Task-specific warm-ups were effective when used in baseball; however, no evidence exists to support task-specific warm-up in other domains.
- Upper body static stretching warm-ups of a duration ≤60 s had no impact on power outcomes. Long–duration (>90 s) static stretching can also be conducted without performance decrement, but more data are needed to validate this finding.
- Passive heating/cooling warm-ups do not appear to have any significant acute performance effects, although flexibility in the days following fatiguing eccentric exercise can be enhanced with this mode of warm-up.
- Additional studies are needed to clarify the effects of upper body maximum isometric contraction, dynamic and PNF stretching, and vibration training warm-ups.
- Further investigation is especially needed across all warm-up modes to validate recommendations of using warm-up as a means of injury prevention.

Clinical applications (author commentary)

Based on the evidence of this review, an optimum upper body warm-up regimen should contain a combination of high-load dynamic warm-ups to enhance performance and short-duration (<60 s) static stretching for flexibility gains. Assuming at least a general application of previously noted correlations between flexibility and injury risk[46 47] to the upper body, these flexibility gains may have some preventative effects. A simple and effective general shoulder warm-up, for example, could involve a combination of high-intensity activities to induce postactivation potentiation in all three planes of movement, along with static stretching of the pectorals, trapezius, latissimus dorsi and deltoids to maintain flexibility. The high-load exercises and static stretches to be used in sport-specific warm-ups should closely mirror the required movements and mechanics of the sport (eg, throwing, batting) rather than using only a general protocol. As noted previously, further research is necessary to validate the efficacy task-specific warm-up in domains beyond baseball and static stretching for injury prevention.

CONCLUSIONS

Our systematic review found strong evidence for the following: high-load dynamic warm-ups enhance power and strength performance; warm-up swings with a standard weight baseball bat are most effective for enhancing bat speed; short-duration static stretching warm-up has no effect on power outcomes; and passive heating/cooling is a largely ineffective warm-up mode. Maximum isometric contraction may also enhance performance variables. Dynamic stretching and long-duration upper body static stretching warm-up may be able to be performed without adverse performance effects. A striking knowledge gap in upper body warm-up literature is the lack of investigation of injury prevention outcomes.

What this study adds?

- A common recommendation of using warm-up exercises to prevent upper body injuries is not supported by any investigations.
- There is strong evidence that dynamic, high-load upper body warm-ups effectively enhance strength and power outcomes.
- Using static stretching in upper body warm-ups that last less than 60 s can be prescribed to enhance flexibility without impacting power and strength outcomes.

Contributors All three authors collaborated to provide the concept and focus for this review, have approved the manuscript, and agreed to be accountable for all aspects of the work. JMM performed the literature searches and selected the articles to be included in this systematic review. He also synthesised, analysed and summarised the positive/neutral/negative/specific outcomes of included articles, scored the included articles according to the PEDro scale, and drafted the introduction, methods, results, and the majority of the discussion and conclusion. BJA drafted portions of the discussion and conclusion, made significant revisions to the entire manuscript, and served as a consultant for the PEDro scoring and analysis of outcomes. MH scored the included articles according to the PEDro scale, performed the meta-analysis, made significant revisions to the entire manuscript, and served as a consultant regarding the analysis of outcomes.

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