McGawley, K., Spencer, M., Olofsson, A., Andersson, E. (2021). Comparing active, passive, and combined warm-ups among junior alpine skiers in -7°C. *International Journal of Sports Physiology and Performance (IJSPP), 16*(8), 1140-1147. http://dx.doi.org/10.1123/IJSPP.2020-0300

Comparing Active, Passive, and Combined Warm-Ups Among Junior Alpine Skiers in −7°C

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Abstract

Purpose: Warming up in very cold climates and maintaining an elevated body temperature prior to a race is challenging for snow-sport athletes. To investigate the effects of active (ACT), passive (PAS), and a combination of ACT and PAS (COM) warm-ups on maximal physical performance in a subzero environment.

Methods: Ten junior alpine skiers completed 3 experimental trials in −7.2 ± 0.2°C. The ACT involved 5 minutes of moderate cycling, 3 × 15-second accelerations, a 6-second sprint, 5 countermovement jumps (CMJs), and a 10-minute passive transition phase, while in PAS, participants wore a lower-body heated garment for 24 minutes. In COM, participants completed the active warm-up, then wore the heated garment during the transition phase. Two maximal CMJs and a 90-second maximal isokinetic cycling test followed the warm-up.

Results: CMJ performance was likely ($P = .150$) and very likely ($P = .013$) greater in ACT and COM, respectively, versus PAS. Average power output during the cycling test was likely ($P = .074$) greater in ACT and COM versus PAS. Participants felt likely to almost certainly warmer ($P < .01$) and more comfortable ($P = .161$) during ACT and COM versus PAS. In addition, participants felt likely warmer ($P = .136$) and very likely more comfortable ($P = .161$) in COM versus ACT.

Conclusions: COMresultedinsignificantly improved CMJ performance versus PAS, while both ACT and COM led to likely improved 90-second cycling performance. Participants felt significantly warmer during ACT and COM versus PAS, and likely warmer in COMversusACT.Therefore,acombined warm-up is recommended for alpine skiers performing in subzero temperatures.

Keywords: cold, heated garment, priming, skiing, winter sports

Warming up prior to competition is common practice among athletes and has been reported to improve performance across a wide range of sports[1,2]. One of the main benefits of warming up is an elevation in muscle temperature, which appears to have a positive effect on various mechanisms of muscle function and metabolism[2,3]. Other nontemperature-related physiological effects of warm-up may include enhanced ˙VO2 kinetics[4,5] and muscle postactivation poten-tiation (PAP)[6]. Psychologically, conducting a warm-up prior to competition also provides athletes with an opportunity to implement cognitive techniques into their preparatory routines[7].

Warm-up methods are often described as active (ie, involving muscular work to generate heat) or passive (ie, generating heat via external sources, such as hot-water baths, saunas, electric blankets, and/or heated clothing). An active warm-up induces metabolic and neural benefits that differ from a passive warm-up, with the associated muscle work during an active warm-up increasing energy expenditure[2]. If not correctly monitored and controlled, this may result in fatigue[8]. Passive warm-up methods, on the other hand, allow for the preservation and restoration of energy stores, thereby avoiding or reversing the potentially negative effects of an active warm-up. Given the distinct mechanisms and consequences associated with active and passive warm-ups, a combination of the 2 may be optimal. That is, passive methods may be implemented after active exercise in order to maintain or further elevate muscle temperature while simultaneously resting the metabolic systems[9].

Winter-sport athletes regularly compete in subzero tempera-tures. Not only is conducting a warm-up in such conditions challenging, but so too is maintaining an elevated body temperature during the transitional phase between the end of the warm-up and the start of the competition. Cook et al[10]. showed that performance was optimized in elite bob-skeleton athletes when an active, high-intensity warm-up was followed by the addition of a survival garment for heat retention during the passive transition phase to the start of performance. The authors suggested that this was an easy-to-administer intervention, a consideration that is crucial in competition settings. The study was, however, performed at room temperature (for reported practical reasons), and the effects of using combined active and passive warm-up methods with winter-sport athletes have yet to be investigated in subzero temperatures.

Alpine ski racing is a complex sport from an energetic perspective, requiring an explosive start, well-developed strength to overcome high forces and eccentric loads, and endurance to minimize the inevitable development of fatigue[11]. The relative demands on the aerobic and anaerobic energy pathways have been reported as ∼ 35% to 45% and 55% to 65%, respectively, during a single slalom/giant slalom run[12,13]. Additional physical challenges require alpine skiers to adopt streamlined and aerodynamic posi-tions, as well as to make tight turns in rapid succession[14]. Despite the unique physical challenges associated with alpine skiing and the potential for improving skiing performance through an opti-mized warm-up, no studies have investigated the effects of differ-ent warm-up strategies on performance in the cold among alpine skiers. Given the limited experimental control possible on snow, due to unstable environmental conditions, standardized laboratory-based measurements of explosive and sustained power output offer valuable testing alternatives[15].

The aim of the current study was to investigate the effects of active (ACT), passive (PAS), and combined ACT and PAS (COM) warm-up procedures on maximal performance during countermovement jump (CMJ) and 90-second cycling time-trial (TT90) tests conducted with trained alpine skiers in a controlled, subzero environment. An additional aim was to investigate the differences in physiological and perceptual responses to the dif-ferent warm-up protocols. It was hypothesized that COM would lead to improvements in measures of physical performance com-pared to ACT and PAS but that no meaningful differences would be observed between these latter 2 groups.

Methods

Participants

Ten junior alpine skiers (6 males and 4 females; mean ± SD age: 18.0 ± 0.8 y, height: 175.0 ± 7.2 cm, body mass: 73.3 ± 5.8 kg) participated in this study. The athletes provided written informed consent prior to testing, and for those aged <18 years (n = 2), consent was also obtained from a parent or guardian. The study was preapproved by the regional ethical review board in Umeå, Sweden (no. 2017-375-31M). Athletes reported 12 ± 2 years of training experience and 11 ± 2 years competing in alpine skiing. Analysis of training diaries over the 12 months preceding the study indicated 547 ± 129 hours of total annual training and 472 ± 106 annual training sessions, of which 216 ± 77 hours and 101 ± 42 sessions were performed on snow. In the 4 weeks prior to the study, athletes had performed 63 ± 12 hours of training over 55 ± 10 sessions, of which 33 ± 12 hours of training over 15 ± 7 sessions were performed on snow.

Study Overview

Participants completed 4 exercise trials during the preseason period (in Oct), with 48 hours separating each trial. All exercise trials were performed in a climate chamber where temperature and relative humidity were measured immediately before and after each test as 7.2 ± 0.2°C and 58.8 ± 6.0%, respectively (Kestrel 5500 Weather Meter, Nielsen-Kellerman Company, Boothwyn, PA). To control ambient conditions, the chamber utilized a hypoxia controller (Hypoxico, New York, NY), which was set to sea level (20.9%O2) and a customized air-conditioning system controlling room temperature with a stated precision of ±0.5°C. The first exercise trial involved a preliminary submaximal step test on an SRM cycle ergometer (Schoberer Rad Meßtechnik GmbH, Jülich, Germany) involving 6 × 4-minute stages, followed by a familiarization to the CMJ and TT90 performance tests. The SRM cycle ergometer was set to isokinetic mode with cadence standardized at 85 rpm throughout all the tests. The 3 subsequent experimental trials involved 1 of the 3 warm-up protocols (ACT, PAS, or COM) prescribed in a random-ized order, with the CMJ and TT90 tests following the respective warm-up and the 2 tests separated by 2 minutes of passive rest. Participants recorded their food intake for 48 hours prior to the first experimental trial and replicated this diet for the 48 hours prior to the next 2 experimental trials. Training clothing was also standardized during each trial, with participants wearing thermal tights, a base top layer, a training jersey and jacket, gloves, and a hat.

Submaximal Step Test and Familiarization Session

The submaximal step test was used to determine gross efficiency (GE), which was subsequently used for the calculation of anaerobic energy production during the TT90. The SRM cycle ergometer was calibrated prior to all testing, and the setup measurements (ie, the position of the handlebars and saddle) were recorded for each individual for subsequent replication. After a 10-minute warm-up at 90 W for females and 134 W for males, participants completed the continuous 6 × 4-minute submaximal test starting at 100 W and increasing by 10 W per stage for females and at 150 W and by 16 W per stage for males. Expired air was recorded continuously using a portable gas analyzer (MetaMax3B_R2, Cortex Biophysik GmbH, Leipzig, Germany), which was calibrated prior to all trials using gases of known concentrations (16.0% O2 and 4.5% CO2, Air Liquide, Kungsängen, Sweden) and a 3-L syringe for volume measurements (M9474-C; Medikro Oy, Kuopio, Finland). The $\dot{V}O_2$ and RER data were subsequently averaged over the final minute of each submaximal stage. The GE was determined as the ratio between power output and metabolic rate, with the metabolic rate being calculated according to Weir[16].

A familiarization to the CMJ and TT90 performance tests used in the experimental trials (described in more detail below) was carried out after the submaximal test. The CMJ protocol was demonstrated by an experienced researcher and participants subsequently practiced the movement until the technique was deemed satisfactory. Three test jumps were then performed and the coefficient of variation (CV) for the best 2 jumps was calculated as (mean ± SD) 2.4 ± 1.5%. During the TT90 familiarization, participants were instructed to maximize performance by cycling as hard as possible over the entire 90 seconds using a pacing strategy that would generate the highest mean power output (ie, equivalent to covering the furthest possible distance). While not calculated in the current study, the CV for maximal 90-second cycling efforts has previously been reported for noncyclists as 2.4%[17], while the mean CV for elite track cyclists performing maximally over ∼60 to 70 seconds (ie, a 1-km time trial) is ∼0.7% to 1.5%[18,19]. Given the time constraints of the athletes and their prior familiarity with maximal jumping and cycling as part of their regular training and testing routines, one familiarization session was considered sufficient in the current study.

Experimental Trials

On arrival at the laboratory, participants warmed-up using 1 of the 3 experimental interventions, ACT, PAS, or COM, then completed the CMJ and TT90 tests (Figure 1). The warm-up protocols were evidence-informed and were developed in cooperation with junior and national team coaches to ensure ecological validity. The ACT warm-up commenced with 5 minutes of cycling at a "moderate" (3 out of 10) rating of perceived exertion (RPE). After a 1-minute rest, participants performed 3 × 15-second progressive accelerations at self-selected intensities from "hard" to "very hard" (RPE values of 5 and 7 out of 10, respectively), separated by 45 seconds of recovery, and after a further 2 minutes of rest completed a 6-second maximal sprint. Two minutes of rest followed the 6-second sprint, after which 5 CMJ repetitions were performed with kettlebells in each hand, to increase PAP, weighing a total of 20% to 25% of the individual's body mass. The jumps were separated by 15 seconds of rest and a 10-minute transitional phase completed the ACT warm-up, where participants rested passively in the cold chamber prior to commencing the CMJ test.

In the PAS warm-up, participants wore an additional lower-body garment (Heat Pant with Novaheat; Helly Hansen, Oslo, Norway) heated to 40°C for 24 minutes while seated in the cold chamber. The garment was fitted with heat pads that covered the gluteal, quadriceps, and hamstring muscle groups, and participants were fitted with either a small or large size. There was a 1-minute transitional phase to remove the garment prior to commencing the CMJ test. In the COM warm-up, participants completed the ACT warm-up, as described above, then put the lower-body heated garment on prior to commencing the 5 weighted CMJ repetitions. The garment remained on during the 10-minute passive rest period and was removed immediately prior to commencing the CMJ test.

The 2 CMJ tests were performed on an infrared contact mat (Muscle Lab Jump; Ergotest, Norge), which estimates the height of the rise of the center of gravity above the ground from flight time. The 2 jumps were separated by 15 seconds of passive rest and the highest jump was used for data analysis. Participants were instructed to stand with their hands on their hips before squatting to a depth of 90°, then immediately jump as high as possible with the hands remaining on the hips throughout the jump. They were retested if the protocol was performed incorrectly.

After a 2-minute passive rest, the TT90 was performed on the same SRM cycle ergometer as previously described, with cadence fixed at 85 rpm. Participants were provided with the same instructions as described for the familiarization trial (ie, to maximize performance over the entire 90-s period). The respiratory face mask was fitted at the start of the 2-minute passive rest period, allowing sufficient time for the system to stabilize prior to the start of the test. Respiratory variables were measured continuously throughout the TT90 test and the raw breath-by-breath data were interpolated to second-by-second values.

The instantaneous metabolic requirement (in watts) during the TT90 was calculated by dividing the instantaneous power output during the test with the average GE from the 2 final stages of the submaximal test. The instantaneous anaerobic metabolic rate (measured in watts during the TT90) was then computed as the difference between the metabolic requirement and the aerobic metabolic rate (in watts) determined from the Weir equation[16], assuming 100% carbohydrate utilization during the TT90. Total anaerobic energy production (in Joules) was then calculated by integrating the instantaneous anaerobic metabolic rate over time (ie, 90 s). The anaerobic energy production was alsoexpressedas anO_2 deficit bymultiplying the anaerobic energy production with a constant of 0.047801 (mL O_2 equivalent per Joule) according to Weir[16].

Subjective ratings of thermal sensation and thermal comfort were recorded at baseline, at 5-minute intervals throughout the warm-up and 2 minutes after completing the TT90. For thermal sensation, a 20-point scale was used (10 [maximal hot], 0 [neutral], and −10 [maximal cold])[20], while thermal comfort was measured using a 4-point scale (0 [comfortable] and 4 [uncomfortable])[21].

Statistical Analysis

Data were assessed for practical significance using magnitude-based inferences. All data were log-transformed before analysis to reduce bias arising from nonuniform error, and this was performed using a customized statistical spreadsheet[22]. The spreadsheet calculates standardized difference or effect sizes (ES, 90% confidence limits [CL]) using the pooled SD. Data for relative (in percentage) differences are presented as mean ± 90% CL. Furthermore, the probabilities to establish whether the true (unknown) differences were lower, similar to, or higher than the smallest worthwhile difference were calculated. The smallest worthwhile difference was estimated as 1% for performance trials, based on previous findings using cycling[23]. For other nonperformance data, the smallest worthwhile difference was calculated as 0.2 multiplied by the between-participant SD. Quantitative chances of higher or lower differences between treatments were evaluated qualitatively as <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, almost certain. If the chance of higher or lower differences was >5%, the true difference was assessed as unclear. The mechanistic inference refers to the threshold chances of 5% for substantial magnitudes.

Data were also analyzed using statistical tests with significance set at $P < .05$. One-way repeated measures analysis of variance tests were used to compare differences between warm-up treatments during the CMJ and TT90 tests. Sphericity was checked using Mauchly's test and in the case of any significant effects, post hoc t tests were used to locate pairwise differences. Two-way repeated measures analysis of variance tests with 2 within-participant factors were used to compare differences between time points and warm-up treatments.

Results

Maximal CMJ performance was likely but not significantly greater (2.9 ± 4.1%; $P = .150$) following ACT compared to PAS and was very likely and significantly greater (6.8 ± 4.9%; $P = .013$) following COM compared to PAS, with no substantial or significant differences observed for ACT versus COM (Figure 2).

Average power output attained during the TT90 was likely greater following ACT compared to PAS (2.2 ± 2.3%) and COM compared to PAS (3.2 ± 2.5%), with no substantial differences observed for ACT versus COM (Table 1). There was no statistically significant effect of warm-up treatment on average power output ($P = .074$). Anaerobic energy production was likely greater after ACT compared to PAS (4.5 ± 4.5%), with no substantial differences reported for other comparisons between trials. Again, there was no significant effect of warm-up treatment on anaerobic energy production ($P = .350$). Furthermore, no substantial or significant differences were evident for average $\dot{V}O_2$, ventilation, or aerobic energy production between the 3 warm-up trials. Power output and anaerobic and aerobic energy production calculated for the 6 consecutive 15-second sections of the TT90 are shown in Figure 3. Power output was likely greater for PAS compared to ACT over the initial 15-second period (11.6 ± 13.0%), but for the subsequent two 15-second periods was very likely greater for ACT compared to PAS (7.7 ± 3.7% and 7.9 ± 5.4%, respectively). In addition, power output was likely to very likely greater for COM compared to PAS during the second, third, and fourth 15-second periods (6.1 ± 6.8%, 9.8 ± 5.5%, and 5.6 ± 5.0%, respectively). No substantial differences between any of the warm-ups were apparent for the last two 15-second periods. For anaerobic energy production, differences were very likely greater for ACT compared to PAS during the second and third 15-second periods (15.5 ± 9.1% and 17.7 ± 12.0%, respectively), and likely to very likely greater for COM compared to PAS over the same 2 periods (9.7 ± 11.1% and 21.8 ± 13.0%, respectively). In contrast, aerobic energy production was likely greater for COM compared to PAS during the last two 15-second periods only (5.3 ± 6.0% and 6.0 ± 5.7%, respectively). There was a significant main effect of time for all variables ($P < .001$), but no significant main effect of warm-up treatment ($P > .05$).

Ratings of thermal sensation and thermal comfort recorded at baseline, at 5-minute intervals throughout the warm-up and 2 minutes after completing the TT90 are presented in Figure 4. There were no substantial differences in thermal sensation for the 3 warm-up conditions at baseline, but participants were likely warmer 5 minutes into the warm-up in ACT compared to PAS and very likely to almost certainly warmer after 10 to 20 minutes. Similarly, in COM compared to PAS, participants were very likely warmer 5 minutes into the warm-up and almost certainly warmer after 10 to 20 minutes. In addition, participants were likely warmer in COM compared to ACT after 20 and 25 minutes. Following the TT90, participants were likely warmer following both ACT and COM compared to PAS. There were significant main effects of time ($P < .001$) and warm-up treatment for thermal sensation, with participants feeling significantly warmer in both ACT ($P = .003$) and COM ($P = .008$) compared to PAS, but with no differences identified between ACT and COM ($P = .136$). There were no substantial differences in thermal comfort for the 3 warm-up conditions at baseline or after 5 or 10 minutes. Participants were likely to very likely more comfortable after 15 to 25 minutes during COM compared to PAS, and very likely more comfortable after 25 minutes during ACT compared to PAS. In addition, participants were very likely more comfortable after 15 minutes during COM compared to ACT. Following the TT90, participants were likely more comfortable following COM compared to ACT and PAS. There was a significant main effect of time for thermal comfort ($P < .001$), but no main effect of warm-up treatment ($P = .161$).

Discussion

Using a group of trained junior alpine skiers, the aims of the current study were (1) to investigate the effects of ACT, PAS, and COM warm-ups on CMJ and TT90 performance in a subzero environment and (2) to investigate the physiological and perceptual responses to these different warm-up protocols. In support of the hypothesis, performance in the CMJ was very likely and significantly improved inCOMcompared to PAS. Contrary to the hypothesis, however, CMJ performance was likely (albeit not significantly) greater in ACT compared to PAS, and there were no substantial or significant differences in CMJ performance between ACT and COM. Moreover, while performance in the TT90 tests was likely improved following ACT and COM compared to PAS, there was no statistically significant effect of warm-up treatment on average power output.

The likely to very likely improvement in CMJ performance following ACT and COM compared to PAS may be related to the inclusion of the 5 weighted CMJs at the end of the active warm-up, which were used to induce a PAP response (ie, an increase in muscle force after a conditioning contractile activity, such as a series of maximal or near-maximal dynamic exercises)[24,25]. The significant improvement in CMJ performance for COM compared to PAS (∼6.8%), but not for ACT compared to PAS (∼2.9%), suggests a potential benefit of supplementary passive heating either during and/or after the weighted CMJs in addition to the active warm-up used in the current study. While the mean difference between ACT and COM was not substantial or significant, it was greater than the CV of the measure, which suggests an advantage that would be worth applying in practice.

The likely improvement in average 90-second power output during the TT90 following ACT (∼2.2%) and COM (∼3.2%) compared to PAS may be attributed to the relatively short, explosive cycling warm-up that was prescribed[26]. Specifically, Tomaras and MacIntosh[26] demonstrated a positive effect of performing one 6-second cycling sprint as part of an active warm-up, as was prescribed in the current study, on power output during subsequent maximal cycling. Despite no statistically significant effect of warm-up treatment on average 90-second power output in the current study, the relative improvement following COM versus PAS was greater than the CV values that have previously been reported for maximal cycling over 60 to 90 seconds (ie, ∼0.7%–2.4%)[17–19]. This again suggests a potential practical advantage of applying additional passive heating after an active warm-up.

In Figure 3, it can be seen that power output was likely higher for PAS than ACT in the first 15-second period, but that both power output and anaerobic energy production were then likely to very likely lower for PAS compared to both ACT and COM over the subsequent two to three 15-second periods. Since the overall average 90-second power output was likely greater in ACT, this implies a more aggressive pacing strategy adopted in PAS. While speculative, it may be that the lack of an active warm-up in PAS equipped the athletes with a relative freshness, due to energy sparing, which led to a relatively fast start that was later unsustainable, reflecting a greater initial rate of fatigue. This supposition remains to be investigated.

The effect of actively warming-up likely to almost certainly, and statistically significantly, led to participants feeling warmer, with substantially higher thermal sensation scores in the 5 to 20 minutes post baseline during ACT and COM compared to PAS. Although not significantly different, supplementing the active warm-up with passive heating was likely to have an additional warming effect, with higher thermal sensation scores reported after 20 and 25 minutes (ie, after putting on the lower-body heated garment) in COM compared to ACT. Thermal comfort was also likely to very likely greater following ACT versus PAS, and following COMversus ACT (ie, when supplementary passive heating was prescribed). However, there was no statistically significant main effect of warm-up treatment on thermal comfort. These findings suggest that an active warm-up in the cold may enhance an athlete's thermal perceptions and that a supplementary heating garment appears to exert an additional beneficial effect. While not measured in the current study, these outcomes may be related to increased body temperature in ACT and COMcompared to PAS, as well as in COM compared to ACT. This is supported by recent research showing both core and skin temperature to be elevated when wearing an upper-body heated garment in cool (8°C) conditions during a 25-minute transitional phase following an active warmup[27]. Greater thermal comfort and sensation were also reported with the heated jacket in this study, and subsequent 2000-m rowing timetrial performance (lasting ∼7 min) was improved.

The warm-up protocols prescribed in the current study were based on evidence-informed practices[2] and aimed to variably increase and maintain muscle temperature as well as to prime and recover a range of physical capacities and physiological systems. They were developed in collaboration with highly experienced (ie, junior and national team) ski coaches to ensure that results would be of practical use. Although the inclusion of a control group would have been advantageous, it was not possible due to concerns around potential injury and was therefore deemed dispensable from a real-world perspective. The 2 performance tests, while not completed on skis or snow, assessed key physical capacities required of alpine skiers, such as coordination, power, strength, and aerobic/anaerobic capacities[28]. While it was paramount to achieving experimental control that the current study was conducted in a laboratory setting, future field-based studies performed on snow would certainly allow for greater ecological validity. This would enable greater involvement of isometric and eccentric muscle contractions, which are characteristic of alpine skiing[29], rather than the predominantly concentric contractions involved in the current study.

Practical Applications

Results from the current study suggest that a combined active and passive warm-up may have beneficial effects on maximal performance and thermal perceptions when compared to a passive-only warm-up. An active-only warm-up also incurred beneficial effects when compared to a passive-only warm-up, but the relative differences were lower than for the combined warm-up. As such, a combined warm-up involving active and passive methods is recommended for alpine skiers performing in subzero temperatures. Realworld challenges associated with on-snow competitions, which have been reported to include delays, the environment, and logistics[30], are further considerations when planning warm-up routines.

Conclusions

This is the first study to compare the effects of active, passive, and combined active and passive warm-up strategies on maximal performance in a subzero laboratory environment using experienced winter-sport athletes. Findings have shown that the use of a combined warm-up resulted in very likely and significant beneficial effects on countermovement jump performance compared to passive-only heating. Both active and combined warm-ups led to likely although not significantly improved 90-second cycling performance. Participants also felt warmer during both active and combined warm-ups compared to passive-only heating, while the addition of passive heating to an active warm-up had some further beneficial effects on perceptions of thermal sensation. Therefore, the addition of passive heating after an active warm-up may provide some performance and perceptual advantages for athletes.

Acknowledgments

The authors would like to acknowledge the contributions and support of Jonas Enqvist (Swedish Ski Federation) and Anna-Karin Jejlid (Jämtlands Gymnasieförbund) during the planning and implementation of this study, aswell as the alpine ski athletes from Jämtlands Gymnasium who volunteered to participate.

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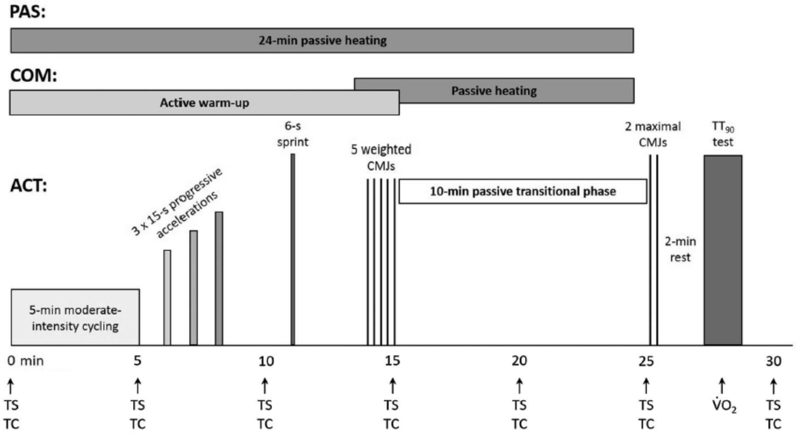

Figure 1 — A schematic illustration of the ACT, PAS, and COM warm-up protocols. ACT indicates active; CMJ, countermovement jump; COM, combination of ACT and PAS; PAS, passive; TT_{90}, 90-second isokinetic cycling time trial; TS, thermal sensation; TC, thermal comfort; $\dot{V}O_2$, oxygen uptake.

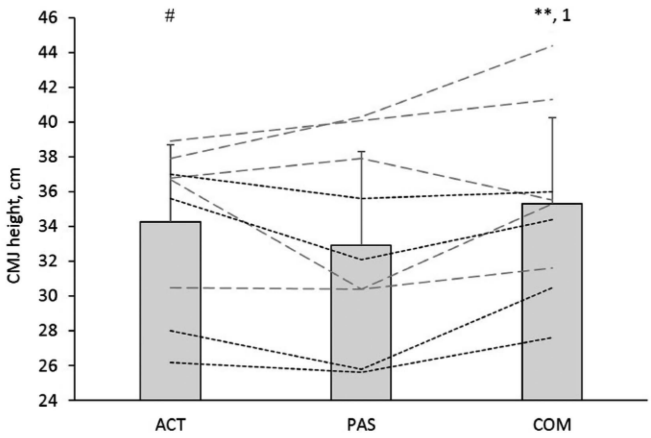

Figure 2 — Mean (SD) maximal CMJ height (in centimeters) following ACT, PAS, and COM warm-ups with individual performances marked as gray dashed lines (males) and black dotted lines (females). ACT indicates active; COM, combination of ACT and PAS; CMJ, countermovement jump; PAS, passive. Substantial likelihood of differences between treatments is shown as #likely (75%–95%) versus PAS; **very likely (95%–99.5%) versus PAS. Statistically significant differences are shown as [1]greater than PAS ($P < .05$).

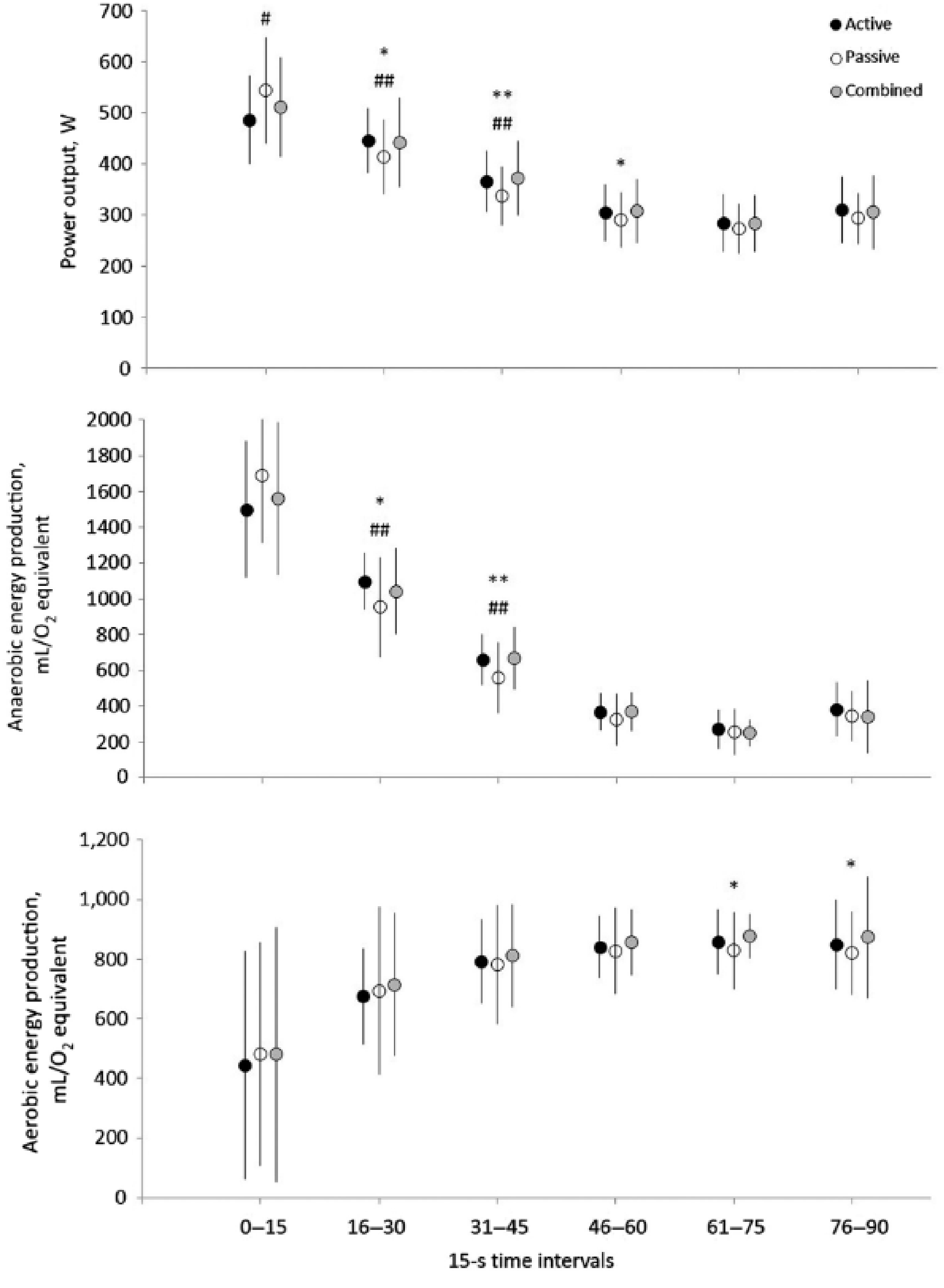

Figure 3 — Mean (SD) 15-second values for power output and anaerobic and aerobic energy production during the 90-second isokinetic cycling time trial. Substantial likelihood of differences between treatments is shown as #likely (75%–95%) and ##very likely (95%–99.5%) for active versus passive; *likely and **very likely for combined versus passive.

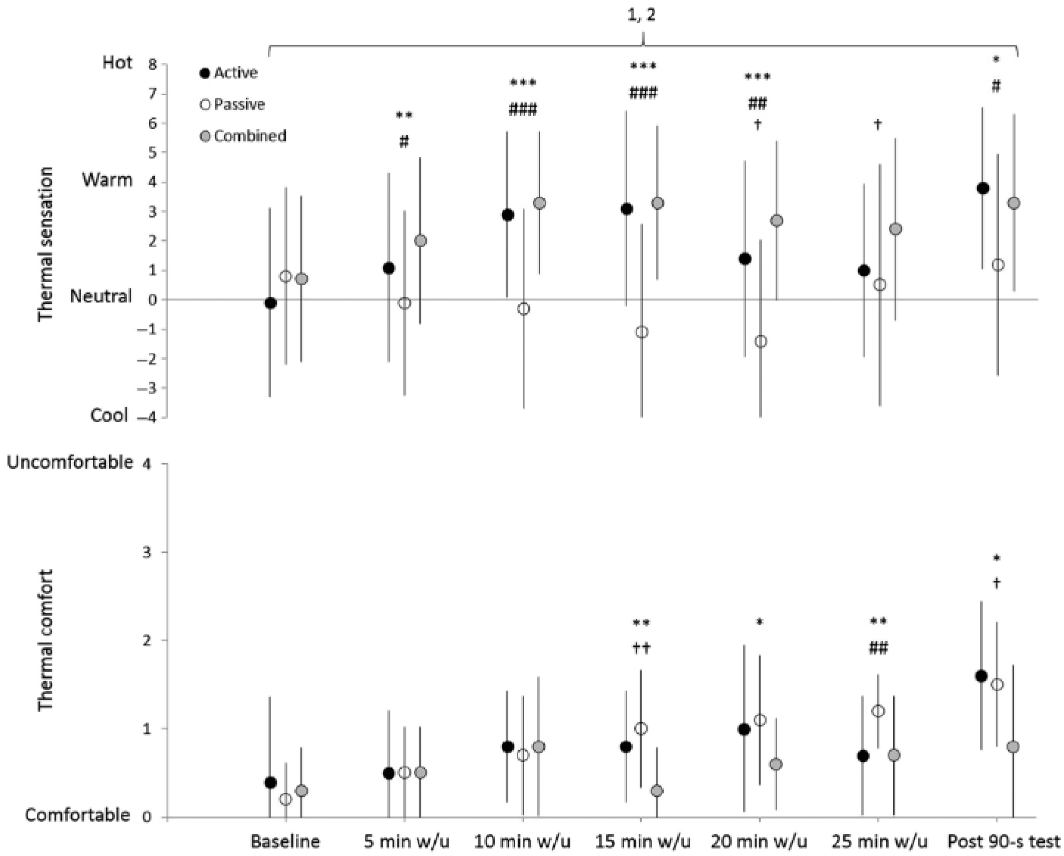

Figure 4 — Mean (SD) values for subjective ratings of thermal sensation and thermal comfort at baseline and at 5-minute intervals throughout the warm-up (w/u) and 2 minutes after the 90-second cycle test. Substantial likelihood of differences between treatments is shown as #likely, ##very likely, and ###most likely for active versus passive; *likely (75%–95%), **very likely (95%–99.5%), and ***most likely (>99.5%) for combined versus passive; †likely and ††very likely for combined versus active. Statistically significant differences are shown as [1]active warmer than passive (P = .003); [2]combined warmer than passive ($P = .008$).

Table 1 Mean (SD) Average PO, $\dot{V}O_2$, $\dot{V}_E$, and Aerobic and Anaerobic Energy Production during the 90-Second Isokinetic Cycle Time-Trial Test Following ACT, PAS, and COM Warm-Ups

				Magnitude of differences: effect size ± SD (*qualitative rating*[a])		
90-s average	**ACT**	**PAS**	**COM**	**ACT vs PAS**	**COM vs PAS**	**ACT vs COM**
PO, W	366 (52)	358 (54)	370 (59)	0.14 ± 0.15 (*Likely*)	0.19 ± 0.16 (*Likely*)	0.05 ± 0.18 (*Unclear*)
$\dot{V}O_2$, L/min	2.97 (0.48)	2.96 (0.51)	3.08 (0.62)	0.04 ± 0.30 (*Unclear*)	0.19 ± 0.26 (*Unclear*)	0.16 ± 0.25 (*Unclear*)
$\dot{V}_E$, L/min	119 (27)	119 (29)	121 (20)	0.00 ± 0.26 (*Unclear*)	0.10 ± 0.27 (*Unclear*)	0.11 ± 0.27 (*Unclear*)
Aerobic energy, L/min	93.3 (14.9)	92.8 (15.7)	96.5 (19.4)	0.04 ± 0.30 (*Unclear*)	0.19 ± 0.26 (*Unclear*)	0.16 ± 0.25 (*Unclear*)
Anaerobic energy, kJ	89.6 (14.4)	86.3 (19.6)	88.5 (15.4)	0.27 ± 0.28 (*Likely*)	0.14 ± 0.23 (*Unclear*)	0.09 ± 0.15 (*Unclear*)

Abbreviations: ACT, active; COM, combination of ACT and PAS; PAS, passive; PO, power output; $\dot{V}_E$, minute ventilation; $\dot{V}O_2$, oxygen uptake.
[a]Qualitative ratings are substantial likelihood of differences between treatments: 75% to 95%, *likely*; >5% chance of higher or lower differences, *unclear*.