Journal of Science and Medicine in Sport xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance

Courtney J. McGowan[a,b,*], Kevin G. Thompson[a,b], David B. Pyne[a,c], John S. Raglin[d], Ben Rattray[a,b]

[a] University of Canberra Research Institute for Sport and Exercise (UCRISE), University of Canberra, Australia
[b] Discipline of Sport and Exercise Science, University of Canberra, Australia
[c] Discipline of Physiology, Australian Institute of Sport, Australia
[d] School of Public Health, Indiana University Bloomington, United States of America

ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form 12 April 2015
Accepted 24 April 2015
Available online xxx

Keywords:
Core temperature
Swim performance
Passive heating

ABSTRACT

Objectives: The lengthy competition transition phases commonly experienced by competitive swimmers may mitigate the benefits of the pool warm-up. To combat this, we examined the impact of additional passive and active warm-up strategies on sprint swimming performance.
Design: Counterbalanced, repeated-measures cross-over study.
Methods: Sixteen junior competitive swimmers completed a standardised pool warm-up followed by a 30 min transition and 100 m freestyle time-trial. Swimmers completed four different warm-up strategies during transition: remained seated wearing a conventional tracksuit top and pants (Control), wore an insulated top with integrated heating elements (Passive), performed a 5 min dryland-based exercise circuit (Dryland), or a combination of Passive and Dryland (Combo). Swimming time-trial performance, core and skin temperature and perceptual variables were monitored. Time variables were normalised relative to Control.
Results: Both Combo (−1.05 ± 0.26%; mean ± 90% confidence limits, $p = 0.00$) and Dryland (−0.68 ± 0.34%; $p = 0.02$) yielded faster overall time-trial performances, with start times also faster for Combo (−0.37 ± 0.07%; $p = 0.00$) compared to Control. Core temperature declined less during transition with Combo (−0.13 ± 0.25 °C; $p = 0.01$) and possibly with Dryland (−0.24 ± 0.13 °C; $p = 0.09$) compared to Control (−0.64 ± 0.16 °C), with a smaller reduction in core temperature related to better time-trial performance ($R^2 = 0.91$; $p = 0.04$).
Conclusions: Dryland-based exercise circuits completed alone and in combination with the application of heated tracksuit jackets during transition can significantly improve sprint swimming performance. Attenuation in the decline of core temperature and a reduction in start time appear as likely mechanisms.

1. Introduction

In swimming, the effectiveness of a warm-up strategy is determined by the intensity and duration of the swimming and dryland elements, and the time between warm-up end and competitive event start, here termed the transition phase.[1–3] After the pool warm-up, swimmers must change into their racing swimsuit, confer with their coach and report to marshalling ∼15–20 min prior to race start,[3] thus transition phases of 30–45 min are not uncommon.[3]

Several studies have demonstrated that reducing the transition from 45 to 20 min,[3] or to 10 min,[4] yields faster 200 m swimming performance (∼1.5% and ∼1.4%, respectively). Importantly, core temperature (T_{core}) remained elevated during the shorter transition.[3] It seems there is a greater risk of a significant decline in T_{core} with longer transitions. Indeed muscle temperature (T_{muscle}) declines immediately following exercise, with a significant reduction evident after ∼15–20 min of recovery.[5]

However, it is difficult to alter swimming competition schedules by such large (>25 min) margins. New methods need developing to assist swimmers in maintaining elevated body temperature and

---

[*] Corresponding author at: University of Canberra Research Institute for Sport and Exercise (UCRISE), University of Canberra, Australia.
E-mail address: courtney.mcgowan@canberra.edu.au (C.J. McGowan).

http://dx.doi.org/10.1016/j.jsams.2015.04.012
1440-2440/

Please cite this article in press as: McGowan CJ, et al. Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *J Sci Med Sport* (2015), http://dx.doi.org/10.1016/j.jsams.2015.04.012

muscle activation throughout lengthy transition phases. We postulate that the decline in body temperature, in particular T_{core}, during transition could be offset by combining a sport-specific active warm-up (i.e., pool warm-up) with passive heating and/or additional active warm-up strategies. Recently the combination of active warm-up and passive heating (via heated tracksuit pants), during transition improved T_{muscle} maintenance and power output during a sprint cycling task.[6,7] There appears to be a sound basis for additional passive heating to enhance body temperature maintenance during lengthy transitions in competitive swimming. The combination of passive heating and activities such as box jumps, known to induce postactivation-potentiation (PAP) related changes,[8] during transition may yield additional performance benefits.

The objective of this study was to determine whether the application of additional passive heat and/or the completion of dryland-based activation exercises within the transition phase could improve sprint swimming performance. Specifically, we investigated if any observed differences in the maintenance of T_{core} during transition were related to overall swimming time-trial performance.

2. Methods

Sixteen national junior swimmers (age 16 ± 1 yr; $n = 11$ males, stature 1.79 ± 0.08 m, 72.2 ± 9.8 kg; $n = 5$ females, 1.67 ± 0.06 m, 61.6 ± 1.5 kg; mean ± standard deviation) provided written informed consent to participate in the study. The swimmers had a personal best 100 m freestyle time of 59.41 ± 3.48 s (mean ± 90% confidence limits). This study was approved by the University of Canberra's Human Research Ethics Committee.

Using a randomised cross-over design, each swimmer completed four testing sessions within a fortnight (two sessions per week) during an aerobic training phase, separated by 48 h. Swimmers completed all testing in either a morning (06:00–08:00 am) or afternoon (17:00–19:00 pm) timeslot as per their normal training routine, with each swimmer acting as their own control and tested within the same time slot for all their sessions. Familiarisation with the experimental protocols and equipment was completed a week prior to testing commencement.

In each session, swimmers completed a 25 min standardised pool warm-up followed by a 30 min transition phase and 100 m freestyle time-trial. The standardised pool warm-up entailed: 400 m freestyle (easy pace); 3 × 100 m individual medley (100 m: kick, drill, swim); 3 × 100 m freestyle (80, 90, 95% race pace); 4 × 50 m (15 m race pace, 35 m easy); 4 × 25 m freestyle (dive start, race pace). The 30 min transition consisted of three segments: (1) post-pool warm-up (30–21 min pre-time-trial) swimmers changed into their race swimsuit and tracksuit; (2) swimmers remained seated (21–16 min pre-time-trial) with minimal activity unless required to perform the dryland-based exercise circuit; (3) swimmers entered a simulated marshalling area for the final 15 min prior to the time-trial.

In all conditions, swimmers wore a t-shirt and tracksuit (top and pants) and remained seated throughout the transition phase (*Control* condition) unless otherwise stated. The *Control* condition was designed to mimic the contemporary race preparations undertaken by competitive swimmers. During transition, three additional warm-up strategies were investigated: *Passive*, swimmers wore a tracksuit jacket with additional heating elements sewn into the garment over the chest (pectoralis major) and lower back (latissimus dorsi and quadratus lumborum) regions (City heated jacket, Venture Heated Clothing, Melbourne, Australia), along with a t-shirt and standard tracksuit pants. The heating elements were powered by a 7.4 V lithium ion battery and set to 51 °C. The swimmers wore the heated jacket throughout transition until immediately prior to the time-trial. In *Dryland*, swimmers wore the same apparel as during Control and completed a 5 min dryland-based exercise circuit between 21 and 16 min prior to time-trial start. The circuit was designed to simulate common swimming movements in a sequence replicating the kinetic chain of a swim start: 3 × medicine ball (2 kg) throw downs (underwater arm pull through), 3 × 10 s simulated underwater butterfly kick whilst in a streamline position holding a BodyBlade® (Mad Dogg Athletics Inc., California, USA) oscillation device above the head, and 3 × 0.4 m box jumps (jumping off the start blocks). All exercises were completed at maximum effort, with the circuit completed twice and 10 s rest taken between each exercise. The *Combo* strategy involved a combination of the *Passive* and *Dryland* warm-up strategies. Swimmers wore a heated jacket throughout transition, including during the dryland circuit, and until immediately prior to time-trial start.

Swimmers were requested to maintain the same nutrition (no caffeine in the 12 h prior) and sleep routine prior to each testing session and refrain from completing heavy exercise (in the pool or gym) within two days prior and on the day of testing. With the cooperation of the coaches, training volume and intensity were also kept consistent (on a weekly basis) throughout the study duration. Quantitative feedback on swimming performance (e.g. times and stroke characteristics) was delayed until study completion.

Pool warm-ups and time-trial swims were performed in a 50 m indoor pool (pool temperature 27.2 ± 0.4 °C, air temperature 25.8 ± 0.4 °C, relative humidity 52.4 ± 1.3%). Swimmers began the time-trials from a dive start, utilising starting blocks. Overall and 25 m split-times were recorded by an elite coach (holding an Australian State-National level licence) using a manual stopwatch (SVAS003 Seiko, Tokyo, Japan). Footage from digital video cameras (Canon Legria FS21, Tokyo, Japan) positioned at the 5, 15, 25 and 45 m marks was used to determine start[9] and turn times[10] as well as mid-pool velocity ($\mathrm{m\,s^{-1}}$), stroke rate (Hz), stroke length (m) and stroke efficiency index ($\mathrm{m^2\,stroke^{-1}\,s^{-1}}$) for both time-trial laps through established methods.[10–12]

Ingestion of a temperature sensor (CorTemp$^{\mathrm{TM}}$ Ingestible Core Body Temperature Sensor, HQ Inc., Palmetto, USA) 6 h prior to each testing session permitted measurement of T_{core}. Skin temperature (T_{skin}) sensors (DS1922L Thermochron iButton®, Maxim Integrated Products, Inc., Sunnyvale, USA) were fitted to swimmers at four sites: chest, forearm, mid-thigh, and mid-calf to estimate mean T_{skin}.[13] Capillary blood lactate concentration ($\mathrm{La^-}$; Lactate Pro, Arkray, Shiga, Japan) and heart rate (Polar RS400, Polar Electro Oy Kempele, Finland) were monitored using previously described methods.[14,15] Sample points for T_{core}, T_{skin} and HR were: pre-pool warm-up, immediately post-pool warm up, pre-dryland circuit, post-dryland circuit, pre-time-trial, one and four min post-time-trial. $\mathrm{La^-}$ was sampled post-pool warm up, pre-time-trial, one and four min post-time-trial with peak post-time-trial $\mathrm{La^-}$ concentration determined from the higher of the post-time-trial sample points.

Ratings of perceived exertion (RPE) were determined using the 10-point Borg scale[16] following the pool warm-up, dryland circuit and time-trial. Swimmers views regarding competition warm-up strategies, and their opinions relating to the additional warm-up strategies were assessed via questionnaires (multiple choice and Likert format) created for this study. The questionnaires were completed (1) prior to study commencement; (2) prior to each testing session; (3) after each testing session, and (4) at study conclusion.

Statistical analysis was performed using SPSS software (version 21; SPSS Inc., Chicago, USA) with significance set at $p \leq 0.05$ and $p \geq 0.05$–$p \leq 0.10$ determined as possibly different.[17] Effect size (ES) was calculated using Cohen's d with the ranges of 0.2–0.6, 0.61–1.19 and >1.20 considered small, medium and large effects respectively.[18] Precision of estimation was indicated with 90%

Please cite this article in press as: McGowan CJ, et al. Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *J Sci Med Sport* (2015), http://dx.doi.org/10.1016/j.jsams.2015.04.012

confidence limits. All raw time-based data was analysed using a one-way within-participant analysis of variance (ANOVA) comparing all conditions. To estimate differences in performance time, all raw time-based data was normalised against Control and analysed using a one-way within-participant ANOVA comparing the three intervention conditions (Passive, Dryland, Combo) relative to Control. Relationships between 100 m time-trial performance and change in T_{core} during transition (calculated from group mean T_{core} values recorded at (1) post-pool warm-up and (2) pre-time-trial) for each warm-up condition were evaluated with a Pearson's product-moment correlation (GraphPad Software Inc., V6, La Jolla, USA). Mean stroke characteristics were analysed using a one-way within-participant ANOVA.

Change scores were calculated for T_{core}, T_{skin} and HR between the time points of (1) post-pool warm-up and pre-time-trial, and (2) pre-dryland and post-dryland exercise circuit (when performed). Where appropriate, differences in change score data were analysed using a two-way repeated-measures ANOVA accounting for timing and condition. T_{core}, T_{skin} and HR values recorded at the individual sample points were also analysed using a two-way repeated-measures ANOVA. Analysis of La− data was completed in a similar fashion. Bonferroni adjustment was conducted where relevant on ANOVA results. RPE data was analysed using the Wilcoxon signed rank test. All questionnaire data was analysed using frequencies to determine the percentage response swimmers provided for the various questions.

3. Results

Compared to Control (60.70 ± 3.36 s; mean ± 90% confidence limits) 100-m swim time-trials were significantly faster for Combo (59.90 ± 3.70 s; −1.05 ± 0.26%; $p = 0.00$; ES, 0.27) and Dryland (60.26 ± 3.50 s; −0.68 ± 0.34%; $p = 0.02$; ES, 0.18), and marginally faster for Passive (60.37 ± 3.15; −0.43 ± 0.36%; $p = 0.49$; ES, 0.12), (Fig. 1A). Start times were faster in Combo (6.86 ± 0.19 s; −0.37 ± 0.08%; $p = 0.00$; ES, 0.92) and possibly faster in Passive (7.03 ± 0.24 s; −0.20 ± 0.11%; $p = 0.08$; ES, 0.45) compared to Control (7.23 ± 0.17 s), (Fig. 1B). Turn times were possibly faster for Passive (9.14 ± 0.43 s; −1.23 ± 0.65%; $p = 0.05$; ES, 0.89) and Dryland (9.12 ± 0.52 s; −1.25 ± 0.70%; $p = 0.09$; ES, 0.86) compared to Control (10.37 ± 0.82 s). Split times for the 25–50 m section were faster for Passive (16.04 ± 0.32 s; −0.50 ± 0.18%; $p = 0.00$; ES, 0.73) and possibly faster for Combo (16.12 ± 0.30 s; −0.42 ± 0.24%; $p = 0.08$; ES, 0.64) compared to Control (16.54 ± 0.30 s). Mean stroke efficiency index was higher (3.5 ± 0.3 m^2 $stroke^{-1}$ s^{-1}; $p = 0.03$; ES, −0.35) in Passive compared to Control (3.3 ± 0.2 m^2 $stroke^{-1}$ s^{-1}), with no other significant differences in stroke characteristics recorded.

T_{core}, T_{skin}, HR and La^- readings were not significantly different between conditions at baseline or following pool warm-up. T_{core} increased by ~0.7 ± 0.1 °C during pool warm-up in all conditions. During transition, T_{core} decreased under all conditions, though the decline was less in Combo (−0.13 ± 0.25 °C; $p = 0.01$; ES, −1.18; from 37.86 ± 0.33 °C to 37.73 ± 0.29 °C) and possibly less in Dryland (−0.24 ± 0.13 °C; $p = 0.09$; ES, −1.36; from 37.76 ± 0.44 °C to 37.53 ± 0.48 °C) compared with Control (−0.64 ± 0.16 °C; from 37.88 ± 0.37 °C to 37.25 ± 0.36 °C), (Fig. 2). A smaller reduction in T_{core} during transition was also highly correlated with faster overall time-trial performance ($R^2 = 0.91$; $p = 0.04$). T_{skin} was higher immediately pre-time-trial in Passive (0.87 °C; $p = 0.04$; ES, −1.35) and Combo (1.18 °C; $p = 0.03$; ES, −2.35) compared with Control (Table 1). La^- concentrations only differed once between conditions with peak post-time-trial La^- higher in Passive ($p = 0.03$; ES, −0.60) versus Control (Table 1). Completion of the dryland circuit (Dryland and Combo) elicited a ~22–29 beats per min rise in HR ($p = 0.00$; ES, −2.48) compared to when the circuit was not completed. HR was not different between conditions immediately pre-time-trial (Table 1).

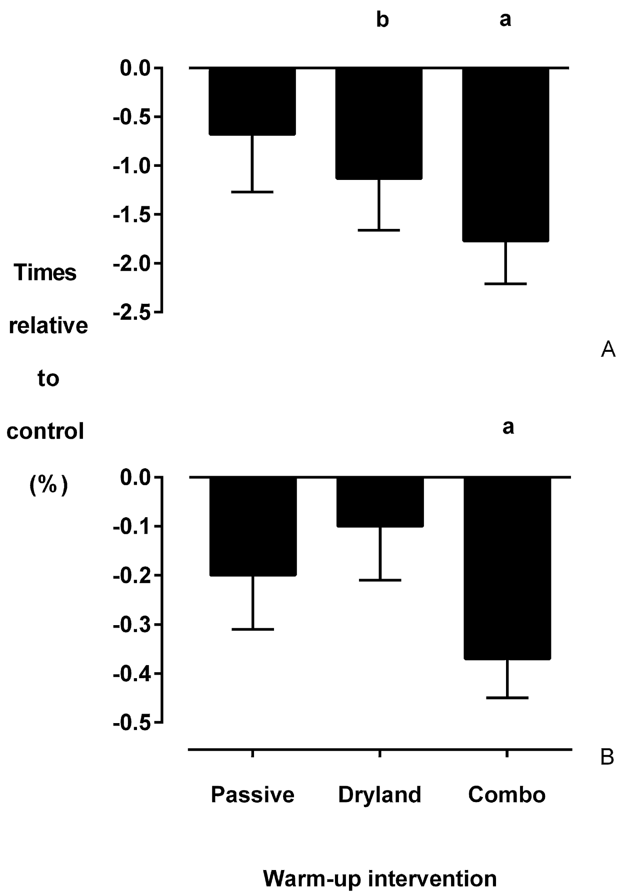

Fig. 1. One hundred meter freestyle time-trial times for the three additional warm-up intervention conditions (Passive, Dryland, Combo). Times were normalised against the Control condition (no additional warm-up). (A) Overall 100 m freestyle time-trial times. (B) Time to 15 m (start time). Data are presented as mean ± 90% confidence limits. Significantly different to Control ^{a} $p \le 0.01$, ^{b} $p \le 0.05$.

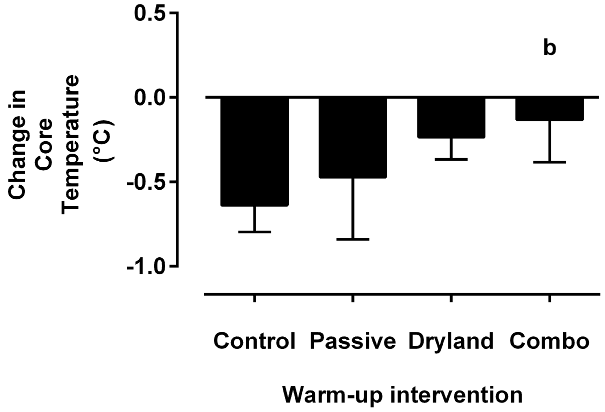

Fig. 2. Change in core temperature (T_{core}) during the 30 min transition phase, from post-pool warm-up to pre 100 m freestyle time-trial, for each additional warm-up intervention (Passive, Dryland, Combo) and for Control (no additional warm-up). Data are presented as mean ± 90% confidence limits. Significantly different to Control ^{b} $p \le 0.05$.

RPE was not different between conditions following the pool warm-up or post-time-trial. Completion of the dryland circuit yielded a median 1.5 point rise in Dryland ($p = 0.03$) and 2 point rise in Combo ($p = 0.02$) with a 3.3 point (range 0–4 points) rise in

Please cite this article in press as: McGowan CJ, et al. Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *J Sci Med Sport* (2015), http://dx.doi.org/10.1016/j.jsams.2015.04.012

Table 1
Heart rate (HR), lactate (La^-) and skin temperature (T_{skin}) values recorded immediately post pool warm-up and pre time-trial with calculated values sampled at 1 and 4 min post time-trial (peak post time-trial) presented.

	Measure	Control	Passive	Dryland	Combo
Post pool warm-up	*HR (bpm)*	119 ± 10	114 ± 8	110 ± 9	111 ± 10
	La^- *(mmol/L)*	2.1 ± 0.3	2.7 ± 0.6	2.3 ± 0.6	1.8 ± 0.3
	T_{skin} *(°C)*	29.1 ± 0.3	29.3 ± 0.4	28.8 ± 0.4	28.9 ± 0.4
Pre time-trial	*HR (bpm)*	95 ± 8	94 ± 6	98 ± 8	99 ± 6
	La^- *(mmol/L)*	1.1 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	1.0 ± 0.1
	T_{skin} *(°C)*	33.1 ± 0.3	33.9 ± 0.3[a]	33.3 ± 0.3	34.3 ± 0.1[a]
Peak post time-trial	*HR (bpm)*	156 ± 8	152 ± 6	154 ± 4	160 ± 5
	La^- *(mmol/L)*	8.6 ± 1.1	10.2 ± 1.2[a]	9.4 ± 0.8	9.2 ± 1.0
	T_{skin} *(°C)*	33.1 ± 0.5	33.7 ± 0.4	32.8 ± 0.4	34.1 ± 0.7

All data are mean ± 90% confidence limits.
[a] Significantly different to control $p < 0.05$.

the interquartile range reported for both conditions. There were no differences between conditions regarding pre-time-trial motivation levels with all swimmers confirming they employed similar intensities of effort across all conditions for the time-trials. Prior to study commencement, swimmers ranked the four conditions in order of preference for competition use: Combo (69%), Control (25%), Passive (6%) and Dryland (0%). Following study completion, swimmers re-ranked the conditions: Combo (50%), Dryland (38%), Passive (12%) and Control (0%). All swimmers stated they would choose to utilise the heated jackets and dryland-based exercise circuits in competition if possible.

4. Discussion

An improvement in 100 m freestyle time-trial performance was demonstrated when dryland-based activation exercises were completed alone (~0.7%), and in combination with the wearing of a heated tracksuit jacket (~1.1%), during a 30 min transition phase which followed a contemporary swimming warm-up, compared to when no intervention was utilised during transition. Because enhancements in performance of as little as ~0.4% in swimming can increase the chances of earning a medal at the elite level,[19] these observed improvements are likely to be practically significant. Furthermore, we demonstrated that a smaller decline in T_{core} during transition was strongly associated with faster time-trial performance. Overall, the Combo strategy was considered to be the most effective intervention for eliciting faster time-trial performance.

Elevated T_{core} and/or T_{muscle} prior to competition are recognised as key determinants for sprint- and power-based events[20] by facilitating increases in muscle fibre conduction velocity,[21] muscle metabolism[22] and ATP utilisation rate.[23] In the present study, T_{core} increased during the pool warm-up by a similar magnitude (~0.7 ± 0.1 °C) to previous reports.[3] However during transition, T_{core} declined within all conditions, with a significant ~0.6 °C reduction recorded under the Control condition. This magnitude of reduction in T_{core} is greater than previously reported,[3,5,24] though a longer transition phase (more common in swimming competitions) was investigated in this study (30 versus 10–20 min). Under the three intervention conditions however, the mean decline in T_{core} during transition was reduced, with the Combo and Dryland interventions in particular eliciting substantially smaller reductions in T_{core}. In addition, we demonstrated that these smaller reductions in T_{core} during transition, i.e. improved T_{core} maintenance, were strongly associated with enhanced subsequent time-trial performance. These findings are in accordance with previous results demonstrating that better T_{core}/T_{muscle} maintenance within the transition phase is the likely mechanism responsible for improved lower leg power production[24] and power production in sprint cycling.[6,7]

The application of passive heating alone was not as effective at limiting T_{core} decline during transition as the combination of passive heating and activation exercises. Previous work however has demonstrated that heated tracksuit pants alone were sufficient in maintaining T_{muscle} during a 30 min transition.[6,7] In the present study T_{skin} values immediately pre-time-trial were higher in the two conditions in which the heated jackets were worn. T_{skin} is correlated with changes in T_{muscle},[25] suggesting that although passive heating alone did not maintain T_{core}, T_{muscle} may have been maintained in these conditions. In turn, these greater T_{skin} readings coincided with improved start times, with the fastest start times recorded in the Passive and Combo conditions. These outcomes are practically significant as the swim start at the international competitive level contributes up to 30% of total race performance.[26] High velocity movements (e.g., the swim start) are also more temperature-dependent[27] than low velocity movements with the rate of deterioration in muscle performance strongly associated with reductions in T_{muscle}.[28] It is likely that the heated jackets contributed to improved start times through elevated T_{muscle} immediately prior to the time-trial.

The dryland-based exercise circuit completed alone, or in combination with the application of passive heat, resulted in a smaller decline in T_{core} compared to Control. This observation is consistent with data indicating that dryland-based exercise attenuates the decline in T_{core}[5,29] as well as T_{muscle}.[5] The dryland circuit may also have played a “priming” or “re-activation” role. Although the 15 min marshalling period might have diminished any PAP effect, improvements in power production can occur up to 18.5 min following a PAP stimulus.[30]

Swimmers were unable to be completely blinded to the interventions so our observations may have been influenced in part by a placebo effect. However swimmers reported being equally motivated, and applied similar levels of effort across the time-trials. We therefore consider it unlikely that an additional benefit was yielded by an improved perception of “readiness”. Our findings are also in line with earlier reports indicating that both passive heat maintenance[6,7,24] and dryland-based exercise[9] are effective methods for improving subsequent swimming performance. Finally, due to unavoidable logistical constraints, swimmers were tested in morning and afternoon sessions. To limit the direct influence of diurnal variation on performance and T_{core} we ensured each individual swimmer acted as their own control, and was tested within the same time slot, for all their testing sessions.

5. Conclusions

Time-trial performance (100 m freestyle) was faster when dryland-based activation exercises were completed alone, and in combination with the wearing of heated tracksuit jackets, during a 30 min transition phase which followed a contemporary

Please cite this article in press as: McGowan CJ, et al. Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *J Sci Med Sport* (2015), http://dx.doi.org/10.1016/j.jsams.2015.04.012

swimming warm-up, compared with a traditional swimming-only warm-up. Although T_{core} declined during the 30 min transition, completion of dryland-based activation exercises separately, and in combination with the application of passive heating during transition, attenuated the reduction. More effective preservation of T_{core} and T_{skin} was deemed the likely primary mechanism for the enhancement of both initial start and overall sprint swimming performance.

Practical implications

- Heated tracksuit jackets and dryland-based exercises are simple interventions that can be implemented in real-world competition settings
- The combination of heated tracksuit jackets and dryland-based exercises provided the optimal strategy for maintaining T_{core} during lengthy transitions
- Completion of dryland-based exercises both separately and in combination with the wearing of heated tracksuit jackets are worthwhile strategies for enhancing sprint swimming performance

Acknowledgments

This project was funded by the Faculty of Health at the University of Canberra. The authors thank the swimmers and coaches for participating in the present study. Special thanks must also go to Pathum Bandara, Paul Fellows, Beth Logan and Vy Vu, undergraduate students at the University of Canberra for their assistance in data collection. The contribution of Julian Jones, Head of Strength and Conditioning at the Australian Institute of Sport, in developing the dryland exercise circuit is gratefully acknowledged.

References

1. Bishop D. Warm up II. *Sports Med* 2003; 33(7):483–498.
2. Mujika I, de Txabarri RG, Maldonado-Martín S et al. Warm-up intensity and duration's effect on traditional rowing time-trial performance. *Int J Sports Physiol Perfom* 2012; 7(2):186–188.
3. West DJ, Dietzig BM, Bracken RM et al. Influence of post-warm-up recovery time on swim performance in international swimmers. *J Sci Med Sport* 2013; 16(2):172–176.
4. Zochowski T, Johnson E, Sleivert G. Effects of varying post-warm-up recovery time on 200-m time-trial swim performance. *Int J Sports Physiol Perfom* 2007; 2(2):201–211.
5. Mohr M, Krustrup P, Nybo L et al. Muscle temperature and sprint performance during soccer matches beneficial effect of re-warm-up at half-time. *Scand J Med Sci Sports* 2004; 14(3):156–162.
6. Faulkner SH, Ferguson RA, Gerrett N et al. Reducing muscle temperature drop post warm-up improves sprint cycling performance. *Med Sci Sports Exerc* 2013; 45(2):359–365.
7. Faulkner SH, Ferguson RA, Hodder SG et al. External muscle heating during warm-up does not provide added performance benefit above external heating in the recovery period alone. *Eur J Appl Physiol* 2013; 113(11):2713–2721.
8. Faigenbaum AD, McFarland JE, Schwerdtman JA et al. Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. *J Athl Train* 2006; 41(4):357–363.
9. Kilduff LP, Cunningham DJ, Owen NJ et al. Effect of postactivation potentiation on swimming starts in international sprint swimmers. *J Strength Cond Res* 2011; 25(9):2418–2423.
10. Thompson K, Haljand R, MacLaren D. An analysis of selected kinematic variables in national and elite male and female 100-m and 200-m breaststroke swimmers. *J Sports Sci* 2000; 18(6):421–431.
11. Costill D, Kovaleski J, Porter D et al. Energy expenditure during front crawl swimming: predicting success in middle-distance events. *Int J Sports Med* 1985; 6(5):266–270.
12. Craig AB, Pendergast DR. Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Med Sci Sports Exerc* 1979; 11(3):278–283.
13. Ramanathan N. A new weighting system for mean surface temperature of the human body. *J Appl Physiol* 1964; 19(3):531–533.
14. Tanner R, Gore C. *Physiological tests for elite athletes*, 2nd Ed Champaign, IL, Human Kinetics, 2013.
15. Pyne DB, Boston T, Martin DT et al. Evaluation of the Lactate Pro blood lactate analyser. *Eur J Appl Physiol* 2000; 82(1–2):112–116.
16. Borg G. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; 14(5):377–381.
17. Curran-Everett D, Benos DJ. Guidelines for reporting statistics in journals published by the American Physiological Society. *Am J Physiol Endocrinol Metab* 2004; 287(2):189–191.
18. Hopkins W, Marshall S, Batterham A et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41(1):3–12.
19. Pyne DB, Trewin CB, Hopkins WG. Progression and variability of competitive performance of Olympic swimmers. *J Sports Sci* 2004; 22(7):613–620.
20. Bishop D. Warm up I. *Sports Med* 2003; 33(6):439–454.
21. Gray SR, De Vito G, Nimmo MA et al. Skeletal muscle ATP turnover and muscle fiber conduction velocity are elevated at higher muscle temperatures during maximal power output development in humans. *Am J Physiol Regul Integr Comp Physiol* 2006; 290(2):376–382.
22. Gray SR, Soderlund K, Watson M et al. Skeletal muscle ATP turnover and single fibre ATP and PCr content during intense exercise at different muscle temperatures in humans. *Pflügers Arch* 2011; 462(6):885–893.
23. Febbraio M, Carey M, Snow R et al. Influence of elevated muscle temperature on metabolism during intense, dynamic exercise. *Am J Physiol Regul Integr Comp Physiol* 1996; 271(5):1251–1255.
24. Kilduff LP, West DJ, Williams N et al. The influence of passive heat maintenance on lower body power output and repeated sprint performance in professional rugby league players. *J Sci Med Sport* 2013; 16(5):482–486.
25. Asmussen E, Bøje O. Body temperature and capacity for work. *Acta Physiol Scand* 1945; 10(1):1–22.
26. Mason B, Cossor J. What can we learn from competition analysis at the 1999 Pan Pacific Swimming Championships? *Paper presented at the XVIII International Symposium on Biomechanics in Sports Applied Program: Applications of Biomechanical Study in Swimming*, Hong Kong, China, The Chinese University of Hong Kong, 2000, p. 75–82.
27. Binkhorst R, Hoofd L, Vissers A. Temperature and force-velocity relationship of human muscles. *J Appl Physiol* 1977; 42(4):471–475.
28. Racinais S, Oksa J. Temperature and neuromuscular function. *Scand J Med Sci Sports* 2010; 20(3):1–18.
29. Lovell R, Kirke I, Siegler J et al. Soccer half-time strategy influences thermoregulation and endurance performance. *J Sports Med Phys Fitness* 2007; 47(3):263–269.
30. Chiu LZ, Fry AC, Weiss LW et al. Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res* 2003; 17(4):671–677.

Please cite this article in press as: McGowan CJ, et al. Heated jackets and dryland-based activation exercises used as additional warm-ups during transition enhance sprint swimming performance. *J Sci Med Sport* (2015), http://dx.doi.org/10.1016/j.jsams.2015.04.012