Title: Transition phase clothing strategies and their effect on body temperature and 100m swimming performance.

Andy Galbraith and Aimee Willmott

University of East London, School of Health, Sport and Bioscience, Water Lane, Stratford, England. E15 4LZ.

Corresponding author:

Andy Galbraith

University of East London

School of Health, Sport and Bioscience

Water Lane, Stratford, E15 4LZ.

United Kingdom

Tel: 0208 223 3371

E-mail: A.J.Galbraith@uel.ac.uk

Word count: 3796

Abstract

Objective: Effective warm ups are attributed to several temperature related mechanisms. Strategies during the transition phase, preceding swimming competition, have been shown to prolong temperature-related warm up effects. The purpose of this study was to evaluate the effects of two different clothing strategies during the transition phase, on subsequent 100 m maximal swimming performance.

Methods: Nine competitive swimmers (3 female, 21±3 yrs; 6 male 20±2 yrs, mean performance standard 702 FINA POINTS, mean 100 m seasons best time 61.54 s) completed their own 30 minute individual pool warm up, followed by 7 minutes changing time and a 30 minute transition phase, straight into a 100 m maximal effort time trial. During the transition phase swimmers remained seated, either wearing warm or limited clothing. Swimmers returned 1 week later, where clothing conditions were alternated.

Results: Post transition phase skin and core temperature remained higher in the warm clothing condition compared to the limited clothing condition (Mean Core: 36.90±0.17°C, 36.61±0.15°C, $P<0.01$; Mean Skin: 33.49±0.59°C, 31.94±0.59°C, $P<0.01$). 100 m finish times were 0.6% faster in the warm clothing condition compared to the limited clothing condition (62.63±7.69 s, 63.00±7.75 s, $P<0.01$).

Conclusion: Wearing warm clothing during a 30-minute transition phase improved swimming performance by 0.6%, compared to limited clothing.

Keywords: Competition, Measurement, Physiology, Testing

Introduction

Swimming is a highly competitive sport that reaches its pinnacle every four years at the Olympic Games. Medals are won and lost by margins as small as 0.01 s, therefore athletes and coaches are constantly looking for methods that give them an advantage over their competitors (Pyne, Trewin, and Hopkins, 2004). Warm up routines preceding physical activity are commonly used to aid performance. When designed well, they can prime and prepare an athlete both mentally and physically to optimise performance (Taylor, Sheppard, and Plummer, 2009). Body movement during warm up increases muscle temperature, reduces muscle stiffness, improves contractile performance and readies skeletal muscles for exercise (Kilduff et al., 2013; McGowan et al., 2015). Optimal body temperature prior to swimming enables faster reaction times, which are crucial in sprint swimming, where fast reaction times equate to 30% of overall race speed (McGowan et al., 2016).

In sporting environments there is usually a period of time, called the transition phase, that follows the end of the warm up and precedes the start of competition (Kilduff et al., 2013). During this phase studies have reported drops in core and muscle temperature. For example, West et al (2013) reported that by 20 minutes post-warm-up, 40% of the rise in core temperature, gained via the warm-up, had been lost. Faulkner et al (2012) report similar findings for muscle temperature, detailing ~1.2°C drop in muscle temperature 30-minutes post-warm-up, which equated to a loss of ~45% of the muscle temperature gain afforded by the warm-up. A short transition phase is therefore important in order to maintain the effects of the warm up. A 5 minute transition between warm up and exercise performance did not result in a decrease in core temperature or impact subsequent exercise performance in the work of Frikha et al. (2016), however significant temperature drops have been highlighted 15 minutes post warm up (McGowan et al., 2017). A transition phase of 10 minutes has previously resulted in a 1.4% improvement in 200 m swim time, compared to a 45 min phase (Zachowski, Johnson, and Sleivert, 2007).

This recommended time frame is not possible at national and international swimming competitions, where athletes must report to a call room ~15-20 minutes before the start of their scheduled race time

(FINA, 2015a; McGowan et al., 2015). Transition phase strategies may therefore offer an opportunity for athletes to gain an advantage over their competitors, by maintaining muscle and body temperature and maximising the benefits from the warm up. The use of heated garments worn in a land-based warm up, during a transition phase, has been shown to result in significantly higher core temperatures and 0.8-1.3% faster 100 m swimming time (McGowan et al., 2017; McGowan et al., 2016). Furthermore Wilkins and Havenith (2017) demonstrated that the use of heated garments during a 30-minute passive recovery transition phase, attenuated the decline in skin and muscle temperature compared with a control condition, resulting in a 0.8% improvement in 50 m swimming time. Heated clothing garments may not be affordable for all swimmers, however simple clothing strategies during the transition phase may provide a suitable alternative. No study to date has compared the effects of different standard clothing strategies, during the transition phase, on the maintenance of body temperature and the impact on subsequent swimming performance.

The purpose of this study therefore, was to examine whether clothing strategies during the transition phase can improve swimming performance. It was hypothesised that following a swimmers pool warm up, the more clothing worn during a 30-minute transition phase, the higher core and skin temperature will be, resulting in faster subsequent 100 m swimming times.

Methods

Participants

Nine swimmers from the London Aquatic Centre Performance Programme volunteered to take part in the study. All swimmers completed normal training loads, during an anaerobic phase of training and were injury free for at least 4 weeks prior to testing. Participants competed over a range of distances (Table 1), however all participants were experienced at racing over 100 m. All participants provided written informed consent for this study and study protocols were submitted to, and approved by, the University of East London, School of Health, Sport and Bioscience research ethics committee. The work described has been carried out in accordance with the Declaration of Helsinki, for experiments involving human participants.

** Table 1 **

General study design

A randomised crossover design was used, where each swimmer completed two testing sessions with different transition phase strategies (limited clothing and warm clothing). Testing was carried out on consecutive Monday evenings between 4-6pm during usual training hours, following a weekend of rest. Participants were instructed to arrive for testing in a rested and fully hydrated state, at least 3 hours post-prandial and having abstained from caffeine intake for 12 hours.

Prior to each testing session participants warmed up as normal in the pool, following their regular individual 30-minute warm up plan. This involved a mixture of steady state, tempo and race pace swimming efforts, along with technical drills. The participants then had 7 minutes to dry off and change into their racing costume. They then remained seated for the following 30 minutes during the transition phase, before completing a 100 m maximum effort time-trial using their main stroke. Reaction Time (RT), 15, 25, ^{1st}50, ^{2nd}50 and total 100-meter times were recorded. Splits and overall times were not relayed to the swimmers until both conditions had been completed.

During the transition phase the limited clothing condition involved wearing a standardised club T-shirt (65% polyester, 35% cotton), while the warm clothing condition involved wearing a standardised club T-shirt (65% polyester, 35% cotton), hooded top (80% polyester, 20% cotton; fabric weight: 320gsm), trousers (65% polyester, 35% cotton), gloves (95% polyester, 5% elastane), socks, and trainers.

Measurements

Core ($T_{tympanic}$) and skin (T_{skin}) temperature were recorded pre warm up (Pre_{WU}), immediately post warm up ($Post_{WU}$), and then again before (Pre_{TP}) and after ($Post_{TP}$) the 30-minute transition phase, prior to the start of the 100 m time-trial. Thermal comfort was recorded at the start of the 30-minute transition phase, at 10 and 20 minutes into the transition phase and at end of 30-minute transition phase. Reaction time (RT), 15 m, 25 m and 50 m split times as well as overall 100 m time were recorded. Immediately following the 100 m sprint, RPE was recorded.

All warm ups and time trials were carried out at the London Aquatic Centre 50 m pool. The pools atmospheric temperature and pool water temperature were recorded immediately prior to each testing session. Mean pool water temperature was recorded at 27.3±0.3°C, while mean pool atmospheric temperature was recorded at 27.9±0.2°C.

50 and 100 m time was recorded using Omega Electronic Timing System (Omega Quantam AQ electronic timing system, Swiss Timing Ltd, Corgemont, Switzerland) operated by a certified user, and recorded to the nearest tenth. 15 m and 25 m times were recorded using a Finis Stopwatch (3X-100model), by a level 3 qualified coach. The coach also took 50 m and 100 m times as backup times. All times were recorded from the sound of the starting buzzer (StartTime IV) to the desired distances.

RT was measured also using Omega Electronic Timing System (Omega Quantam AQ electronic timing system, Swiss Timing Ltd, Corgemont, Switzerland) and OBS11 starting blocks. RT is the time

measured between the starting buzzer and the first movement from the swimmer leaving the blocks. The time was reported in seconds to the nearest 0.1 s

T_{skin} was recorded using a non-contact infrared thermometer (Thermoscan Singlie, DT-8861) at four sites of the body (Figure 1): Chest (C), Arm (D), Thigh (H) and Leg (J), in accordance with Ramanathan (1964), using markers outlined by Winslow (Mitchell and Wyndham, 1969). A 2 cm/2 cm square was drawn on each participant in permanent marker pen to standardise measuring sites, with T_{skin} recorded at a distance of 5 cm away from the skin surface. In a comparison with a wired lab-based system (Squirrel SQ2020 Series Data Logger, Grant Instruments, Cambridgeshire UK), the non-contact thermometer recorded values 0.19% (0.06±0.14°C) higher on average, from repeated measurements across the four sites using both devices. Core temperature ($T_{tympanic}$) was recorded via tympanic measurements, using a Braun ThermoScan ExacTemp (Braun GmbH, Kronberg, Germany). All measures were taken three times, with the mean value reported. Body temperature was calculated using the formula proposed by Burton (1935)

Mean Skin Temperature (MST) = 0.3 (C + D) + 0.2 (H + J)

Mean Body Temperature (MBT) = 0.64 ($T_{tympanic}$) + 0.36 (MST)

** Figure 1 **

Participants RPE (Borg, 1982) was recorded as soon as the 100 m swim was finished. Thermal comfort was assessed using the ASHRAE 7-point scale, in accordance with Zhang and Zhao (2008).

Statistical analysis

Statistical Analysis was carried out using SPSS software (version 22; SPSS Inc.) with significance set at $P<0.05$. Data was checked for normality of distribution. Repeated measures ANOVA checked for effects of clothing type (limited and warm) on the measured parameters. Paired samples T-tests were used to compare individual differences in performance time, skin and core temperature. A Wilcoxon

test was used to analyse thermal comfort due to the non-normally distributed data. Effect sizes are presented using Cohen's *d*. The thresholds for Cohen's *d* were interpreted as follows: small *d* = 0.2; moderate *d* = 0.5; large *d* = 0.8.

Results

Performance measures

There was a significant effect for clothing worn during the transition phase on all performance measures. The assumption of sphericity was violated and the Greenhouse-Geisser epsilon used ($F_{1.36, 10.89} = 7.09$, $P=0.02$, $\eta_{p^2}=0.47$). Reaction time and all split times, were significantly faster after the warm clothing transition phase, compared with the limited clothing transition phase. The warm clothing transition phase resulted in 0.59% improvement in 100 m swimming performance (62.63 ± 7.69 s vs. 63.00 ± 7.75 s; $t_8 = 3.97$, $P<0.01$, $d=0.1$).

** Table 2 **

Thermal comfort

There was no significant difference in thermal comfort between the warm and limited clothing conditions at Pre_{WU} (0.0±0.5; 0.0±0.5), $Post_{WU}$ (-0.9±0.3; -0.7±0.5) or Pre_{TP} (-0.7±0.5; -0.2±0.4). Thermal comfort $Post_{TP}$, was significantly higher ($z = -2.70$, $P=0.01$ $d=>2.0$) in the warm compared with the limited clothing condition (1.6±0.5; -1.2±0.7).

Skin and Core temperature

There was a significant effect for clothing worn during the transition phase on the temperature measures. The assumption of sphericity was violated and the Greenhouse-Geisser epsilon used ($F_{1.84, 14.73} = 65.13$, $P<0.01$, $\eta_{p^2}=0.89$). There was no significant difference in $T_{tympanic}$ and T_{skin} (°C) between the warm and limited clothing conditions at Pre_{WU} ($T_{tympanic}$ 36.88±0.11; 36.87±0.17: T_{skin} 32.72±0.47; 32.57±0.54), $Post_{WU}$ ($T_{tympanic}$ 35.24±0.54; 35.12±0.47: T_{skin} 28.38±1.01; 28.29±1.09) or Pre_{TP} ($T_{tympanic}$ 36.18±0.34; 36.14±0.23: T_{skin} 31.70±0.57; 31.78±0.56). $T_{tympanic}$ and T_{skin} (°C) remained significantly higher $Post_{TP}$ in the warm clothing condition, compared to the limited condition ($T_{tympanic}$ 36.90±0.17; 36.61±0.15, $t_8 = 6.35$, $P<0.01$ $d=1.8$: T_{skin} 33.49±0.59; 31.94±0.59, $t_8 = 12.51$, $P<0.01$ $d=>2.0$).

** Figure 2 **

RPE

There was no significant difference (P=0.10, d=0.6) in mean RPE between the warm and limited

clothing conditions (17.6±0.7; 18±0.7).

Discussion

The key findings from this study were that $T_{tympanic}$, T_{skin} and thermal comfort, were all significantly higher Post$_{TP}$ in the warm clothing condition, when compared with the limited clothing condition. Consequently, participants recorded significantly faster (0.59%) 100 m swimming times in the warm clothing condition.

Body temperature begins to decline soon after the warm up ends, with notable reductions around 15 minutes post warm up (Mohr et al., 2004), therefore a short transition phase between finishing the warm up and commencing exercise performance is recommended. A short transition phase is not always possible in swimming events, where athletes must report to a call room ~15-20 minutes before the start of their scheduled race time (FINA, 2015a; McGowan et al., 2015). Consequently, strategies to maintain body temperature and extend the benefits of the warm up during the transition phase are important. The current study reveals that the quantity of clothing worn during the transition phase is an important factor in helping to reduce drops in $T_{tympanic}$ and T_{skin}. This is the first study to report that a warm clothing strategy during the transition phase attenuates the decline in $T_{tympanic}$, T_{skin} and thermal comfort, resulting in a 0.59% improvement in 100 m swimming performance. Pyne et al (2004) suggest that a swimmers chance of medaling in a major competition can be markedly increased by improving performance by as little as 0.4%. The 0.6% improvement in performance offered here by a warm clothing transition phase strategy, seems a worthwhile consideration for swimmers of all abilities.

In the warm clothing condition, participants appeared to reap most of the benefit afforded by the maintenance of $T_{tympanic}$ and T_{skin} in the transition phase, during the second 50 m split of the 100 m performance trial (Table 2). In the warm clothing condition, participants were 0.13 and 0.23 s quicker respectively for the first and second 50 m split times, when compared with the limited clothing condition. These findings are however in contrast to Wilkins and Havenith (2017) who report that most of the gains in a 50 m swim were made in the first 25 m split, suggesting maintenance of body temperature during the transition phase may be of greater benefit to shorter distance events. Zochowski et al (2007) however, observed a 1.4% better 200 m swim performance following a 10 minute transition phase,

compared with a 45 minute phase. Whilst there may be a number of underlying reasons as to why a shorter a transition phase improved performance, better maintenance of body temperature during the shorter transition phase may play a key role. Further research is needed to investigate whether competitors in longer distance swimming events may also benefit from giving consideration to their transition phase clothing strategy.

Previous research has mainly focused on maintaining warm up effects via passive heating during the transition phase. Following a land-based warm-up, Faulkner et al (2012) studied the effects of standard tracksuit trousers (control), compared to tracksuit trousers with integrated heating elements (passive heating), during a 30-min transition phase prior to sprint cycling. During the transition phase, Vastus Lateralis muscle temperature remained elevated in the passive heating trial compared to the control (P<0.01). Consequently, peak and relative power output were 9.6 and 9.1% higher during the subsequent sprint cycle trial, in the passive heating compared to the control condition (P<0.05). Similar findings were seen where the use of passive heating, via heated trousers, during a 30-min recovery phase, attenuated the post warm-up drop in muscle temperature, compared with a non-heated control (Raccuglia et al., 2015). In swimming, McGowan et al (2017) investigated the combined use of a tracksuit jacket with integrated heating elements and a land-based warm-up (combo), compared with a conventional tracksuit and passive rest (control). Core temperature decline during the transition phase was attenuated (−0.2°C ± 0.1°C versus −0.5°C ± 0.1°C, P=0.02) in the combo condition, compared with the control. Subsequent 100 m performance was significantly (P<0.01) faster (0.8% ± 0.4%) in combo condition. Finally, McGowan et al (2016) compared the use of four different strategies during a 30-minute transition phase. A conventional tracksuit top and trousers (control); an insulated top with integrated heating elements (passive); a 5min dryland-based exercise circuit (dryland) and a combination of passive heating and dryland exercise (combo). Core temperature declined less (−0.13±0.25°C; P=0.01) during the transition phase when the combo strategy was applied, compared to the control (−0.64±0.16°C). 100 m swimming performance was significantly faster (1.3 and 0.7% respectively) following the combo (59.90±3.70 s) and dryland (60.26±3.50 s) transition phase strategies, compared to the control (60.70±3.36 s). Wilkins and Havenith (2017) provide an interesting insight into

the benefits of heated garments during passive recovery, reporting a 2.3°C higher skin temperature post recovery period and a 0.8% improvement in 50 m swimming performance, following the use of a heated jacket during a passive recovery transition phase, when compared with a standard tracksuit jacket. Although interestingly, no difference in core temperature post recovery period was reported between the conditions.

Land-based warm-ups alone and when combined with the use of passive heating, have previously been shown to attenuate the decline in muscle and core body temperature during a transition phase, leading to improved exercise performance (Faulkner et al., 2012; McGowan et al., 2016; McGowan et al., 2017; Wilkins and Havenith, 2017). Heated clothing garments may not be affordable for all swimmers, furthermore at national and international competitions swimmers must report to the call room ~15-20 minutes before the scheduled start of their race time (FINA, 2015a; McGowan et al., 2015). This period is not always conducive to a land-based warm-up, due to race hat and suit checks (FINA, 2015b). Therefore simple transition phase clothing strategies may be the best methods available to a number of swimmers. The current study demonstrates that adopting a warm clothing strategy, compared with a limited clothing strategy, during the transition phase, attenuates the decline in $T_{tympanic}$, T_{skin} and thermal comfort and results in a 0.59% improvement in 100 m swimming performance.

Practical applications

The key findings of the current study are that an attenuated decline in $T_{tympanic}$, T_{skin} and thermal comfort during a transition phase and a subsequent improvement in swimming performance, can be achieved by simply adopting a warm clothing strategy during the transition phase. This strategy provides athletes with an alternative to heated garments, which previous research has focused on (Faulkner et al., 2012; Raccuglia et al., 2015; McGowan et al., 2016; McGowan et al., 2017; Wilkins and Havenith, 2017), demonstrating performance gains can be made via the implementation of a warm clothing strategy. This is useful for junior swimmers and aspiring elite swimmers where funds and equipment may not be accessible. This study therefore provides useful information that can be implemented into age group as well as youth and senior swimmers race day routines. It should be noted however, that the performance

gains reported with heated garments appear to be slightly higher than those reported in the current study. For example, Wilkins and Havenith (2017) report a performance gain of 0.8% in a 50 m swim, following the use of a heated jacket during the transition phase. Thermal comfort data in the current study, demonstrated that participants did not report feelings of being too warm (+3 thermal comfort), therefore it is feasible to assume that swimmers would be comfortable enough to implement a warm clothing transition phase strategy, without feelings of thermoregulatory distress. Subjective feedback from the swimmers highlighted that in the limited clothing condition they felt as though they 'could not get going', which supports the faster reaction and split times, during the 100 m performance trial, seen in the warm clothing condition. All participants reported that they would implement a warm clothing strategy into their race day routines and carefully consider the clothing they wear during the transition phase. A further novel aspect of the current study, was that performance benefits were seen across the range of swimming strokes (butterfly, backstroke, breaststroke and freestyle), compared with previous research which focused on freestyle swimming (McGowan et al., 2016; McGowan et al., 2017; Wilkins and Havenith, 2017).

Pool warm-up considerations

An interesting additional finding from the current research was that $T_{tympanic}$ and in particular T_{skin}, decreased during the pool warm-up. $Post_{WU}$ $T_{tympanic}$ saw a decrease of 1.7°C, whilst T_{skin} decreased by 4.3°C from the Pre_{WU} values (Figure 2). This raises questions about the effectiveness of pool warm-ups at maintaining $T_{tympanic}$ and $T_{skin,}$ warranting further research into this area.

Limitations

When asking participants to perform at maximal efforts there are limitations regarding the true effort from the participants, which may affect validity of the data (Ueda and Kurokawa, 1995). This study did not measure heart rate or blood lactate after the 100 m maximal effort swim, therefore the level of engagement of the swimmers during this task is uncertain. However due to the competitive level of the participants used in this study, it was expected that when asking highly trained athletes to perform at maximal effort, that they fully comply. The small differences seen between swimmers performance

times and their personal best times for that distance are also reflective of the fact that they fully engaged in the task.

Future research

Water temperature was shown to result in decreased $T_{tympanic}$ and T_{skin} during the pool warm-up. Future research investigating the effects of $Post_{TP}$ temperature and its associated effects on backstroke swimming are recommended. Backstroke races start from the water, therefore temperature maintenance during the transition phase for these athletes may be of increased importance, to prevent further temperature drops below baseline during the time spent in the pool, prior to the start of the race. Including muscle temperature readings in future research, along with $T_{tympanic}$ and T_{skin}, may add an additional level of detail to further advance our understanding of this topic.

Conclusion

Swimmers can be advised that combining active pool warms up with a warm clothing transition phase strategy, is a useful way to maintain warm up benefits and maximise sprint-swimming performance. A warm clothing strategy attenuated the decline in $T_{tympanic}$ and T_{skin} during a 30 minute transition phase, improving 100 m swimming performance by 0.59% (0.37 s).

Key Findings

• An attenuated decline in $T_{tympanic}$, T_{skin} and thermal comfort, during a transition phase, can be achieved by simply adopting a warm clothing strategy during the transition phase.

• Where passive heating garments are not available, a warm clothing strategy during the transition phase improved 100 m swim performance by 0.59% (0.37 s).

• $T_{tympanic}$ and in particular T_{skin}, decline during a pool warm-up. This raises questions about the effectiveness of pool warm-ups at maintaining body temperature.

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Table 1. Participant characteristics

Participant	Gender	Age (yr)	Height (cm)	Weight (kg)	Main Stroke	Main Distance	100m Time* (sec)	FINA points **
1	F	24	173.5	65.7	Butterfly	200/400	62.64	713
2	M	18	182.2	80.1	Breaststroke	100/200	64.81	733
3	M	18	181.5	70.8	Freestyle	100/200	50.81	786
4	F	19	175.1	62.5	Freestyle	50/100	57.68	735
5	F	20	174.0	60.6	Breaststroke	50/100	74.72	638
6	M	19	176.2	68.0	Breaststroke	50/100	64.27	739
7	M	21	181.1	72.0	Breaststroke	50/100	69.12	605
8	M	19	180.4	78.0	Freestyle	100/200	54.47	638
9	M	22	180.3	74.0	Butterfly	200/400	55.30	731
Mean (± SD)		20	178.3	70.2			61.5	702

100m times are swimmers fastest 100m swims within the last 12 months in a 50m swimming pool
** *FINA points are a numerical value differing from the World Record (WR) in each event. WR = 1000 points.*

Table 2. Mean (± SD) performance times (s) in the limited and warm clothing conditions.

Time Point	Limited Clothing	Warm Clothing	Difference	Effect Size (*d*)
RT	0.71 ± 0.06	0.69* ± 0.06	-0.02 ± 0.02	0.3
15m	8.12 ± 1.37	8.04* ± 1.39	-0.08 ± 0.07	0.1
25m	12.79 ± 1.46	12.70** ± 1.45	-0.09 ± 0.06	0.1
First 50m	29.63 ± 3.82	29.50** ± 3.80	-0.13 ± 0.10	0.03
Second 50m	33.36 ± 4.00	33.13* ± 3.94	-0.24 ± 0.26	0.1
100m	63.00 ± 7.75	62.63** ± 7.69	-0.37 ± 0.28	0.1

* Significantly quicker than limited clothing condition, $P<0.05$

** Significantly quicker than limited clothing condition, $P<0.01$

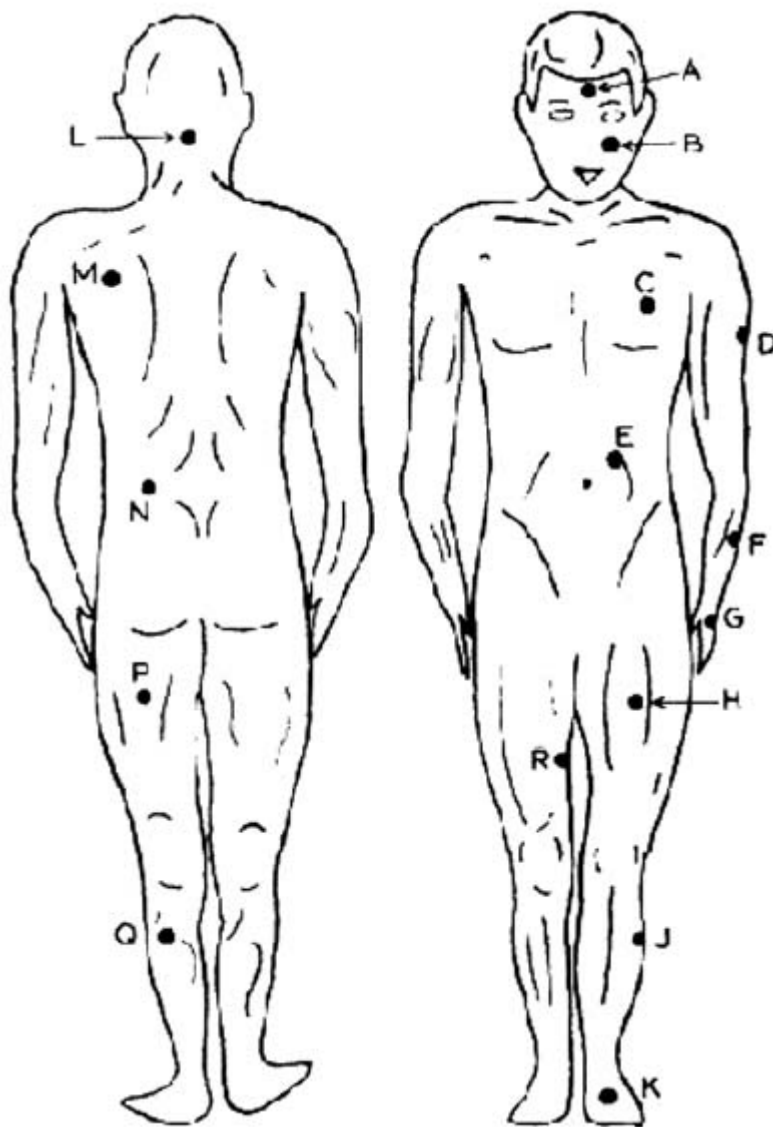**Figure 1. Winslow sites of skin temperature measurement.**

*Figure 2. Mean Ttympanic and Tskin across the four time points, during the warm and limited clothing conditions. Error bars are presented as ±SD. *Significantly (P < .01) higher than limited clothing condition.*