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Application of Therapeutic Hot and Cold Agents Result in Altered Measurement of Skinfold Thickness

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Abstract

Introduction: Accurate determination of body composition is crucial for athletic assessment and training. The International Society for the Advancement of Kinanthropometry suggest that skinfold measurements may be affected by conditions such as recent training, competition, saun, a swimming or showering, as heat may increase values due to an associated increase in blood flow; however this effect has not previously been demonstrated. Methods: This intervention trial, with crossover design, aimed to investigate the effect of modified skin surface temperatures following topical thermal applications on skinfold thickness at the bicep and tricep. Skinfold thickness (SF) and skin surface temperature pre- and post-application of a heated pad and cold gel pad was recorded in 54 young adults. Results: Heat application led to a small, but significant, reduction in tricep SF and no significant change in bicep SF, while cold application resulted in a small, but significant, increase in bicep SF but not tricep SF. These changes may be attributed to alterations in tissue extensibility and creep rate. Conclusions: This study indicates that topical application of heat or cold can influence skinfold measurement, highlighting the importance of standardising measurement conditions. However, further research is needed to clarify whether this is a biological effect or a technical error of measurement.

Keywords: Anthropometry, Skinfold thickness, Cryotherapy, Thermotherapy

Resumen

Introducción: La determinación precisa de la composición corporal es crucial para la evaluación y el entrenamiento atlético. La Sociedad Internacional para el Avance de la Cineantropometría sugiere que las mediciones de los pliegues cutáneos pueden verse afectadas por condiciones como el entrenamiento reciente, la competencia, la natación en sauna o la ducha, ya que el calor puede aumentar los valores debido a un aumento asociado en el flujo sanguíneo; sin embargo, este efecto no se ha demostrado previamente. Métodos: Este ensayo de intervención, con diseño cruzado, tuvo como objetivo investigar el efecto de las temperaturas superficiales de la piel modificadas después de aplicaciones térmicas tópicas en el grosor del pliegue cutáneo en el bíceps y el tríceps. Se registró el grosor del pliegue cutáneo (GF) y la temperatura de la superficie de la piel antes y después de la aplicación de una almohadilla térmica y una almohadilla de gel frío en 54 adultos jóvenes. Resultados: La aplicación de calor condujo a una reducción pequeña, pero significativa, en el GF del tríceps y ningún cambio significativo en el GF del bíceps, mientras que la aplicación de frío resultó en un aumento pequeño, pero significativo, en el GF del bíceps pero no en el GF del tríceps. Estos cambios pueden atribuirse a alteraciones en la extensibilidad del tejido y la velocidad de deslizamiento. Conclusiones: Este estudio indica que la aplicación tópica de calor o frío puede influir en la medición de los pliegues cutáneos, lo que resalta la importancia de estandarizar las condiciones de medición. Sin embargo, se necesitan más investigaciones para aclarar si se trata de un efecto biológico o de un error técnico de medición.

Palabras Clave: Antropometría, Grosor de los pliegues cutáneos, Crioterapia, Termoterapia

Introduction

Detailed determination of body composition is an important factor in athletic assessment and training programmes (Ackland et al. 2012), providing a valuable evaluation tool for personal improvements and training techniques (Toselli, 2021). Many gold standard techniques for determining body composition, such as hydrostatic weighing and dual-energy X-ray absorptiometry (DEXA) (Shim et al. 2014), are not commonly used within sports as athletes can be unwilling to take time away from intensive training to undergo laboratory based assessments (Ackland et al. 2012). Calipers measuring skinfold thickness, an indicator of subcutaneous fat, are commonly used for field based assessments in sport due to the portability, cost and reduced time, with results in close agreement to those obtained from gold standard techniques when undertaken by experienced anthropometrists (Shim et al. 2014). As these anthropometric measurements are typically measured at monthly or bimonthly intervals (Ackland, Elliot and Bloomfield, 2009), use of a standardised technique is crucial to determine subtle changes in body composition occurring over short time periods. This has been globally improved by the development of measurement protocols, initially published in the book 'Anthropometrica' (Norton & Olds, 1996), and subsequently corrected and improved in the International Society for the Advancement of Kinanthropometry (ISAK) publications 'The International Standards for Anthropometric Assessment' (ISAK, 2001; Marfell-Jones et al. 2006; Stewart et al. 2011; Esparza-Ros et al. 2019). Previous authors have cautioned against measuring skinfolds after training, competition, sauna (Esparza-Ros et al. 2019), swimming or showering (ISAK, 2001) or, according to Stewart et al. (2011), following exposure to heat due to suggestions that dehydration and the heat-induced hyperaemia to the area may influence skinfold thickness. Indeed, a previous edition of the anthropometric standards (ISAK, 2001) proposed that these conditions would increase skinfold thickness; however evidence to support this is limited.

Since many athletes are reluctant to sacrifice training time (Ackland et al. 2012), skinfold measurements are often undertaken during convenient periods such as immediately prior to, or post, exercise. As tissue temperatures fluctuate throughout athletic training sessions (Saltin & Hermansen, 1966) through influences such as warm up exercises to decrease muscle stiffness (Ackland et al. 2009) and post-training showers, tissue temperature is likely to be inconsistent during these opportune moments. Furthermore, the use of passive warm-up techniques preceding stretching has gained traction due to its observed enhancement of range of motion and performance (Racinais, Cocking & Périard, 2017). In contrast, an increase has also been seen in cold application methods (cryotherapy) such as water immersion and ice pack use before and after exercise, with studies reporting conflicting findings related to improvements in performance (Kalli & Fousekis, 2020). Additionally, both heat and cold application are used therapeutically as analgesia (Wang et al. 2021) and for increasing tissue repair rate (Nadler, Weingand and Kruse, 2004), and may therefore be used throughout athletic training sessions, particularly during half time and short spells on the sideline (Bleakley and Costello, 2013). This may coincide with anthropometric assessment opportunities, resulting in potential for skinfold sites to be subject to both internal and therapeutic thermal influences. As there is an increased likelihood of extremity injury in sports, thermal treatments are most commonly applied to the limbs, more specifically at joints such as the ankle, knee, shoulder and elbow (Jutte et al. 2012). Therefore, skinfold sites adjacent to these areas are the most likely to be subjected to thermal influences.

This study aimed to compare skinfold thickness at modified skin surface temperatures following topical thermal applications in a young adult population. It was hypothesised that there would be no significant effect of temperature application to skinfold measurements at the tricep or bicep.

Material and Methods

Participants

Physically active participants without existing skin conditions or a pacemaker were recruited on a voluntary basis via email and social media, including sport club groups. Institutional ethical approval was granted and all participants were informed of the study procedures and provided written consent. All participants were measured by a Level 1 ISAK accredited anthropometrist to ensure quality assurance occurred, with skinfolds not exceeding a 5% technical error of measurement (TEM). Participants were requested to refrain from physical activity and consumption of food, alcohol and caffeine for one hour prior to attendance due to their effects on core temperature and extremity blood flow (Kanlayanaphotporn & Janwantanakul, 2005; Franklin, Green and Cable, 1993). In addition, participants were required to rest indoors for a minimum of 30 minutes prior to measurements being taken to allow skin surface temperature to stabilize (Du et al. 2014). Baseline measures were taken prior to receiving heat and cold application. The order of heat application was not randomised due to evidence that cold application results in a longer period of intramuscular cooling, while surface and muscle temperature return to baseline temperature more rapidly following heat treatment (Bleakley and Costello, 2013; Mochlovitz, 1996).

Measure 1 Assessment

Skinfold landmarks and measurement of the bicep (SF_B) and tricep (SF_T) were made on the right arm in accordance with standard ISAK protocol (Esparza-Ros et al. 2019). Landmarks were left in situ upon identification by the anthropometrist and used for repeated measurements after each therapy application. All measurements were undertaken in duplicate using a segmometer (University of Western Australia, Crawley, Australia), a Lufkin W606PM anthropometric tape (Cooper Industries, Houston, Texas) and Harpenden® calipers (HSK-BI, British Indicators, West Sussex, UK). Where duplicate values were greater than 10% apart, a third measure was undertaken and the mean of the closest two measures used in further analysis. Skin surface temperatures of the tricep (T_T) and bicep (T_B) at the midpoint of the skinfold landmarks were recorded prior to skinfold measurement to the nearest 0.1°C using an infrared digital thermometer (IR – 380, Benetech, Palo Alto, CA, USA). Core temperature (T_C) was measured using an infrared ear thermometer (MST ST613, ProAct Medical, Northamptonshire, UK), also with an accuracy of 0.1°C. Room temperature remained at 18-21°C, measured and recorded with a calibrated room thermometer.

Heat Application and Assessment

A temperature controlled heat pad (HK55, Beurer, Ulm, Germany) was preheated for a minimum of 10 minutes to reach the peak temperature of setting 3. The heat pad was fastened to the upper arm as a cuff, ensuring skinfold sites were covered, and skin contact maintained for 15 minutes to achieve a constant temperature. This time frame was determined through equipment tests, as rate of change in skin surface temperature approached 0 (Kissinger, 1956) and agreed with results of previous studies on heat pad application and intramuscular temperature (Mochlovitz, 1996). All time frames were recorded using a digital timer. After heating, measurement of T_C was repeated, and participants proceeded to remove the heat pad from the skinfold sites in order for skin surface temperature to be recorded as previously described. Between duplicate measurements the cuff was replaced over the sites to minimise skin surface temperature heat loss. The cuff was removed from sites in the same manner to allow SF_T and SF_B to be repeated in duplicate. The heat pad was then fully removed and participants rested for 20 minutes to allow the skin to cool down significantly. This time frame was set based on equipment trials and results from previous studies (Draper and Ricard, 1995).

Cold Application and Assessment

T_C, T_T and T_B were determined prior to cold application. A reusable cold gel pad (Hypagel Q2291, AllSports Medical, London, UK) was removed from the freezer and inserted into an elasticated sleeve wrap (Hypagel Sleeve Wrap, AllSports Medical, London, UK). Equipment tests were inconclusive; previous studies using this cryotherapy mechanism have also reported problems with inconsistent cooling effects (Kennet et al. 2007). Bleakley & Hopkins (2010) reviewed the rate and magnitude of tissue temperature reduction with various cryotherapy modalities and confirmed that significant cooling of the skin surface temperature occurs within the first 5 minutes, and plateau's at approximately 10-15 minutes. For this reason, the ice gel pad wrap was applied for 10 minutes. Surface temperature and skinfolds were measured again, replacing the cold gel pad between recordings as described for the heat pad. To control for variability in temperature following cryotherapy application a cut-off temperature of 21.6°C was set; this figure was based on mean results from a cryotherapy study using a similar participant group and room temperature range, with a more reliable cooling technique (Uchio et al. 2003). Participants in the present study whose skin surface temperatures were not below this level were excluded from analysis. The site that did achieve a surface temperature of ≤21.6°C was included for analysis due to the localised effects of cryotherapy in practice (Meeusen and Lievens, 1986).

Data Analysis

Sample size was determined using Cohen's tables (1992), which identified 26 participants were required to detect a large effect of heat application, at a 0.80 confidence level when $p \leq 0.05$. TEM was used to determine anthropometric accuracy of each skinfold measure under each condition, with <5% taken as appropriate. Data distribution was determined using a one-sample Kolmogorov-Smirnov test. A paired samples t-test was used to determine differences in skinfold thickness measurements at measure 1 temperature and following heat and cryotherapy application, with statistical significance taken as $p \leq 0.05$. To determine the meaningfulness of statistical differences, Cohen's D effect sizes were calculated and interpreted with the following thresholds: 0.2, trivial; 0.6, small; 1.2, moderate; 2.0, large; 4.0, very large; ≥4.0, extremely large) (Hopkins et al. 2009). A Pearson's correlation was used to determine the relationship between skinfold thickness at measure 1, and change in SF_T and SF_B measurement following heat and cryotherapy application for both absolute and percentage change. Arbitrary correlation limits of r=0.0-0.19 very weak, 0.2-0.39 weak, 0.4-0.59 moderate, 0.6-0.79 strong and 0.8-1.0 very strong applied. All analysis occurred using R with Jamovi Interface (software version 2.3.19). Data presented as mean ± SD.

Results

Fifty-four physically active participants (33F, 21M; 21.7±1.9 years) completed the study, although data was discarded from 16 participants at the tricep (12M, 4F) and 7 participants at the bicep (5M, 2F) due to skin surface temperatures exceeding 21.6°C following cryotherapy application. This resulted in analysis being completed on all 54 participants for heat application, and 38 participants (9M, 29F; 21.7±2.1 years) for SF_T and 47 participants (16M, 31F; 21.8±2.0 years) for SF_B following cryotherapy application. Core temperature (36.01 ± 0.98°C) remained constant following heat and cryotherapy application.

Following heat application, a significant temperature increase was achieved versus measure 1 for both T_T (36.96±1.1°C, p<0.001, d=5.5) and T_B (37.36±1.18°C, p<0.001, d=5.4). Following the cool down period, mean T_T (31.43±1.57°C, p<0.001, d=1.6) and T_B (32.09±1.19°C, p<0.001, d=1.3) remained greater than measure 1 temperatures. Following cryotherapy application, T_T (14.1±4.29°C, p<0.001, d=5.4) and T_B (15.11±4.45°C, p<0.001, d=5.2) significantly cooled in those meeting the temperature cut off inclusion criteria.

Relative TEMs for skinfold measures ranged between 2.35% and 3.69% and were taken as appropriate (Table 1).

Table 1. Tricep and bicep skinfold absolute and relative technical error of measurement under different conditions

Measure 1			Heat Application		Cryotherapy Application	
	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)	Absolute TEM (mm)	Relative TEM (%)
SF_T	0.41	2.35	0.41	2.43	0.40	3.08
SF_B	0.24	3.22	0.25	3.39	0.27	3.69

SF_T = Tricep Skinfold; SF_B = Bicep Skinfold; TEM = Technical Error of Measurement

When compared to measure 1, following heat application there was a significant decrease in SF_T measure (p=0.005, d= 0.1, -2.4%) but not SF_B measure (p=0.785, d= 0.0, -0.66%). Following cryotherapy application there was no significant change in SF_T measure (p=0.2, d= 0.0, -1.3%), but there was a significant increase in SF_B (p=0.05, d= 0.1, 3.53%) (Table 2).

Table 2. Tricep and bicep skin temperature and skinfold thickness under different conditions

Measure 1				**Heat Application**			**Cryotherapy Application**		
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
SF_T (mm)	17.36	7.90	[15.2, 19.5]	16.94*	7.61	[14.9, 19.0]	18.25	7.1	[15.9, 20.6]
SF_B (mm)	7.52	4.11	[6.40, 8.64]	7.47	3.97	[6.39, 8.55]	8.21*	4.15	[6.94, 9.34]

*Note: Measure 1 refers to the initial measure; * denotes statistical significance.*

There was a correlation for all SF_T measures in absolute and percentage change terms compared to measure 1 under both heat and cryotherapy application, with a weak correlation reported under heat application and moderate correlation reported under cryotherapy application. A significant weak correlation was reported for SF_B compared to measure 1 under heat application in absolute terms only, with a very weak correlation reported for all other SF_B measures under both heat and cryotherapy application (Table 3).

Discussion

This is the first known study to examine the effect of modified skin surface temperatures following topical thermal applications on skinfold thickness in the upper arm. Contrary to the hypotheses of previous authors, exposure to heat did not cause an increase in skinfold measurements at the bicep and tricep sites. Instead, the present study suggests a small but significant reduction in tricep skinfold measurement following heat application, and a small but significant increase in bicep skinfold measurement following cold application. The demonstration of skin surface temperature directly affecting skinfold thickness within the upper arm is important in the ongoing refinement of anthropometric measurement protocols.

Table 3. Correlation Matrix for SF_T and SF_B Across Heat and Cold Application compared to Measure 1

	SF Thickness			
	Heat Application (mm)	**Heat Application (% Change)**	**Cryotherapy Application (mm)**	**Cryotherapy Application (% Change)**
SF_T Measure 1 (mm)	$r = 0.34$ $p = 0.01$*	$r = 0.30$ $p = 0.03$*	$r = 0.54$ $p < 0.001$*	$r = 0.45$ $p = 0.004$*
SF_B Measure 1 (mm)	$r = 0.27$ $p = 0.05$*	$r = 0.14$ $p = 0.30$	$r = 0.16$ $p = 0.30$	$r = 0.14$ $p = 0.33$

*Note: SF_T = Tricep Skinfold; SF_B = Bicep Skinfold; Measure 1 refers to the initial measure; SF refers to skinfold; Heat and Cold Application (mm) refers to the absolute change in SF from Measure 1; % change refers to the percentage change in SF thickness from measure 1; * denotes statistical significance*

Effect of Heat and Cold

Since recordings at the tricep decreased following application of the heat pad, contradicting the prediction by Stewart et al. (2011) that heat-induced hyperaemia would cause an increase in skinfold measurement, it is possible that temperature may have influenced a phenomenon known as 'creep rate' during measurements post heat application. Creep rate is the rate of deformation of viscoelastic materials upon pressure application, which continues finitely until a state of equilibrium has occurred (Shankman and Mankse, 2014), and in skinfold measurements this can be observed in the moving needle of the caliper dial upon application (Stewart et al. 2011). This effect is standardised in ISAK protocol by recording measurements two seconds after initial application of the caliper (Stewart et al. 2011); however temperature in the region of 37-40°C is known to increase creep rate (Shankman and Mankse, 2014). As mean skin surface temperature at both skinfold sites reached this range, and adipose tissue is viscoelastic (Geerligs et al. 2008; Sommer et al. 2013), the reduction in measurements following heat may result from an accelerated rate of compression leading to lower values being recorded at the two second interval. Since the reduction was significant only for SF_T, the larger skinfold site, this theory is supported, as greater adipose thickness is known to have a larger influence on compression (Stewart et al. 2011). This rationale is further upheld by results from a previous study on the effect of hydration on skinfold measurements (Norton et al. 2000). Skinfolds were compared pre- and post-exercise in a hydrated and dehydrated state, using a heated chamber to enhance fluid losses in the dehydration trial. Mean sum of seven skinfold sites decreased in both the hyperhydrated group (-2.8±4.5mm) and the hypohydrated group (-4.1±8.2mm). Although temperature was not discussed in Norton et al, it is reasonable to infer that tissue temperature was increased in both groups as exercise is known to generate heat (Ackland et al. 2009). A further temperature increase is likely in the group subjected to the heated chamber (40-45°C) (Du et al. 2014). This environmental temperature overlaps the range known to increase creep (Shankman & Manske, 2014), which could explain the greater reduction in skinfold thickness in those subjected to environmental heat. These findings lend support to the creep rate mechanism as a justification for the results observed in the present study. Although the decrease in the Norton et al. (2000) study was not significant, it is possible this was due to inadequate sample size (n=8) as no power or sample size calculation was determined (Bacchetti et al. 2005). Similarly, the lack of decrease observed in SF_B following cryotherapy application compared to measure 1 continues to align with the proposed creep mechanism, as creep rate decreases in cold tissues (Shankman & Manske, 2014). While this does not explain the increase observed in SF_B, this may be due to other factors such as technical errors.

This current study revealed a correlation between baseline measurements and subsequent changes (both absolute and percentage) following heat and cold applications in SF_T, and heat application in SF_B (absolute change only). This suggests that localised alterations in temperature exert an effect on skinfold measurements, and the magnitude of this effect may be modulated by the participant's subcutaneous fat levels. Individuals with higher baseline skinfold measurements exhibited more pronounced changes, although correlation coefficients were weak. As such, further investigation is warranted to comprehensively elucidate the impact of temperature on skinfold measures, with a larger sample size and a wider demographic range of baseline skinfolds.

The observed changes in skinfold measurements, although statistically significant, were small; -0.42mm at the tricep following thermotherapy, and +0.89mm at the bicep following cryotherapy. This prompts consideration of the practical importance of these observations, since skinfold measurements can be subject to various sources of error, including operator variability (Perini et al. 2005) and differences in skin elasticity (Gomes et al. 2020). However, in elite sport, sum of skinfolds is considered a more accurate and reliable outcome of body composition assessment

(Kasper et al. 2021) than conversion to % body fat. As such, the effects may be multiplied should similar changes be observed at other skinfold sites.

Reliability of measurements

In anthropometric measurement, variability may stem from biological change or technical errors (Perini et al. 2005). This study found changes during heat and cold exposure, with acceptable intra-observer reliability (Sicotte et al. 2010); mean TEM values were <5% in all groups. However, confirming biological change is crucial. Observationally, the anthropometrist noted skinfolds felt suppler following heat application in comparison to measure 1, allowing the double fold to be grasped and separated from underlying muscle with greater ease. However, increased challenges in the differentiation between muscle and fat during skinfold palpation and lift under the cold test conditions were experienced, and participants reported measurements were less comfortable. This may indicate physical changes within the tissue are responsible for the relationship observed, and may be attributable to changes in extensibility, defined as the ability of the skin to be extended away from the body until resistance is met (Remvig et al. 2009). Extensibility is known to increase with heat and decrease at low temperatures (Nadler, Weingand and Kruz, 2004). An altered grasp on the skinfold may have been obtained as a result, with a concomitant effect on the measurement. Ultrasound (US) technology for the measurement of subcutaneous adipose tissue, which does not involve pressure and tissue compression and is also not influenced by viscosity or elasticity of the tissue (Nösslinger et al. 2022), has been utilised since the 1960's (Bullen et al. 1965). Whilst skinfold calipers have the added advantage of portability, ease of use and relatively low cost, recent research has suggested US may be preferable compared to skinfold calipers, as it has greater precision (Hoffmann et al. 2022) and accuracy in a diverse athletic population (Gomes et al. 2020). Future research may wish to utilise US to confirm the biological effect of therapeutic hot and cold agents on subcutaneous fat.

Study Strengths and Limitations

Lehmann (1990, as cited by Draper, Castel & Castel, 1995) suggested mild, moderate and vigorous heating is achieved when tissue temperature increases by at least 1.0°C, 2°C to 3°C, 4°C+ respectively. Therefore, together with the significant alteration in skin surface temperature at both treatment sites shows modification of skin surface temperature was successfully achieved using heat and cold application enabling determination of the effect of temperature upon tissues. Higher temperatures were observed at both sites following heat application and 20 minutes post-cooling versus the baseline temperature, suggesting the cool down period was insufficient.

Due to residual heat from the heated pad, conduction of heat from participants' skin and the inability of cold gel pads to undergo phase change (Sunitha, 2010; Kennet et al. 2007), the cold gel pad was not a constant temperature throughout application (Sunitha, 2010). Participants with a higher skin temperature prior to cryotherapy application therefore had an accelerated rate of conduction caused by the increased temperature gradient; use of an alternative cryotherapy method with the ability to undergo phase change, such as crushed ice, would reduce this effect in future studies. However, it should be noted that the study methodology was representative of normal cryotherapy application in sport settings. Future studies should investigate the effects of cold in isolation to heat to prevent residual heat influencing results.

In a review of body composition methods in sports practice, Kasper (2021) reports that skinfold measurements are more accurate when taken by experienced anthropometrists, such as those trained in the ISAK protocol. To support increased accuracy and reproducibility of the results, with no potential for inter-measurer error, data were collected by a single level 1 ISAK accredited anthropometrist in the current study. Additionally, whilst Esparza-Ros (2022) identified four different skinfold calipers to be valid, but not interchangeable, an earlier study by Shim et al. (2014) noted that use of Harpenden® and Holtain® calipers produced greater inter-rater reliability when compared to Lange® calipers. Cintra-Andrade et al. (2023) acknowledges that the Harpenden® skinfold caliper is accepted as the main tool within the international academic community, and therefore, in the present study, Harpenden® calipers were utilised. Additionally, the retention of landmarks across all measurements is likely to have improved the reliability of the results; inconsistent identification of landmarks by anthropometrists has been shown to cause a 2-3mm mean variation in skinfold thickness (Ruiz, Colley and Hamilton, 1971).

Whilst the narrow age range of participants may be considered a limitation, the young adult population recruited for the present study reduces the risk of results being influenced by age related changes known in many of the mechanisms discussed, and may be considered the most likely population group to be participating in elite sport where cryotherapy and thermotherapy are utilised. Additionally, Sugihara et al. (1991) found that maturity of collagen fibres with age causes an increase in skin extensibility, Mattar (2011) concluded that vasoconstrictive responses in blood flow are decreased in older subjects, and Durnin and Womersley (1974) suggest skinfold compressibility reduces with age. Future research may wish to explore whether the current findings are reproduced in other population groups.

Conclusion

This study found that temperature has an effect on skinfold measurements in a young adult population, although results show that the direction of change is contradictory to that described in the International Standards for Anthropometric Assessment (Stewart et al. 2011). This may be attributable to an increased rate of compression caused by the influence of heat on creep rate, although other factors including tissue extensibility may contribute. When regular anthropometric assessment is used to determine changes in body composition and assess training programmes, anthropometrists should ensure measurements are taken when skin surface temperature is expected to be relatively constant, and refrain from measuring skinfold thickness following topical application of heat or cold. Future studies should confirm the biological changes observed in this study utilising US technology, and further research may wish to explore the effect at alternative skinfold sites, and in different populations.

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Full access to data on request.

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The Authors have no conflict of interest to declare.

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All the participants included in the study provided written informed consent.

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