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HANDSTAND ON PARALLEL BARS: TEMPERATURE DIFFERENCES OF PALMS AFTER STATIC AND DYNAMIC LOAD

STOJA NA ROKAH NA BRADLJI: RAZLIKE V TEMPERATURI DLANI PO STATIČNI IN DINAMIČNI OBREMENITVI

ABSTRACT

The temperature of palms and their differences after different loading have not been well studied. Our research question was how palm temperature differs in human hands after different 30-second loads (handstand and swinging in handstand) on low parallel bars. A high-quality thermal imaging camera was used to measure 38 students from the University of Ljubljana, Faculty of sport. Palm temperatures were measured before the load was applied, immediately after load and every 30 seconds for a period of 5 minutes after the load. Each hand was divided into 9 different Regions of Interest (ROIs). Mean (XA), standard deviation (SD), maximum and minimum, and number of pixels were calculated. According to our results, there was no difference between the left and right hands. The temperature immediately after loading decreased significantly in both loads and then increased above the level as before loading. After static loading, the temperature decrease is smaller and then increases faster than after dynamic loading. For both loads, the temperature is higher 5 minutes after the load than before the load. We need to further investigation how long it takes for the hand temperature to reach the pre-load temperature.

Keywords: palm temperature, thermal imaging, handstand, swing in handstand, parallel bars

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IZVLEČEK

Temperature dlani in njihove razlike po različnih obremenitvah niso dobro raziskane. Naše raziskovalno vprašanje je bilo, kako se razlikuje temperatura dlani v človeških rokah po različnih 30 sekundnih obremenitvah (stoji na rokah in kolebih v stoji na rokah) na nizki bradlji. S kakovostno termovizijsko kamero smo izmerili 38 študentov Fakultete za šport Univerze v Ljubljani. Temperature dlani so bile izmerjene pred obremenitvijo, takoj po obremenitvi in vsakih 30 sekund v obdobju 5 minut po obremenitvi. Vsaka dlan je bila razdeljena na 9 različnih območij zanimanja (ROI). Izračunani so bili povprečje (XA), standardni odklon (SD), maksimum in minimum ter število slikovnih pik. Glede na naše rezultate ni bilo razlike med levo in desno roko. Temperatura takoj po obremenitvi se je pri obeh obremenitvah bistveno znižala in nato narasla nad nivo kot pred obremenitvijo. Po statični obremenitvi je padec temperature manjši in nato narašča hitreje kot po dinamični obremenitvi. Pri obeh obremenitvah je temperatura 5 minut po obremenitvi še vedno višja kot pred obremenitvijo. Nadaljnje raziskave so potrebne, da bi ugotovili, kako dolgo traja, da temperatura dlani doseže temperaturo pred obremenitvijo.

Ključne besede: temperature dlani, slikanje s termokamero, stoja na rokah, koleb v stoji na rokah, bradlja

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INTRODUCTION

The oldest organized sport is gymnastics and handstand is one of the basic and most essential gymnastics skills. It requires extraordinary muscular activity and strength of the upper extremities, the activity of which has an antigravity function. It is included in routines of artistic gymnastics repeatedly, therefore requires an extraordinary level of strength abilities of the upper body. Balancing in this inverted position is a complex process based on physical and physiological principles. Handstands are performed on various apparatuses with larger (e.g. floor) and smaller (e.g. parallel bars) support surfaces, whose stability and mechanical properties influence the difficulty of balance. If the centre of gravity is already out of the support base due to a small deflection, the difficulty of a handstand increases (Gautier et al. 2009; Hedbávný, Sklena, et al. 2013; Hedbávný, Bago, and Kalichová 2013; Kochanowicz et al. 2015, 2019; Omorczyk et al. 2018; Rohleder and Vogt 2018). Such performances require specific muscle activation, which varies according to the gymnast's experience and condition. To improve and develop the handstand, gymnasts must move to apparatus that requires a hand grip, such as the parallel bars. Consequently, the support surface is still stable, while the strategy to maintain the handstand can cause a change in the position of the wrist (Kochanowicz et al. 2019). It is well known that for a well-balanced handstand, the execution of wrist and shoulder moments is essential (Kerwin and Trewartha 2001; Mohammadi 2016; Rohleder and Vogt 2018; Yeadon and Trewartha 2003). Discomfort and subsequent skin injuries may be caused by repetitive loads and friction, which have an effect on the increase in temperature (Zhang and Mak 1999). When injured, thicker skin requires greater friction and longer duration of exposure, while thinner skin is more likely to blister or be injured (Sulzberger M. B. et al. 1966). Skin injuries occur on artistic gymnastics apparatus, where the gymnasts' palms are exposed to frictional forces that, in combination with pressure, can cause shear forces on the skin that affect blood circulation (Pušnik, Čuk, and Hadžič 2017; Zhang and Roberts 1993; Zhang, Turner-Smith, and Roberts 1994), or more accurately, the microcirculation. Anatomical and microstructural differences between the palmar and dorsal sides were found in studies of the microcirculation on both sides (Gulyaev et al. 1995; Sangiorgi et al. 2004).

The movement of the hand consists of two basic patterns called precision grip and power grip. In the field of sports, there is a whole range of activities in which the hands form a power grip, and disciplines in which the body hangs (artistic gymnastics, sport climbing, fitness, crossfit, etc.). Most of these disciplines and activities take place in a room temperature environment, but there is a lack of data on how palm loading directly affects the palm and hand. In power grip, the main force is applied by the extrinsic muscles, which therefore play a key role in the movement (Napier 1956).

Infrared thermal imaging has become accepted as a non-destructive testing method and is increasingly used in various areas of research and industry (Qu, Jiang, and Zhang 2020). Human health is strongly correlated with body and tissue temperature, which is within a narrowly defined range in healthy individuals under standardised environmental conditions, so deviations may indicate pathological processes, physical abnormalities, or defects (Kesztyüs, Brucher, and Kesztyüs 2022). Especially in sports and exercise science, thermography is used extensively as a tool to promote human health, evaluate athletic performance, examine exercise-induced superficial vascular changes, monitor injuries, and attempt to develop optimal training and results (Gómez-Carmona et al. 2020; Gulyaev et al. 1995; Hildebrandt, Raschner, and Ammer 2010; Kasprzyk-Kucewicz et al. 2020; Kwon et al. 2010; Martínez-Nova et al. 2021; Perpetuini et al. 2021; Sousa et al. 2017; Zontak et al. 1998).

The differences in palm temperature were compared when performing simple elements on uneven bars with and without the use of magnesium carbonate (Pušnik and Čuk 2014). The temperature remained constant without the use of magnesium carbonate, while the temperature of the palm increased with the use of magnesium carbonate. The short-term effects of loading on palm temperature for different forms of gymnastic rings were compared (Pušnik et al. 2017), and depending on the different shapes of the rings, statistical differences were found in the decrease of palm temperature after loading. The differences in palm temperature after static and dynamic loading were studied (Šibanc et al. 2021) and discovered that the temperature decreased significantly immediately after the load was applied for both loads and then increased above the level before the load was applied. After the static load, the temperature reached a consistently higher level after 3 minutes, while temperatures continued to rise after the dynamic load throughout the measurement period.

Few studies were found that focused on hand temperature: when applying pressure or load to the palms or handling objects at room temperature in a given time frame (Bennett, Goubran, and Knoefel 2015), the effect of cooling the hand on fatigue during high-intensity bench press (Kwon et al. 2010), the response of skin temperature to exercise (Zontak et al. 1998) and generally discovered an initial cooling of the hand immediately after loading. resulting to a constant decrease in finger temperature followed by rewarming of the hands, reflecting the dominance and balance of thermoregulatory reflexes and hemodynamics in the later phase of exercise. To reduce swelling and inflammation, local cooling was used in rehabilitation or between intense exercise sessions.

Under thermoneutral conditions, the temperature dynamics of the surface of the human body at rest is determined mainly by peripheral blood flow. This is controlled by the extent of vasoconstriction, which in turn is almost entirely controlled by the sympathetic nervous system (Hall and Guyton 2016). However during a long swing on rings, blanching of the skin after the application of pressure is a well-known phenomenon (Pušnik et al. 2017), although the associated changes in skin temperature have not been well studied.

The thermograms in recent research (Pušnik et al. 2017; Šibanc et al. 2021) showed a different temperature distribution in the area of the hands, so we focused on more regions of interest (ROI) depending on the load. Healthy skin temperatures should be considered symmetrically distributed (Mercer and De Weerd 2014), also a study measuring palm temperatures after hang (Šibanc et al. 2021) showed no asymmetries between the left and right hands after the load was applied. However, there are proven asymmetries in gymnastics (Čuk and Marinšek 2013; Pajek et al. 2016) and a study that showed a left-right asymmetry of hand temperature after cold stress (Sundqvist 2017). From the above studies (Bouzida, Bendada, and Maldague 2009; Gulyaev et al. 1995; Hildebrandt et al. 2010; Lahiri et al. 2012; Pušnik et al. 2017; Šibanc et al. 2021), it was found that the differences in the temperature of the skin of the palm during the formation of a grip during the execution after the loads and different amplitude of these loads were very different.

The recovery phase of temperature is not well studied. In the research of Gulyaev et al (Gulyaev et al. 1995) temperatures returned to the pre-occlusion level after 2-3 minutes. The time period chosen for our measurement was 5 min, although the study by Bennett et al (Bennett et al. 2015) showed some different patterns after a 10-minute recovery period. The aim of this study was to observe what happens to palm temperature after static (handstand) and dynamic loads (swinging in handstand, referred to as "swing" in the following text) in an inverted position when the whole body is above the grip point. Determined load for measurements was 30 seconds, which is an average for routines on uneven bars, rings, pommel horse, parallel bars and high bar, that usually last between 20 and 50 seconds (Aarkaev and Suchilin 2004).

METHODS

In gymnastics hall at the University of Ljubljana, Faculty of Sport of the 38 healthy subjects (27 women and 11 men; students of Faculty of Sport), who volunteered to participate in the study and all attended classes and lectures of artistic gymnastics at university. They were 22.1 years (±2.9) old, 1.73 m (±0.10) tall, and had a body weight of 72.2 kg (±12.5). Ethical approval was obtained from the Ethics Committee of the Faculty of Sport, University of Ljubljana (12_2018). The Declaration of Helsinki was followed. All included subjects provided written informed consent and were familiar with handstands from previous lectures. They were in the hall for acclimatization 15 minutes before the start of the first measurement. They were asked not to drink alcohol or smoke for 24 h, not to consume caffeine for 12 h, and not to use creams or lotions on their hands for 12 h before the measurements (Fernández-Cuevas et al. 2015). The skin on their hands was not allowed to be visibly damaged.

The measurement protocol was developed and adapted according to our hypotheses:

1. The temperature of the palms decreases after the static load in handstand.
2. The temperature of the palms increases after the dynamic load in swing during the handstand.

We measured the hand temperature of the subjects on the palmar side. Thermal images were taken before loading, immediately after loading, and then for 5 min (indicated as "300 s" in the following tables) at 30-s intervals (12 thermograms per subject per loading). Each load lasted for 30 s. During thermal imaging, the subject was seated with hands resting on the table with fingers at approximately the level of the heart and on an additional insulating surface to prevent heat loss into the table. Subjects performed two tasks on low parallel bars (wooden surface, vertical axis of the profile 5 cm ± 0.1 cm; horizontal axis of the profile 4 cm ± 0.1 cm (Federation Internationale de Gymnastique 2022)). For the first load, students performed a handstand for 30 s while leaning on a wall behind them, as shown in Figure 1a. The support provided by the wall in the handstand allowed subjects to remain still without additional compensatory movements for keeping balance. In the second load, the students swung back and forth in the handstand for 30 seconds while being spotted by two other students (see Figure 1b). The angle of the swing was approximately 15-20°, and subjects required additional force to maintain balance and swing.

Figure 1. (a) Handstand, (b) Swing in Handstand.

(a) *(b)*

Subjects were randomly and equally assigned for task order. The cylindrical power grip was used for both tasks. The measurements took place in the gymnastics hall of the Faculty of Sport of the University of Ljubljana. The temperature in the hall was 23 °C and the relative humidity was 40%. 15 minutes before the start of the first measurement of thermal images, all subjects were in the hall for acclimatization. They were asked not to use creams or lotions on their hands for 12 hours, not to consume caffeine for 12 hours, and not to smoke or drink alcohol for 24 hours prior to the measurements (Fernández-Cuevas et al. 2015). The skin on their hands was not visibly damaged.

A high-quality thermal imaging camera (FLIR T650sc FLIR Systems, Oregon, USA) was used for the study. The camera has a 45° wide-angle lens (f = 13.1 mm) with a field of view (FOV) of 45° × 34°, a continuous zoom (8×), a minimum focus distance of 15 cm, and a spatial resolution of 1.23 mrad (IFOV). The emissivity can be adjusted in steps of 0.01 from 0.10 to 1.00. The camera was calibrated prior to research measurements at the LMK Laboratory for Metrology and Quality at the Faculty of Electrical Engineering, University of Ljubljana (LMK is the holder of the Slovenian National Standard for Thermodynamic Temperature. As a national laboratory for temperature and relative humidity and an accredited calibration laboratory, it has CMCs calibration measurement capabilities that are among the best in Europe and the world in the respective measurement ranges, which confirms its accuracy). The resolution of the camera is 640 × 480 pixels, which corresponds to 307,200 pixels of temperatures in a single thermogram. This high resolution is important for a comprehensive analysis of the selected ROIs (Perić et al. 2019). The detector type was an uncooled microbolometer with the FPA operating in the spectral range of 7.5 µm to 14 µm, a specified accuracy of ±1% of reading or 1 °C in the temperature range of 5 °C to 120 °C, at ambient temperatures of 10 °C to 35 °C, and a noise-equivalent temperature difference NETD < 30 mK. Measurements were corrected for reflected temperature, optics transmission, atmospheric transmission, and external optics. Image analysis in the associated software environment (ResearchIR Max from (FLIR Systems, Oregon, USA) allowed the analysis of various ROIs, e.g., spots, areas, automatic detection of hot/cold spots, temperature differences, isotherms, line profiles, alarms, temporal temperature dependency, etc.

Each hand was divided into nine ROIs (polygons) using the ResearchIR application, as shown in Figure 2: palm, thumb, index finger proximal phalanx, index finger distal phalanges, middle finger proximal phalanx, middle finger distal phalanges, ring finger proximal phalanx, ring finger distal phalanges and little finger. The boundary of ROI must be at least 7 pixels away from the edge of the observed surface to avoid the influence of the size-of-source effect (Pušnik and Geršak 2021). The ROIs from Figure 2 are also shown in Table 1, again with the abbreviations used in the following text for each ROI. Polygons 1-9 represent the right hand and polygons 11-19 represent the left hand.

Figure 2. ROIs on hands.

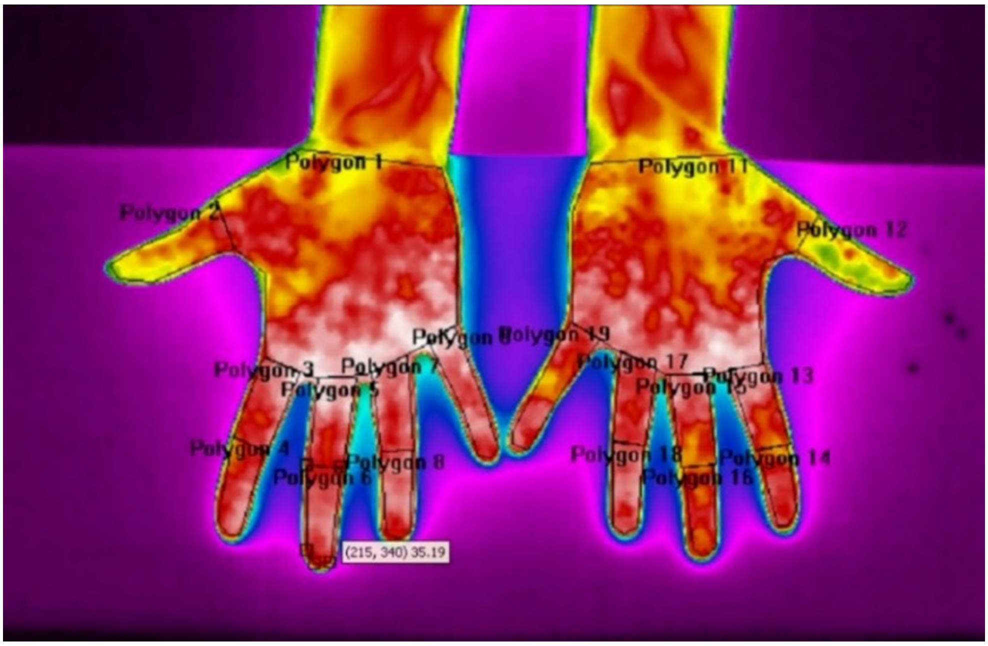

Table 1. ROIs on each hand.

Hand	Polygon	ROI	abbreviation
Right Hand	Polygon 1	Palm	P-R
	Polygon 2	Thumb	T-R
	Polygon 3	Index Finger Proximal Phalanx	IPP-R
	Polygon 4	Index Finger Distal Phalanges	IDP-R
	Polygon 5	Middle Finger Proximal Phalanx	MPP-R
	Polygon 6	Middle Finger Distal Phalanges	MDP-R
	Polygon 7	Ring Finger Proximal Phalanx	RPP-R
	Polygon 8	Ring Finger Distal Phalanges	RDP-R
	Polygon 9	Little Finger	LF-R
Left Hand	Polygon 11	Palm	P-L
	Polygon 12	Thumb	T-L
	Polygon 13	Index Finger Proximal Phalanx	IPP-L
	Polygon 14	Index Finger Distal Phalanges	IDP-L
	Polygon 15	Middle Finger Proximal Phalanx	MPP-L
	Polygon 16	Middle Finger Distal Phalanges	MDP-L
	Polygon 17	Ring Finger Proximal Phalanx	RPP-L
	Polygon 18	Ring Finger Distal Phalanges	RDP-L
	Polygon 19	Little Finger	LF-L

From ResearchIR, data for each ROI were exported to Excel for Windows 10 (Microsoft corp.): Mean (XA), standard deviation (SD), maximum and minimum, number of pixels. We calculated the sum of the temperature differences of the section before the task until the end of the 5th minute using the formula $\Sigma(Tn-Tn+1)$; and the temperature differences from the first to the last measurement using the formula $T1-Tn+1$, where n represents the time series.

Statistical analyses were performed in SPSS 25.0 (IBM corp.): Kolmogorov-Smirnov test, means (XA), standard deviations (SD), standard errors (SE), for each sector variable. A paired Student's t-test and Spearman-Brown rank correlation (to determine the reliability of the measurement) were calculated to compare the temperature difference between support and swing, to compare the temperature difference between left and right sectors, and to compare the temperature difference between time series in each task. Excel software was used to generate the figures and graphs.

RESULTS

The Kolmogorov-Smirnov test did not show normal distribution for the variables. As expected and found in other studies, no significant difference was found between men and women. The results in our study are presented for the left hand because there were no significant differences between the left and right hands.

Table 2 shows the temperature difference immediately after load application for handstand and swing and 300 seconds after load application. Immediately after load application, all values decrease for all ROIs, for both loads. For all ROIs, the decrease is greater after swing than after handstand. Immediately after load application, the difference between static and dynamic load is greatest for the little finger, while it is least for the palm. The greatest decrease in temperature after loading was for the little finger after the swing (2.99 °C) and the least decrease was for the proximal phalanx of the middle finger after the handstand (2.04 °C). There were no statistical differences between static and dynamic loading immediately after load application, nor 5 minutes after load application. At 5 minutes after load application, the temperatures increased above the initial value. Except for the palm, where there is no difference between the temperatures after static and dynamic loading, the temperatures after handstand are higher than after swing. The greatest difference between handstand and swing is in the distal phalanges of the middle finger, which (along with the distal phalanges of the index and ring fingers) also have the highest temperature increase at 5 minutes after handstand. The lowest increase after 5 minutes is for the proximal phalanges of the index, middle, and ring fingers after the swing

Table 3 shows the significant differences in temperature by time and region before and after load application for 30 seconds each in a 5-minute period, with $p < 0.05$ indicating a significant difference in temperature by a paired t-test. After the handstand, there is a significant difference for the proximal phalanges of the middle and ring fingers up to 240 s, and for the proximal phalanx of the index finger up to 210 s, while for all other ROIs the significant difference persists up to 150 s after load application. After swinging, the temperatures for the proximal phalanges of the middle and ring fingers are significantly different even after 240 s after load application, while for all other ROIs the temperatures are significantly different after 210 s after dynamic load application.

Table 4 shows the temperature differences between handstand and swing, where the values given indicate a difference by t-test ($p < 0.05$). For the palm, the only significant temperature difference is 30 s after load application. The temperatures of the distal phalanges of the middle finger are significantly different for the longest time, 150 s after the application of the load. The proximal phalanges of the index and middle fingers are significantly different for a shorter time than the distal phalanges of the same fingers. All phalanges of the ring finger differ significantly only 30 and 60 seconds after load application. The palm, distal phalanges of the index finger, and all phalanges of the ring finger do not differ significantly immediately after load application.

Table 2. Temperature difference for handstand and swing immediately after load ($XA0_{HA}$-$XA0_{SW}$) and after 300 seconds ($XA300_{HA}$-$XA300_{SW}$) for left hand by ROI.

Variable	**XA0/°C**	**$XA0_{HA}$-$XA0_{SW}$ /°C**	**p(ttest) 0/°C**	**XA300/°C**	**$XA300_{HA}$-$XA300_{SW}$ /°C**	**p(ttest) 300/°C**
Handstand P[a]-L	-2.07	-0.20	0.491	0.34	0	0.685
Swing P[a]-L	-2.27			0.34		
Handstand T[b]-L	-2.02	-0.30	0.911	0.46	-0.13	0.689
Swing T[b]-L	-2.32			0.33		
Handstand IPP[c]-L	-2.18	-0.31	0.597	0.31	-0.2	0.938
Swing IPP[c]-L	-2.49			0.11		
Handstand IDP[d]-L	-2.36	-0.32	0.715	0.52	-0.26	0.584
Swing IDP[d]-L	-2.68			0.26		
Handstand MPP[e]-L	-2.04	-0.27	0.849	0.33	-0.19	0.981
Swing MPP[e]-L	-2.31			0.14		
Handstand MDP[f]-L	-2.30	-0.36	0.759	0.61	-0.35	0.699
Swing MDP[f]-L	-2.66			0.26		
Handstand RPP[g]-L	-2.09	-0.27	0.653	0.34	-0.13	0.964
Swing RPP[g]-L	-2.36			0.21		
Handstand RDP[h]-L	-2.68	-0.27	0.990	0.54	-0.17	0.770
Swing RDP[h]-L	-2.95			0.37		
Handstand LF[i]-L	-2.58	-0.41	0.704	0.43	-0.13	0.672
Swing LF[i]-L	-2.99			0.30		

Note: [a] P = Palm; [b] T = Thumb; [c] IPP = Index finger proximal phalanx; [d] IDP = Index finger distal phalanges; [e] MPP = Medial finger proximal phalanx; [f] MDP = Medial finger distal phalanges; [g] RPP = Ring finger proximal phalanx; [h] RDP = Ring finger distal phalanges; [i] LF = Little finger. XA0= sum temperature difference right after applying load, XA300 = sum temperature 300 seconds after applying load.

Table 3**.** Differences based on t-test in temperature by time and region for support and swing for the left hand.

Variable	**−30 / s**	**0 / s**	**30 / s**	**60 / s**	**90 / s**	**120 / s**	**150 / s**	**180 / s**	**210 / s**	**240 / s**	**270 / s**	**300 / s**
Handstand P[a]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.129	0.164	0.157	0.391	0.401
Swing P[a]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.294	0.465	0.255
Handstand T[b]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.005**	0.073	0.182	0.094	0.146	0.335
Swing T[b]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.036**	**0.001**	0.781	0.131	0.092
Handstand IPP[c]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.008**	0.120	0.044	0.491
Swing IPP[c]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	0.208	0.151	0.094
Handstand IDP[d]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	0.193	0.107	0.167	0.034	0.064
Swing IDP[d]-L		**0.000**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.009**	**0.012**	0.782	0.232	0.320
Handstand MPP[e]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.012**	**0.008**	0.139	0.386
Swing MPP[e]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.030**	0.026	0.102
Handstand MDP[f]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	0.096	0.110	0.119	0.089	0.224
Swing MDP[f]-L		**0.000**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.014**	0.852	0.098	0.371
Handstand RPP[g]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.007**	**0.013**	0.636	0.140
Swing RPP[g]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.018**	0.019	0.574
Handstand RDP[h]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.015**	0.312	0.103	0.347	0.150	0.391
Swing RDP[h]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.013**	**0.003**	0.470	0.446	0.434
Handstand LF[i]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.010**	0.623	0.100	0.276	0.249	0.237
Swing LF[i]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.083	**0.000**	0.583	0.685	0.367

Note: [a] P = Palm; [b] T = Thumb; [c] IPP = Index finger proximal phalanx; [d] IDP = Index finger distal phalanges; [e] MPP = Medial finger proximal phalanx; [f] MDP = Medial finger distal phalanges; [g] RPP = Ring finger proximal phalanx; [h] RDP = Ring finger distal phalanges; [i] LF = Little finger.

Table 4. Differences based on ttest between the handstand and swing time series (where stated values indicates difference by t-test ($p < 0.05$)) for left hand.

Variables	**−30 / s**	**0 / s**	**30 / s**	**60 / s**	**90 / s**	**120 / s**	**150 / s**	**180 / s**	**210 / s**	**240 / s**	**270 / s**	**300 / s**
P[a]-L		0.128	**0.008**	0.064	0.172	0.124	0.196	0.426	0.807	0.760	0.706	0.934
T[b]-L		**0.026**	**0.003**	**0.004**	**0.046**	**0.044**	0.142	0.221	0.527	0.329	0.290	0.653
IPP[c]-L		**0.025**	**0.006**	**0.004**	**0.035**	0.058	0.112	0.180	0.312	0.254	0.122	0.382
IDP[d]-L		0.070	**0.007**	**0.003**	**0.032**	**0.031**	0.074	0.146	0.228	0.167	0.126	0.397
MPP[e]-L		**0.049**	**0.001**	**0.002**	**0.044**	**0.040**	0.061	0.099	0.183	0.175	0.242	0.264
MDP[f]-L		**0.044**	**0.003**	**0.003**	**0.026**	**0.019**	**0.033**	0.075	0.149	0.091	0.074	0.249
RPP[g]-L		0.060	**0.003**	**0.007**	0.076	0.074	0.087	0.200	0.336	0.400	0.693	0.510
RDP[h]-L		0.167	**0.021**	**0.017**	0.089	0.048	0.122	0.234	0.409	0.453	0.378	0.618
LF[i]-L		**0.030**	**0.003**	**0.003**	**0.041**	**0.034**	0.116	0.183	0.471	0.459	0.419	0.705

Note: [a] P = Palm; [b] T = Thumb; [c] IPP = Index finger proximal phalanx; [d] IDP = Index finger distal phalanges; [e] MPP = Medial finger proximal phalanx; [f] MDP = Medial finger distal phalanges; [g] RPP = Ring finger proximal phalanx; [h] RDP = Ring finger distal phalanges; [i] LF = Little finger.

Figure 3 shows the mean temperature differences of all measured subjects for handstand and swing for the left and right hands for all measured ROIs in the hands. The two graphs on the left side of the figure show the temperature differences for support and the graphs on the right side of the figure show the temperature differences for swings. The top two diagrams show the left hand, while the bottom two diagrams show the right hand. There were only slight differences between the left and right hands for both loads, while the significant difference between the loads can be seen in Figures 3 and 4, although Table 2 showed no significant differences immediately after the load and 5 minutes later. For all ROIs, the temperature was higher 300 seconds after loading than before loading. The palm temperature begins to rise faster than the other ROIs for both loads, although this is much more evident after swinging. As can be seen in Table 2, temperatures in the distal phalanges of the little finger and ring finger decrease the most immediately after loading, and the temperature decrease after swinging is greater than after handstand. For all ROIs, the temperature increases to the initial value faster after the handstand than after the swing, and at 300 s after the handstand, the values are higher than after the swing.

Figure 3. Temperature difference for right and left hand during support and swings.

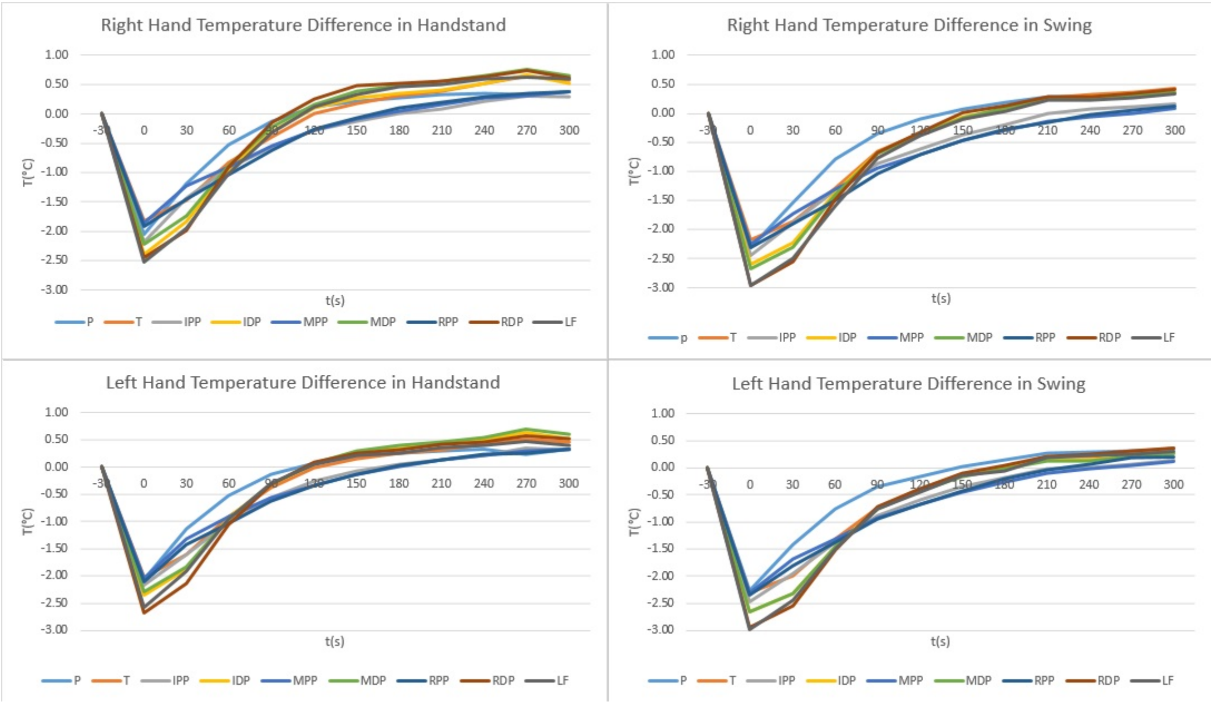

Figure 4 shows the temperature difference between support and swing for each DOI separately. The graphs on the left side of the figure show the temperature values for the palm and all three proximal phalanges; the graphs on the right side show the values for the thumb, all three distal phalanges, and the little finger. The values for the index, middle and ring fingers are in the same row for each finger. For the palm, there was no significant difference between support and swing except at 30 s (see also Table 3), and the difference is also small and short for all phalanges of the ring finger. For the distal phalanges of the middle and ring fingers, the temperature difference between supports and swings was larger than for the proximal phalanges, and similar differences exist for the little finger. As can be seen from the curves, the thumb, distal phalanges and little finger respond similarly, while the palm and proximal phalanges of the index, middle and ring fingers respond similarly according to the temperature distribution 5 minutes after applying different loads.

Figure 4. Temperature difference of the left hand in support and swing for different ROIs.

DISCUSSION

The temperature distribution and difference between the left and right hands before and after exercise appeared to be symmetrical in our study. This was also evident in a study in which temperatures were measured after hanging, and in a study in which healthy subjects were measured in a static position, hand temperature was symmetrical (Pauk, Wasilewska, and Ihnatouski 2019). There were studies in artistic gymnastics that showed asymmetries (Čuk and Marinšek 2013; Dallas et al. 2022; Pajek et al. 2016), but the loads considered in this study were symmetrical (e.g., no rotations about the longitudinal or transverse axis, standing on one hand, etc.). Studies of hand temperatures after hanging on the high bar (Šibanc et al. 2021) showed similar results - after loading, possible body asymmetries did not affect temperature differences on the hands.

Table 2, Figures 3 and 4 show significant temperature decrease immediately after both load applications, similar to a research after hang (Šibanc et al. 2021). Immediately after loading, the temperature decrease after dynamic loading is greater than after static loading, while after 5 minutes the temperatures after static loading are higher than after dynamic loading. The largest temperature decrease after loading for the little finger after the swing makes sense – it was shown (Kochanowicz et al. 2019) that during the handstand on the parallel bar, the torque is generated during abduction and adduction movements around the sagittal axis, the parallel bar forces a specific handgrip that shows a more balanced EMG signal of the wrist flexors and extensors. When swinging in the handstand, the centre of gravity moves backward and forward, and in the author's personal experience, the forward movement places the most stress on the little finger to maintain balance. The smallest temperature difference between the loads is at the palm, where the compressive force is similar for static and dynamic loading (see also Table 4). According to Table 3, the proximal phalanges of the middle and ring fingers play an important role in maintaining balance during both loads, more clearly after the handstand than during the other ROIs. After the handstand, the temperature differences are significant for a shorter time than after the swing (except for the proximal phalanges of the middle and ring fingers), whereas after the swing, all ROIs show a significant temperature difference from 210 to 240 seconds after the application of the load.

According to Table 4, the smallest difference between static and dynamic loading is in the palm and ring finger, and in the other fingers the significant differences last longer. It is known that the angles in the shoulder, elbow, hip, and knee joints to maintain a straight body shape are essentially required for a quality handstand (Hedbávný, Sklena, et al. 2013; Rohleder and Vogt 2018; Uzunov 2008). Consequently, the body's centre of gravity must be stable over the hands and head, and without gaps between the shoulders and ears, axial alignment at the spine is required (Rohleder and Vogt 2018; Uzunov 2008). Gymnasts with better strength abilities may dare to perform the corrective movements to a greater extent, but they usually choose a three-part balancing strategy. Gymnasts who have less strength abilities use the three-segment balancing strategy exceptionally and for a shorter time. Their corrective movements are performed on the basis of the four-segment strategy, which results in a poorer quality of execution of the handstand (Hedbávný, Bago, et al. 2013). In this study, the grip in the handstand did not have to be firm, and maintaining balance was easier if you had the wall at your back. In swinging, it was also easier to maintain balance when supported on both sides, although changing the position of the wrist in the extreme positions of forward and backward swinging required a different strategy for maintaining the handstand (Kochanowicz et al. 2019).

Comparison of the results of this study with the study in which the load was in hang (Šibanc et al. 2021). The measurement protocol was similar, the position of the hands is now parallel, while during hanging they are behind each other and the momentum in the handstand is relatively small, so there is practically no friction between hands and bars. The temperature differences after hanging are much higher. The temperature decrease immediately after the load is applied is greater after hanging because the grip must be stronger during hanging. The load on the hands in handstand is less than in hanging, which allows faster regeneration of the hands and faster return to the initial state. Also the temperatures are higher after 5 minutes in hanging and swinging in hanging than after supporting and swinging in supporting. The difference between static and dynamic load is interesting and almost opposite - after hanging the biggest differences are after 150 seconds, while after handstand most differences are up to 120 seconds.

Strength and limitations

Because of the large database, Tables with all values were not included.

With this study, we continued to question the dynamics of temperature distribution after loads. According to our results, further investigations should be conducted to obtain more information about the time for skin temperature to reach its value before the load, to be determine when skin is ready for the next load without the risk of potential skin damage.

The values for the thumb are correct for this angle of measurement, but since the main contact with apparatus is on the inner side of the thumb, measuring separately and from a different angle would give different temperatures. To get more precise data, the thumb should be measured from a different angle.

The use of an accurate (calibrated) non-contact temperature device is necessary when we observe low temperature differences (in the order of a tenth of a degree Celsius). It is not enough to rely on any non-contact temperature device because low-cost radiation thermometers and thermal imagers are not capable of accurate or consistent measurement of temperature differences.

CONCLUSION

In this study, we examined a fundamental gymnastic skill – the handstand. The handstand is a complex posture, and adding another task to this posture, such as the swing, severely restricts the system and affects the hands differently (Gautier et al. 2009). According to our study and a previous study on hanging (Šibanc et al. 2021), the principle of temperature changes is the same whether the heart is below or above the grip. In any exercise with the grip (handstand, hanging...) there is always a decrease in blood flow, which means that the palm and fingers cool down immediately after the load and then try to return to the initial state. While this knowledge comes from students of various sports, it could also be used by gymnasts, acrobats, physical education teachers, and many others who practice this skill to improve handstand performance. Handstand can also be used for conditioning exercises for the anterior part of the deltoid muscle and the rectus femoris (these 2 muscles showed increased activity during handgrip on parallel bars). It appears that both muscles are heavily used to control the balance of the body over the shoulder and hip joints when a handstand is held.

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Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethical Commission of the University of Ljubljana’s Faculty of Sport (13. 9. 2018; 12_2018).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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