TEMPERATURE DIFFERENCES OF THE PALMS AFTER STATIC AND DYNAMIC LOAD IN SUPPORT ON PARALLEL BARS

Karmen Šibanc[1], Maja Pajek[1], Ivan Čuk[1], Igor Pušnik[2]

[1] University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia
[2] University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia

Original article *DOI: 10.52165/sgj.15.3.349-366*

Abstract

In sports and exercise science, thermography is used extensively to evaluate athletic performance, to study exercise-induced superficial vascular changes, and to monitor injuries. There is a lack of research and literature on palm temperatures after different loads and our question was how palm temperature differs after static and dynamic loading on the parallel bars since the application is so varied (competitive and recreational sports, physical education, rehabilitation). Thirty-eight students from the Faculty of Sport at the University of Ljubljana were measured using a high-quality thermal imaging camera. Palm temperatures were measured before the load was applied, immediately after the load, and every 30 seconds for a period of 5 minutes after the load. Each hand was divided into nine different regions of interest (ROIs). Mean (XA), standard deviation (SD), maximum and minimum, and number of pixels were calculated. Our study showed that the temperature in the palm decreased immediately after the load, and then began to increase. Within 5 minutes, it reached higher values than before the application of the load, and after swings (dynamic load), the temperature values were higher than after support (static load). Different loads have different effects on the temperature of the hand.

Keywords: *palm temperature; thermal imaging; parallel bars; support; swing in support*

INTRODUCTION

Infrared thermal imaging has gained widespread acceptance as a non-destructive testing method and is increasingly utilized across various research and industrial sectors. Infrared thermography is employed for several purposes, including the detection of internal manufacturing defects in materials, measurement of thermophysical parameters in materials, identification of internal damage within structures and material strength, assessment of energy efficiency in buildings, detection of leaks in buildings and electrical systems, as well as applications in civil engineering, aerospace for energy conversion detection, stress analysis, and healthcare (Qu, Jiang, and Zhang 2020).

The human body's temperature is closely associated with health status, with the normal body temperature range being defined as a relatively narrow span, typically ranging from 36.1°C to 37.2°C at room temperature. Hyperthermia, albeit rarely hypothermia, serves as an indicator of an underlying medical condition or physical abnormality that necessitates medical attention (Kesztyüs, Brucher, and Kesztyüs 2022).

The surface of the human body emits infrared radiation, which can be precisely measured within specific wavelengths using an infrared detector (Lahiri et al. 2012). In the realm of sports and exercise science, where human health promotion is a key focus, thermography finds extensive application. It serves as a valuable tool for evaluating athletic performance, investigating exercise-induced superficial vascular changes, monitoring injuries, and striving to develop optimal training techniques and outcomes (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).

Gymnastics, considered the oldest organized sport, involves gymnasts performing routines that consist of various elements and combinations in competitive settings. The duration of routines performed on parallel bars, rings, uneven bars, high bar, and pommel horse typically ranges from 20 to 50 seconds, with an average duration of around 30 seconds. Each element is initially defined by the gymnast's position on a piece of apparatus, followed by their touch or grip on that apparatus. Finally, an element is described by the movement that leads to the final position (Aarkaev and Suchilin 2004).

Hand movements in gymnastics encompass two fundamental patterns: precision grip and power grip (Napier 1956). These gripping techniques are also employed in various other sports and activities such as fitness, sport climbing, crossfit, and more. However, there is a notable lack of knowledge concerning the effects of palm loading on the temperature of the hand and palm, taking into consideration environmental temperature variations.

In the context of a power grip, extrinsic muscles play a crucial role in generating movement and supplying the primary force required. In artistic gymnastics, where gymnasts' palms are exposed to frictional forces due to their interaction with the equipment, skin injuries can occur (Pušnik, Čuk, and Hadžič 2017; Zhang and Mak 1999).

One study (Zontak et al. 1998) demonstrated the influence of exercise on the skin temperature where loading was steady and led to a constant decrease in finger temperature. Later, in a resting stage the hands rewarmed as a result of the dominance and balance of thermoregulatory reflexes and hemodynamics. Finger temperature consistently decreases with graded loading due to the continuous dominant vasoconstrictor response. This response aims to reduce inflammation and swelling. In cases of intensive exercise or rehabilitation, local cooling has been employed as a method to alleviate these effects. The study by Kwon et al. (2010) investigated the impact of hand cooling on fatigue during intensive bench pressing.

Surprisingly, there is a limited body of research that focuses on the application of load to the palm or the handling of objects at room temperature within a specific timeframe. One study, conducted by Bennett, Goubran, and Knoefel in 2015, examined hand temperature after five minutes of pressure application, noting an immediate cooling effect upon load application.

Short-term loading effects on palm temperature were also explored in the context of different gymnastic ring shapes in a study by Pušnik et al. (2017). Following loading, variations in palm temperature decrease were observed, dependent on the specific ring shapes used. Additionally, the influence of magnesium carbonate on palm temperature was investigated during the execution of simple elements on uneven bars by Pušnik and Čuk in 2014. The study found that palm temperature increased when magnesium carbonate was used but remained constant when it was not.

Further insights were gained through research by Šibanc et al. (2021) during static and dynamic load applications while hanging on a high bar. In these experiments, temperatures initially decreased after load application, then began to rise. Within five minutes of measurement, the temperatures exceeded the levels recorded before the load was applied. Interestingly, the decrease in temperature was more pronounced after static load as compared to dynamic load, and for both types of loads, temperatures increased above their initial baseline levels before load application.

Support on the parallel bars is not only a basic element of artistic gymnastics, but it is also used in physiotherapy as an important tool for the rehabilitation process of patients with spinal cord injuries or acute strokes (Augustine and Nair 2021; Rowald et al. 2022; Shulga et al. 2020; Spiess, Steenbrink, and Esquenazi 2018). Furthermore, the parallel bars are versatile sports equipment that extends beyond competitive gymnastics. They serve as essential apparatus in home training, and also in recreational sports and physical education in schools (Kovač et al. 2011; Rasmussen 1971), where, according to the curriculum, children learn elements, such as hanging and supporting.

There are some studies on the palm temperature during hanging, swinging in hanging and performing different elements on rings or parallel bars (Pušnik and Čuk 2014; Pušnik et al. 2017; Šibanc et al. 2021), but there is still a lack of studies on the palm temperature and its differences after different loads. Therefore, in our study we have investigated the temperature differences in the palm after dynamic and static loads during the support on parallel bars. It is a frequently performed element, but we do not have data on the temperature distribution of the palms, the most important and only contact with the apparatus. What is needed is not only data on the temperature distribution and difference immediately after the application of various loads, but also for a certain time after the application of the load, when the human body reacts and tends to return to the state before the application of the load. A study conducted by Šibanc et al. in 2021 investigated temperature differences in the palms following the application of a load while hanging. We now wish to acquire data regarding palm temperature when supporting and swinging on the parallel bars, involving both static and dynamic loads. In training routines, exercises must often be repeated, as highlighted by Aarkaev and Suchilin in 2004. However, a continual increase in palm temperature due to loading may raise concerns about the development of blisters on the palms. This type of data is useful to optimize training scheduling, exercise repetitions, and breaks to avoid skin injuries.

METHODS

We measured 38 healthy subjects (11 men and 27 women), students at the Faculty of Sport, University of Ljubljana,. They had a body weight of 72.2 kg (±12.5), they were 1.73 m (±0.10) tall, and were 22.1 years (±2.9) old. All participating subjects provided written informed consent, as we adhered to the principles outlined in the Declaration of Helsinki. The study was approved by the Ethics Committee of the Faculty of sport of the University of Ljubljana (12_2018).

The measurement protocol was developed and adapted on the basis of our hypotheses:

1. temperature of the palm decreases after the static load in support;
2. temperature of the palm increases after the dynamic load in the swing in support.

Each load lasted 30 seconds. The subjects' hand temperatures were measured before loading (indicated as "-30 s" in the following tables), immediately after loading (indicated as "0 s" in the following tables), and then for 5 min (indicated as "300 s" in the following tables) at 30-second intervals. Thus, 12 thermograms were recorded per subject and per loading. For thermography (see Figure 1), each subject was seated in a chair with hands on the table, backs of hands up, and on an insulating surface to prevent heat loss into the table. Fingers were approximately at the level of the heart. Subjects performed two tasks on parallel bars (wooden surface, vertical axis of the profile 5 cm ± 0.1 cm; horizontal axis of the profile 4 cm ± 0.1 cm (Fédération Internationale de Gymnastique, 2022)). The first task consisted of standing still in support for 30 seconds (Figure 2a), and the second task consisted of swinging in support (hereafter noted as "swings") for 30 seconds (Figure 2b), where the swing range was fixed (30-45° from vertical). Subjects were assigned tasks randomly. The rest period between loads was the thermal imaging period. The tasks were performed with a cylindrical power grip. The measurements took place in the gymnasium at the Faculty of Sport, University of Ljubljana. For acclimatization at 23°C and a relative humidity of 40% in the gymnasium, all subjects were in the hall 15 minutes before the start of the first measurement. Before the measurements, subjects were asked not to smoke or drink alcohol for 24 hours, not to consume caffeine for 12 hours, and not to use creams or lotions on their hands for 12 hours (Fernández-Cuevas et al., 2015). There was no visible damage to the skin on their hands.

In the study we used a high-resolution thermal imager (FLIR T650sc FLIR Systems, Oregon, USA). The specified accuracy of the imager in the temperature range of 5 °C to 120 °C is ±1% of reading or 1 °C, at environmental temperatures of 10 °C to 35 °C. Prior to our research, the imager was calibrated at LMK - Laboratory of Metrology and Quality at the Faculty of Electrical Engineering, University of Ljubljana[1], to confirm its accuracy, which

[1] LMK is the holder of a national standard for thermodynamic temperature in Slovenia. As a national laboratory for temperature and relative humidity and accredited calibration laboratory it holds CMCs – calibration measurement capabilities

was better in the applied range. The temperature corrections obtained during calibration were applied accordingly. The imager has an uncooled detector (microbolometer), operates in the spectral range of 7.5 µm to 14 µm, and has the noise equivalent temperature difference NETD < 30 mK. The imager has a wide-angle lens 45° (f = 13.1 mm), with the field of view FOV 45° x 34° mm, spatial resolution 1.23 mrad (IFOV), continuous zoom (8x) and the minimum focus distance 15 cm. The emissivity can be adjusted in steps of 0.01 from 0.10 to 1.00. Image analysis was performed in the associated software environment (ResearchIR Max from (FLIR Systems, Oregon, USA), which allows analyses of various regions of interest (ROIs), e.g. areas, spots, automatic detection of hot/cold spots, temperature differences, isotherms, line profiles, alarms, etc. The imager resolution is 640x480 pixels, which corresponds to 307200 pixels in a single thermogram. The high resolution is important for a detailed analysis of the selected ROIs (Perić et al. 2019).

Each hand we divided into nine ROIs (polygons) as shown in Figure 3: palm, thumb, proximal phalanx index finger, distal phalange, middle finger proximal phalanx, middle finger distal phalanges, ring finger proximal phalanx, ring finger distal phalanges and little finger. ROIs shown in Figure 3 are listed in Table 1 and the abbreviations are used in the following text for each ROI. Polygons 1-9 represent the right hand and polygons 11-19 represent the left hand. The boundaries of ROI are at least 7 pixels away from the edge of the observed area to minimize the influence of the size-of-source effect (Pušnik and Geršak 2021), a rather important issue in thermal image analysis, which was taken into account when drawing the ROIs.

From ResearchIR, data for each ROI were exported to Excel (Microsoft corp.): mean (XA), standard deviation (SD), maximum and minimum, number of pixels. We calculated two new variables : the sum of the temperature differences of the section before the task until the end of the 5th minute using the equation $\Sigma(T_n\text{-}T_n{+}1)$, where n represents the time series; and the temperature differences from the first to the last measurement using the equation $T_1\text{-}T_n{+}1$.

We used SPSS 25.0 (IBM corp.) for statistical analyses: 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 in support, 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.

---

that are among the best in Europe and worldwide in the respective fields of measurement.

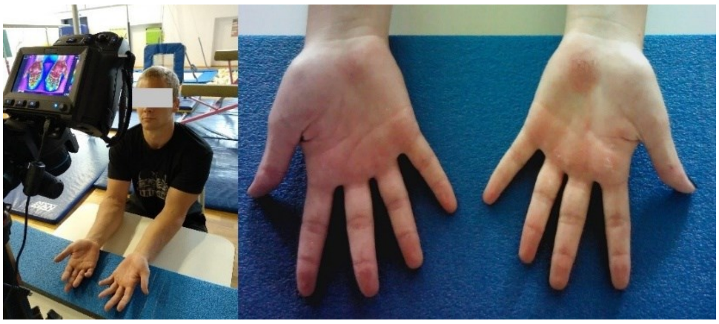
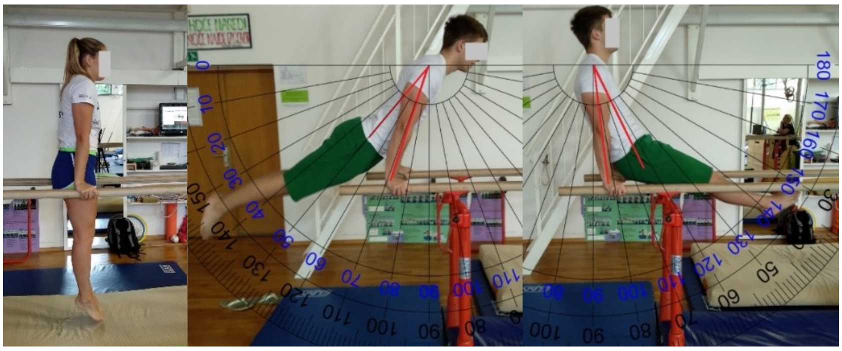


Figure 1. Camera setting for thermal imaging; position of hands during thermal imaging



(a) (b)

Figure 2. (a) Support and (b) Swing in support.

Figure 3. Thermal image and ROIs on hands.

Table 1.

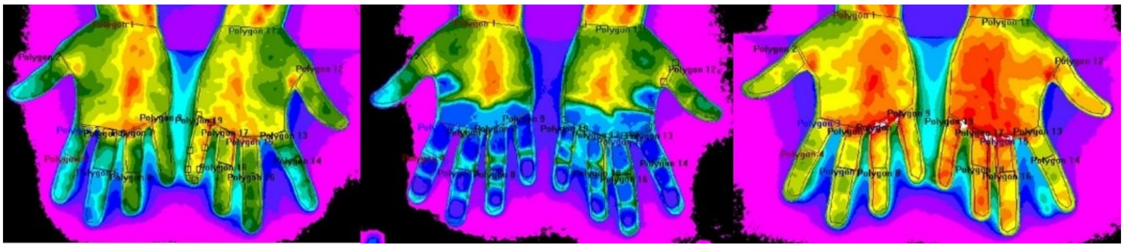
ROIs on each hands.

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

RESULTS

The variables were not normally distributed according to the Kolmogorov-Smirnov test. As noted in other studies and therefore expected, no significant difference was found between men and women. The results in our study are presented for the left hand (there were no significant differences between the left and right hands, as can also be seen in Figure 4).

Table 2 shows the temperature difference immediately after load application during support and swing, and 300 seconds after load application, while Figure 4 is presented as an example of temperatures after support. All values decrease immediately after load application for all ROIs, for both loads. The temperature drop is smaller after swinging than after propping, but the difference between support and swing is not significant. The greatest decrease of temperature immediately after load is after swinging for the little finger and the distal phalanges of the ring and middle fingers, and the greatest difference, although not significant, is for the thumb (see also Figure 6).



(a) (b) (c)

Figure 4. Example of Palm Temperature (a) before load, (b) immediately after support, (c) 300 s after support

Significant temperature differences by time and region before and after load application for 30 seconds each in a 5-minute period, where $p < 0.05$ indicates a significant difference in temperature by a paired t-test are shown in Table 3. After support for the palm, thumb, and all three distal phalanges, the temperature difference was significant up to 180 s immediately after loading, and up to 210 s for the little finger. After support for all three proximal phalanges, the temperature difference was significant over a longer period of time, between 240 s and 270 s. After swing for the palm, thumb, and index finger proximal phalanx, the temperature differences were significant for up to 240 s; for the other ROIs, the temperature differences were significant for a longer period, up to 270 s. For all distal phalanges and the little finger after swings the difference was not significant at 240 s.

The temperature differences between support and swing are shown in Table 4. For palm there was no significant difference, seen also in Figure 6. Immediately after the application of the load, a significant difference between loading was observed only for the thumb, where there was a significant difference of up to 120 s (and no significant difference at 90 s). For all three proximal phalanges, a significant difference was from 30 s (60 s for middle finger proximal phalanx) to 240 s; from 30 s to 210 s for distal phalange of index and middle finger, and from 30 s to 180 s for ring finger distal phalange and little finger.

The temperature differences between support and swing are shown in Table 4. For palm there was no significant difference, seen also in Figure 6. Immediately after the application of the load, a significant difference between loading was observed only for the thumb, where there was a significant difference of up to 120 s (and no significant difference at 90 s). For all three proximal phalanges, a significant difference was from 30 s (60 s for middle finger proximal phalanx) to 240 s; from 30 s to 210 s for distal phalange of index and middle finger, and from 30 s to 180 s for ring finger distal phalange and little finger.

Table 2.

Temperature difference for support and swing right after load ($XA0_{SU}$-$XA0_{SW}$) and after 300 seconds ($XA300_{SU}$-$XA300_{SW}$) for left hand by ROI.

Variable	XA0/°C	$XA0_{SU}$-$XA0_{SW}$ /°C	p(ttest) 0/°C	XA300/°C	$XA300_{SU}$-$XA300_{SW}$ /°C	p(ttest) 300/°C
Support P[a]-L	-2.05	-0.13	0.550	0.39	0.02	0.244
Swing P[a]-L	-2.18			0.41		
Support T[b]-L	-1.79	-0.52	0.743	0.34	0.02	0.156
Swing T[b]-L	-2.31			0.36		
Support IPP[c]-L	-2.03	-0.15	0.456	0.34	-0.33	0.710
Swing IPP[c]-L	-2.18			0.01		
Support IDP[d]-L	-2.22	-0.17	0.274	0.46	-0.24	0.339
Swing IDP[d]-L	-2.39			0.22		
Support MPP[e]-L	-1.91	-0.15	0.552	0.39	-0.3	0.718
Swing MPP[e]-L	-2.06			0.09		
Support MDP[f]-L	-2.26	-0.17	0.275	0.53	-0.23	0.337
Swing MDP[f]-L	-2.43			0.30		
Support RPP[g]-L	-1.88	-0.18	0.523	0.47	-0.31	0.729
Swing RPP[g]-L	-2.06			0.16		
Support RDP[h]-L	-2.56	-0.23	0.313	0.54	-0.25	0.312
Swing RDP[h]-L	-2.79			0.29		
Support LF[i]-L	-2.37	-0.29	0.556	0.56	-0.23	0.400
Swing LF[i]-L	-2.66			0.33		

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
Support P[a]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	0.116	0.155	0.320	0.088
Swing P[a]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.003**	**0.002**	**0.000**	**0.029**	0.129	0.871
Support T[b]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.008**	**0.016**	0.076	0.085	0.552	0.144
Swing T[b]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.003**	**0.001**	**0.001**	**0.009**	0.194	0.748
Support IPP[c]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.003**	**0.027**	0.878	0.440
Swing IPP[c]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.015**	**0.001**	**0.003**	**0.016**	0.326	0.635
Support IDP[d]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.014**	**0.016**	0.059	0.341	0.843	0.103
Swing IDP[d]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.014**	**0.002**	0.064	**0.021**	0.569
Support MPP[e]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.010**	**0.026**	**0.010**	0.588
Swing MPP[e]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.005**	**0.001**	0.216
Support MDP[f]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.004**	**0.008**	0.056	0.291	0.631	0.147
Swing MDP[f]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.007**	0.087	**0.007**	0.510
Support RPP[g]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.005**	**0.001**	0.064	0.505
Swing RPP[g]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.046**	0.175
Support RDP[h]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.017**	**0.025**	0.372	0.205	0.702	0.057
Swing RDP[h]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.001**	**0.011**	0.169	**0.024**	0.679
Support LF[i]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.008**	**0.018**	**0.038**	0.617	0.129	0.058
Swing LF[i]-L		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**	**0.017**	0.072	**0.011**	0.826

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 support and swing time series (where stated values indicate 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		0.251	0.118	0.145	0.512	0.476	0.458	0.486	0.699	0.783	0.850	0.884
T[b]-L		**0.001**	**0.003**	**0.013**	0.059	**0.035**	0.121	0.179	0.380	0.489	0.638	0.968
IPP[c]-L		0.243	**0.027**	0.017	**0.008**	**0.006**	**0.003**	**0.008**	**0.010**	**0.020**	0.055	0.125
IDP[d]-L		0.286	**0.014**	**0.002**	**0.003**	**0.002**	**0.008**	**0.011**	**0.023**	0.055	0.141	0.388
MPP[e]-L		0.145	0.063	**0.014**	**0.020**	**0.005**	**0.008**	**0.012**	**0.035**	**0.042**	0.064	0.187
MDP[f]-L		0.319	**0.021**	**0.002**	**0.003**	**0.002**	**0.006**	**0.015**	**0.027**	0.054	0.145	0.377
RPP[g]-L		0.153	**0.031**	**0.007**	**0.004**	**0.002**	**0.009**	**0.016**	**0.030**	0.038	0.051	0.170
RDP[h]-L		0.235	**0.016**	**0.002**	**0.003**	**0.004**	**0.013**	**0.026**	0.075	0.094	0.208	0.467
LF[i]-L		0.065	**0.005**	**0.001**	**0.006**	**0.005**	**0.012**	**0.039**	0.078	0.272	0.277	0.542

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 5 shows the mean temperature differences of all measured subjects for support and swing in support for the right and left hands for all measured ROIs.

There was little difference between the right and left hands for both loads, while the significant difference between the loads is shown in Figures 5 and 6, although Table 2 showed no significant differences immediately after the load was applied and 5 minutes later. For all ROIs, the temperature was higher 300 seconds after loading than before loading. After all loads, the ring finger distal phalanges had the greatest temperature drop (as also seen in Table 2); the palm recovered faster than all other fingers (1.5 minutes faster on average). For all ROIs, temperature recovered after bracing, and increased faster than after swings. In addition, the temperatures of the ROIs increased to greater values 300 seconds after support than after swings. After swings, the temperature decrease was larger than the temperature before loading.

As can be seen from the curves in Figure 5, the temperature rises above the initial value (before loading) for the support was between 100 seconds and 160 seconds after loading, while the temperatures of the ROIs after swings reached their initial values between 170 seconds and 250 seconds after loading. Temperature changes after support increased until 270 s and then began to decrease. A temperature decrease after swings was not observed after 300 seconds (except for the distal phalanges of the ring finger and the little finger on the left hand, as also shown in Figure 6).

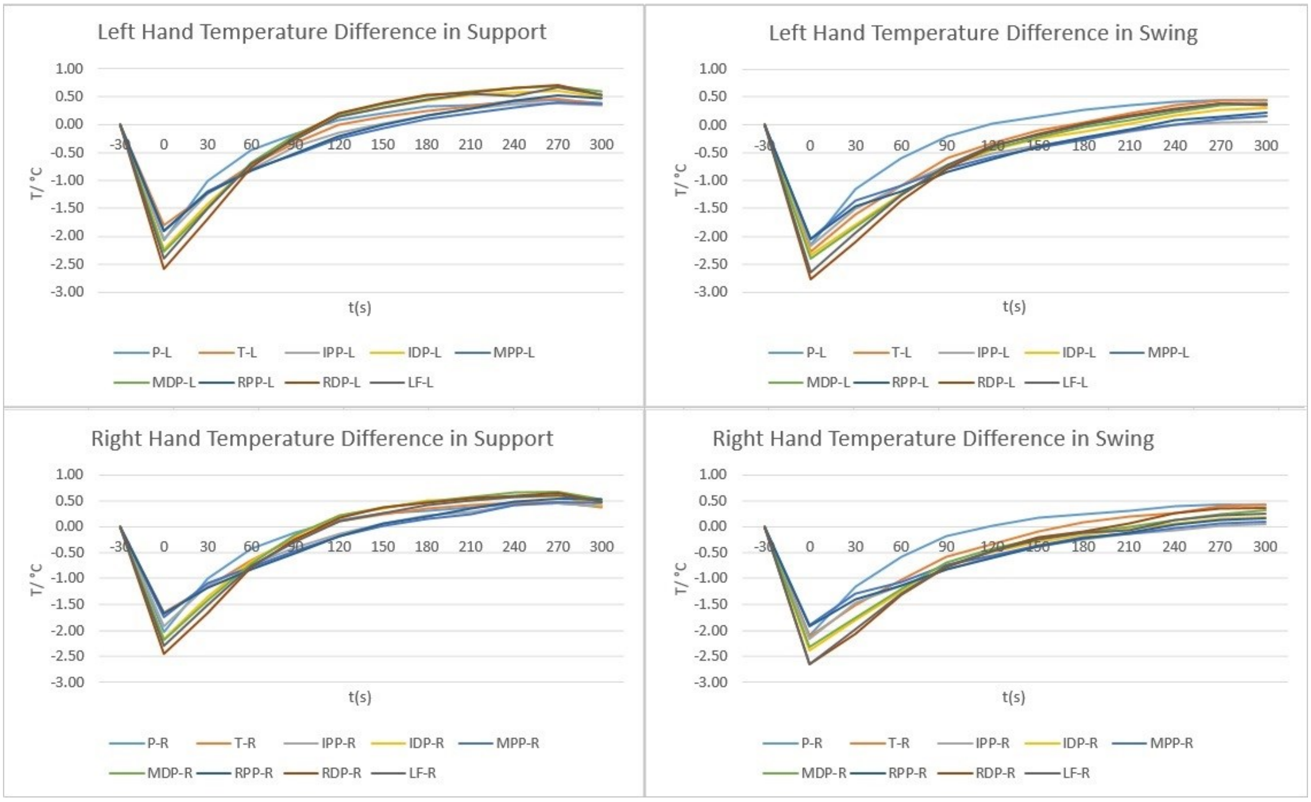


Figure 5. Temperature difference for the right and left hand during support and swings. The two graphs on the left side of the figure show the temperature differences for support, and the graphs on the right side of the figure show the temperature differences for swings. The top two diagrams show the left hand, while the bottom two diagrams show the right hand.


Palm
Thumb
Index Finger Proximal Phalanx
Index Finger Distal Phalange
Middle Finger Proximal Phalanx
Middle Finger Distal Phalange
Ring Finger Proximal Phalanx
Ring Finger Distal Phalange
Little Finger
T/°C
t(s)
-30 0 30 60 90 120 150 180 210 240 270 300
1.00 0.50 0.00 -0.50 -1.00 -1.50 -2.00 -2.50 -3.00
Support
Swing in Support

Figure 6. Temperature differences of the left hand in support and swing for different ROIs. 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

Figure 6 shows the temperature difference between support and swing for each DOI separately. For the palm, there was no significant difference between support and swing in support, even for the thumb after 120 seconds (as also seen in Table 4). For the little finger and all distal phalanges, the temperature difference between support and swing in support was greater than for proximal phalanges. The increase in temperature above baseline was faster and greater after support than after swings, as can be seen in Figure 5. After support, distal phalanges of the index, middle, and ring fingers reached the initial temperature value after 90 seconds, while after swings they reached the initial value after 180 seconds. Only for the thumb, the temperature drop immediately after loading was different for support and swing (larger drop after swing by almost 1 °C compared to support). For all ROIs after support, temperature values begin to decrease after 270 seconds, which was not the case for temperature values after swing (except for the ring finger distal phalanges and little finger, as shown in Figure 5).

DISCUSSION

In our study, there was no significant difference in temperature distribution and no difference between the left and the right hands. The loads included in this study appeared to be symmetrical - supports and swings are symmetrical by positions and/or movements (compared to studies in artistic gymnastics that consider asymmetries (Čuk and Marinšek 2013; Dallas et al. 2022; Pajek et al. 2016)), and did not include movements such as hanging on one hand, rotations around the transverse or longitudinal axis. As a consequence, load application had no influence on the temperature differences of the palms due to possible body asymmetries. Something similar was observed in the study where temperatures were measured after hanging on high bar (Šibanc et al. 2021).

As shown in Tables 2, 3 and Figures 4, 5, and 6, the temperature decreased significantly immediately after the application of static and dynamic loading for all ROIs. In our measurements, the thumb was the only part of the hand where the temperature difference between support and swing was significant immediately after loading, implying that different loads affect the thumb differently. The skin contact with the bar and thumb was mainly on the inner side of the thumb, and the angle of our settings was not ideal for measuring the temperature of the thumb. Although thumb temperature decreased the least after bracing (also seen in a study for hang (Šibanc et al. 2021)– meaning that in both studies this occurred after a static load was applied), the temperature decrease after swings was the smallest for the proximal phalanges of the ring and middle fingers. The greatest temperature decrease was for the ring finger and distal phalanges after both loads. This implies that the distal phalanges mainly provide a secure grip, and balance the body on the bar. Further studies are recommended to confirm these results, although as personally experienced by authors, the distal phalanges of the ring finger are more stressed during bracing and swings, and the thumb ensures greater balance during the execution of swings than during support. Following the cylindrical power grip, in which the thumb is oriented differently compared to digits 2-5, is an important anatomical feature of the hand that allows for this opposite orientation and a much stronger grip (Anon 2016). The difference between the proximal and distal phalanges can be seen in Figure 5.

According to Table 3, temperatures differed significantly for longer periods after swings. With the difference in the rate of temperature rise (also seen in the curves in Figure 5) and the temperature difference, the load was higher during swings; during support, the response to the temperature rise was slower and lower. After support, the palm is the only ROI where there was no significant difference between support and swing in any measured time. Corresponding to the different biomechanics of support and swings - in swinging, the body's centre of gravity oscillates from back to front, whereas in support, the centre of gravity is above the point of support (Čuk, Ivan and Karacsony 2016; Čuk 1996; Kolar, Kolar, and Štuhec 2002). The fingers play a different role in different positions of the swing, while the load on the palm remains similar in supports and swings, which explains our results.

The temperatures reach the values before applying the load much faster after support than after swings (Figure 5). After 5 minutes of load application, no significant temperature difference was observed (Table 3), and according to Figures 5 and 6, the temperatures started to decrease after reaching the highest value between 240 and 270 seconds. In a similar study (Šibanc et al., 2021), where palm temperatures were measured after hanging and swinging in the hanging position, the temperatures increased to a higher constant level 3 or 4 minutes after hanging. Similar trends were not observed after swinging in the hanging position. Further research on this issue is needed.

A possible explanation for the lower palm temperature could be reduced blood flow to the palm during the performance of elements in the hanging position (Pušnik et al., 2017). Blood flow in the skin is usually measured with a laser Doppler flowmeter or venous occlusion plethysmography. Advantages of this method include high temporal resolution (measurements are performed continuously) and specificity for cutaneous microcirculation. To evaluate and investigate this hypothesis further, future studies should also measure blood volume flow through the radial artery.

Support and swings on the parallel bars are fundamental elements in gymnastics used at various athletic levels and in rehabilitation. These elements are not limited to competitive sports but are widely employed to achieve various goals.

Although swings in support were not executed exactly as in competitive gymnastics in our study, learning the elements of artistic gymnastics is a long-term process. The most crucial factor in learning is the use of appropriate methodological progressions (Čuk, Ivan and Karacsony, 2016; Čuk, 1996), and teaching progressions should adhere to basic pedagogical principles. “Each progression step should include a movement structure similar to the desired element” (Kolar et al., 2002). This means that our research marks a fundamental beginning on this topic to understand the differences in hand temperature after different loads. It represents an ongoing extension of research on the hand (Šibanc et al., 2021), where loads in the hanging position were one of the main areas of investigation. Another extreme and fundamental position of interest to researchers is the handstand, in which the entire body is above the point of grasp. Given the increasing development of outdoor gyms and equipment, similar studies under outdoor conditions and on bars made of different materials (wood, metal, plastic) should be considered.

CONCLUSIONS

We are aware that there are still many hidden facts about our human activities that we do not know. Exercise and sport science is trying to uncover these facts. One of the hidden facts is how the skin of the human palm responds to different loads. In a previous study, we investigated hanging and swinging on the high bar, where the heart was positioned below the plane of the grip during hanging, and all blood vessels were vertically oriented (to simplify). However, contrary to our expectations, we observed a decrease in palm temperature after the exercise. In our current article, we explore support and the generation of momentum during support, where the heart is positioned above the grip, and the blood vessels follow two distinct directions: first, vertically upward from the heart, and then vertically downward. This phenomenon has not been observed in previous literature. To ensure results that are comparable to those of the aforementioned study, it was necessary to replicate the measurement methods, enhancing the validity and reliability of our research. By doing so, we also enable other researchers to replicate our work.

The results are generally similar in the sense that the temperature decreases after the load and increases during regeneration. All the grips used in the study required the subject to handle their entire body mass. However, ergonomics may also benefit from these results, as the duration the palm skin is under load and the time it takes to recover to baseline are essential factors for a safe environment, not only in sports but also in the workplace.

To conclusively establish the general knowledge regarding expected changes in palm temperature, further studies should be conducted with subjects in a handstand position, with the heart directly over the vertical orientation of the grip.

Artistic gymnastics is a sport, but its elements find wide application in recreational sports, physical education classes in schools, home-based fitness, and more. In recent years, outdoor gyms with various exercise equipment have gained popularity, with parallel bars being one of the preferred choices for developing muscle strength (Fernandez-Rodriguez et al. 2020). The use of parallel bars in rehabilitation programs is also on the rise. Further research on this topic is necessary to comprehend the temperature dynamics in the palms.

Our study revealed a decrease in palm temperature immediately after the load was applied, followed by a subsequent increase. Within 5 minutes, higher values were reached compared to the pre-load state. As a result, our first hypothesis is accepted, and the second hypothesis is rejected. The temperature difference after swings is greater than after support. Different loads exert distinct effects on hand temperature. After support, the temperature decrease was the least pronounced for the thumb. The distal phalanges play a crucial role in providing a secure grip and maintaining balance on the bars, hence the temperature decrease was most significant in these regions.

STRENGTH AND LIMITATIONS

Because of the large database, tables including all values were not included.

According to our results, further studies should be conducted to obtain more information about the time when the skin temperature returns to its pre-load value. In the study where the load was suspended from the high bar, we began to question the effectiveness of rest in preventing skin injury. Further research is needed to determine when the skin is ready for the next load without the risk of potential skin damage. It may even be possible to calculate and plot a cooling curve for the hands. This information can be crucial for coaches and athletes during the training process.

While the values for the thumb are accurate for this measurement angle, given that the main contact with the apparatus occurs on the inside of the thumb, taking separate measurements from a different angle would yield different temperatures. To obtain more precise data, measurements of the thumb should be taken from a different angle.

To observe small temperature differences, typically on the order of a tenth of a degree Celsius, one should not rely on non-contact temperature devices, as inexpensive radiation thermometers and thermal imagers are not capable of consistently and accurately measuring such temperature differences. Therefore, the use of an accurate and calibrated non-contact temperature device is necessary.

ACKNOWLEDGMENTS

Funding: The authors acknowledge the financial support from the Slovenian Research Agency (research core funding No. P2-0225 and P5-0147).

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 its 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.

.

REFERENCES

Aarkaev, L., and N. Suchilin. 2004. *How to Create Champions : The Theory and Methodology of Training Top-Class Gymnasts*. Meyer & Meyer Fachverlag und Buchhandel GmbH (October 1, 2004).

Anon. 2016. "Power- Cylindrical Grip – Functional Anatomy of the Hand." Retrieved May 20, 2021 (https://functionalanatomyofthehand.wordpress.com/2016/04/14/anatomy-of-the-hand-3/).

Augustine, J., and Remya M. N. 2021. "Effectiveness of Task Oriented Walking Intervention on Improving Balance in MCA Stroke Patients." *~ 103 ~ International*

Journal of Physical Education, Sports and Health 8(2):103–8.

Bennett, S. L., Goubran R., and Knoefel, F. 2015. "Measurements of Change in Thermal Images Due to Applied Pressure." Pp. 30–35 in *2015 IEEE International Symposium on Medical Measurements and Applications, MeMeA 2015 - Proceedings*. Institute of Electrical and Electronics Engineers Inc.

Čuk, I., and Karacsony I. 2016. *Parallel Bars (Methods, Ideas, Curiosities, History)*. Brezovica pri Ljubljani: I. Čuk.

Čuk, I., and Marinšek M. 2013. "Landing Quality in Artistic Gymnastics Is Related to Landing Symmetry." *Biology of Sport* 30(1):29–33. doi: 10.5604/20831862.1029818.

Čuk, I. 1996. "Development and Analysis of the New Gymnastics Element (Cast to Salto Forward from the Parallel Bars)." University of Ljubljana, Faculty of sport.

Dallas, G., Dallas C., Kolovou, V., Pappas, P., Mellos, V. and Paradisis, G. 2022. "Acute Effects of Bilateral and Unilateral Whole Body Vibration Training on Jumping Ability, Asymmetry, and Bilateral Deficit on Former Artistic Gymnasts." *Science of Gymnastics Journal* 14(1):59–71. doi: 10.52165/sgj.14.1.59-71.

Federation Internationale de Gymnastique. 2022. *Apparatus Norms*.

Fernández-Cuevas, I., Bouzas Marins, J.C., Arnáiz Lastras, J., Gómez Carmona P. M.,, Piñonosa Cano, S., Mi García-Concepción, M. A., and Sillero-Quintana, M. 2015. "Classification of Factors Influencing the Use of Infrared Thermography in Humans: A Review." *Infrared Physics and Technology* 71(March):28–55. doi: 10.1016/j.infrared.2015.02.007.

Fernández-Rodriguez, Emilio Francisco, Rafael Merino-Marban, Oscar Romero-Ramos, and Ivan Lopez-Fernández. 2020. "A Systematic Review about the Characteristics and Patterns of Use of Outdoor Gyms." *Journal of Human Sport and Exercise* 15(June):S688–707. doi: 10.14198/jhse.2020.15.Proc3.21

Gómez-Carmona, P., Fernández-Cuevas, I., Sillero-Quintana, M., Arnaiz-Lastras, J. and Navandar. A. 2020. "Infrared Thermography Protocol on Reducing the Incidence of Soccer Injuries." *Journal of Sport Rehabilitation* 29(8):1222–27. doi: 10.1123/JSR.2019-0056.

Gulyaev, Yu V., A. G. Markov, L. G. Koreneva, and P. V. Zakharov. 1995. "Dynamical Infrared Thermography in Humans." *IEEE Engineering in Medicine and Biology Magazine* 14(6):766–71. doi: 10.1109/51.473272.

Hildebrandt, C., Raschner, C., and Ammer, K.. 2010. "An Overview of Recent Application of Medical Infrared Thermography in Sports Medicine in Austria." *Sensors* 10(5):4700–4715. doi: 10.3390/s100504700.

Kasprzyk-Kucewicz, T., Szurko, A., Stanek, A., Sieroń, K., Morawiec, T., and Cholewka, A.. 2020. "Usefulness in Developing an Optimal Training Program and Distinguishing between Performance Levels of the Athlete's Body by Using of Thermal Imaging." *International Journal of Environmental Research and Public Health* 17(16):1–13. doi: 10.3390/ijerph17165698.

Kesztyüs, D., Brucher, S., and Kesztyüs, T. 2022. "Use of Infrared Thermography in Medical Diagnostics: A Scoping Review Protocol." *BMJ Open* 12(4):1–5. doi: 10.1136/bmjopen-2021-059833.

Kolar, E., Andlovic Kolar K., and Štuhec, S. 2002. "Gymnastics: Comparative

Analysis of Selected Biomechanic Characteristics between a Support Backward Swing and Support Swing for the 1#fr1/4 Straddle-piked Forward Salto on the Parallel Bars." *Sports Biomechanics* 1(1):69–78. doi: 10.1080/14763140208522787.

Kovač, M., Markun Puhan, N., Lorenci, B, Novak, L., Planinšec, J., Hrastar, I., Pleteršek, K. and Muha, V.. 2011. *Program Osnovna Šola, Športna Vzgoja, Učni Načrt*. Ljubljana: Ministrstvo za šolstvo in šport: Zavod RS za šolstvo.

Kwon, Y. S., Robergs R. A., Kravitz, L. R., Gurney, B. A., Mermier, C. M. and Schneider, S. M.. 2010. "Palm Cooling Delays Fatigue during High-Intensity Bench Press Exercise." *Medicine and Science in Sports and Exercise* 42(8):1557–65. doi: 10.1249/MSS.0b013e3181d34a53.

Lahiri, B. B., Bagavathiappan, S., Jayakumar, T., and Philip, J.. 2012. "Medical Applications of Infrared Thermography: A Review." *Infrared Physics & Technology Journal* 55(4):221–35. doi: 10.1016/j.infrared.2012.03.007.

Martínez-Nova, A:, Jiménez-Cano, V. M., Caracuel-López, J. M., Gómez-Martín, B., Escamilla-Martínez, E. and Sánchez-Rodríguez, R.. 2021. "Effectiveness of a Central Discharge Element Sock for Plantar Temperature Reduction and Improving Comfort." *International Journal of Environmental Research and Public Health Article Int. J. Environ. Res. Public Health* 18:6011. doi: 10.3390/ijerph18116011.

Napier, J. R. 1956. "The Prehensile Movement of the Human Hand." *Pathology and Basic Sciences* 38-B(4):902–13.

Pajek, M, Hedbávný P., Kalichová, M., and Čuk, I.. 2016. "The Asymmetry of Lower Limb Load in Balance Beam Routines." *Science of Gymnastics Journal* 8(1):5–13.

Perić, D., Livada, B., Perić, M., and Vujić, S.. 2019. "Thermal Imager Range: Predictions, Expectations, and Reality." *Sensors* 19(15). doi: 10.3390/s19153313.

Perpetuini, D., Formenti, D., Cardone, D., Filippini, C., and Merla, A.. 2021. "Regions of Interest Selection and Thermal Imaging Data Analysis in Sports and Exercise Science: A Narrative Review." *Physiological Measurement* 42(8). doi: 10.1088/1361-6579/ac0fbd.

Pušnik, I., and Čuk, I.. 2014. "Thermal Imaging of Hands during Simple Gymnastics Elements on the Wooden Bar with and without the Use of Magnesium Carbonate." *Science of Gymnastics Journal* 6(1):67–72.

Pušnik, I., Čuk, I. and Hadžič, V.. 2017. "Influence of New Anatomic Ring Design on Palm Skin Temperature." *Science of Gymnastics Journal* 9(1):61–70.

Pušnik, I., and Geršak, G.. 2021. "Evaluation of the Size-of-Source Effect in Thermal Imaging Cameras." *Sensors* 21(607). doi: 10.3390/s21020607.

Qu, Z., Jiang, P., and Zhang, W.. 2020. "Development and Application of Infrared Thermography Non-Destructive Testing Techniques." *Sensors (Switzerland)* 20(14):1–27. doi: 10.3390/s20143851.

Rasmussen, C. W. 1971. "DigitalCommons @ UNO A Curriculum Guide for Senior High School Physical Education in the Council Bluffs Community School District."

Rowald, A., Komi, S., Demesmaeker, R., Baaklini, E., Hernandez-Charpak, S. D., Paoles, E., Montanaro, H., Cassara, A., Becce, F., Lloyd, B., Newton, T., Ravier, J., Kinany, N., D'Ercole, M., Paley, A., Hankov, N., Varescon, C., McCracken, L., Vat, M., Caban, -…- and Courtine, G. 2022. "Activity-Dependent Spinal Cord Neuromodulation Rapidly Restores Trunk and Leg Motor Functions after Complete Paralysis.” *Nature Medicine* 28(2):260–71. doi: 10.1038/s41591-021-01663-5.

Shulga, A., Savolainen, S., Kirveskari, E. and Mäkelä, J. P. 2020. “Enabling and Promoting Walking Rehabilitation by Paired Associative Stimulation after Incomplete Paraplegia: A Case Report.” *Spinal Cord Series and Cases* 6(1). doi: 10.1038/s41394-020-0320-7.

Šibanc, K, Čuk, I., Pajek, M. and Pušnik. I. 2021. “Palm Temperature Differences after Static and Dynamic Load on High Bar.” *Sensors*. doi: 10.3390/s21134497.

Sousa, E., Vardasca, R., Teixeira, S., Seixas, A., Mendes, J. and Costa-Ferreira, A. 2017. “A Review on the Application of Medical Infrared Thermal Imaging in Hands.” *Infrared Physics and Technology* 85.

Spiess, M. R., Steenbrink, F. and Esquenazi, A. 2018. “Getting the Best Out of Advanced Rehabilitation Technology for the Lower Limbs: Minding Motor Learning Principles.” *PM and R* 10(9):S165–73. doi: 10.1016/j.pmrj.2018.06.007.

Zhang, M., and Mak, A. F. T.. 1999. “In Vivo Friction Properties of Human Skin.” *Prosthetics and Orthotics International* 135–41. Retrieved May 18, 2021 (http://www.oandplibrary.org/poi/1999_02_135.asp).

Zontak, A., Sideman, S. Verbitsky, O. and Beyar, R.. 1998. “Dynamic Thermography: Analysis of Hand Temperature during Exercise.” *Annals of Biomedical Engineering* 26(6):988–93. doi: 10.1114/1.33.

Corresponding author:

Karmen Šibanc
Faculty of Sport, University of Ljubljana
Gortanova 22, 1000 Ljubljana, Slovenia
e-mail: karmen.sibanc@fsp.uni-lj.si
Tel. num.: +38640473193

Article received: 8. 5. 2023
Article accepted: 21. 9. 2023