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Acute effects of partial-body cryotherapy on isometric strength: maximum handgrip strength evaluation

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Abstract:	The aim of the study was to evaluate the influence of a single partial-body cryotherapy (PBC) session on the maximum handgrip strength (JAMAR Hydraulic Hand dynamometer). Two hundred healthy adults were randomized into a PBC group and a control group (50 males and 50 females in each group). After the initial handgrip strength test (T0), the experimental group performed a 150 seconds session of PBC (temperature range between -130 and -160 °C), whilst the control group stayed in a thermo neutral room (22.0 ± 0.5 °C). Immediately after, both groups performed another handgrip strength test (T1). Data underlined that both groups showed an increase in handgrip strength values, especially the experimental group (Control: T0=39.48 kg, T1=40.01 kg; PBC: T0=39.61 kg, T1=41.34 kg). The analysis reported also a statistical effect related to gender ($F=491.99$, $P<0.05$), with females showing lower handgrip strength values compared with males (females=30.43 kg, males=52.27 kg). Findings provide the first evidence that a single session of PBC leads to the improvement of muscle strength in healthy people. The results of the study implies that PBC could be performed also before a training session or a sport competition, to increase hand isometric strength.
Response to Reviewers:	RE: JSCR-08-7978, entitled "Acute effects of partial-body cryotherapy on isometric strength: maximum hand grip strength evaluation" Dear Editor, We would like to thank the reviewers for their review. We have addressed every comment made and marked the changes in the manuscript in red bold font.

Make sure your human use informed consent is worded per author instructions and that if you include anyone who is under the age of 18 years of age, parental or guardian consent has been given and noted in this section. Please give the age range if your mean and SD suggest the subjects may have been under the age of 18 years.
A: We have included the Ethics Committee approval of our project and we have added in the manuscript that everyone was all of age.
2. Make sure that your affiliation information or contact information for the corresponding author are on the title page of the paper as the title only page is used for the blinding;
A: We have double-checked carefully all files and confirm that affiliation information or contact information only appear in the title page, as required by the JSCR.

3. Make SURE you have all your tables and figures attached and noted in the paper both text and where it should be placed.
A: We have double-checked carefully all figures and tables and we confirm that each one of them is presented as separated attachments. In the main document figures and tables are noted and along the text is clarified where they should be placed. To the bottom of the text figures and tables captions are displayed.

4• Very IMPORTANT ---Table files must be MADE in Word NOT copied into Word!
A: All table files are made in Word.

5. No PDFs submitted just Word and appropriate files e.g., PPT for figures as a final pdf will be produced by EM for your approval.
A: All submitted files are in Word.

6. Check all formatting and titling and make sure it is correct or this can delay publication in the process. Please read carefully the newest author instructions as well and comply.
A: We have double-checked all formatting and titling and they confirm the correctness of all submitted files.

7. Make sure each table and figure is cited in the text and part of the revision, not just the original submission.
A: We have double-checked carefully all tables and figures and they confirm that each one of them is cited correctly in the text and part of the revision, not just the original submission.

8. No black eyes or masking of the face of subjects in pictures.
A: We have added a picture of the cryo-cabin without masking the face of the subject.

Reviewer 1
1. Rationale for the time in PBC, why hand grip strength, prior exposure or use of it and familiarization.
A: We have already included the information about rationale for the time in PBC (we cited the reference number 11), we have already included motivations the reasons that led us to evaluate handgrip strength and we have also added the motivations about the choice of assess the handgrip strength by an hydraulic dynamometer. We have also added information about use of PBC and familiarization with the testing protocol.

2. Abstract unclear as you use this rotation information that is not clear why? Methods unclear as to the type of PBC used.
A: We have modified our abstract. We have already include the information about the type of PBC used to the first version of the manuscript (Space Cabin, Criomed Ltd, Kherson, Ukraine).

3. Use term sex as gender is more than XX XY. Also men and women as we know the species is human.
A: We agree with the reviewer. We had replaced the term sex by the term gender (p. 9 line 8)

4. Compare HGS to other normative data so we can see context.
A: The aim of our study was to evaluate the effect on handgrip strength referable to a single partial-body cryotherapy as Δ from T0 to T1 as different moments before and

after PBC session and not the absolute handgrip strength values. Nevertheless, we compared the mean and standard deviation handgrip strength values emerged in our study with previously published normative international data, selecting them by age groups and gender. We obtained for male group, as presented in Table 2, from 47.8 to 52.3 with a standard deviation equal to 6.7-7.8 kg, who showed means values about 46.2-51.6 with a standard deviation equal to 9.6-10.3 kg (Dodds et al., 2014). Also European and North American males reported a similar range (50-51 kg as median 25th-75th percentile), while are certainly higher the normative reference values for the German males with means from 47.8 to 57.3 kg (Steiber, 2016). About females our means had a range from 28.4 to 31.7, with standard deviation equal to 6.5-8.7, and these values are higher than British ones 27.5-31.4 with standard deviation 6.0-6.4 kg, but even if lower than generalized European and North American females data (30-31 kg as median 25th-75th percentile). Normative reference values for the German females of the same age classes, are no doubtless heigher than our collected data, with means from 29.8 to 38.0 kg (Steiber, 2016).
Actually, interpopulation variability in Europe is evident if different national specific researches are compared: for example, the normative values from Switzerland (Werle at al., 2009) were on average of 11% higher than British ones (Dodds, et al., 2014). More recently, German normative reference values have pointed out even higher levels than Swiss's ones (Steiber, 2016). Hight variability is documented among different populations also if you compare normative groups coherent by age and gender both into Europe, for example between north and south populations (Massy-Westropp et al., 2011). Moreover, among populations that belong to different continents: HGS values are highest among those from Europe/North America, lowest among those from South Asia, South East Asia and Africa, and intermediate among those from China, South America, and the Middle East. (Leong et al., 2016).
Dodds RM, Syddall HE, Cooper R, Benzeval M, Deary IJ, Dennison EM, et al. (2014) Grip Strength across the Life Course: Normative Data from Twelve British Studies. PLoS ONE 9(12): e113637. doi:10.1371/journal.pone.0113637.
Leong DP, Teo KK, Rangarajan S, Kutty VR, Lanas F, Hui C, Quanyong X, Zhenzhen Q, Jinhua T, Noorhassim I, AlHabib KF, Moss SJ, Rosengren A, Akalin AA, Rahman O, Chifamba J, Orlandini A, Kumar R, Yeates K, Gupta R, Yusufali A, Dans A, Avezum Á, Lopez-Jaramillo P, Poirier P, Heidari H, Zatonska K, Iqbal R, Khatib R, Yusuf S. Reference ranges of handgrip strength from 125,462 healthy adults in 21 countries: a prospective urban rural epidemiologic (PURE) study. J Cach Sarcop Musc.. 2016 Apr 12. doi:10.1002/jcsm.12112.
Massy-Westropp N.M., Gill T.K., Taylor A.W., Bohannon R.W., Hill C.L., 2016. Hand Grip Strength: age and gender stratified normative data in a population-based study. BMC Res Notes. 2011; 4: 127. Published online 2011 Apr 14. doi: 10.1186/1756-0500-4-127.
Steiber N., 2016. Strong or Weak Handgrip? Normative Reference Values for the German Population across the Life Course Stratified by Sex, Age, and Body Height. PLoS One. 2016; 11(10): e0163917. Published online 2016 Oct 4. doi: 10.1371/journal.pone.0163917.
Werle S, Goldhahn J, Drerup S, Simmen BR, Sprott H, et al. (2009) Age- and gender-specific normative data of grip and pinch strength in a healthy adult Swiss population. J Hand Surg [Eur]. 34: 76–84.

5 Figure of the experimental PBC should be added, no black eyes.
A: A figure of the PBC used in the experimental protocol was added, see Figure 1.

6. Effect sizes needed
A: We added partial eta-square (η2) effect sizes

7. What time of year for environmental conditions
A: We have included that information to the manuscript (Procedures).

8. I am so confused PBC did it include the upper body musculature, in a room temp etc. you need figure, digitals and detailed methods.
A: We have included information about body exposition during a PBC session to the manuscript (introduction and methods) and a figure of the experimental PBC.

9. Reliability of the testing, ICCRs.
A: Using the Intraclass Correlation Coefficient (ICC) and the ANalysis Of VAriance

(ANOVA) the variance due to the trials, the days and the subjects are assessed. It is current practice to classify as “excellent repeatability” ICC values in the range 80%–100% and as “good repeatability” ICC values in the range 60%–80%, whereas values below 60% indicate “poor repeatability” (Bartko, J., 1966. "The intraclass correlation coefficient as a measure of reliability." Psychol Report 19: 3-11.). Results of the present study showed a high intraclass correlation (ICC 0.987) (95% CI .975, .992), as added in the result session. The standard error of the mean (SEM) was also calculated and added in Table 2. A 95% confidence interval was considered, as added in the statistical analysis session.

Reviewer #2

1. Interesting paper but the data on cryotherapy is variable, so why not more than one measure, other data etc. See work in JSCR on negative things on cold immersion as it takes down whole body performance, see two papers on this from Kraemer WJ our editor’s lab. Why so limited dependent variable set as used? The introduction needs to be hypothesis driven based on this variability of recovery etc and underlying physiology on nerve conduction velocities etc. to allow the reader to see the basis of your hypothesis. It also needs to be clear what the practical question is that you are trying to address. How is the answer to this question important to the field as this is not clear or obvious? How is this study and impactful study and not trivial as this needs more clarity as well. The key issue here is to make sure you set up your approach to the problem.

A: We thank the reviewer for the recommended references, we added them in our paper. We noticed that Kraemer WJ in 2010 used only one measure (power output) in his study about the benefits of a dynamic exercise warm-up after cold-water immersion. We have chosen to evaluate one measure because our goal was to give empirical support to those who daily perform whole-body cryotherapy by a pratical fied instrument as a handgrip dynamometer. In literature (De Nardi, 2015), a similar dependent variable set has been used for evaluate flexibility after a single PBC session. We have modified the introduction, the experimental approach to the problem and the practical applications sessions.

2. The formatting of the paper needs another look and careful formatting. The Experimental Approach to the Problem must be clear as to how this design will be able to test the hypothesis and answer the practical question posed in the introduction.
A: We have double-checked all formatting and titling in line with the journal's website for instructions to authors. We have modified the experimental approach to the problem session.

3. The methods must be clear so that the study can be replicated as to equipment, subjects context of training level and where they are in their training cycle and rationales for the design for each independent and dependent variable as we need to know more about the subjects, any procedures, etc. This needs to be very highly specific as to source of equipment etc. you need some figures with the equipment as it is abstract as presented.
A: We have added more information about age of subjects and their context of training level, rationale for the handgrip strength and PBC exposure. We have also added a figure of the cryocabin used in our study (see fig.1).

4. The statistical analysis is non-existent as to how the data were analyzed in respect to the hypotheses to be tested. What was the test retest reliability e.g., ICCRs SEM and what are your confidence intervals.
A: A: Using the Intraclass Correlation Coefficient (ICC) and the ANalysis Of VAriance (ANOVA) the variance due to the trials, the days and the subjects are assessed. It is current practice to classify as “excellent repeatability” ICC values in the range 80%–100% and as “good repeatability” ICC values in the range 60%–80%, whereas values below 60% indicate “poor repeatability” (Bartko, J., 1966. "The intraclass correlation coefficient as a measure of reliability." Psychol Report 19: 3-11.). Results of the present study showed a high intraclass correlation (ICC 0.987), as added in the result session. The standard error of the mean (SEM) was also calculated and added in Table 2. A 95% confidence interval was considered, as added in the statistical analysis session.

	5. Subject informed consent must be consistent with the author guidelines and wording needed as JSCR uses the MSSE ACSM guidelines per the author instructions. A: We have included the Ethics Committee approval of our project and we have added in the manuscript that everyone was all of age. 6. What is the training background coming into the study and what time of year etc were they tested. A: We have added the time of the year when subjects were tested and also information about prior exposure to cryostimulation. 7. What about controls for time of day testing, nutrition, hydration etc. A: We have included information about controls for time of day testing, nutrition, hydration etc. (METHODS-Subjects). 8. The clarity of the paper needs to be improved a bit and qualified where appropriate as you need to stick to what your experimental design can tell us with your data and limit speculation or qualify it and make sure statements are referenced. A. We agree with the reviewer, we have tried to improve the clarity of our paper. 9. The discussion needs to reflect what you found, how it relates to the literature and then what it means physiologically or from a practical aspect and each paragraph should be logical in sequence as at present it is a bit hard to follow. A: We have modified our discussion. 10. The practical application should be relevant to the coach, make sure in any revision allowed you do not call for more research in this section. What should the coach or practitioner now do after reading your paper, does it affect practice is the key factor in this section, check it over. A: We have modified our practical applications session. 11. Check JSCR literature base for related papers for connection for this line of research in the journal check JSCR literature base for related papers for connection for this line of research in the journal. A: We double-checked JSCR literature: we had already included a related paper about the effects of a single whole-body cryotherapy exposure on physiological, performance and perceptual responses of professional academy soccer players (Russel et al., 2016). We have added a recent paper about the use of the jamar dynamometer (Guerra et al., 2016) and the paper suggested before written by Kraemer WJ and colleagues (2010). 12. Any grant funding and not representative of the NSCA or endorsed by it per author instructions needs to be carefully worded, see new author guidelines for this. A: Authors rewrote the Acknowledgements session. 13. Make sure you double check your subtitles (see author instructions and writing tips) and also language for proper grammar and syntax and if needed get help. A: All subtitles were double checked in line with the author instructions and writing tips. A native English speaker revised grammar and syntax of the entire paper.

MANUSCRIPT TITLE: Acute effects of partial-body cryotherapy on isometric strength: maximum handgrip strength evaluation

RUNNING TITLE: Cryotherapy influence on hand grip strength

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Abstract

The aim of the study was to evaluate the influence of a single partial-body cryotherapy (PBC) session on the maximum **handgrip** strength (JAMAR Hydraulic Hand dynamometer). Two hundred healthy adults were randomized into a PBC group and a control group (50 males and 50 females in each group). **After the initial handgrip strength test (T0), the experimental group performed a 150 seconds session of PBC (temperature range between -130 and -160 °C), whilst the control group stayed in a thermo neutral room (22.0 ± 0.5 °C). Immediately after, both groups performed another handgrip strength test (T1).** Data underlined that both groups showed an increase in handgrip strength values, especially the experimental group (Control: T0=39.48 kg, T1=40.01 kg; PBC: T0=39.61 kg, T1=41.34 kg). The analysis reported also a **statistical** effect related to gender ($F=491.99$, $P<0.05$), with females showing lower handgrip strength values compared with males (females=30.43 kg, males=52.27 kg). Findings provide the first evidence that a single session of PBC leads to the improvement of muscle strength in healthy people. The results of the study implies that PBC could be performed also before a training session or a sport competition, to increase hand isometric strength.

Keywords

cryocabin, hand dynamometer, muscle performance, cryostimulation

INTRODUCTION

Muscle contraction is defined by the changes in length of the muscle during contraction: it can be classified into isotonic or isometric. Isometric contraction occurs when the muscle tenses without changing its length. It is required in some sports (for example climbing and gymnastics) and in physical and handwork activities. Isometric contraction is typical of muscles found in the hands and forearms. Many daily functions and sporting events require high activity levels of the flexor muscles of the forearms and hands. The most common method of assessment for grip strength is the use of a handheld dynamometer. This measurement may provide over all body strength and muscles performance, individual nutritional status and **well-being**, by a simple and non-invasive evaluation **(28).** During gripping activities, the muscles of the flexor mechanism in the hand and forearm create grip strength, while the extensors of the forearm stabilize the wrist **(31).** It is known that temperature is a relevant determinant of muscles performance **(19, 22). With regards to the cold, it can induce for example increased tissue stiffness (27), decreased nerve conduction velocity and decreased muscle contractility. These effects could reduce athletic performance (11).** Isotonic and isometric strength respond differently due a decrease in temperature **(14, 26, 18). In fact we know (30) that dynamic activities are more susceptible to the inhibitory effects of cold than isometric contractions. Thus interestingly** some studies reported that a cold application is an effective way to increase isometric strength **(18,** 5). The human body responds to cold applications with vasoconstriction to maintain the core temperature. After this first response usually the opposite phenomenon occurs, that is vasodilation, which increases muscle blood-flow with increased oxygen supply, therefore potentially improving muscle performance (**10**).

Cryotherapy is the application of cold agents: it is based on body temperature diminution through, for instance, immersion into cold-water, application of ice packs or ice vests. Its use is widespread in sports medicine today and the application of cold has been found to decrease the inflammatory reaction, the pain threshold, swelling, edemas and to reduce the recovery time both after acute and chronic injuries **(29, 16, 17).** One of the latest methods in sports medicine and science is whole-body cryotherapy (WBC). WBC is based on the stimulation with very cold air of the organism of minimally dressed subjects (usually from -110°C up to -160°C), either in a specially designed chamber (WBC) or a cabin (partial-body cryotherapy, PBC), for a short period (generally from 150 seconds to 180 seconds), aiming to cause the vasoconstriction of skin vessels (2). **The substantial difference between these two kinds of cryostimulation treatments is that during a cryocabin session (PBC) the head is not exposed (see figure 1).** WBC **and PBC are** repeatedly used in sports practice to

hasten the recovery after high-intensity exercise and increase the range of motion (**8, 10**). In the last decades, despite the increasing popularity of WBC **and PBC** in sports and exercise medicine, few studies have investigated the effectiveness of **these treatments** on muscle-performance recovery after exercise in adults (1, **8**), but to the authors' best knowledge, no studies have examined the acute effects of **cold dry air exposure** on the maximum isometric strength. **The hypothesis of this study were therefore that a single PBC session would not significantly worsen the handgrip maximum isometric strength**. Considering the small differences in physiological reactions between WBC and PBC short exposure **(15)**, the aim of the present study was to test the hypothesis that a single PBC session could influence the maximum **handgrip** strength as measured by a hydraulic hand dynamometer. **There are many categories of handled dynamometer, and according to the literature (31), the handgrip dynamometer is a method of assessment which can provide the practitioner the most accurate choice, in addition to be an inexpensive tool and easy to use on the field.**

METHODS

Experimental Approach to the Problem

There are limited data about the effects of the cryogenic temperatures on isometric strength. Consequently, to evaluate the effects of a single PBC session performed before a maximum handgrip strength test, one hundred healthy men and one hundred healthy women were required to be present for one time at the testing venue. Both men and women populations were divided in experimental and control groups to assess the differences in maximum isometric strength after 150 seconds of standing rotations carried out in a cryocabin or in a thermo neutral room. **The study was a 2 (Control or PBC) x 2 (T0 and T1) design. This allowed us to determine the impact of the PBC on handgrip maximum isometric strength.**

Subjects

All volunteers **were adults** and underwent an initial physical examination by the qualified physician; all participants with epicondylitis, chronic shoulder pain, episodes of fractures wrist, and disabilities in their upper extremities and contradictions to PBC were excluded from the study. **Subjects were all recreational athletes and were not accustomed to partial body treatments. To minimize the effects of circadian variation, the timing of measurements were consistent between trials. Subjects were also instructed to refrain from consuming alcohol, caffeine, theine or hot drinks 24 hours before testing commenced in order to avoid influencing the recorded variable. In addition, participants were required not to undertake exercise for 24 hours prior to the laboratory trial.** They were also instructed not to take medications or supplements during the study. One hundred men and one hundred women were enrolled in the study**, approved by the National Medical Ethics Committee,** and signed a written informed consent. The research was undertaken in compliance with the Helsinki Declaration. Subjects were then randomly divided into a PBC and a control group (50 males and 50 females in each group). Socio-demographic information for each group is shown in Table 1.

****INSERT TABLE 1 NEAR HERE****

Procedures

Upon arrival, the participants were made to sit for 30 minutes wearing only swimwear, socks and wooden clogs to acclimate to the room temperature (22.0 ± 0.5 °C). Following acclimation, each participant performed the maximal handgrip strength test of the dominant hand (**17**) using a portable JAMAR Hydraulic Hand dynamometer (Sammons Preston Rolyan Nottinghamshire, UK) as recommended for use in healthy people (4,3). It was regulated for each subject: fitting the hand and allowing flexion at the metacarpophalangeal joints. **When the individual adjustment operations were completed, each subject performed three submaximal voluntary isometric contractions maintained for 5 seconds as familiarization to the testing protocol**. The scale of the dynamometer indicated **handgrip** strength in kilograms (kg).

Our experiment was conducted in May and June. The testing protocol consisted of three maximal voluntary isometric contractions maintained for 5 seconds with rest period of at least 60 seconds; the highest value was used for the determination of the maximal grip strength. The procedure and the methodology used during the **handgrip** strength test were carried out according to the standards **(20).** Specific verbal instructions were given to subjects before the evaluations and the experiments were performed with verbal encouragement **(24).**

The PBC group, following the baseline **handgrip** strength measurement (T0 PBC), completed one treatment in a cryocabin (Space Cabin, Criomed Ltd, Kherson, Ukraine), **an open tank equipped with a mobile lift which allows to adjust the height of every subject, so the guest is exposed to the very cold dry air up to the shoulders, with the neck and the head out of the cabin. This device can accommodate only one subject for each session (see figure 1). The** 150 seconds duration and set temperature range between -130 and -160 °C were used as recommended for cryocabin sessions **(13).** During the session subjects wore swimwear, a pair of gloves, woolen socks and wooden clogs. Participants were instructed to turn around continuously (standing rotations) in the cabin for the 150 seconds session. The control group, following the baseline measurement (T0 Control), was instructed to perform the same movements (standing rotations) for the same duration (150 seconds) in the turned off cryocabin (22.0 ± 0.5 °C). After the cryocabin treatment (T1 PBC) or control duty (T1 Control), the maximal handgrip strength test was repeated.

****INSERT FIGURE 1 NEAR HERE****

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) for windows (SPSS 22.0, Inc., Chicago, IL, USA) was used for statistical analysis. Data are presented as mean ± standard deviation (SD).

A series of independent t-tests was used to evaluate any possible differences in the anthropometric characteristics and differences among **handgrip** strength values both in female and male PBC and control groups.

A mixed-design repeated measures ANOVA was used to analyze handgrip strength values. Time (T0,T1) was the within-subjects factor, whereas Group (PBC and control) and Gender were the between-subjects factors. For all analyses, statistical significance was set at $\alpha = 0.05$.

Partial eta-square (η^2) effect sizes were determined and interpreted using the following criteria: 0.01 = small; 0.06 = medium; and 0.13 =large.

RESULTS

Age, weight, height, BMI were not significantly different between PBC and control groups at baseline (P>0.05) both in male and in female groups. Descriptive statistics regarding the **handgrip** strength values in all groups of participants are shown in Table 2. Whereas control group increased **handgrip** strength (mean values) from T0 to T1 around 0.5 kg in both genders, PBC group showed an increase of around 1.5 kg in males **(Fig.2)** and around 2 kg in females **(Fig.3).**

****INSERT TABLE 2 NEAR HERE****

****INSERT FIGURE 2 NEAR HERE****

****INSERT FIGURE 3 NEAR HERE****

A high intraclass correlation emerged (ICC 0.987), (95% CI .975, .992) The results of the ANOVA showed a significant main effect of exercise (continuously standing rotations) in both groups ($F_{1.196}$=45.59, P<0.05, **η2=.189**) on **handgrip** strength increase and a significant Exercise x Group interaction ($F_{1.196}$=12.77, P<0.05**, η2=.061**). Both PBC and control groups showed an increase in **handgrip** strength values compared with T0 (T0=39.55 kg, T1=40.68 kg), especially in the experimental group (Control: T0=39.48 kg, T1=40.01 kg; PBC: T0=39.61 kg, T1=41.34 kg) **(Fig.4-5).** The analysis reported also a significant effect of Gender ($F_{1.196}$=491.99, P<0.05**, η^2=.715**), with female participants showing lower **handgrip** strength values compared with male participants (females=30.43 kg, males=52.27 kg).

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****INSERT FIGURE 4 NEAR HERE****

****INSERT FIGURE 5 NEAR HERE****

DISCUSSION

The aim of this study was to test the hypothesis that a single PBC session **would not significantly worsen the handgrip maximum isometric strength** as measured by a hydraulic hand dynamometer in a large population of healthy men and women. We found an increase, compared to baseline, of the maximum handgrip strength after a short time period (150 seconds) both in the control group and in PBC group. Our results confirmed that immediately after a PBC session there was a more remarkable increase in **handgrip** strength compared to baseline and to the control group. **Although further investigation is warranted, from a practical perspective, the use of PBC may be important for individuals who practice activities where isometric strength is required (e.g., climbing and racket sports).**

The results reported in the present study are in line with others that evaluated the effect of cold agents on the maximal isometric force (5, **18, 30**). In fact, a 10-minute cold bath provided an increase of the maximum isometric force production of the hip extensor significantly greater than that of the control and hot bath (water at 43°C) groups (5). Furthermore Burke et al. found a **gender** difference in the cold group, with men experiencing greater increases. Additionally, a previous study verified that after placing ice on the arm for 15 minutes, muscle force increased significantly and, in line with our findings, even in the control group there was a minimal increase in strength compared to baseline (**18**). **Also Vieira et al. (30) reported that 20 minutes of ice-pack application increased isometric peak torque of plantar flexors ($p<0.001$) in healthy men.**

The muscle temperature **immediately after a PBC session is not known**, but is known (**13**) that skin temperature of the forearm is near to 23°C. **Only one study, to the authors' best knowledge, evaluated the muscle temperature after a WBC session: Costello et al. (7) measured vastus lateralis temperature and recorded significantly lower temperatures ($p<0.05$) only after 20, 30, 40, 50 and 60 min after WBC. No significant differences ($p>0.05$) were found immediately and 10 min after the cryogenic exposure.** Therefore, it has been documented that a reduction on muscle temperature below the threshold of 27°C could decrease the maximal isometric force level (6). Hence, it would make sense, according to Westerlund (**32**), to assume that a single **cold dry air** exposure in PBC does not lead to reach the threshold of 27°C for the muscle temperature **immediately after the session**, under which a decrease of the maximal isometric force level occurs. To confirm this, immediately after a PBC exposure we noticed an increase of the maximal hand grip strength, that may be induced by the vasodilation occurred after the PBC session, which determines an increased

blood flow to muscles and, according to Nodehi Moghadami et Dehghane (**18**), this may have a beneficial effect on muscle function. **At the same time other authors (12, 30) suggested that the increase in isometric strength after cold exposures could depend to a compensatory mechanism that fosters the recruitment of higher threshold motor units in response to the inhibition caused by cooling, considering that this mechanism is prominent in isometric contractions due to lower dependence on this activity in relation to tissue stiffness caused by cooling.**

PRACTICAL APPLICATIONS

The results of the present study provide the first evidence that a single session of PBC **can have a significant and positive impact on isometric** strength in healthy people. This is of practical value for coaches and practitioners aiming to include this treatment in order to improve isometric strength. Again, our results represent a new approach to the longstanding problem of the PBC protocols standardization. In fact, in the light of what has emerged, **it is now clear that coaches can scheduled PBC sessions** also before a training session or a competition, such for example climbing, **racket sports** and gymnastics ring performances, where hand isometric strength is required.

REFERENCES

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FIGURE LEGENDS:

Figure 1. Subject during a cryocabin (Space Cabin, Criomed Ltd, Kherson, Ukraine), session.

Figure 2. T test partial-body cryotherapy male group before cryotherapy (PBC T0) versus partial-body cryotherapy male group after cryotherapy session (PBC T1) $p<0.007$.

Figure 3. T test partial-body cryotherapy female group before cryotherapy (PBC T0) versus partial-body cryotherapy female group after cryotherapy session (PBC T1) $p<0.0001$.

Figure 4. T test partial-body cryotherapy female and male groups before cryotherapy (Control T0) versus partial-body cryotherapy female and male groups after cryotherapy session (Control T1) $p<0.007$.

Figure 5. T test partial-body cryotherapy female and male groups before cryotherapy (PBC T0) versus partial-body cryotherapy female and male groups after cryotherapy session (PBC T1) $p<0.0001$.

Table 1

Table 1. Socio-demographic information of the participants (mean ± SD). PBC, partial-body cryotherapy.

Groups	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
Male				
PBC (n=50)	42.42 ± 14.17	178.02 ± 7.1	79.41 ± 9.52	25.21 ± 3.14
Control (n=50)	37.12 ± 9.32	177.2 ± 5.3	76.12 ± 12.01	24.18 ± 3.61
Female				
PBC (n=50)	41.26 ± 11.73	165.0 ± 5.1	62.0 ± 7.95	22.79 ± 2.79
Control (n=50)	39.56 ± 11.38	167.12 ± 6.2	64.94 ± 7.79	23.38 ± 3.03

Table

Table 2. Descriptive statistics of handgrip strength values (kg) at T0 and T1 in each group of participants. PBC, partial-body cryotherapy. **SD= standard deviation. SEM= standard error of the mean.**

Gender	Groups		T0	T1
Female	Control (n=50)	Mean	31.15	31.68
		SD	5.43	4.99
		SEM	**0.77**	**0.70**
	PBC (n=50)	Mean	28.47	30.43
		SD	4.45	4.06
		SEM	**0.63**	**0.57**
	Total sample (n=100)	Mean	29.81	31.05
		SD	5.12	4.57
		SEM	**0.51**	**0.46**
Male	Control (n=50)	Mean	47.81	48.35
		SD	6.74	6.54
		SEM	**0.95**	**0.92**
	PBC (n=50)	Mean	50.75	52.27
		SD	8.77	7.76
		SEM	**1.24**	**1.09**
	Total sample (n=100)	Mean	49.28	50.31
		SD	7.92	7.41
		SEM	**0.79**	**0.74**
Female + Male	Control (n=100)	Mean	39.48	40.01
		SD	10.35	10.18
	PBC (n=100)	Mean	39.61	41.35
		SD	13.16	12.59
	Total sample (n=200)	Mean	39.55	40.68
		SD	11.81	11.44

Figure

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Figure

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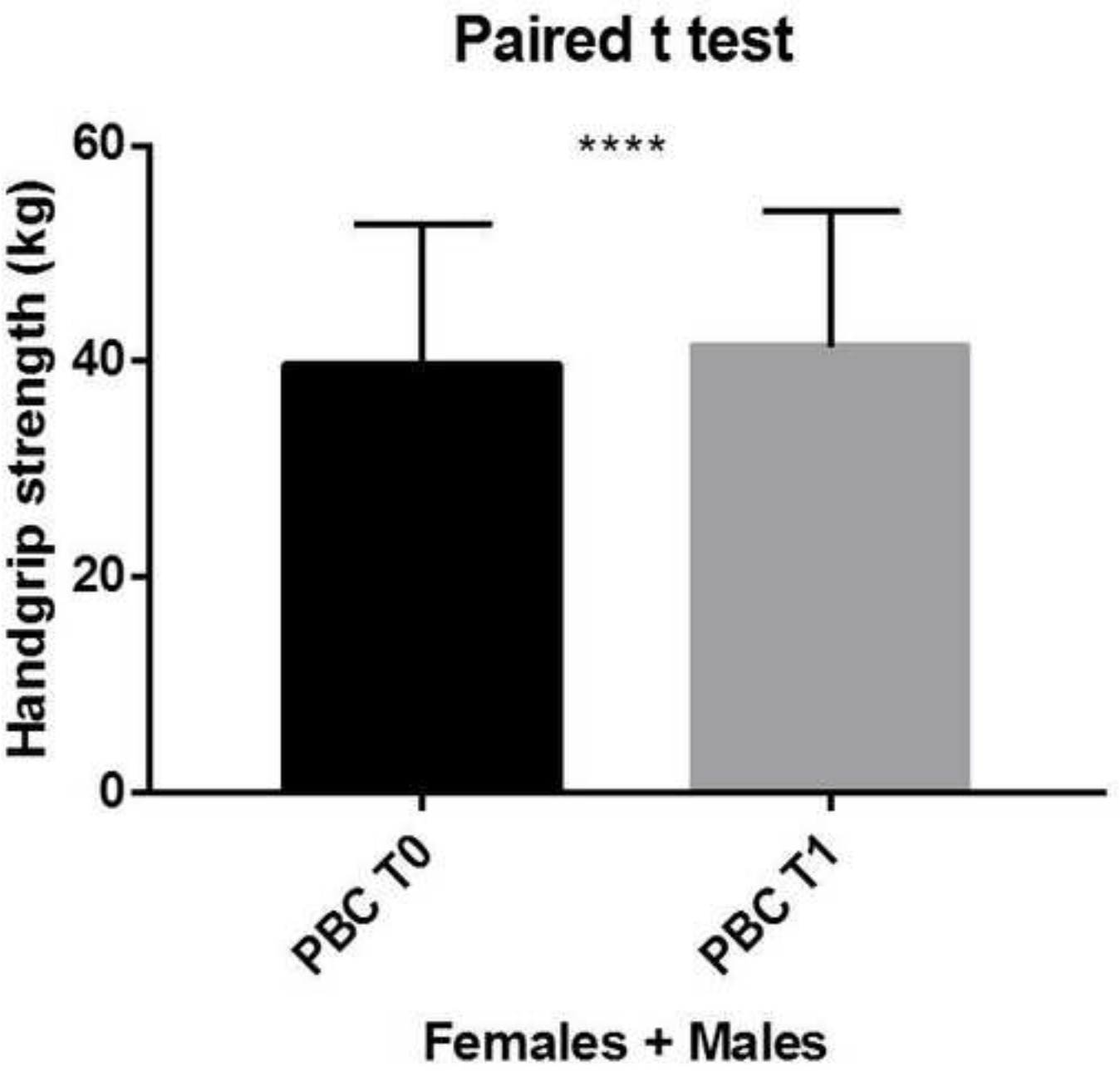

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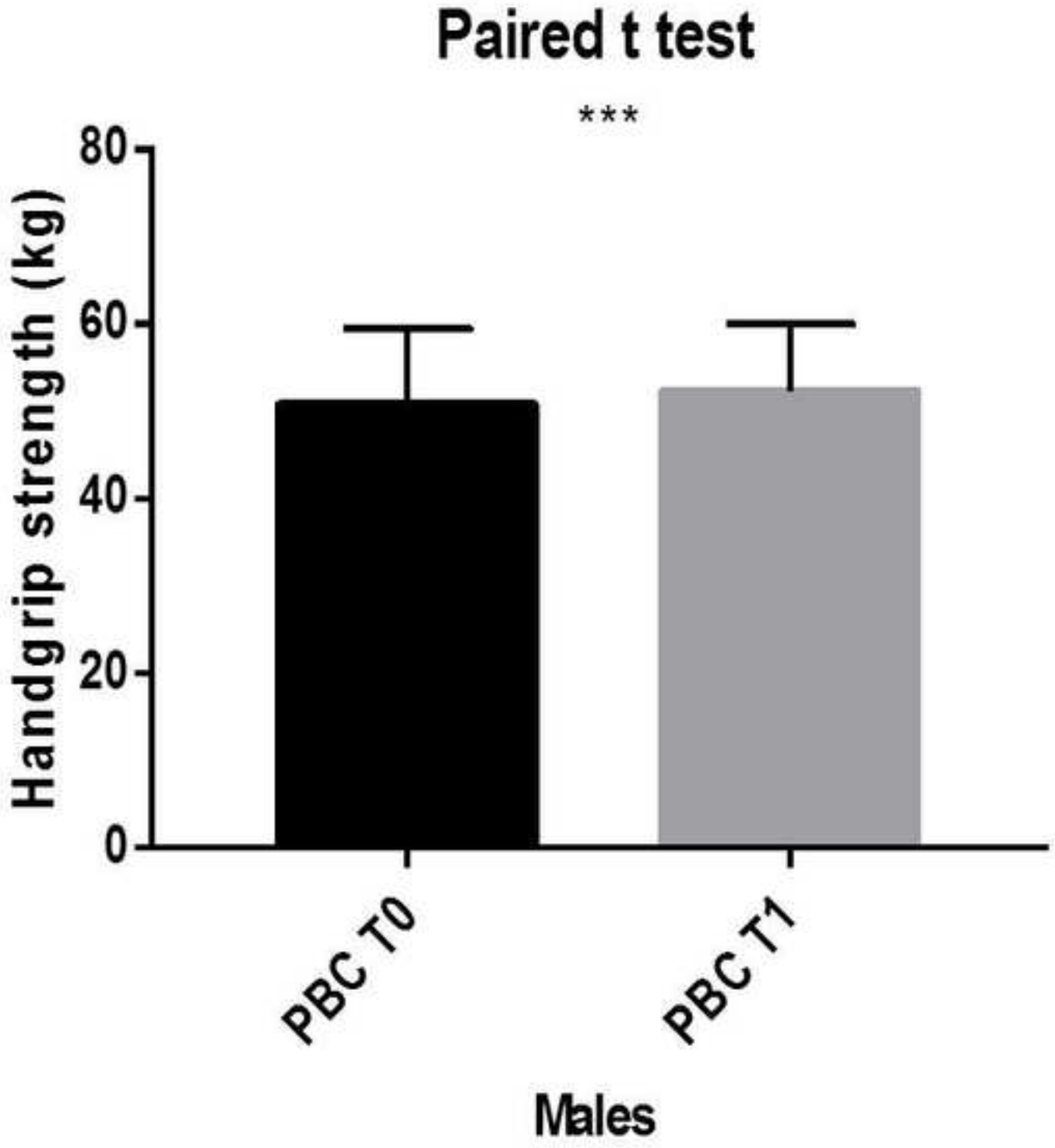

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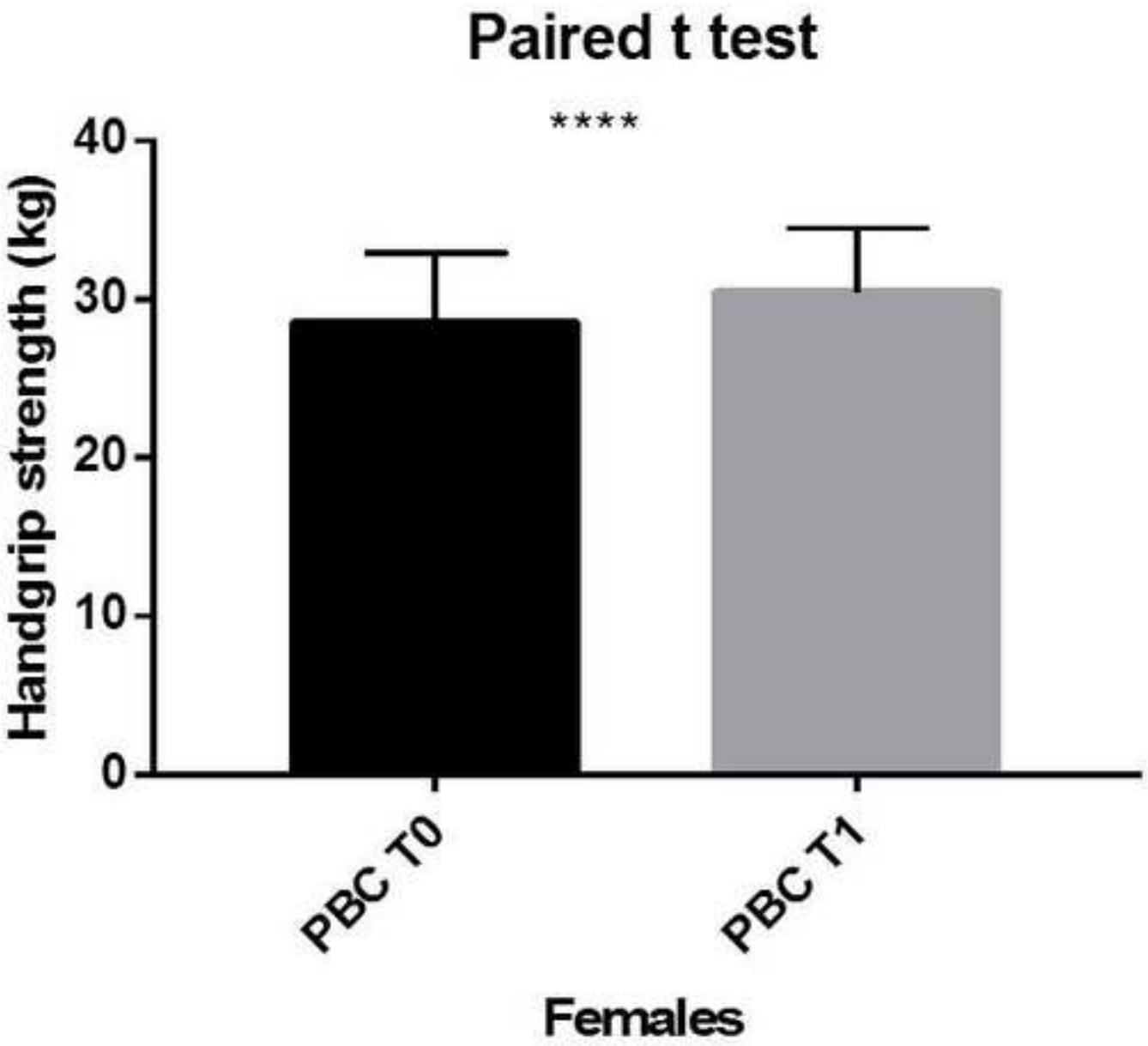

Figure

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