Effects of Cold Water Immersion on Knee Joint Position Sense in Healthy Volunteers.

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The purpose of this study was to determine the effects of cryotherapy, in the form of cold water immersion, on knee joint position sense. In this randomised cross-over trial, fourteen healthy volunteers, with no previous knee injury or pre-existing clinical condition, participated in this study. The intervention consisted of a thirty minute immersion, to the level of the umbilicus, in either cold (14 ± 1°C) or tepid water (28 ± 1°C). Approximately one week later, in a randomised fashion, the volunteers completed the remaining immersion. Active ipsilateral limb repositioning sense of the right knee was measured, using weight-bearing and non weight-bearing assessments, employing video recorded 3D motion analysis. These assessments were conducted immediately pre and post a cold and tepid water immersion. No significant differences were found between treatments for the absolute (p = 0.29), relative (p = 0.21) or variable error (p = 0.86). The average effect size of the outcome measures was modest (range -0.49 to 0.9) and all the associated 95% confidence intervals for these effect sizes crossed zero. These results indicate that there is no evidence of an enhanced risk of injury following a return to sporting activity, after cold water immersion.

Key words: Cryotherapy, Joint Position Sense, Proprioception, Pre-Cooling, Knee Injury
Introduction

Cryotherapy or “cold therapy” is commonly employed by physiotherapists, clinicians, athletes and others for various clinical reasons. Cryotherapy has been used for decades by sports people to decrease pain, swelling, secondary hypoxic injury, arterio/venous constriction, relieve muscle spasm, facilitate movement and to reduce core and skin temperature (Knight, 1995). More recently cryotherapy before exercise, or pre-cooling, has been reported to improve endurance activities in humid conditions (see Quod et al 2006 for a review). Similarly a number of authors have suggested that pre-cooling may allow individuals with multiple sclerosis to exercise with greater physical comfort (White et al 2000, Kinnman et al 2000). However, cryotherapy users should also consider the potential negative effects of pre-exercise cryotherapy on proprioception and neuromuscular functioning.

Decreases in muscle temperature, following cryotherapy, have been shown to reduce muscle force and muscle power (Sargeant 1987), possibly due to a reduction of myosin ATPase activity. Similarly reductions in tissue temperature have been shown to decrease nerve conduction velocity (Algafly & George 2007), by reducing action potential propagation. Limited research is available on the potential of cryotherapy, especially in the form of cold water immersion, to reduce proprioceptive acuity. Proprioceptive acuity, which is a component of the sensorimotor system (Riemann and Lephart 2002a, 2002b), has previously been defined as an individual’s ability to sense joint position, movement and force to discriminate movements of their limbs (Gandevia et al 2002). Muscle spindles
and skin stretch receptors play a major role in position sense (Proske and Gandevia 2009). As cold water decreases skin, intramuscular and rectal temperature (Peiffer et al 2009a, 2009b), where the muscle spindles and skin stretch receptors are located, it is possible that knee joint position sense may be altered. The resultant abnormal proprioception could potentially predispose musculoskeletal pathology by altering movement control and hence leading to abnormal stresses being exerted on tissues (Baker et al 2002).

To date no study has addressed the effects of cold water immersion on knee Joint Position Sense. Several studies have suggested that cryotherapy before exercise may change the biomechanical properties of the joint, resulting in inadequate peripheral feedback and potentially lead to injury when rehabilitation or exercise is resumed (Uchio et al 2003, Hopper et al 1997, Surenkok et al 2008, Oliveira et al., 2010). As cold exposure has previously been shown to reduce nerve conduction velocity (Algafly and George 2007, Ochs and Smith 2004), balance (Makinen et al 2005) and alter neuromuscular transmission in muscles (Coulange et al 2006), it is possible that cold water immersion could also reduce knee joint position sense. Five studies (Surenkok et al 2008, Uchio et al 2003, Hopper et al 1997, Sekihara et al 2007, Oliveira et al al 2010) have previously reported a reduction in joint position sense acuity post cryotherapy treatment, while four others (Thieme et al 1996, LaRiviere and Osternig, 2004, Dover and Powers, 2004, Wassinger et al 2007) reported no effect. The joints assessed by these studies include; the shoulder (Dover and Powers, 2004, Wassinger et al 2007), knee (Thieme et al 1996, Uchio et al 2003, Surenkok et al
Therefore, the aim of the present study was to determine if cold water altered healthy subjects’ knee joint position sense post immersion. Both weight-bearing and non weight-bearing clinical assessment of knee joint position sense, using 3D motion analysis, were used before and after a water immersion to determine if cold water immersion reduces knee joint position sense.

Methods

Design

This was a prospective, randomised, cross-over design where volunteers acted as their own controls. The volunteers were immersed at two temperatures (detailed below) and these sessions were separated by six to ten days. The order of the testing was randomly assigned using a random number generator. Ethical approval of the design of this trial was gained from the University of Limerick’s Research Ethics Committee and signed informed consent was gained from each participant before any data collection took place.

Volunteers

Fifteen participants (9 male, 6 female) with a mean age of 23.2 (range 21.9 to 25.1) years agreed to participate in this study. One male participant dropped out of the study as they were unable to attend the second testing session due to personal commitments. The anthropometric data of the 14 subjects, who
completed the study, is displayed in table 1. Subjects were excluded from the study if they had Reynaud’s disease, ankle or knee injuries in the past twelve months, a history of ear or vestibular conditions. Subjects were also excluded if they were not between the ages of 18-40 or if they were not comfortable with being blind-folded during testing.

Intervention

All subjects reported to the test location on two separate occasions, once for cold water (14°C ± 1°C) immersion treatment and once for tepid water (28°C ± 1°C) immersion (control). The temperature of the water immersions was measured using a digital aquarium thermometer. In both the cryotherapy and the control session subjects were seated in a water tank and immersed to the level of the umbilicus for a duration of thirty minutes. The water was stirred at regular intervals by the experimenter. Male subjects wore only shorts, while female subjects were allowed to wear shorts and a t-shirt. Immediately after the water immersion the subjects were asked to towel dry their body, change into dry shorts and t-shirts and transfer to the lab. On both occasions the subject completed the joint position sense tests immediately before and after the water immersion (approximately 5 minutes post immersion). During the initial visit demographic data included the subject age, height, weight, lower limb dominance was measured and recorded (Table 1). Limb dominance was determined by asking the subjects which leg they would normally kick a ball with.
**Outcome measure**

Knee joint position sense was assessed under both weight bearing and non-weight bearing test conditions. All of the measurements were performed in a controlled environment as this has previously been shown to improve reliability (Piriyaprasarth and Morris, 2007). Before the commencing testing, all subjects were familiarised with the procedures by explanation, demonstration and at least two practise repetitions. All testing procedures were performed in an isolated room, by the same experimenter who was not blinded to the experimental design. To eliminate vestibular and visual information subject wore blind-folds (Olsson et al 2004) and wore headphones over which white noise was played during the testing procedures. Active ipsilateral matching was chosen as it is a commonly used and validated method of assessing knee joint position sense (Olsson et al 2004).

For all the trials described below three reflective markers were attached to 2cm cloth adhesive and then positioned on the greater trochanter, the lateral epicondyle of the femur and the lateral malleolus of the right limb (Harato et al 2008). These markers were used to facilitate the recording of the internal joint angle throughout the trials. During the immersion period, these markers were removed from the subject. However, the cloth adhesive backing remained on the subject in order for the three markers to be placed at the same location following the immersion. Knee joint angle was recorded using an Eagle 5-camera system (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 400 Hz. The cameras were placed between 3-5 metres around the subject at various heights of
0.5-1.5 metres to facilitate the recording of the movement of the markers during the trials. The system was calibrated each morning before testing with an L-frame and a wand, as described in the manufacturers’ guidelines. This system has previously been shown to have excellent reliability for reporting knee motion (Ford et al 2003). A default Butterworth 4th order zero-phase-shift filter (20 Hz cut-off) was used to smooth the data before exporting it into Microsoft Excel 2000 to calculate error scores.

For the non-weight bearing assessment, subjects were positioned in a seated position where the leg was resting at approximately 90° of flexion and the popliteal fossa did not touch the edge of the seat (Panics et al 2008). The limb was then extended by the examiner at a slow steady speed (~10°/s) to a randomly assigned index angle of approximately ~ 35°, ~ 55° or ~ 70° of flexion (Aydog et al 2005). The examiner asked the subjects to hold this position for ~5 seconds, which the subject was asked to remember with particular emphasis on the knee joint, and then the examiner returned the leg to its starting position at the same angular velocity. This time period, which has been used previously (Mohammadi et al 2008), enables the subject to become aware of the position of their limb. Subjects were then asked to actively reproduce the predetermined target angle with the ipsilateral limb. Subjects attempted to replicate the predetermined angle three times (Olsson et al 2004) and the average was taken. Taking the average of several trials has previously been shown to be more reliable compared to taking a single measurement (Piriyaaprasarth and Morris, 2007). After the assessment of each angle subjects were asked to leave the chair.
and walk around briefly. This assisted the subjects to concentrate on the new test angle and not the previous angle.

For the weight bearing assessment of knee joint position sense a similar protocol that has previously been described was utilised (Mir et al 2008, Stillman and McMeeken 2001). The weight bearing assessment included two unique movements; a) flexion to extension and b) extension to flexion. For both movements subjects wore blindfolds, and were allowed to place their left hand on a flat table for balance. This table stood at a height of 0.5 metres. Subjects were instructed to stand with approximately 95% of their body weight directed through their right foot, and with the back foot touch-weight bearing (Hopper et al 2003). The starting position of flexion to extension movement was a semi-squat (~ 60°), with the right hand placed across the chest so not to obscure the markers. Subjects extended the weight bearing right leg, at a slow angular velocity, until instructed to stop (~45°). Subjects were instructed to “remember” this position while focusing on the knee joint position as they held the test position for approximately 5 seconds, return to the normal erect stance (~ 7 seconds). Finally the subjects reproduced the unilateral flexed position while concentrating on the knee. For the extension to flexion movement the starting position was a normal erect stance. Whilst wearing blindfolds and with their right hand across their chest, subjects were instructed to place approximately 5% of their weight on their left foot. They then flexed their right limb until instructed to stop (~45°). Subjects and were instructed by the experimenter to “remember” this position while focusing on the knee as they held the position isometrically (~ 5 seconds). After this subjects returned to an erect stance (~ 7
seconds) before attempting to reproduce the unilateral flexed position, while concentrating on the knee. The holding times used in this study have previously been used in other published material (Mir et al 2008).

For both these procedures subjects repeated the movements three times (Mir et al 2008) after the predetermined angle was established. Similar to the study of Stillman and McMeeken (2001) the target angle was subjectively judged by the experimenter for both movements (flexion to extension approximately 43.4° and extension to flexion approximately 44.3°). For the purpose of this study the absolute mean error, the average error in the three trials ignoring the direction of the error, relative error, the average of the errors in the three trials taking into account the direction of the error and variable error the standard deviation of the three relative error measurements were analysed (Olsson et al 2004). The reliability of the chosen method (using mean differences and 95 % limits of agreement) was established in these 14 subjects using the pre experimental and pre control results. The mean difference for absolute error between the first and second test was 0.037°, with a standard deviation of 3.1°, and limits of agreement (mean difference ± 1.96 times the standard deviation) ranging form -6.039° to 6.113°.

Data analysis

The Statistical Package for the Social Sciences (SPSS) for windows (version 15.0, SPSS Inc, Chicago, IL, US) was used for statistical analysis. For each trial the absolute error was calculated by subtracting the reproduced angle for the
target angle. A positive angle represents an overestimation and a negative value represents an underestimation. The middle 3 seconds of the reproduced angle, correct to 3-decimal place, was used to analyse the data. Data are presented as means and 95% CI. Three scores were calculated for the absolute, relative and variable. Variables were tested for normal distribution with the Shapiro-Wilk test. The results were the normalised and analyzed using a 2x2x5 (ice/control x pre/post x 5 angles) mixed-design analysis of variance for repeated measure (ANOVA) to determine if differences existed between control and cold application sessions, pre and post treatment and the five sectors of movement. The current study had an 80% power to detect a 1.6° difference between experimental and control experimental conditions. For all analysis, statistical significant was set at p < 0.05. In order to calculate effect sizes (Cohen’s d) and associated 95% confidence intervals for the change in joint position sense before and after the cryotherapy treatment Cohen’s d was calculated using the following method: (mean of post-test – mean of pre-test) / (pooled standard deviation of pre-test and post-test) (Morris 2008). To interpret the strength of the effect sizes values from 0-0.2 were interpreted as being weak, 0.21-0.5 as modest, 0.51-1 as moderate and values that were greater than 1 were interpreted as being a strong effect (Cohen et al 2007).

Results

No significant differences, between pre and post tests with both the cold and tepid water using a repeated measures ANOVA, were found for absolute error (p = 0.29), relative error (p = 0.21) or variable error (p = 0.86) scores (see Tables
2). In addition, no other main effects or interactions were found to be significant. Figure 1 illustrate the point estimates for the effects sizes (Cohen’s d) and associated 95% confidence intervals for the five angles on the day of the cold water immersion and five on the day of the tepid water immersion. The average effect size of the cold water immersion was modest, with effect sizes ranging from -0.1 to 0.9 with a positive number represented an increase in joint position sense error. For the tepid water treatment the average effect size was weak, with point estimates ranging from -0.3 to 0.6 (figure 1).

**Discussion**

This study aimed to investigate whether cold water immersion reduced knee joint position sense in healthy participants. No significant difference in knee joint position sense following cold water immersion for thirty minutes was detected. Our findings are similar to that of other published material using different cryotherapy protocols and joint position sense assessments (Thieme et al 1996, Uchio et al 2003, LaRiviere and Osternig, 2004, Dover and Powers, 2004, Wassinger et al 2007, Sekihara et al 2007). Despite previous research showing changes in thixotropy of the forearm muscles following cold water immersion (Lakie et al, 1986), to date no published study has elucidated the biomechanic and neurophysiologic effects on the healthy knee joint and this study is the first to address the potential decrease in joint position sense acuity post cold water immersion.
In relation to the methodological design of this study a temperature of 14°C for thirty minutes was used, as similar protocols have previously been used by other researchers using pre exercise cryotherapy (White et al 2000, Marsh and Sleivert, 1999). Similarly this duration has been noted as the minimum required for clinicians and physiotherapists to use in order to suppress the metabolism of the knee and reduce inflammation (Knight 1995). During the five minute delay between leaving the water tank and commencing joint position sense testing it is possible that skin and muscle temperature increased in the experimental group (cold water immersion) and this may also be a factor in the findings of the study. This point is supported by Surenkok et al (2008) and Uchio et al (2003) who indicated that joint position sense is normalized at 5 and 15 minutes following the application of a cold pack/spray and a cooling pad respectively. However, after cold water immersion it is more likely that individuals would take time to dry off and change into dry clothing before exercise. The rationale behind this protocol was also to prevent the possibility of the subjects experiencing an effect during the assessment from wet clothing. Similarly, having the control group performing the assessments in wet clothing was not desirable, as this may have altered their results. The current study emulated a pre exercise cryotherapy protocol to Marsh and Sleivert (1999), who reported improvements in short term cycling performance following treatment, and delayed 10 minutes between the end of the cold water immersion and the commencement of a warm up (Marsh and Sleivert 1999). This time delay, similar to the current study, was necessary for each subject to dry off, dress, and transfer to the assessment area (Marsh and Sleivert 1999). Consequently, we believe that the results of this study are valuable to those concerned about the increased risk of proprioceptive related
injury following cold water immersion, as they emulate a protocol supporting the use of pre exercise cryotherapy.

Weight bearing and non weight bearing assessments were both included as it has been suggested that weight bearing assessments have more clinical relevance for assessing proprioceptive function in relation to injury (Waddington et al 1999). On the other hand non weight bearing assessments replicate other movement patterns including the swing phase in gait (Stillman and McMeeken 2001) and limb position prior to heel strike (Co et al 1993). Combining both assessment techniques provided this study with a better evaluation of proprioceptive acuity in the form of knee joint position sense following cryotherapy. The error in knee joint position sense reported in this study is similar to that of a number of studies, in both the weight bearing (Mir et al 2007) and non weight bearing assessment (Panics et al 2008, Stillman 2000, Olsson et al 2004).

Previous work has attributed a reduction in joint position sense following cryotherapy to reduced skin temperatures, a reduction in nerve conduction velocity, the eventual blocking of conduction and alterations in motor output (Uchio et al 2003, Surenkok et al 2008). A potential reason why Hopper at al (1997) found a significant reduction in ankle inversion reproduction is the temperature of the water. These authors used a water immersion of 9°C lower that the present study (i.e. 5°C) and this may explain the reduction due to increased skin and intramuscular temperature. This temperature elicited a 14°C drop in skin temperature, measured at the anterolateral aspect of the ankle, using this temperature. The reporting of skin, muscle and core temperature would
allow for a more comprehensive comparison of this study to other published material. However, significant reduction in skin and intramuscular temperature have recently been reported following similar immersion protocols (14.3°C for 20 minutes to the level of the mid-sternum) to the current study (Peiffer et al 2009a, 2009b). Peiffer et al have reported reductions in skin (right calf, right quadriceps, right biceps, and chest) and muscle temperature (rectus femoris) to 21°C and 32°C respectively after 20 minutes immersion (2009a, 2009b). Approximately five minutes after immersion, the time the current study started the assessments, these values only deviated minimally. This reduction is approximately 4°C less than that reported by Hopper et al (1997) and may explain the disparity in the findings.

The degree of skin, muscle and joint cooling experienced is important in the assessment of joint position sense, as nerve conduction velocity has been shown to decrease linearly with tissue cooling (Ruiz et al 1993). It has previously been reported that to reduce nerve conduction velocity by approximately 10% a skin temperature of 12.5-13.5°C is required (McMeeken and Cocks 1984). Similarly, Algafly and George (2007) reported that a skin temperature of 15°C was required for a reduction of 17% in nerve conduction velocity and 10°C for a reduction of 33%. Despite not measuring nerve conduction velocity or skin temperature, from the information derived from similar studies (Peiffer et al 2009a, Peiffer et al 2009b, McMeeken and Cocks 1984, Algafly and George 2007) we can deduce that subjects experience a reduction in nerve conduction velocity of less than 10%. The results of this study, assessed 5 minutes after cold water immersion, indicated that the ability to derive knee joint position sense is
capable of withstanding the degree of muscle, joint and skin cooling experienced
during the immersion or indeed to observe a reduction in knee joint position
sense that tissue temperature along with nerve conduction velocity has to be
reduced further. As a protocol commonly employed by sports people was
utilised in the current study, it does not exclude the possibility that a different
protocol, using a different duration, temperature of modality, would reduce knee
joint position sense. Despite the use of a mixed-design analysis of variance for
repeated measure, some of the variables in the current study were not normally
distributed and this is a statistical limitation. In addition, the current study was
only powered to detect large discrepancies in knee joint position sense and
smaller increases in joint position sense error would have been outside the scope
of the study.

Physiotherapists, coaches, athletic trainers and clinicians all administer
cryotherapy, in the form of cold water immersion, for a number of reasons
including the reduction of pain, swelling, to relieve muscle spasm and the
facilitate of movement. The benefits of using cold water immersion for athletes
(Quod et al 2006), injured individuals (Cochrane 2004) and people with multiple
sclerosis (White et al 2000) has been well publicised. However, Thieme et al
(1996), Uchio et al (2003), Surenkok et al (2008), as recently reviewed by
Costello and Donnelly (2010) have all highlighted the potential of various
modalities of cryotherapy to reduce proprioceptive acuity and hence predispose
injury. The change in joint position sense accuracy following this protocol
proved statistically insignificant (table 2). The evaluation of effect sizes
(Cohen’s d) and associated 95% confidence intervals supports these findings (figure 1).

Further research is required to examine whether different application durations and location of application of ice-packs, cooling pads, whole body cryotherapy or spray have a negative effect on joint position sense. Similarly no published study has assessed the potential of any of the modalities of cryotherapy, listed above, to alter joint position sense acuity in elite athletes, patients with multiple sclerosis or an injured population. Joint position sense is not the only component of proprioception which has the potential to be altered following a cold application. Further research could also assess other aspects of proprioception including balance, touch acuity and force reproduction in the immediate aftermath of a cryotherapy application.

**Conclusion**

In conclusion, no evidence of impaired knee joint position sense was found in healthy subjects following a cryotherapy protocol commonly employed in athletic training. These results were obtained using an accurate technique (3D motion analysis) of measuring knee joint position sense. Furthermore, our study provides no evidence of an enhanced risk of injury, due to a detriment in angle proprioception, following this specific cryotherapy protocol. However, further research is required to address the equivocal evidence that exists regarding the effects of different durations and temperatures of cryotherapy applications on proprioceptive acuity.
References


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body temperatures, and vessel diameter. *Journal of Science and Medicine in Sport, 12*: 91-96.


**Figure 1:** Effect sizes (Cohen’s d ± 95% confidence intervals) showing the influence of both the cold and tepid water on knee Joint Position Sense (JPS). E-F denotes extension to flexion and F-E denotes flexion to extension.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Female (n = 6)</th>
<th>Male (n = 8)</th>
<th>Total (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.1 ± 0.7</td>
<td>23.4 ± 1.2</td>
<td>23.3 ± 1.0</td>
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<tr>
<td>Height (cm)</td>
<td>169.1 ± 6.5</td>
<td>181.4 ± 7.1</td>
<td>175.7 ± 9.1</td>
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<tr>
<td>Weight (kg)</td>
<td>63.9 ± 9.4</td>
<td>78.9 ± 6.0</td>
<td>72.0 ± 10.8</td>
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<tr>
<td>BMI (kg/m(^2))</td>
<td>22.4 ± 3.3</td>
<td>24.0 ± 1.5</td>
<td>23.2 ± 2.6</td>
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<tr>
<td>Limb Dominance</td>
<td>Right (n = 6)</td>
<td>Right (n = 8)</td>
<td>Right (n = 14)</td>
</tr>
</tbody>
</table>

**Table 1** Characteristics of the fourteen subjects who completed the study (mean ± SD)
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Absolute error</th>
<th></th>
<th></th>
<th></th>
<th>Relative error</th>
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<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
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<tr>
<td>~55</td>
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<tr>
<td>~75°</td>
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<td>3.2</td>
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<td>0.6</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
<td>1.6</td>
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<tr>
<td>Extension-</td>
<td>4.3</td>
<td>3.3</td>
<td>4.4</td>
<td>5.5</td>
<td>2.2</td>
<td>2.6</td>
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<tr>
<td>Flexion</td>
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<td>5.9</td>
<td>6.7</td>
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<td>-5.8</td>
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<td>Flexion-</td>
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<tr>
<td>Extension</td>
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<td>-4.6</td>
<td>1.8</td>
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</table>

Exp = Cold water immersion, Con = Tepid water immersion