**Title**

Recovery Profiles of Eccentric Hamstring Strength in Response to Cooling and Compression.

**Declaration of interest:** none.

## Abstract

### Introduction

The effectiveness of different forms of cryotherapy and combined compression (cryo-compression) commonly used in sport to enhance recovery following exercise are not fully understood. Therefore, the exploration of protocols that use contemporary cryo-compression is warranted. The purpose of the study was to investigate the effectiveness of using a cryo-compression device to recover hamstrings eccentric strength following a fatiguing exercise.

### Methods

Eighteen healthy male adult footballers were randomly allocated to receive cryo-compression or rest following a lower limb fatiguing protocol. Cryo-compression was applied for 15-minutes, target temperature of 10°C, and high intermittent pressure (5-75 mm Hg) using the Game Ready® device. Rest consisted of 15-minutes in a prone position on a plinth. To induce hamstring fatigue, participants performed the Yo-Yo intermittent fatigue test (IFT). Skin surface temperature ($T_{sk}$) and hamstring eccentric strength measures were taken at three time points; pre-IFT, immediately post-fatigue test (IPFT), and immediately post-intervention (IPI) (rest or Game Ready®). Participants returned one week later and performed the Yo-Yo IFT again and were exposed to the opposite intervention and data collection.

### Results

Significant decreases in $T_{sk}$ over the posterior thigh were reported for all timepoints compared to pre cryo-compression temperatures ($p=<0.05$). Overall data displayed no significant main effects for timepoint or condition for PT or AvT ($p=<0.05$). There was no timepoint *x* condition interaction for PT or AvT ($p=<0.05$). Collapse of the data by condition (CC / R) demonstrated no significant effect for time for PT or AvT ($p=>0.05$).

### Conclusions

No significant changes in HES occurred after exposure to cryo-compression or rest applied immediately following the Yo-Yo IFT. Further investigations to maximise beneficial application of contemporary cryo-compression applications in sport are required. Multiple measures of performance over rewarming periods, within competitive training schedules after sport-specific training are required to develop optimal cooling protocols for recovery.

**Keywords**

Cryotherapy; Sports; Torque; Hamstring Muscles, Skin Temperature.

## Introduction

Fatigue is a key aetiological factor associated with non-contact injuries in football and has been shown to have an adverse effect on football performance (Marqués-Jiménez et al 2017). The lasting acute effects of hamstring fatigue during match play have been well documented, with current literature highlighting a reduction in eccentric function (Opar et al 2012) existing up to 96 hours post-fatigue. (Rhodes et al 2018). Many interventions to reduce the incidence of hamstring injuries have been well researched (Bahr et al 2015), with the consensus across literature indicating that training the muscle eccentrically and increasing its resistance to load has the greatest success (Bourne et al 2018). Importantly, despite these interventions being employed, the occurrence of these non-contact musculoskeletal injures has not reduced (Hawkins et al 2001; Ekstrand et al 2016). Subsequently during eccentric loading or performance, athletes are often subjected to delayed onset muscle soreness (DOMS) (Nogueira et al 2019) and muscle damage (Ihsan et al 2016). DOMS as a result of exercise has been documented as a major contributory factor to decreased muscle function post fatigue, with deficits being reported up to 72+ hrs post exercise (Nogueira et al 2019). Consequently, the importance of recovery strategies in football is evident and commonly cryotherapy is utilised to reduce symptoms of post-exercise fatigue to optimise subsequent performance through often congested training and fixture schedules.

It is considered that cooling modalities reduce the symptoms of DOMS by controlling the release of histamines and prostaglandins associated with the inflammatory response (Bleakley et al 2012; Hohenauer et al 2015; Chan et al 2016). Although, contrasting evidence debates whether cooling improves acute recovery through facilitation of muscle metabolites (Ishan et al 2016). Evidence further indicates that cooling induces a reduced pain response (Allan & Mawhinney 2017) and thus, may increase the perception of the athlete that recovery has taken place. Alternatively, research suggests that cooling shortly after resistance exercise may have a negative effect on muscle adaptation and could be detrimental to the long-term development of the athlete (Roberts et al 2015). Predominantly research investigates cold-water immersion (CWI) despite cryo-compressive devices prominent in sports medicine and performance departments for recovery. Limited evidence is available on their use and effects (Holwerda et al 2013; Hawkins & Hawkins 2016) consequently optimal recovery protocols using cryo-compressive devices are unknown.

The Game Ready® (Game Ready; Global, UK) device provides continuous circumferential cooling with compression through circulation of ice water and is commonly cited as an efficient recovery tool for injury or post-surgical management (Murgier & Cassard 2014). Intermittent pneumatic compression and cooling was applied to the hamstring region through a fabric wrap attached to the device which transports a mix of crushed ice and water pumped through to chambers of the wrap with air to provide compression. Manual manipulation through ratio of ice to water can be adapted to control target temperature. Cyclical inflation and deflation of the Game Ready® device (~3-minute cycles) with variable pressure settings range between 5 to 75 mm Hg (Holwerda et al 2013). Investigation of optimal periodisation of contemporary methods of cryo-compression compared to passive recovery is limited in the evidence base and research existing in this area is predominantly focused on CWI (Gill et al 2006; Roberts et al 2015) or whole-body cryotherapy chambers (Haq et al 2018). Furthermore, measures to quantify the effect of cooling predominantly draw conclusions from physiological responses (Gill et al 2006), whereas the addition of functional biomechanical investigation such as eccentric hamstring strength is limited. Biomechanical measurement of eccentric strength is often quantified through temporal changes in peak isokinetic torque via isokinetic dynamometry, with studies investigating lower limb strength outputs in relation to sports injury risk (Rhodes & Alexander 2018; Isik et al 2018). Furthermore, previous reliability of the Nordic exercise is reported (Opar et al 2013), with subsequent studies reporting the Nordbord® testing method as a reliable field-based method to quantify strength and assessment of imbalances (Opar et al 2013; Buchheit et al 2016). Notably physiological reductions of skin surface temperature ($T_{sk}$), is recognised following cryotherapy, through the application of Infrared Thermography (IRT), to obtain whether deeper physiological responses occur post superficial cooling (Moreira et al 2017). To our knowledge however, no data exists that considers the effect of the Game Ready® as a recovery method investigating both physiological and biomechanical outcomes in footballers following fatiguing exercise.

The aim of the present study therefore is to investigate hamstrings eccentric strength (HES) responses following exposure to the Game Ready® cryo-compression device applied as a recovery modality after a bout of fatiguing exercise replicating the demands of football. We hypothesise that cooling will significantly reduce $T_{sk}$ and that cryo-compressive exposure will affect levels of eccentric hamstring strength recovery profiles compared to passive intervention of rest. The findings of this study aid the understanding of the potential use of contemporary methods of cryo-compression to attenuate eccentric exercise fatigue in football populations, impacting decision-making of sports medicine and performance practitioners.

## Methods

### Trial Design

This study was a randomised crossover design. Independent variables were the cooling intervention, population group, and fatigue protocol and time points between interventions. Dependent variables included skin surface temperature and eccentric strength of the hamstrings using the Nordbord®.

**Participants**

Eighteen healthy male football players volunteered to take part (23.8±3.5 years, height 174.3±8.0 cm, weight 71.2±11.6 Kg, BMI = 23.4). Participants were included if they took part in first team of the British Universities & Colleges Sport standard (BUCS) football, with a minimum of training and competitive fixtures accumulative of 3-4 sessions per week, injury free and with a normal BMI (BMI = 18.5 - 25). Participants were not eligible if they presented with any lower limb pain, history of lower limb injury or surgery in the last six months, outside the age range of 18-40 years old or had any known neurological compromise to cold, such as Raynaud's. The process of this study commenced according to the 2013 Declaration of Helsinki and was approved by the university ethics committee. After reading the participant information, volunteers completed a Physical Activity Readiness Questionnaire (PAR-Q) and provided written and verbal consent prior to commencement of data collection.

**Procedure**

Data collection took place in a movement analysis laboratory. To minimise the influence of pre-existing fatigue from competitive fixtures or normal training schedules, participants were advised to not partake in any fatiguing exercise other than their normal training regime and playing fixture that week. Testing of the two conditions took place three days after a competitive fixture (match day +3). Participants were randomly allocated (randomization.com) to receive either cryo-compression (CC) or passive intervention (rest for 15-minutes in prone lying) (R), returning one week later for exposure to the opposite intervention. On arrival to the movement analysis laboratory, participants underwent a 15-minute acclimatisation period supporting previous study methods (Rhodes & Alexander 2018), to ensure a steady thermal state with anthropometric measurements collected during the acclimatisation period. Data was collected at three timepoints; pre-IFT, IPFT and IPI (CC or R). The term 'immediately' implies that all measures were taken within 10 seconds after exposure to fatigue or the intervention (CC or R).

**Yo-Yo Intermittent Fatigue Test (IFT)**

Participants performed the Yo-Yo IFT (Level 1) protocol detailed previously (Bangsbo et al 2008) with an aim to provide an overall measure of physical fitness initiating fatigue from high-intensity intermittent running. On completion of the IFT, measures of EHS and $T_{sk}$ were collected and participants were exposed to receive CC or R as per the randomisation allocation.

**Hamstrings Eccentric Strength**

Quantification of the functional strength of the hamstrings was completed utilising the Nordbord (VladPerformance, Queensland, Australia), where bilateral strength metrics of AvT and PT were utilised for analysis. During the eccentric strength measures completed on the NordBord all participants were told to execute maximal effort, performing a single set of three repetitions. Prior to completion the anthropometric profile of the player is entered in to the ValdPerformance Scoreboard application. Measures included height (cm), weight (kg) and knee position on the NordBord (cm). A note of the players knee position was documented by the researcher to ensure standardisation from pre-post intervention testing during the protocol. Participants lower legs are hooked in to the $360^{o}$ sensors, asked to cross their arms across their chests and keeping hips neutral lowering themselves down as far as they can or to the point of break where they are told to use their hands to stop themselves falling to the floor. Once completed the information from the sensors on the Nordbord is exported to the ValdHub software, where the individual player output is translated. An average score of the three repetitions was taken for analysis for both AvT and PT from the ValdHub.

**Cryotherapy Application**

A clinically relevant cooling dose of 15-minutes via the Game Ready® device was applied, supporting previous cooling dosage representative of pitch-side or half-time applications in sports medicine (Bleakley et al 2012). Target temperature was manually set to 10°C and high compression (75 mm Hg) as per manufacturer options, with standard ~3-minute pneumatic intermittent cyclic pressure application, applied to the dominant limb using the thigh wrap. Once the intervention period had finished, $T_{sk}$, and eccentric knee flexor strength data were collected in the same way as pre-intervention/pre-fatigue data collection.

**Skin Surface Temperature ($T_{sk}$)**

Posterior thigh $T_{sk}$ was collected via infrared thermology (IRT) (ThermoVision A40M, Flir Systems, Danderyd, Sweden) at pre-IFT, IPFT and IPI. Protocol for measuring $T_{sk}$ followed the Thermographic Imaging in Sports and Exercise Medicine (TISEM) guidelines (Moreira et al 2017). Participants were requested not to drink any alcohol, intake any stimulant beverage at least 12 hours before testing commenced, avoid fatigue inducing exercise 24-hours before testing, refrain from heavy meals, application of moisturising creams or exposure to UV-rays (De Oliveira et al 2018). This process minimised external factors that may affect local cooling interventions and standardised the study protocol. The area of skin monitored over the dominant hamstring was determined via a region of interest (ROI) as recommended in the TISEM guidelines (Moreira et al 2017). To create an anatomical region of interest over the posterior thigh, application of thermally inert skin surface markers formed a framework (Hardaker et al 2007). Location of inert markers created a polygon shape for ROI analysis over the hamstring region. Originating from the ischial tuberosity, to both lateral and medial borders of the thigh, moving inferiorly to the condyles of the femur, eliminating the popliteal fossa. The thermal imaging camera was situated at a height of 135 cm from the ground, positioned perpendicular to the anterior lower limb, with participants laying prone on a soft mat. The setup follows standard clinical set up with an emissivity camera setting of 0.97-0.98 (Moreira et al 2017). Ambient room temperature monitored at the point of testing for each participant was consistent. Thermographic images were analysed using software, Thermacam Researcher version 2.8 (FLIR Systems).

**Statistics**

A univariate repeated measures general linear model was used to quantify main effects for time and condition. Interaction effects were quantified, and significant main effects in recovery duration were explored using post hoc pairwise comparisons with a Bonferonni correction factor. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity were completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared ($\eta^2$) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138). All statistical analysis was completed using PASW Statistics Editor 26.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$, and all data are presented as mean ± standard deviation.

**Results**

Mean ± SD data for temporal response of recovery on PT and AvT after cooling or rest is displayed in Table 1 and Figures 1 and 2.

**** Insert Table 1 here ****

****Insert Figure 1 Here****

****Insert Figure 2 Here****

**Skin Surface Temperature ($T_{sk}$) (°C)**

$T_{sk}$ data demonstrated statistically significant decreases following cryo-compression exposure over the posterior thigh ROI for all timepoints compared to pre cryo-compression temperatures, IPFT ($P = \leq 0.001$) (Table 1).

**Isokinetic Dynamometry**

*Peak Torque (PT)*

Overall data displayed no significant main effects for timepoint ($F = 0.329, P = 0.721, \eta^2 = 0.06$) or condition ($F = 0.253, P = 0.616, \eta^2 = 0.02$) were displayed for PT. There was no timepoint *x* condition interaction ($F = 0.105, P = 0.900, \eta^2 = 0.002$) for PT. Collapse of the data by condition (CC / R) demonstrated no significant effect for time (CC: $F = 0.419, P = 0.660, \eta^2 = 0.16$; R: $F = 0.190, P = 0.828, \eta^2 = 0.07$) for PT.

*Average Torque (AvT)*

Overall data for AvT displayed no significant main effects for timepoint ($F = 0.824, P = 0.441, \eta^2 = 0.16$) or condition ($F = 0.32, P = 0.858, \eta^2 = 0.00$) were displayed. There was no timepoint *x* condition interaction ($F = 0.53, P = 0.949, \eta^2 = 0.01$) for AvT. Collapse of the data by condition (CC / R) demonstrated no significant effect for time (CC: $F = 0.585, P = 0.561, \eta^2 = 0.02$; R: $F = 0.281, P = 0.756, \eta^2 = 0.11$) for AvT.

**Discussion**

The aim of the study was to investigate physiological and biomechanical responses of a cryo-compressive device applied as a recovery modality after a bout of fatigue compared to rest. Although mean differences were displayed in PT and AvT following the YoYo IFT and after each intervention (Table 1), no significant main effects were displayed in AvT or PT for HES immediately following either intervention (R / CC) compared to pre-IFT or IPFT measures. Significant decreases in $T_{sk}$ were reported IPI for CC (Table 1), however temperature fell outside of the suggested therapeutic range for beneficial physiological responses to occur (Kennet et al 2007). Biomechanical function was quantified through measures of EHS and physiological $T_{sk}$ responses in a population of healthy male footballers. Results are indicative toward acute muscle strength loss over time following eccentric contractions (Douglas et al 2017) although non-significant reductions displayed in the present study were not consistent with previous research highlighting reductions of 20-30% in hamstring strength post soccer specific protocols (Greig 2008). With the Yo-Yo IFT initiating only a 7-12% decrease in strength metrics in the current study suggest may be a reason for the insignificant reductions in strength and subsequent non-significant changes post intervention. This may be attributed to the exclusion of sprinting and high-speed multi directional running within the Yo-Yo IFT, potentially decreasing the exposure of the hamstrings to high velocity and high load movement patterns. Future research should consider high velocity; high load fatiguing protocols to induce higher levels of fatigue and determine further effectiveness of recovery strategies.

The non-significant changes may also be attenuated to the superficial skin temperatures achieved from the cooling modality and with only functional measure of hamstring strength taking place immediately following exposure without consideration of a rewarming period of observation. Although statistically significant reductions in $T_{sk}$ were reported post cryo-compression over the posterior hamstring ($P$ = < *0.05*), average $T_{sk}$ did not meet suggested therapeutic range of between 10-15°C (Kennet et al 2007), with the lowest $T_{sk}$ recorded at 15.9°C in the current study. Although reflecting shorter cooling exposures to imitate applied management of injury or recovery sessions in sporting environments (Chan et al 2016), it is evident that to achieve therapeutic response a longer duration or cooler target temperature may affect resultant strength parameters. That said, phase change capabilities of cooling modalities influence $T_{sk}$ response and consequently duration of exposure, and as such requires consideration for adaptation of cooling protocols. Modalities with more efficient phase change may produce lower $T_{sk}$ for the same duration. Chan et al (2016) applied a dosage time of 15-minutes in a comparable protocol to ours using the same contemporary cooling device as a recovery method following a maximal cycling test. Our findings are consistent with their results (Chan et al 2016; Allan & Mawhinney 2017), whereby agreement that no significant differences in recovery markers were noted following the same intervention dose and cooling modality. Although differences in recovery outcomes measures and testing environment reduce direct comparison of results between the studies.

Cryotherapy following resisted exercise may cause attenuation of the desired adaptive muscle strength response (Douglas et al 2017) and the avoidance of immediate cooling in this scenario is advised (Ihsan et al 2020). Alternatively, acute strength output has been shown to be negatively affected by local cooling applications (Alexander & Rhodes, 2019). This is largely observed following exposure to CWI (Leeder et al 2012; Fröhlich et al 2014), or without the consideration of fatigue (Alexander & Rhodes, 2019), therefore it is difficult to confer whether the Game Ready® device produces synonymous effects on muscle strength parameters. Debate as to whether passive recovery is preferable to cooling following fatiguing exercise is evident, however due to the additional effects on perceived soreness and psychological influences, cooling remains a popular recovery option in sport and considered an effective way to reduce symptoms of acute onset post-exercise fatigue (Leeder et al 2012). Perception of cooling in respect to recovery was not quantified in the current study however.

Suggestions in literature report a quadratic relationship between $T_{sk}$ and intramuscular muscle tissue temperatures in response to superficial cooling (Hardaker et al 2007); hypothetically, changes in muscle strength observed over a longer re-warming period may pose further consideration into the impact on strength recovery. In this context, recent studies report similar findings through investigation of concentric quadriceps strength following direct cooling over the anterior thigh whereby strength did not return to pre-intervention scores over a longer observed rewarming period (Rhodes & Alexander 2018; Alexander & Rhodes 2019). Further comparison with longer applications of cold via Game Ready® may achieve therapeutic skin temperatures consistent with previous studies and modalities such as CWI. Consequently, we assume greater or different effects on EHS in a recovery context. Observation of eccentric hamstring strength over a rewarming period may have been beneficial, as we assume that intramuscular temperatures may have continued to fall after the removal of cooling. In addition, consideration must be given to the timing of cooling and the justification for its use. This presents a contemporary debate within multi-disciplinary performance departments surrounding the timing and appropriateness of cooling modalities as a recovery intervention. Ultimately, sports medicine and performance practitioners need to consider possible risks and benefits offered by cryotherapy / cryo-compression for recovery. It is evident that time frame, mode and dose of cryotherapy / cryo-compression require further investigation in this context reflected through a battery of performance measures that reflect physical and psychological perturbations following fatiguing exercise. Future studies should aim to decipher the mechanisms of cryotherapy and consider the multiple variables influencing application and optimisation of cooling strategies using cryo-compression.

Justification to identify relevant recovery modalities using cryotherapy and to define optimum recovery protocols in sport are highly suggestive throughout current literature (Chan et al 2016; Oakley et al 2013). The current study supports the applied nature of research for practical applications; however, it is not without its limitations. Firstly, we anticipated the fatiguing protocol in the current study to effectively induce eccentric muscle fatigue in the hamstrings (Greig, 2008) and although reductions in strength following the IFT were noted in the data, the non-significant strength loss results make it difficult to determine the extent of the effect of conditions (CC / R) on eccentric strength recovery. Therefore, it may be more appropriate for future studies to investigate such interventions within real sports settings that replicate sport-specific training to induce fatigue using a range of multi-measure objective and subjective performance indicators. Future studies should consider follow-up measures at increments over a longer period to investigate further observations of change in eccentric strength. This may support further investigation of known biomechanical responses to cooling through rewarming periods and provide useful data through assessment of relevant applied clinical markers and outcomes measures advantageous in the field. Current results cannot be extrapolated to female subjects; therefore, future methodologies may consider gender response to similar practices of fatigue and recovery effect of such protocols. Future research considerations would benefit investigation of eccentric muscle strength after longer or cooler dose applications. The comparison of Game Ready® to Cold Water Immersion protocols for recovery may also be useful as both modalities are commonly applied in elite sport settings, yet agreement on optimal applications is not yet fully elucidated. This may present beneficial information to help determine optimal responses to different cryo-compressive modalities for lower limb recovery in sport.

## Conclusion

Acute response in HES after exposure to cryo-compression or rest applied immediately following a fatiguing protocol reported non-significant changes. Consequently, several factors influencing these findings require further exploration to maximise beneficial application of contemporary cryo-compression applications in sport. The application of simultaneous cooling with intermittent compression significantly reduced $T_{sk}$ over the posterior thigh, although longer dose durations may be recommended (>~15) to achieve therapeutic range. Consequently, this may influence beneficial physiological responses in deeper tissues optimising practical applications of cryo-compression as a recovery strategy in sport. The consideration of optimum application of cooling to enhance recovery from muscle-damaging exercise is required as the continuation of muscle strength declines is not desirable for subsequent performance demands in sport. Optimal recovery methods in sport, including the proposed benefits of contemporary cryotherapeutic protocols are yet to be determined and require sport-specific fatigue protocols or in-season data capture with multi-measures of performance representative of the sport to ensure greater ecological validity. Studies that compare multiple performance measures including perceptual response require further consideration, alongside the investigation of periodisation and dose-response of contemporary cryo-compression modalities to benefit individualised recovery approaches in sport.

## Clinical Relevance

- No significant changes in EHS reductions were noted following cryo-compression or rest following the YoYo IFT.
- Cryotherapeutic dose-response relationships applied after muscle-damaging exercise require further investigation to optimise understanding of cooling recovery strategies.
- Multi-measure of performance over rewarming periods, within competitive training schedules are required to develop optimal cooling protocols advantageous for recovery.

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**Captions to Tables and Figures**

Table 1. Skin Surface Temperature ($T_{sk}$) (°C), Peak (PT) (N·m) and Average Torque (AvT) (N·m) for the dominant limb for each timepoints.

Figure 1. Peak (PT) and Average Torque (AvT) (N·m) for cryo-compression across each timepoint.

Figure 2. Peak (PT) and Average Torque (AvT) (N·m) for rest across each timepoint.