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THE EFFECTS OF WETTED ICE ON DYNAMIC STABILITY OVER A REWARMING PERIOD

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Abstract BACKGROUND During half time or breaks in play cryotherapy is often applied for analgesia for minor musculoskeletal sport injury, however the effect of cryotherapy on dynamic stability is debated. A risk factor for further lower limb injury may be heightened due to a reduction in dynamic postural stability.
OBJECTIVES The purpose of the current study was to investigate the effects of wetted-ice applied for 20-minutes at the ankle on dynamic stability using the star excursion balance test, immediately-post exposure and over a rewarming period of 30-minutes.
MATERIALS AND METHODS Twenty-two healthy male athletes that regular took part in land-based sport were assessed on reach directions of Anterior (Ant), Posteromedial (PM), and Posterolateral (PL) using the modified star excursion balance test (mSEBT) on the non-dominant limb. Thermal imaging quantified skin surface temperature (T_{sk}) over lateral and medial regions. Participants were tested pre-intervention, exposed to 15-minutes wetted-ice cryotherapy application, immediately-post and up to 30-minutes post intervention at 10-minute intervals.
RESULTS Significant decreases in T_{sk} over the medial and lateral regions of the ankle ($p < 0.05$) not returning to pre-cooling temperatures at 30-minutes post. Significant decrease in reach -distance scores (ANT, PL and PM) pre-immediately post and at 10, 20 and 30-minutes post cryotherapy exposure.

CONCLUSION Following wetted ice application to the non-dominant ankle, dynamic postural stability was adversely affected for up to 30-minutes post exposure demonstrated through a decrease in reach scores for ANT, PL and PM directions. Functional performance which requires stabilising mechanisms may be negatively affected and contribute to a heightened risk of injury or further injury in consideration of the findings.

Key words: cryotherapy, balance, star excursion balance test, ankle, stability

Introduction

Many physiological effects of cryotherapy are reported including reductions in oedema, tissue temperature, blood flow and spasm (Enwemeka et al., 2002; Costello et al., 2021). Further, the efficacy of cryotherapy applications in relation to analgesic benefits are noted (Allan et al., 2022), and in combination these reduce the cardinal signs and symptoms of inflammation in acute sports injury (Bleakley et al., 2004). As a therapeutic modality used to induce analgesia (Murray & Cardinale, 2015) athletes with minor musculoskeletal injury often return to play after the application of cryotherapy through a reduction in perceived pain, despite the reported negative effects on functional performance parameters immediately following cooling (Bleakley et al., 2012; Fullham et al., 2015; Alexander et al., 2016). Deficits in sensorimotor feedback induced by local cooling in the lower limb may result in dynamic stability changes (Fullham et al., 2015; Alexander et al., 2016). Although the extent of which is limited, and it is difficult to draw conclusive agreement on the effects of cryotherapy on performance parameters such as neuromuscular control (Kalli & Fousekis, 2019). An integral component of neuromuscular control is dynamic stability (Coughlan et al., 2014). During land-based sports, increases in external load occur (Soligard et al., 2016) directly affecting stabilising structures occur during dynamic movements such as horizontal deceleration (Harper et al., 2022) crossover cutting, side stepping, landing mechanics and contact (Twist & Worsfold, 2014). Impairment to functional performance due to deficits in dynamic stability may heighten injury risk during sport (Soligard et al., 2016; Fullam et al., 2020).

Maintaining balance through transition from dynamic to static motion defines the terms dynamic stability (Goldie et al., 1989). The modified Star Excursion Balance Test (mSEBT) is a recognised objective measure of dynamic stability (Gribble et al., 2012) and recommended for injury assessment, screening and return to fitness protocols in athletic populations (Coughlan et al., 2014). Reductions in dynamic stability with significant decreases in reach distances using the mSEBT immediately following cryotherapy at the ankle are demonstrated previously (Fullam et al., 2015). Comparatively, Fullam et al., (2020) reported that a 15-minute exposure to cryotherapy using the Aircast Cryo/Cuff® at the knee joint is unlikely to adversely affect dynamic stability functionally. Despite significant changes in kinematics evidenced through decreased reach distance for the mSEBT conclusions were based upon the fact that reach distance scores did not surpass smallest detectable difference values (Fullam et al., 2020). Other literature reports no differences observed in SEBT performance between modes of cooling applications (Williams et al., 2013). Therefore, further exploration to determine whether similar findings exist from wetted ice application is warranted. Furthermore, the amount of reduction in postural stability caused by local cooling modalities may differ between the ankle, knee and hip joints (Fullam et al., 2020), thought to be caused by compensatory mechanisms at the ankle and hip conserving temporary knee joint sensorimotor declines observed following local cooling application at the knee (McCollum et al., 1996). Cooling dose, mode and skin surface temperature (T_{sk}) are important variables which can affect severity of adverse functional performance responses to cryotherapy, with longer exposures and lower T_{sk} thought to influence greater effect on parameters such as stability mechanisms (Stal et al., 2003). These require further exploration to determine optimal applications of cooling in sport and mitigate the potential for deleterious effects on functional performance that may lead to heightened injury risks in sport.

Although acute effects of local cooling on kinematics and stability mechanisms using various performance measures are examined (Fullam et al., 2015; Fullam et al., 2020; Williams et al., 2013; McCollum et al., 1996), there is a scarcity of research that observes the effects of cooling at the ankle on functional dynamic stability observed over rewarming periods. The aim of the current study therefore was to investigate the effects of a 15-minute wetted ice application to the ankle on dynamic postural stability over a 30-minute rewarming period quantified through the mSEBT. We hypothesised that reach distance in all three directions of the mSEBT would decrease following cooling and fail to return to pre-cooling measures at the end of the 30-minute rewarming period thought to be caused by the influence of local cooling on the neuromuscular responses required for dynamic stabilisation, postulated from previous studies (Alexander et al., 2018; Alexander & Rhodes, 2019; Fullam et al., 2020).

Material and Methods

Participants

Twenty-two healthy male participants volunteered to take part in the study (Age 20.5 ±1.3 years; Weight 80.14 ±11.21kg; Height 178.32 ±2.98cm; Non-Dominant Limb left n = 21; right n = 1). All volunteers played land-based sport to a semi-professional level. Exclusion criteria encompassed previous ankle joint surgery, lower limb injuries in the past six months, taking regular anti-inflammatory medicine, known contraindications to cryotherapy or referred pain from/to the ankle joint. To increase sample homogeneity in the study all male participation was decided, reducing potential differences to occur because of gender differences in response to cooling (Cankar & Finderle, 2003). Prior to testing, all participants provided written consent to take part. The study was conducted according to the Declaration of Helsinki (2013) and approved by the host university ethics committee.

Testing Protocol

Participants acclimatised for 15-minutes in the testing room to ensure a consistent baseline T_{sk} during this time anthropometric data was gathered (Alexander et al., 2020). The non-dominant limb in each participant was established by rolling a soft football toward the participant and identifying which limb they kicked the ball with as the dominant side (Van Melick et al., 2017).

The mSEBT is a reliable and validated test to identify dynamic balance deficits (Gribble et al., 2012; Picot et al., 2021). With suitable evidence to support the reduction of the original eight reach directions of the SEBT to three, consequently reach lines were marked on the testing surface at angles of 45° and intersected in the centre in the current study (Coughlan et al., 2014; Hertel et al, 2006; Robinson and Gribble, 2008). Participants were tested in three directions, anterior (A), posteromedial (PM) and posterolateral (PL) (Coughlan et al, 2014; Picot et al, 2021; Hertel et al., 2006; Robinson & Gribble, 2008). The reach directions of the mSEBT were achieved by affixing three lengths of zinc oxide tape to the floor (1.5 cm in each direction) based on previous protocols (Coughlan et al., 2014; Fitzgerald et al., 2010). Reliability of the intra-test was previously reported in these directions with a 0.84–0.94 range (Plisky et al., 2009; Van Lieshout et al., 2016). Participants performed three trials in each direction (ANT, PM and PL) of the mSEBT and mean data in each direction used for analysis. Trials were invalid if participants placed excessive weight through the reach foot, removed hands from hips, did not touch onto the tape measure or return to the starting position through loss of balance. In these cases, further additional trials were attempted (Fullam et al., 2015).

Normalising mSEBT scores

Reach distances were normalised by way of measuring participants leg length for the non-dominant limb, taken with the participant laying in supine and measured from the anterior superior iliac spine to the distal point of the ipsilateral medial malleolus using a standard tape measure (Plisky et al, 2009; Gribble & Hertel, 2003). Utilising the equation: mSEBT distance / leg length × 100 = %, scores were normalised to lower limb leg length to calculate maximum distance (%MAXD) accounting for limb length discrepancies (Robinson & Gribble, 2008). Composite scores were calculated by the mean of the three normalised reach direction scores (Table 1).

Skin Surface Temperature (T_{sk})

A reliable measure of T_{sk} can be quantified through thermal imaging (Costello et al,. 2012). T_{sk} was measured via digital, noncontact, infrared thermal imaging (TI) (ThermoVision A40M Thermal Imaging Camera (Flir systems, Danderyd, Sweden)). Emissivity was set at 0.97–0.98 and the TI camera positioned 1.5 m away from a clinical plinth mounted on a tripod at a height of 134cm (Alexander et al., 2020) situated perpendicular to the target region of interest (ROI), following TISEM guidelines (Moreira et al., 2017). T_{sk} data capture was defined by two ROI (medial and lateral ankle joint) (using FLIR TOOLS, Danderyd, Sweden) (Ioannou, 2020), across multiple timepoints: pre-intervention, immediately post-intervention, 10, 20 and 30-minutes post-intervention. Mean±SD T_{sk} for both regions were established during analysis. Three images per ROI, per timepoint were collected for T_{sk} with mean data used for analysis.

Cryotherapy Application

With the participant laying semi-recumbent on a clinical plinth, the same researcher applied a 15-minute dose (Alexander et al., 2021) of wetted ice to the non-dominant ankle, consisting of 2000 mL of cubed ice and 300 mL of room temperature water in a sealed bag (Dykstra et al., 2009), held in place using plastic wrap (Kwiecien et al., 2020). Following the 15-minute application the wetted ice was removed, Tsk capture proceeded followed by performance of the mSEBT. A timer recorded 10, 20- and 30-minutes post rewarming intervals for each timepoint, starting immediately on removal of the wetted ice. Between timepoints of immediately-post exposure, 10, 20- and 30- minutes the participant returned to the plinth and lay still in a semi-recumbent position.

Statistical Analysis

Statistical analysis was conducted using SPSS (Version 27.0) (SPSS, IMB Corporation, Chicago, USA) and level of significance set at $p = <0.05$ for T_{sk} and reach-distance. Data was suitable for parametric testing. For T_{sk} and reach distance in ANT, PL and PM directions of the mSEBT a 1-way repeated-measures analysis of variance compared data across all timepoints (pre-application, immediately-post application, 10-minutes, 20-minutes and 30-minutes post application). Significant main effects for time were explored using a Bonferroni pairwise comparison. Partial eta-squared calculated estimated effect sizes (n^2_p) for all significant main effects and were classified as small (0.01–0.06), moderate (0.06–0.14) or large (>0.14) changes (Cohen, 1988).

Results

Skin Surface Temperature (T_{sk})

Significant decreases in T_{sk} were recorded for the medial and lateral ROI's across all timepoints ($p < 0.05$). Pairwise analysis displayed significant differences between timepoints indicating a rewarming across both ROI's up to 30-minutes post cryotherapy removal, at which T_{sk} had not returned to pre-cooling T_{sk} temperatures (Table 1) (Figure 1). Indicated at the immediately-post cryotherapy timepoint, therapeutic range was met over the medial ROI = 10.5 ±2.8°C, however a lower temperature, outside of the suggested therapeutic range (Kennet et al., 2007) of 9.4 ±2.3°C was displayed at the same timepoint for the lateral ROI (Table 1).

Table 1. Descriptive statistics for T_{sk} ROI's and mean ± standard deviation for normalised maximum excursion distance (excursion distance/leg length × 100) (%) across all timepoints and the statistical significance compared to pre-cooling application and between timepoints.

	Pre-Cooling Application	Immediately Post Application	10-Minutes Post Application	20-Minutes Post Application	30-Minutes Post Application
Medial ROI T_{sk}	28.4 ±1.4	10.5 ±2.8*	19.2 ±1.7*‡	21.4 ±1.6*‡	22.3 ±1.8*‡
Lateral ROI T_{sk}	27.4 ±1.5	9.4 ±2.3*	18.8 ±1.9*‡	20.7 ±1.5*‡	21.5 ±1.6*‡
ANT	74.1 ±6.8	69.9 ±6.2▼	70.9 ±6.3▼	70.2 ±6.1▼	72.9 ±7.0
PL	76.2 ±2.4	72.3 ±2.3▼	73.7 ±2.0▼	72.8 ±2.0▼	74.0 ±2.1
PM	71.9 ±3.3	71.9 ±2.7▼	69.1 ±2.8▼	68.0 ±2.7▼	70.1 ±2.9▼
COMP	74.0 ±10.3	71.3 ±9.4▼	71.2 ±9.2▼	70.3 ±9.0▼	72.3 ±10.1▼

Abbreviations: ANT, anterior; Pl, Posterolateral; PM, Posteromedial; COMP, Composite Score for ANT, PL and PM; ROI, Region of Interest; T_{sk}, Skin Surface Temperature.

* = Significant decrease in T_{sk} compared to pre-cooling application ($p = <0.05$).
‡ = Significant decrease in T_{sk} between post-application timepoints ($p = <0.05$).
▼ = Significant decrease in reach-distance compared to pre-cooling measures ($p = <0.001$).

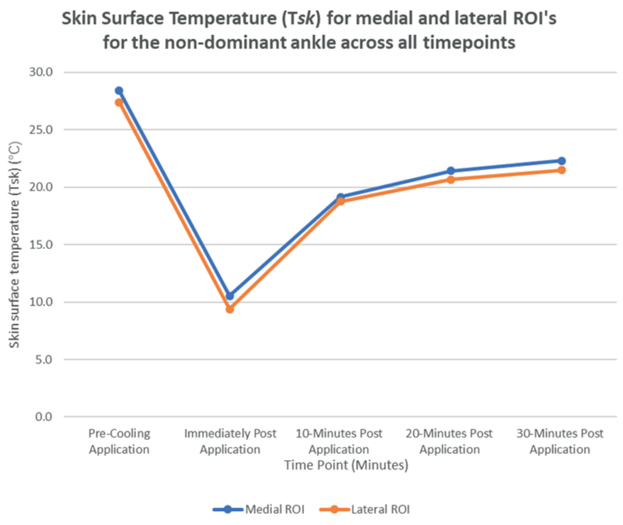

Figure 1. Skin Surface Temperature (T_{sk}) for medial and lateral ROIs for the non-dominant ankle

Modified Star Excursion Balance Test Reach Distances

Overall analysis displayed significant main effects for direction ($F = 3.62, p = 0.00, n^2 = 0.03$), and time ($F = 1.21, p = 0.03, n^2 = 0.02$). Pairwise comparison displayed a significant difference between PL and PM directions ($p < 0.05$). No interaction between time *x* direction was reported ($F = 0.18, p = 1.00, n^2 = 0.00$).

On separation of the data, significant decreases in ANT and PL reach distance were displayed for timepoints immediately, 10- and 20-minutes post ($p < 0.00$) but not at 30-minutes post ($p > 0.05$) compared to pre-cooling stability measures (Figure 2). PM and COMP scores for reach-distance displayed significant decreases across all directions and timepoints ($p < 0.00$) compared to pre-cooling measures (Table 1).

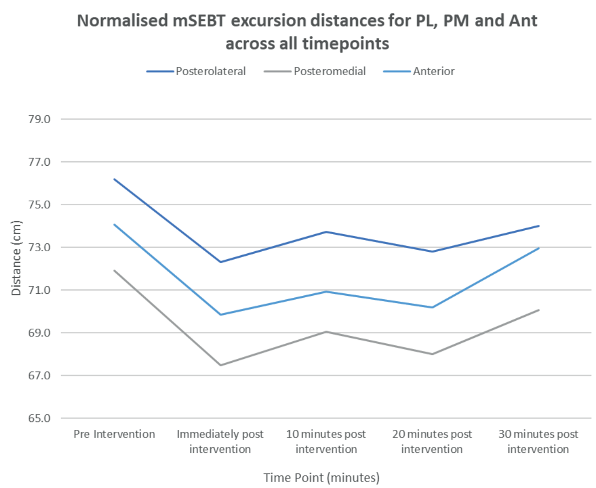

Figure 2. Mean normalised excursion reach distance achieved for PL, PM and ANT across all timepoints

Discussion

The aim of the study was to investigate the effects of wetted ice applied at the ankle on dynamic stability through a functional performance measure (mSEBT) immediately and up to 30-minutes post exposure. Supporting the hypothesis, significant decreases in dynamic stability was displayed following wetted ice application at all timepoints compared to pre-cooling data, for directions (ANT, PL and PM). This was evidenced by significant decreases in reach-distance. Our findings agree with previous literature (Fullam et al., 2015; 2020), however is the first exploratory study to observe changes over a 30-minute rewarming period. A significant decrease in $T_{sk,}$ following wetted ice application was displayed for both ROI's (medial /lateral ankle), across all timepoints compared to baseline. Our T_{sk} results are consistent with previous work over the same rewarming period of investigation (Fullam et al., 2015; Kennet et al., 2007; Alexander & Rhodes, 2019) albeit over different lower limb regions. T_{sk} fell to within therapeutic range (10–15°C) and consistent with previous findings for this modality (Dykstra et al., 2009; Alexander & Rhodes, 2019). Findings have implications on the decision making of sports medicine and performance practitioners in the context of local cryotherapy applications pitch side and the resultant or lasting effects on dynamic stabilising mechanisms in the lower limb. Practitioners should however consider the variables that can impact multi measures of response to cooling modalities and the context of application. Consequently, findings may not be generalisable to other forms of cooling applications and protocol adaptation to maximise intended benefits of cooling need to be considered and applied in practice. The current study reflects the necessity of research required in the topic of optimising cryotherapy application and the influences on mechanisms that support dynamic stabilisation.

We postulate that the significant changes found in dynamic stability are thought to be caused by the influence of cooling on neuromuscular responses and altered proprioceptive feedback mechanisms. The reliance of efficient neuromuscular pathways for dynamic stabilisation is evident (Croix et al., 2015), and as such the reduction in dynamic stability is considered a result of sensorimotor deficits initiated via reductions in T_{sk}. In the current study this is evident up to 30 minutes post, with reach distances not returning to pre-cooling measures. Results therefore suggest that wetted ice applications following minor ankle injury in sport may predispose the athlete to further reductions in dynamic stability supporting previous literature suggestions (Fullam et al., 2015). Sports medicine and performance practitioners should be mindful therefore of the need for adequate rewarming periods post application. Joint stiffness and reduced tissue compliance following local cooling applications (Bleakley et al., 2013) are thought to affect the ability to achieve joint range of motion (ROM) (Paterson et al., 2008). It might be assumed performance of the mSEBT in the current study was affected by such mechanism, with reductions in dorsiflexion for example, however findings are not comparable due to the mode of cooling involved in each study, nor were ankle kinematics quantified alongside performance outcomes in this study and is therefore presumptuous. That said, we might assume that reductions in sagittal-plane kinematics may explain reduced reach distances in all directions based on the findings by Fullam et al. (2015).

Fullam et al (2020) highlights the significance of maximum half-time interval rules from World Rugby being 15 minutes, and consistent with other team-based sports rulings including The International Football Association Board. With findings in the current study suggesting that dynamic stability does not return to baseline measures at 30 minutes post cooling exposure; applying a 15-minute cryotherapy application prior to or during a half-time interval to the ankle without an adequate rewarming period may increase the risk of further injury to stabilising structures if returning to competitive play. Considering the typical length of half-time intervals, and in support of previous work

(Fullam et al., 2015; 2020), the aim of reducing further injury risk should be managed carefully when athletes under the perception of pain reduction through cryotherapy then return to competitive play.

Kinematic observation through movement analysis data is prevalent in previous studies that aim to determine lower limb joint contributions to reach distance when performing the mSEBT (Fullam et al., 2020; Gribble et al., 2007; Hoch et al., 2011), a limitation to the current study is the exclusion of kinematic or electromyographic profiles of participants whilst performing the mSEBT. Furthermore, it would be interesting to determine participants perceptions of stability. Future studies should therefore consider subjective measures of perceived stability, combined with electromyographic and kinematic profiles of the lower limb during multiple tasks which challenge multidimensional mechanisms that contribute to functional performance. In agreement with Lawrence et al. (2015), this may not be accomplished through a single outcome measure. Multi-measure and multi-structure approach to the multiple contributors of performance may provide a holistic approach to understanding the mechanisms which are affected through local lower limb joint cooling observed over a rewarming period.

Conclusion

Results display reductions in dynamic stability following wetted ice cryotherapy application immediately after exposure and up to 30-minutes following removal. Changes in dynamic stability may have implications at half-time or stoppages in competitive play on performance if cryotherapy in the form of wetted ice is applied to the ankle joint and the athlete returns to the field. Considerations around adequate warm-up periods following wetted ice exposure to the non-dominant ankle in athletic populations is advised prior to the return to functional performance which require optimal stabilising mechanisms to inhibit the risk of injury or further injury. Opportunity for further research in this area may benefit from the inclusion of subjective feedback on perceived stability in association with multiple measures of performance and quantification of multiple stabilising structures over rewarming periods in healthy and injured athletes. As such, investigations may provide useful athlete profiles to increase applied knowledge around cryotherapy applications in sport for the benefit of the applied practitioner and athlete.

Key Points

- A 15-minute wetted ice application to the non-dominant ankle decreased skin surface temperature to within therapeutic range over both medial and lateral aspects of the ankle.
- Decreases in reach distance were recorded for Ant, PL and PM directions following wetted ice application and scores did not return to baseline at 30-minutes post application.
- Dynamic stability was adversely affected following a 15-minute, wetted ice application to the non-dominant ankle.
- Considerations regarding the length of rewarming periods post cooling and prior to return to functional activities is important to reduce injury risk in athletes that may return to the field of play following lower limb cryotherapeutic applications.

References

Alexander, J., & Rhodes, D. (2019). Temporal patterns of knee-extensor isokinetic torque strength in male and female athletes following a comparison of anterior thigh and knee cooling over a rewarming period. *Journal of Sports Rehabilitation, 29*(6), 721–729. https://doi.org/10.1123/jsr.2018-0499

Alexander, J., Rhodes, D., Birdsall, D,. & Selfe, J. (2020). Comparison of cryotherapy modality application over the anterior thigh across rugby union positions: A crossover randomised controlled trial. *International Journal of Sports Physical Therapy, 15*(2), 210–220.

Alexander, J., Richards, J., Attah, O., Cheema, S., Snook, J., Wisdell, C., May, K., & Selfe, J. (2018). Delayed effects of a 20-min crushed ice application on knee joint position sense assessed by a functional task during a re-warming period. *Gait & Posture, 62*, 173–178. https://doi.org/10.1016/j.gaitpost.2018.03.015

Alexander, J., Selfe, J., Greenhalgh, O., & Rhodes, D. (2021). Exploratory evaluation of muscle strength and skin surface temperature responses to contemporary cryotherapy modalities in sport. *Isokinetics and Exercise Science, 29*(4), 403–411. https://doi.org/10.3233/IES-200253

Allan, R., Malone, J., Alexander, J., Vorajee, S., Ihsan, M., Gregson, W., Kwiecien, S., & Mawhinney, C. (2022). Cold for Centuries: a brief history of cryotherapies to improve health, injury and post-exercise recovery. *European Journal of Applied Physiology, 122*, 1153–1162. https://doi.org/10.1007/s00421-022-04915-5

Bleakley, C. M., & Costello, J. T. (2013). Do thermal agents affect range of movement and mechanical properties in soft tissues? A systematic review. *Arch Phys Med Rehab, 94*(1), 149–63. https://doi.org/10.1016/j.apmr.2012.07.023

Bleakley, C., Costello, J., & Glasgow, P. D. (2012). Should athletes return to sport after applying ice? A systematic review of the effect of local cooling on functional performance. *Sports Medicine, 42*(1), 69–87. https://doi.org/10.2165/11595970-000000000-00000

Bleakley, C., McDonough, S., & MacAuley, D. (2004). The use of ice in the treatment of acute soft tissue injury: a systematic review of randomised controlled trials. *American Journal of Sports Medicine, 32*(1), 251–261. https://doi.org/10.1177/0363546503260757

Cankar, K., & Finderle, Z. (2003). Gender differences in cutaneous vascular and autonomic nervous response to local cooling. *Clinical Autonomic Research, 13*(3), 214–220. http://doi.org/10.1007/s10286-003-0095-5

Cohen, J. Statistical Power Analysis for the Behavioural Science. 2nd Ed. Hillside, NJ: Lawrence Erlbaum Associates; 1998.

Costello, J. T., McInerney, C. D., Bleakley, C. M., Selfe, J., & Donnelly, A. E. (2012). The use of thermal imaging in assessing skin temperature following cryotherapy: a review. *Journal of Thermal Biology, 37*(2), 103–110. https://doi.org/10.1016/j.jtherbio.2011.11.008

Coughlan, G. F., Delahunt, E., O'Sullivan, E., Fullam, K., Green, B. S., & Caulfield, B. M. (2014). Star excursion balance test performance and application in elite junior rugby union players. *Physical Therapy in Sport, 15*(4), 249–253. https://doi.org/10.1016/j.ptsp.2013.11.005

Croix, M. B. A., Elnagar, Y. O., Iga, J., James, D., & Ayala, F. (2015). Electromechanical delay of the hamstrings during eccentric muscle actions in males and females: implications for non-contact ACL injuries. *J Electro Kinesiol, 25,* 901–906.

Dykstra, J. H., Hill, H. M., Miller, M. G., Cheatham, C. C., Michael, T. J., & Baker, R. (2009). Comparison of cubed ice, crushed ice and wetted ice on intramuscular and surface temperature changes. *Journal of Athletic Training, 44*(2), 136–141. https://doi.org/10.4085/1062-6050-44.2.136

Enwemeka, C. S., Allen, C., Avila, P., Bina, J., Konrade, J., & Munns, S. (2002). Soft tissue thermodynamics before, during, and after cold pack therapy. *Medicine and Science in Sports Exercise, 34*(1), 45–50. https://doi.org/10.1097/00005768-200201000-00008

Fitzgerald, D., Trakarnratanakul, N., Smyth, B., & Caulfield, B. (2010). Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. *Journal of Orthopaedic Sports Physical Therapy, 40*(1), 11–19. https://doi.org/10.2519/jospt.2010.3121

Fullam, K., Caulfield, B., Coughlan, G. F., McNulty, W., Campbell, D., & Delahunt, E. (2020). The effect of cryotherapy application to the knee joint on dynamic postural stability. *Journal of Sports Rehabilitation, 29*(4), 454–462. https://doi.org/10.1123/jsr.2016-0218

Fullam, K., Caulfield, B., Coughlan, G. F., McGroaty, M., & Delahunt, E. (2015) Dynamic postural-stability deficits after cryotherapy to the ankle joint. *Journal of Athletic Training, 50*(9), 893–904. https://doi.org/10.4085/1062-6050-50.7.07

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Archives of Physical Medicine & Rehabilitation, 70*(7), 510–517.

Gribble, P. A., Hertel, J., & Denegar, C. R. (2007). Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. *International Journal of Sports Medicine, 28*(3): 236–242. https://doi.org/10.1055/s-2006-924289

Gribble, P. A., & Hertel, J. (2003). Considerations for Normalizing Measures of the Star Excursion Balance Test. *Measurement Physical Education and Exercise Science, 7*(2), 89–100. https://doi.org/10.1207/S15327841MPEE0702_3

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training, 47*(3), 339–357. https://doi.org/10.4085/1062-6050-47.3.08

Harper, D., McBurnie, A. J., Dos' Santos, T., Erlksrud, O., Evans, M., Cohen, D. D., David, R., Carling, C., & Kiely, J. (2022). Biomechanical and neuromuscular performance requirements of horizontal deceleration: A review with implications for random intermittent multi-directional sports. *Sports Medicine, 52,* 2321–2354. http://dx.doi.org/10.1007/s40279-022-01693-0

Hertel, J., Braham, R. A., Hale, S. A,. & Olmsted-Kramer, L. C. (2006). Simplifying the Star Excursion Balance Test: analyses of subjects with and without chronic ankle instability. *Journal of Orthopaedic Sports Physical Therapy, 36*(3), 131–137. https://doi.org/10.2519/jospt.2006.36.3.131

Hoch, M. C., Staton, G. S., & McKeon, P. O. (2011). Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport, 14*(1), 90–92. https://doi.org/10.1016/j.jsams.2010.08.001

International Football Association Board. Law 7 page 83. https://www.theifab.com/log-documents Accessed August 27th 2020.

Ioannou, S. (2020). Functional Infrared Thermal Imaging: A Contemporary Tool in Soft Tissue Screening. *Scientific Reports, 10*, 9303. https://doi.org/10.1038/s41598-020-66397-9

Kalli, K., & Fousekis, K. (2019). The effects of cryotherapy on athletes' muscle strength, flexibility, and neuromuscular control: A systematic review of the literature. *Journal of Bodywork & Movement Therapy, 24*(2), 175–188. https://doi.org/10.1016/j.jbmt.2019.11.001

Kennet, J., Hardaker, N., Hobbs, S., & Selfe, J. (2007). Cooling efficacy of 4 common cryotherapeutic agents. *Journal of Athletic Training, 42*(3), 343–348.

Kwiecien, S. Y., Mathew, S., Howatson, G., & McHugh, M. P. (2020). The effect of varying degrees of compression from elastic vs plastic wrap on the quadriceps intramuscular temperature during wetted ice application. *Scandinavian Journal of Medicine and Science in Sports*, *29*(8), 1109–1114. https://doi.org/10.1111/sms.13430

Lawrence, E. L., Cesar, G. M., Bromfield, M. R., Peterson, R., Valero-Cuevas, F., & Sigward, S. (2015). Strength, Multi-joint Coordination, and Sensorimotor Processing Are Independent Contributors to Overall Balance Ability. *BioMed Research International.* 561243.

McCollum, G., Shupert, C. L., & Nashner, L. M. (1996). Organizing sensory information for postural control in altered sensory environments. *Journal of Theoretical Biology, 180*, 257–270. https://doi.org/10.1006/jtbi.1996.0101

Moreira, D. G., Costello, J. T., Brito, C. J,. Adamczyk, J. G., Ammer, K., Bach, A. J. E., Costa, C. M. A., Eglin, C., Fernandes, A. A., Fernandez-Cuevas, I., Ferreira, J. J. A., Formenti, D., Fournet, D., Havenith, G., Howell, K., Jung, A., Kenny, G. P., Kolosovas-Machuca, E. S., Maley, M. J., Merla, A., Pascoe, D. D., Quesada, J. I. P., Schwartz, R. G., Seixas, A. R. D., Selfe, J., Vainer, B. G., & Sillero-Quintana, M. (2017). Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature. *Journal of Thermal Biology, 69*, 155–162. https://doi.org/10.1016/j.jtherbio.2017.07.006

Murray, A., & Cardinale, M. (2015). Cold applications for recovery in adolescent athletes: a systematic review and meta-analysis. *Extreme Physiology in Medicine, 12*(4), 17.

Patterson, S. M., Udermann, B. E., Doberstein, S. T., & Reineke, D. M. (2008). The effects of cold whirlpool on power, speed, agility, and range of motion. *Journal of Sports Science & Medicine Med, 7*(3), 387–394.

Picot, B., Terrier, R., Forestier, N., Fourchet, F., & McKeon, P. O. (2021) The Star Excursion Balance Test: An Update Review and Practical Guidelines. Int. *Journal of Athletic Therapy & Training*, *26*(6), 285–293. https://doi.org/10.1123/ijatt.2020-0106

Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., and Elkins, B. (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy, 4*(2), 92–99.

Robinson, R., & Gribble, P. (2008). Kinematic predictors of performance of the star excursion balance test. *Journal of Sports Rehabilitation*, *17*(4), 347–357. https://doi.org/10.1123/jsr.17.4.347

Soligard, T., Schwellnus, M., Alonso, J.-M., Nahr, R., Clarsen, B., Dijkstra, P. H., Gabbett, T., Gleeson, M., Hagglund, M., Hutchinson, M. R., van Rensburg, C. J., Khan, K. M., Meeusen, R., Orchard, J. W., Pluim, L. B., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 1) Internationale Olympic Committee consensus statement on load in sport and risk of injury. *50*(17), 1030–1041. https://doi.org/10.1136/bjsports-2016-096581

Stal, F., Fransson, P. A., Magnusson, M,. & Karlberg, M. (2003). Effects of hypothermic anaesthesia of the feet on vibration-induced body sway and adaptation. *Journal of Vestibular Research, 13*(1), 39–52.

Twist C, & Worsfold, P. (2014). *Science of Rugby.* London: Routledge.

Van Lieshout, R., Reijneveld, E. A. E., ven den Berg, S. M,. Koenders, N., de Leeuw, A., van Oorsouw, R. G., Paap, D., Scheffer, E., Weterings, S., & Stukstette, M. J. (2016). Reproducibility of the modified star excursion balance test composite and specific reach direction scores. *International Journal of Sports Physical Therapy*, *11*(3), 356–365.

Van Melick, N., Meddeler, B. M., Hoogeboom, T. J., Nijhuis-van der Sanden, M. W. G., & van Cingel, R. E. H. (2017). How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults. *PLoS ONE*, *12*(12), 1–9. https://doi.org/10.1371/journal.pone.0189876

Williams, E., Miller, S., Sebastianelli, W., & Vairo, G. (2013). Comparative immediate functional outcomes among cryotherapeutic interventions at the ankle. *International Journal of Sports Physical Therapy, 8*(6), 828–837.

World Rugby Laws of the Game Rugby Union. Law 5 Page 38. Accessed August 27th 2020.

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