DOES THE USE OF A KNEE BRACE CHANGE THE BIOMECHANICS DURING A BADMINTON LUNGE TO THE NET, AND WHAT ARE THE IMPLICATIONS TO INJURY MECHANISMS?

Raúl Valldecabres[1], Ana María de Benito[2], Greg Littler[3], Jim Richards[3]

1 Doctorate School. Valencia Catholic University 'San Vicente Mártir'

2 Physical Activity and Sports Sciences Faculty. Valencia Catholic University 'San Vicente Mártir'

3 Allied Health Research Unit, University of Central Lancashire

Corresponding Author:

Raúl Valldecabres

raul.valldecabres@gmail.com

ABSTRACT

The aim of this study was to determine changes in knee biomechanics during badminton lunges due to fatigue, lunge strategy and knee bracing. Kinetic and kinematic data were collected from sixteen experienced right-handed badminton players. Three factor repeated measures ANOVAs (lunge direction – fatigue – brace) were performed with Least Significant Difference pairwise comparisons. In addition, clinical assessments including; Y-balance test, one leg hop distance and ankle dorsiflexion range of motion were performed pre and post fatigue. The knee showed significantly greater flexion during the forehand lunge compared to backhand. In contrast, the internal rotation velocity and the knee extension moment were greater during backhand. Knee angular velocity in the sagittal plane, peak knee moment and range of moment in the coronal plane and stance time showed significantly lower values post fatigue. In addition, the peak knee adduction moment showed significantly lower values in the braced condition in both the fatigued and non-fatigues states, and no significant differences were seen for peak vertical force, loading rate, approach velocity, or in any of the clinical assessment scores. There appears to be greater risk factors when performing a backhand lunge to the net compared to a forehand lunge, and proprioceptive bracing appears to reduce the loading at the knee.

INTRODUCTION

Badminton is characterized by high intensity effort over short durations (Cabello, 2000), with players needing to move quickly in multiple directions (Jaitner & Gawin, 2007; Kuntze, Mansfield, & Sellers, 2010; Sturgess & Newton, 2008), and to execute shots while maintaining balance and motor control (Grice, 2008). Pivoting, jumping and lunges are the most common movements as players try to reach the shuttlecock or move back to a defensive position as quickly as possible (Gibbs, 1988; Robinson & O'Donoghue, 2008). Valldecabres, de Benito, Casal, & Pablos (2017) quantified that more than 50% of lunge movements were in a diagonal direction and Kuntze, Mansfield, & Sellers (2010) showed 15% of movements were from the centre of the court to the net.

Badminton kinetics and kinematics have been previously studied (Hong, Jun Wang, Kai Lam, & Tak-Man, 2014; Honsg, Wang, Lam, & Cheung, 2014; Kuntze et al., 2010). However, there appears to be a lack of studies investigating the effects of fatigue, which may give a greater understanding of injury risk factors for players and coaches, and assist in the decision making during training when considering shot performance and return to sports post injury.

During badminton 70% of injuries are to the lower limbs (Jafari, Mabani, Golami, & Mabani, 2014; Jørgensen & Winge, 1987; Shah, Ansari, & Qambrani, 2014), with approximately 50% of these being patellar tendinopathy and patellofemoral joint syndrome (Shariff, George, & Ramlan, 2009). Extrinsic mechanisms such as; overtraining, muscle imbalance, lower extremity malalignment or knee joint laxity and training errors have all been reported as contributing factors in Patellofemoral pain (PFP) (Tumia & Maffulli, 2002). In addition, knee abduction moments have also been shown to be important contributors to symptoms (Myer et al., 2015).

PFP is often treated using exercise, foot orthoses, taping and knee braces (Bolgla & Boling, 2011). Knee braces aim to improve the tracking of the patella in the trochlea grove (Paluska & McKeag, 2000). The use of proprioceptive bracing in injury prevention has also attracted some attention during daily activities (Selfe et al., 2011) and sports specific tasks (Hanzlíková et al., 2016; Sinclair, Selfe, Taylor, Shore, & Richards, 2016; Sinclair, Vincent, & Richards, 2017), however little is known about their efficacy when the athlete is in a fatigued state. The aim of this study was to determine the changes in knee kinetics and kinematics during badminton lunges to the net due to; fatigue, lunge direction (forehand and backhand) and knee bracing. It was hypothesized that fatigue would increase knee moments and decrease the stability during the clinical tests, whereas knee bracing would reduce knee moments and increase the stability during the clinical tests, and that the backhand lunge would show the greatest knee moments and angular velocity. In addition, the effect of fatigue and bracing on clinical scores during dynamic stability and weight bearing tests were explored. It was hypothesized that dynamic stability during the clinical tests would decrease and angular velocity would increase during the lunge tasks following fatigue.

MATERIALS AND METHODS

Participants

Sixteen right-handed badminton players (10 males and 6 females) with a mean age of 27.1±9.0 years, height of 172.1±8.9cm and weight of 74.0±16.5 kg, were recruited. All participants reported to be free from any pain or pathology affecting the lower limbs at the time of testing. This study was approved by the STEMH Ethics Committee (Ref. STEMH 671), volunteers gave written informed consent prior to participation and all data collection conformed to the Declaration of Helsinki.

Equipment

Kinematic data were collected using a ten camera Oqus 7 Qualisys motion analysis system at 200 Hz (Qualisys medical AB, Gothenburg, Sweden), and kinetic data were collected at 2000 Hz using two AMTI force platforms. Passive retroreflective markers were placed on the lower limbs using the calibrated anatomical system technique to allow for segmental kinematics to be tracked in 6 degrees of freedom (Cappozzo, Catani, Croce, & Leardini, 1995). In order to reduce measurement error, reflective markers were positioned by a single experienced researcher. Anatomical markers were positioned on the anterior superior iliac spine, posterior superior iliac spine, greater trochanter, medial and lateral femoral epicondyle, medial and lateral malleoli and over the medial and lateral aspects of the first and fifth metatarsals. In addition, clusters of non-collinear markers were attached to the shank and thigh. (figure 1) Markers were also placed over the forefoot, midfoot, and rearfoot aspects of the shoes (figure 1) (Richards, 2018). To enable the fitting of the brace, the thigh and shank marker clusters were placed above and below the brace respectively as described by Hanzlíková et al. (2016). Raw kinematic and kinetic data were exported to Visual3D (C-Motion Inc., USA). Kinematic and kinetic data were filtered using fourth order Butterworth filters with cut off frequencies of 15 and 25 Hz respectively (Hanzlíková et al., 2016).

Procedure

Participants were required to visit the laboratory on two occasions using a randomized order for the knee braced and no braced conditions. The knee brace used was an off the shelf proprioceptive brace (Reaction Brace, DJO Global Inc.) which was applied in accordance with the manufacturer's instructions (figure 1). On arrival, anthropometric measurements were taken. A standardised 10 minute warm-up was performed, which included active stretching of the quadriceps and hamstring muscles (Lam et al., 2017), specifically this involved five repetitions of 30 seconds per muscle; and familiarisation of the lunge tasks, which involved performing as many repetitions as the participants needed to feel comfortable with the task (Gribble, Hertel, & Plisky, 2012). After the warm up 5 lunges to the net were performed to each side (forehand and backhand), from an identical position 45º to the net. Participants were asked to hit the shuttlecock with a top spin shot, with the final step being made with the dominant limb landing on the force plate. The shuttlecock was positioned 0.15 m in front of the net, 0.4 m to the side of the force plate at a height of 1.65 m, figure 2. After the initial assessment, a fatigue protocol was performed which consisted of repeated forward lunges until the point of maximum volitional fatigue (Pincivero, Aldworth, Dickerson, Petry, & Shultz, 2000). This consisted of the lunge distance for each participant being determined as a proportion of the participants' leg length measured from the anterior superior iliac spine (ASIS) to the medial malleolus. A metronome was then used to control the number of lunges which was set to 30 repetitions per minute, a fatigued state was considered to have been reached when the participant could no longer keep up the rhythm (Pincivero et al., 2000). Immediately following the fatigue protocol, participants performed the lunge tasks again, the order of which was randomised. All participants wore their own sport footwear during the lunge tasks. In addition, clinical assessment tests including; the Y balance test, one leg hop distance and ankle dorsiflexion range of motion test (Weir & Chockalingam, 2007) measured using the leg motion system (Calatayud et al., 2015) were conducted pre and post fatigue state, figure 3.

[Figures 1, 2 and 3 near here]

Data Analysis

The peak vertical force, loading rate, approach velocity, stance time, and maximum, minimum, and range of motion of the knee joint angles and moments in the sagittal, coronal and transverse plane were exported from Visual3D.

Statistical Analysis

All data were examined for normality using the Shapiro-Wilks test and found suitable for parametric testing. Three factor repeated measures ANOVA tests (fatigue – lunge direction — brace) were performed with post-hoc comparisons for the lunge tests, and two factor repeated measures ANOVA tests (fatigue – brace) were performed for the dynamic stability and weight bearing tests. In addition, the effect size was reported using Partial eta squared (η_p^2) and statistical significance was set at $p < 0.05$. All statistical analysis was performed using SPSS (v24)

RESULTS

No significant interactions were seen between factors for any of the variables analysed. Significant main effects between pre and post fatigue were seen in the knee flexion angular velocity at heel strike and range of knee angular velocity in the coronal plane during the lunge tasks (table 1), with both parameters showing a 28.2% and 10.8% decrease post fatigue respectively. In addition, significant main effects were seen in stance time, knee abduction moment and range of moment in the coronal plane (table 2), showing 5.3%, 20.2% and 8.5% lower values post fatigue respectively (table 3). When comparing the forehand and backhand tasks significant main effects were seen in the knee flexion angle and transverse plane knee angular velocity at heel strike (table 1). This showed a 4.4% greater knee flexion and 66.2% lower internal rotation velocity during the forehand lunge (table 3). In addition, significant main effects were seen in the knee extension moment (table 2), with the forehand lunge showing a 9.0% lower knee extension moment (table 3). When comparing the braced and no braced conditions, significant main effects were seen in the peak knee adduction moment (table 2), with a 34.8% lower knee moment being seen in the braced condition (table 3). For the force and time data no significant effects were seen for peak vertical force, loading rate, or approach velocity. No significant differences were seen between pre and post fatigue or between brace and no brace for the Y balance test, one leg hop distance or ankle dorsiflexion range of motion test (table 4).

[Tables 1 to 4 near here]

DISCUSSION

The aim of the current investigation was to examine the effects of fatigue, lunge strategy and wearing a knee brace on knee kinetics and kinematics during badminton lunges to the net and clinical scores in experienced badminton players. Key findings for the effect of fatigue showed that the knee flexion angular velocity at heel strike, range of knee angular velocity in the coronal plane. Kinetic data showed that the peak knee adduction moment and coronal plane moment range were all lower post fatigue, which occurred over a shorter stance time. The changes in joint angular velocity, with no corresponding change in joint angles, would indicate that there is a slower movement, however no significant difference was seen in the approach speed. Therefore, this would indicate an increase in joint stiffness in the sagittal and coronal planes defined by Hughes & Watkins (2008) with a lower adaptability as the leg resistance moves into compression over less time during landing. This increase in stiffness is supported by Arampatzis, Schade, Walsh, & Brüggemann (2001) who found that lower limbs stiffness influences athletic performance in sports activities. This could relate to a potential increase in injury risk due to increase stress and strain in the knee joint (Derrick, Dereu, & Mclean, 2002; Dierks, Davis, & Hamill, 2010) and changes to dynamic loads on the lower limbs through an interaction of simultaneous concentric and eccentric contractions when athletes are in a fatigue state (Komi, 2000). One explanation for the decreases in peak knee adduction moment and coronal plane moment range, could be a change in strategy during loading, which may relate to changes in foot position and posture during the lunge. This reduction in the knee adduction moments could be explained by the foot landing in more external rotated position, therefore changing the line of action of the ground reaction force; although no changes were seen in the transverse plane moments at the knee. However, further exploration of such compensatory mechanisms due to foot placement is beyond the scope of this current paper.

When comparing the forehand and backhand tasks significant main effects were seen in the sagittal and transverse planes. During the forehand lunge a greater knee flexion was seen at heel strike with less internal rotation than the backhand lunge. This would indicate a lower injury risk during the forehand lunge, as increases in internal rotation movements have been shown to be an ACL injury risk mechanism (Fornalski, McGarry, Csintalan, Fithian, & Lee, 2008; Myer, Ford, Paterno, Nick, & Hewett, 2008).

When comparing the braced and no braced conditions, a significant reduction in peak knee adduction moment was seen in the braced condition (Table 2 and 3). This would indicate a reduction in the medial compartment contact force (Manal, Gardinier, Buchanan, & Snyder-Mackler, 2015), which has been associated with lower pain levels in knee OA and reductions in knee varum (Miyazaki, 2002). However, the brace used in this study was not a rigid brace and therefore this effect is unlikely to be from any mechanical realignment of the knee, but can be explained by a change in loading strategy due to changes in proprioception. This has been previously seen in several studies during step descent (Akseki, 2008; Baker, Bennell, Stillman, Cowan, & Crossley, 2002; Callaghan, Selfe, Bagley, & Oldham, 2002; Callaghan, Selfe, McHenry, & Oldham, 2008; Selfe et al., 2011), and sports related movement tasks (Hanzlíková et al., 2016; Sinclair et al., 2016), who reported improvements in knee stability and reductions in knee pain.

Interestingly no significant differences were seen between pre and post fatigue or between brace and no brace for the Y balance test, one leg hop distance or ankle dorsiflexion range of motion test. This would indicate that overall performance was unchanged, whereas movement control and strategy during the lunge tasks were affected. This suggests that these clinical scores were not sensitive to potentially clinically important changes that can be associated with knee injury risk factors.

Limitations of this study include; participants wearing their own shoes rather than standardised footwear. Although Park, Lam, Yoon, Lee, & Ryu (2017) suggested that different designs of badminton shoes do not significantly affect lower extremity kinematics, although these did have an effect on subjective perception of comfort. In addition, this study recruited participants who were recreational athletes who had played badminton for at least 2 years, however due to possible differences in technique it is not possible to extrapolate these findings to elite players.

CONCLUSIONS

This study showed no significant differences in approach velocity and loading rate post fatigue, however a greater knee stiffness was seen. In addition, there appears to be greater risk factors when performing a backhand lunge to the net compared to a forehand lunge. These factors should be considered when developing training regimes. Finally, proprioceptive bracing appears to improve the loading patterns at the knee, which should be considered when players are returning to sport after an injury.

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REFERENCES

Akseki, D. (2008). Proprioception of the knee joint in patellofemoral pain syndrome. *Acta Orthopaedica et Traumatologica Turcica*, 316-321. https://doi.org/10.3944/AOTT.2008.316

Arampatzis, A., Schade, F., Walsh, M., & Brüggemann, G.-P. (2001). Influence of leg stiffness and its effect on myodynamic jumping performance. *Journal of Electromyography and Kinesiology*, *11*(5), 355-364. https://doi.org/10.1016/S1050-6411(01)00009-8

Baker, V., Bennell, K., Stillman, B., Cowan, S., & Crossley, K. (2002). Abnormal knee joint position sense in individuals with patellofemoral pain syndrome. *Journal of Orthopaedic Research*, *20*(2), 208-214. https://doi.org/10.1016/S0736-0266(01)00106-1

Bolgla, L. A., & Boling, M. C. (2011). An update for the conservative management of patellofemoral pain syndrome: a systematic review of the literature from 2000 to 2010. *The International Journal of Sports Physical Therapy*, *6*(2), 112-125.

Cabello, D. (2000). *Análisis de las características del juego en el bádminton de competición. Su aplicación al entrenamiento*. Universidad de Granada, Departamento de Educación Física y Deportiva.

Calatayud, J., Martín, F., Gargallo, P., García-Redondo, J., Colado, J. C., & Marín, P. J. (2015). The validity and reliability of a new instrumented device for measuring ankle dorsiflexion range of motion. *The International Journal of Sports Physical Therapy*, *10*(2), 197-202.

Callaghan, M. J., Selfe, J., Bagley, P. J., & Oldham, J. A. (2002). The Effects of Patellar Taping on Knee Joint Proprioception. *Journal of Athletic Training*, *37*(1), 19-24.

Callaghan, M. J., Selfe, J., McHenry, A., & Oldham, J. A. (2008). Effects of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. *Manual Therapy, 13*(3), 192-199. https://doi.org/10.1016/j.math.2006.11.004

Cappozzo, A., Catani, F., Croce, U. D., & Leardini, A. (1995). Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics, 10*(4), 171-178.

Derrick, T. R., Dereu, D., & Mclean, S. P. (2002). Impacts and kinematic adjustments during an exhaustive run: *Medicine & Science in Sports & Exercise*, *34*(6), 998-1002. https://doi.org/10.1097/00005768-200206000-00015

Dierks, T. A., Davis, I. S., & Hamill, J. (2010). The effects of running in an exerted state on lower extremity kinematics and joint timing. *Journal of Biomechanics*, *43*(15), 2993-2998. https://doi.org/10.1016/j.jbiomech.2010.07.001

Fornalski, S., McGarry, M. H., Csintalan, R. P., Fithian, D. C., & Lee, T. Q. (2008). Biomechanical and Anatomical Assessment after Knee Hyperextension Injury. *The American Journal of Sports Medicine*, *36*(1), 80-84. https://doi.org/10.1177/0363546507308189

Gibbs, M. J. (1988). Badminton-Teaching Concepts. *Journal of Physical Education, Recreation & Dance, 59*(8), 92-94.

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

Grice, T. (2008). *Badminton: Steps to Success* (2nd ed.). Champaign, IL: Human Kinetics.

Hanzlíková, I., Richards, J., Tomsa, M., Chohan, A., May, K., Smékal, D., & Selfe, J. (2016). The effect of proprioceptive knee bracing on knee stability during three different sport related movement tasks in healthy subjects and the implications to the management of Anterior Cruciate Ligament (ACL) injuries. *Gait & Posture*, *48*, 165-170. https://doi.org/10.1016/j.gaitpost.2016.05.011

Hong, Y., Jun Wang, S., Kai Lam, W., & Tak-Man, J. (2014). Kinetics of badminton lunges in four directions. *Journal of Applied Biomechanics*, (30), 113-118.

Hughes, G., & Watkins, J. (2008). Lower Limb Coordination and Stiffness During Landing from Volleyball Block Jumps. *Research in Sports Medicine*, *16*(2), 138-154.

Jafari, A., Mabani, M., Golami, M., & Mabani, M. (2014). The Prevalence and Causes of Sport Injuries in Well-Trained Badminton Players of Iran. *International Journal of Basic Sciences & Applied Research*, *3*(1), 40-44.

Jaitner, T., & Gawin, W. (2007). Analysis of badminton smash with a mobile measure device based on accelerometry. En *ISBS-Conference Proceedings Archive* (Vol. 1).

Jørgensen, U., & Winge, S. (1987). Epidemiology of badminton injuries. *International journal of sports medicine*, *8*(6), 379-382.

Komi, P. V. (2000). Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of Biomechanics*, *33*(10), 1197-1206. https://doi.org/10.1016/S0021-9290(00)00064-6

Kuntze, G., Mansfield, N., & Sellers, W. (2010). A biomechanical analysis of common lunge tasks in badminton. *Journal of Sports Sciences*, *28*(2), 183-191. https://doi.org/10.1080/02640410903428533

Lam, W.-K., Ryue, J., Lee, K.-K., Park, S.-K., Cheung, J. T.-M., & Ryu, J. (2017). Does shoe heel design influence ground reaction forces and knee moments during maximum lunges in elite and intermediate badminton players? PloS one, 12(3), e0174604.

Manal, K., Gardinier, E., Buchanan, T. S., & Snyder-Mackler, L. (2015). A more informed evaluation of medial compartment loading: the combined use of the knee adduction and flexor moments. *Osteoarthritis and Cartilage*, *23*(7), 1107-1111. https://doi.org/10.1016/j.joca.2015.02.779

Meyer, E. G., & Haut, R. C. (2008). Anterior cruciate ligament injury induced by internal tibial torsion or tibiofemoral compression. *Journal of Biomechanics*, *41*(16), 3377-3383. https://doi.org/10.1016/j.jbiomech.2008.09.023

Miyazaki, T. (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. *Annals of the Rheumatic Diseases*, *61*(7), 617-622. https://doi.org/10.1136/ard.61.7.617

Myer, G. D., Ford, K. R., Di Stasi, S. L., Foss, K. D. B., Micheli, L. J., & Hewett, T. E. (2015). High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: Is PFP itself a predictor for subsequent ACL injury? *British Journal of Sports Medicine*, *49*(2), 118-122. https://doi.org/10.1136/bjsports-2013-092536

Myer, G. D., Ford, K. R., Paterno, M. V., Nick, T. G., & Hewett, T. E. (2008). The Effects of Generalized Joint Laxity on Risk of Anterior Cruciate Ligament Injury in Young Female Athletes. *The American Journal of Sports Medicine*, *36*(6), 1073-1080. https://doi.org/10.1177/0363546507313572

Paluska, S. A., & McKeag, D. B. (2000). Knee braces: current evidence and clinical recommendations for their use. *American family physician*, *61*(2), 411-418.

Park, S.-K., Lam, W.-K., Yoon, S., Lee, K.-K., & Ryu, J. (2017). Effects of forefoot bending stiffness of badminton shoes on agility, comfort perception and lower leg kinematics during typical badminton movements. *Sports Biomechanics*, *16*(3), 374-386. https://doi.org/10.1080/14763141.2017.1321037

Pincivero, D. M., Aldworth, C., Dickerson, T., Petry, C., & Shultz, T. (2000). Quadriceps-hamstring EMG activity during functional, closed kinetic chain exercise to fatigue. *European journal of applied physiology*, *81*(6), 504–509.

Richards, J. (2018). *The Comprehensive Textbook of Clinical Biomechanics*. Elsevier Health Sciences.

Robinson, G., & O’Donoghue, P. (2008). A movement classification for the investigation of agility demands and injury risk in sport. *International Journal of Performance Analysis in Sport, 8*(1), 127-144. https://doi.org/10.1080/24748668.2008.11868428

Selfe, J., Thewlis, D., Hill, S., Whitaker, J., Sutton, C., & Richards, J. (2011). A clinical study of the biomechanics of step descent using different treatment modalities for patellofemoral pain. *Gait & Posture, 34*(1), 92-96. https://doi.org/10.1016/j.gaitpost.2011.03.019

Shah, S. A. A., Ansari, M. A., & Qambrani, M. R. (2014). The occurrence of knee injury in badminton: a case study of sindh. *Research Journal of Physical Education & Sports Science*, *19-30*, 19.

Shariff, A. H., George, J., & Ramlan, A. A. (2009). Musculoskeletal injuries among Malaysian badminton players. *Singapore medical journal, 50*(11), 1095.

Sinclair, J. K., Selfe, J., Taylor, P. J., Shore, H. F., & Richards, J. (2016). Influence of a knee brace intervention on perceived pain and patellofemoral loading in recreational athletes. *Clinical Biomechanics*, *37*, 7-12. https://doi.org/10.1016/j.clinbiomech.2016.05.002

Sinclair, J. K., Vincent, H., & Richards, J. D. (2017). Effects of prophylactic knee bracing on knee joint kinetics and kinematics during netball specific movements. *Physical Therapy in Sport, 23*, 93-98. https://doi.org/10.1016/j.ptsp.2016.08.005

Sturgess, S., & Newton, R. U. (2008). Design and Implementation of a Specific Strength Program for Badminton: *Strength and Conditioning Journal*, *30*(3), 33-41.

https://doi.org/10.1519/SSC.0b013e3181771008

Tumia, N., & Maffulli, N. (2002). Patellofemoral Pain in Female Athletes: *Sports Medicine and Arthroscopy Review*, *10*(1), 69-75. https://doi.org/10.1097/00132585-200210010-00010

Valldecabres, R., de Benito, A. M., Casal, C. A., & Pablos, C. (2017). 2015 Badminton world championship: Singles final men's vs. women's behaviours. *Journal of Human Sport and Exercise*, *12*(3proc), 775-788. https://doi.org/10.14198/jhse.2017.12.Proc3.01

Weir, J., & Chockalingam, N. (2007). Ankle joint dorsiflexion: assessment of true values necessary for normal gait. *International Journal of Therapy and Rehabilitation*, *14*(2), 76-82.