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HASAN, Hosni, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>, CHOW, Jia Yi and KERR, Graham

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Changes in organisation of instep kicking as a function of wearing compression and textured materials

Hosni Hasan[1,4,5*] , Keith Davids[2] , Jia Yi Chow[3] & Graham Kerr[1,4]

[1]*School of Exercise and Nutrition Science, Queensland University of Technology, Victoria Park Road, Kelvin Grove 4059, QLD Australia,*
+61451113652, hosni.hasan@hdr.qut.edu.au,

[2]*Centre for Sports Engineering Research, Sheffield Hallam University, Broomgrove Road, Sheffield S10 2NA, United Kingdom,*
+01142252255, k.davids@shu.ac.uk,

[3]*Physical Education and Sports Science, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore,*
+67903194, jiayi.chow@nie.edu.sg,

[4]*Movement Neuroscience, Institute of Health and Biomedical Innovation, Queensland University of Technology, Kelvin Grove 4059, QLD Australia,*
+61731386303, g.kerr@qut.edu.au,

[5]*Faculty of Sports Science and Recreation, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia.*

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*Corresponding author:

Hosni Hasan
School of Exercise and Nutrition Sciences,
Victoria Park Road, Kelvin Grove 4059,
Queensland, Australia
Telephone: +61451113652

E-mail: hosni.hasan@hdr.qut.edu.au

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Abstract

This study investigated effects of wearing compression garments and textured insoles on modes of movement organisation emerging during performance of lower limb interceptive actions in association football. Participants were six skilled (age = 15.67 ± 0.74 years) and six less-skilled (age = 15.17 ± 1.1 years) football players. All participants performed 20 instep kicks with maximum velocity in four randomly organized insoles and socks conditions, a) Smooth Socks with Smooth Insoles (SSSI); b) Smooth Socks with Textured Insoles (SSTI); c) Compression Socks with Smooth Insoles (CSSI); and d), Compression Socks with Textured Insoles (CSTI). Results showed that, when wearing textured and compression materials (CSSI condition), less-skilled participants displayed significantly greater hip extension and flexion towards the ball contact phase, indicating larger ranges of motion in the kicking limb than in other conditions. Less-skilled participants also demonstrated greater variability in knee-ankle intralimb **(angle-angle plots)** coordination modes in the CSTI condition. Findings suggested that use of textured and compression materials increased attunement to somatosensory information from lower limb movement, to regulate performance of dynamic interceptive actions like kicking, especially in less-skilled individuals.

Keywords:

Textured insoles, clinical compression socks, instep kick, somatosensory information, attunement

Introduction

Successful performance of interceptive actions in sports such as kicking a ball with the instep of the foot requires the assembly of a movement pattern which facilitates the development of high velocities in distal segment (knee and ankle joint) (Davids, Lees, & Burwitz, 2000). Interceptive actions, such as kicking, are complex tasks in which both spatial and temporal constraints on action have to be satisfied as functional movement system degrees of freedom are (re)organised by the performer (Davids et al., 2000).

Most previous research on kicking behaviours has investigated changes in participants differing in skill levels (Chow, Davids, Button, & Koh, 2007; Egan, Verheul, & Savelsbergh, 2007) and has examined the effects of practice (Anderson & Sidaway, 1994; Chow, Davids, Button, & Koh, 2008; Hodges, Hayes, Horn, & Williams, 2005). Chow et al. (2007) investigated coordination changes in participants, differing in skill levels, as they kicked a ball over a barrier. Results showed that skilled and intermediate level participants produced less joint involvement at the proximal (i.e., hip movement) compared with novices. Anderson and Sidaway (1994) investigated changes in coordination associated with practice of instep kicking over 10 weeks, showing that novice kicking coordination patterns changed significantly from pre to post test, displaying significant increases in maximum foot velocity. They also found that novice movement topological characteristics **(relative motions of hip and knee)** become more similar to those displayed in expert performance (in the post-test). They suggested that the novice had begun to acquire a functional set of relative motions **(representing skilled performance)** for the kicking task after extended weeks of practice.

Previous research on kicking shows that emergence of coordination differs between individuals of different skill levels and after extended practice. In this study, we investigated whether organisation of kicking movements would also differ due to effects of enhanced somatosensory feedback received from kicking limbs. This is a relevant issue because there is evidence that use of textured (Steinberg, Tirosh, Adams, Karin, & Waddington, 2015; Steinberg, Waddington, Adams, Karin, Begg, et al., 2015; Steinberg, Waddington, Adams, Karin, & Tirosha, 2015; Waddington & Adams, 2003; Wheat, Haddad, Fedirchuk, & Davids, 2014) and compression materials (Hasan, Davids, Chow, & Kerr, 2016; Woo, Davids, Liukkonen, Jaakkola, & Chow, 2014) can improve attunement to movement information, providing enhanced haptic and proprioceptive stimulation (Orth et al., 2013). Improved perceptual-motor performance in previous research is believed to be due to enhanced somatosensory system functioning during mechanical interactions with textured and compression materials, which stimulate specialized cutaneous receptors located on the plantar soles of the feet (Orth et al., 2013; Qiu et al., 2013). These cutaneous receptors continually provide afferent information to support adjustments in maintaining equilibrium and dynamic balance. They are sensitive to specific spatio-temporal scales of mechanical energy stimulation and continuously distinguish intensity of action, velocity and acceleration in lower limbs (Orth et al., 2013).

Textured socks have been used as an intervention tool in previous research to enhance the stimulation of the plantar surface area of the foot in order to increase somatosensory feedback in balancing adults (Wheat et al., 2014). Textured socks design in their study (a sock with texture on the side) was similar to insoles used in previous research (e.g., Maki, Perry, Norrie, & McIlroy, 1999), which utilised surface indentations to stimulate cutaneous mechanoreceptors. Taken together, the findings of previous studies suggest that complementary use of textured (Wheat et al., 2014) and compression socks (Woo et al., 2014) might increase afferent sensory information from the feet to facilitate performance of dynamic interceptive actions in sport (Orth et al., 2013). This is important because Han, Anson, Waddington, and Adams (2014) linked good proprioceptive acuity to skilled sport performance, possibly underpinning success in elite sport.

Here we sought to understand whether the functional variability induced in the sensorimotor system may be enhanced by *interactions* of textured and compression materials during motor performance (Davids, Shuttleworth, Button, Renshaw, & Glazier, 2004). We investigated **using quantitative and qualitative methods** whether organisation of kicking actions would be constrained in participants by wearing **compression and textured materials**. Finally, we examined whether proposed benefits of wearing **compression and textured materials**, through enhanced proprioceptive information from the lower limb, would be dependent on participant skill level (by level of attunement to somatosensory information) to constrain modes of movement organisation and enhance kicking performance (Han et al., 2014; Han, Waddington, Anson, & Adams, 2013).

Methods

Participants

Twelve youth males (right foot dominant) were participants in this study. Six skilled participants (n = 6; age = 15.67 ± 0.74 years; height = 165.17 ± 8.03 cm; mass = 57.67 ± 8.25 kg) were recruited from local football clubs and had at least four years participation in competitive football and formal training throughout the year. Six less-skilled participants (n = 6; age = 15.17 ± 1.1 years; height = 169.17 ± 6.46 cm; mass = 50.83 ± 4.01 kg) had never played competitively and had little playing experience at recreational level. All wore their own regularly-used indoor football or sport shoes, as well as a pair of tight shorts and a shirt for all test and practice sessions. Voluntary and informed consent were obtained from all participants and parents and testing procedures in this study were approved by the ethics committee of Nanyang Technological University, Singapore.

Instep kicks

All participants were required to kick a stationary ball (FIFA-approved size 5) as hard as possible (on a synthetic surface within a laboratory) into an empty goal **(3 m x 2 m)**. **The distance between the ball and goal was 6.1 m (Hasan et al., 2016).** They performed 20 instep kicks [angled approach (Kellis & Katis, 2007; Sinclair et al., 2014), **standardized to all participants**] in four randomly-organised insole and sock conditions: a) Smooth Socks with Smooth Insoles (SSSI); b) Smooth Socks with Textured Insoles (SSTI); c) Clinical Compression Socks with Smooth Insoles (CSSI); and d), Clinical Compression Socks with Textured Insoles (CSTI). All participants were given enough time to warm up, change and become familiarized (5-10 minutes) with wearing different insoles and socks.

Procedures

Seventeen spherical reflective passive markers (15mm) were placed on key anatomical joints using double-sided tape, fixed securely using additional tape to prevent movement during kicking performance. Investigated joints were the acromion process, iliac crest, greater trochanter on right and left sides, medial and lateral epicondyles, medial and lateral malleolus, fifth metatarsal head and first metatarsal head (on the non-kicking foot). Kinematic data (recorded at 200Hz) were captured by eight infrared cameras (Hawk Digital Camera, Motion Analysis Corporation) and connected to the Cortex software (Motion Analysis Corporation, Santa Rosa, CA, USA). Before commencing, a static posture of each participant was captured to record the relative position between each marker (Inoue, Nunome, Sterzing, Shinkai, & Ikegami, 2014). Visual three-dimensional (3D) software (C-Motion V3D, USA) was used (Chow et al., 2007; Lee, Chow, Komar, Tan, & Button, 2014) to construct an eight-segment model consisting of thorax, pelvis, thigh, shank and feet for each participant and to calculate the 3D kinematic variables. 3D Euler joint angles of flexion and extension were derived for hip, knee and ankle from respective segments, defined by marker sets (Chow et al., 2007). Recorded data were filtered using a fourth order low-pass Butterworth (cut-off frequency of 12 Hz) digital filter (Ball, 2011; Lees & Rahnama, 2013).

Textured insoles (Evalite Pyramid Lightweight EVA, 3mm thickness, shore value A50, black) in this study had small pyramidal peaks with centre-to-centre distances of approximately 2.5mm (Hatton, Dixon, Rome, Newton, & Martin, 2012). Smooth insoles (Medium Density EVA, 3mm thickness, shore value A50, black) had a completely flat surface. All insoles (Algeos, Australia) were cut according to participant shoe sizes. The clinical compression socks (Zero Point, Finland) were comprised of small indentations (**textured and** coarse surface) on the sole, ankle and tibia bones, and were constructed from nylon (72%) and lycra (28%), with a clinical compression level of 20-30 mm·Hg. The control socks were smooth football socks, of similar thickness, comprised of 80% cotton and 20% spandex.

Data analysis

Kinematic data from the kicking limb were collected for the duration of the limb movement sequence beginning at the initiation of knee flexion and continuing to the end of peak hip flexion. Based on previous research, relative kinematic variables (Anderson & Sidaway, 1994; Chow et al., 2007; Egan et al., 2007) were recorded to investigate segmental interactions of the kicking limb: a) maximum hip extension; b) maximum hip extension to ball contact phase; c) joint range of motion (JROM) at the hip and knee (Anderson & Sidaway, 1994) as indexed by the difference between the maximum and minimum angles at each joint; d) the time of initiation of knee extension relative to the instant of maximum hip angular velocity (SKE/IMHAV); e) the instant of maximum hip angular velocity with respect to the instant of maximum knee angular velocity (IMHAV/IMKAV); and f), the instant of maximum knee angular velocity with respect to the instant of maximum foot velocity (IMKAV/IMFLV).

A mixed-model ANOVA with one between-participant (less-skilled; skilled) and one within-participant factor (SSSI; SSTI; CSSI; CSTI) was used to compare instep kicks performance **(using the mean value in each kicking condition).** Bonferroni corrections were applied to control Type I errors and violations of the sphericity assumption for repeated measures variables were checked using Mauchley's test of sphericity. When violation of this assumption was apparent, the Hyunh-Feldt method was used to adjust the degrees of freedom of the error term for the F ratios. The Bonferroni method post-hoc test was used to further analyse significant main effects and interactions to determine the location of differences between (skill groups) and within (insoles and sock conditions) factors. Alpha values were set at $p < 0.05$ and the effect sizes were calculated using partial eta squared (η_p^2). All data were analysed using the Statistical Package for Social Sciences (SPSS V21.0, Chicago, IL, USA).

Results

Changes in the ranges of motion at the hip and knee

Maximum hip extension

There was no significant main effect for insole and sock conditions on maximum hip ROM values, $\boldsymbol{p} = \mathbf{0.127}$, $\eta_p^2 = 0.035$ nor group, $p = 0.265$, $\eta_p^2 = 0.021$. There was a significant interaction between Group*Insole/Sock conditions, $\boldsymbol{p} = \mathbf{0.013}$, $\eta_p^2 = 0.074$. Movement organisation in less-skilled participants was constrained by using the textured and compression materials, revealing significant changes in maximum hip ROM values observed in the CSSI condition, compared to the SSSI condition **(**$\boldsymbol{p} = \mathbf{0.046}$).

Range of maximum hip extension to ball contact phase

There was no significant main effect for insole and sock conditions on the range of maximum hip extension values to ball contact phase (Figure 1), p = 0.573, η_p^2 = 0.11 nor group, p = 0.529, η_p^2 =0.007. There was a significant interaction between Group*Insole/Sock conditions, ***p* = 0.005**, η_p^2 = 0.072. Movement organisation in less-skilled participants was constrained by using the textured and compression materials, revealing significant changes in the range of maximum hip extension ROM to ball contact phase observed in the CSSI condition, compared to the SSSI condition **(*p* = 0.010**).

Figure 1 near here

HJROM

There was no significant main effect for insole and sock conditions, nor interactions between Group*Insole/Sock conditions on HJROM values (Table I), p = 0.228, η_p^2 = 0.024, p = 0.329, η_p^2 = 0.020, but the main effect of group revealed significant differences, p = 0.010, η_p^2 = 0.108. In group comparisons, in the same insole and sock conditions, less-skilled participants achieved significantly higher values of HJROM when they were presented with the SSSI **(*p* = 0.030**), SSTI **(*p* = 0.005**) and CSSI conditions **(*p* = 0.004**), compared to skilled participants.

KJROM

There was no significant main effect for insoles and socks conditions, nor interactions between Group*Insole/Sock conditions on KJROM values, p = 0.315, η_p^2 = 0.020, p = 0.332, η_p^2 = 0.019, but the main effect of group showed significant differences, p = 0.003, η_p^2 = 0.143. In group comparisons, in the same insole and sock conditions, skilled participants achieved significantly higher values of KJROM in the CSSI **(*p* = 0.009**) and CSTI conditions **(*p* < 0.01**), compared to less-skilled participants.

Table I near here

Changes in timing relationships between joint segments

SKE/IMHAV

There was no significant main effect for insoles and socks conditions, nor interactions between Group*Insole/Sock conditions on SKE/IMHAV values, p = 0.623, $\eta_p^2 = 0.010$, p = 0.253, $\eta_p^2 = 0.023$, but the main effect of group showed significant differences, p = 0.016, $\eta_p^2 = 0.096$. Skilled participants displayed significantly higher values of SKE/IMHAV in the SSSI **(p = 0.021) and SSTI (p = 0.030)** conditions compared to less-skilled participants.

IMHAV/IMKAV

There was no significant main effect for insole and sock conditions, nor interactions between Group*Insole/Sock conditions on IMHAV/**IMKAV** values, p = 0.213, $\eta_p^2 = 0.027$, p = 0.736, $\eta_p^2 = 0.005$. The main effect of group also showed no significant differences, p = 0.796, $\eta_p^2 = 0.001$.

IMKAV/IMFLV

There was no significant main effect for insole and sock conditions nor interactions between Group*Insole/Sock conditions in **IMKAV**/IMFLV values, p = 0.454, $\eta_p^2 = 0.011$, p = 0.298, $\eta_p^2 = 0.019$, but the group main effect revealed significant differences, p = 0.049, $\eta_p^2 = 0.065$. Less-skilled participants displayed significantly higher values of IMKAV/IMFLV in the SSSI **(p < 0.01**) and CSTI conditions **(p = 0.018**) compared to skilled participants.

Angle-angle plots

Figures 2 and 3 below show hip-knee, knee-ankle angle-angle plots for one representative less-skilled and skilled participant in the four insole and socks conditions. For hip-knee angle-angle plots, data was plotted from maximum hip extension (leg fully extended backwards) until the point of peak hip flexion (similar to Anderson & Sidaway, 1994).

Figure 2 here

For hip-knee angle-angle plots (Figure 2), the representative skilled participant displayed a larger range of hip-knee movement compared to the less-skilled participant. The former also demonstrated greater variability in hip-knee intralimb movement organisation compared to the latter. The skilled participant in the SSTI, CSSI and CSTI conditions showed slight variations in movement topographies across the four insole and sock conditions during the backswing phase towards the ball contact phase, compared to performance in the SSSI condition. In the less-skilled participant, there was less variation of the hip-knee movement between the four insole and sock conditions.

Figure 3 here

Observing knee-ankle angle-angle plots (Figure 3), data were plotted from the point of maximum ankle dorsiflexion until maximum ankle plantarflexion. For knee-ankle intralimb movement organisation, there were variations in movement topographies for both representative participants in the four insole and sock conditions. Performance of the less skilled participant, in the CSSI condition revealed the highest plantarflexion of the ankle and led to greater variability of knee-ankle intralimb movement organisation across all insole and sock conditions (before and after ball contact phase). For the skilled participant, variation in knee-ankle intralimb coordination topographies between the four insole and sock conditions only emerged *after* the ball contact phase.

Discussion

This study determined effects of wearing **compression and textured materials** on kicking movement patterns among skilled and less-skilled football players. Results revealed that some aspects of movement organisation were particularly constrained **(i.e., hip ROM)** by the augmented somatosensory information provided by wearing **compression and textured materials.**

Effects of enhanced somatosensory feedback on skill level of participants

Less-skilled participants were more attuned to available information from the compression and textured materials compared to skilled participants in regulating movement organisation for instep kicking (i.e., hip, knee and ankle ROM). The less-skilled participants here had less experience than the skilled participants and had not yet accustomed to the kicking task (Anderson & Sidaway, 1994). Our data suggest that effects of enhanced somatosensory feedback can support the less-skilled participants to acquire a functional set of relative motions, for regulating movement organization in instep kicking. In the skilled participants, only some minimal effects of enhanced somatosensory feedback were observed on movement (re)organisation of instep kicking (only evident in knee movements). One explanation for these minimal effects is that these participants may have already acquired the specific pattern of movement organisation for regulating kicking actions (the task was highly stable for them), and the augmented somatosensory information was somewhat redundant.

Effects of enhanced somatosensory feedback on range of motion at the hip and knee

Results showed that wearing **clinical** compression socks (in the CSSI condition) produced significant increases in maximum hip extension values, leading to significant increases in the hip range of kicking motion from the backswing to the point of ball contact among less-skilled individuals. In executing a powerful kick, ball velocity largely depends on high foot velocity prior to ball contact (Kellis & Katis, 2007). Previous research (Tsaousidis & Zatsiorsky, 1996) on kicking limb movements before the point of ball **contact** has reported two important factors in producing maximum ball speed. First is kicking limb momentum which results from a coordinated movement and mechanical actions before the ball **contact** phase. The second factor is the energy emerging from muscle work produced during the ball contact phase. With a greater range from the point of maximum hip extension to the ball contact phase, the kicking limb moves with greater momentum (especially at the foot) in producing maximum ball velocity. Our data suggested that less-skilled participants attempted to drive the ball as hard as they could to produce a maximum velocity instep kick. Previous researchers (e.g., Sayers & Morris, 2012) has proposed that increased hip extension at the end of the backswing can potentially increase elastic energy stored in the kicking leg hip flexors prior to the forward swing. In supporting this view, Nunome et al. (2006) emphasized the importance of maximum hip extension angle in producing a coordinated instep kick performance.

Effects of added compression and texture were not significantly different for HJROM and KJROM values in both groups across all insole and sock conditions. The HJROM and KJROM values in CSTI and CSSI conditions were the highest observed when compared to other insole and sock conditions (SSSI condition revealed the lowest range for both variables), but the results were not statistically significant. However, there was a positive trend towards higher HJROM and KJROM values **(especially for the skilled participants)** when wearing textured and compression materials, compared to wearing smooth-non textured and compression materials conditions. As this study only required participants to wear textured and compression materials for short time periods, future work needs to investigate participants wearing these materials for longer duration (i.e., throughout a training programme). This extended period of familiarisation **[i.e., 7-12 weeks (Hartmann, Murer, de Bie, & de Bruin, 2010; Perry, Radtke, McIlroy, Fernie, & Maki, 2008)],** might reveal insights on their increased attunement to augmented somatosensory information over time, enhancing the potential for organisational changes to be seen with increasing practice (Woo et al., 2014).

In this study, HJROM values observed in less-skilled participants were significantly higher than in skilled participants, due to the significantly higher values of hip extension and flexion values. Skilled participants displayed a significantly higher range of KJROM values compared to less-skilled participants, due to higher ranges of knee flexion and extension. Our findings showed that less-skilled participants demonstrated higher hip ROM values, indicating greater involvement of proximal joints (Chow et al., 2007). Skilled participants in this study reduced the dynamic motion of the proximal segment (hip joint), but increased the dynamic involvement of the distal segment (knee joint) (Chow et al., 2007). Higher values of maximum knee flexion is one of the vital factors in producing a coordinated instep kicking performance (Nunome et al., 2006).

For less-skilled participants, enhanced somatosensory feedback did not affect hip-knee intralimb movement patterns, since as all insole and sock conditions revealed similar topographies (Figure 3). Less-skilled participants seemed to rapidly flex the knee after the ball contact phase. For the representative skilled participant, there was a slight variation in hip-knee intralimb movement patterns with enhanced somatosensory feedback. Use of textured-compression materials tended to reduce involvement of hip motion towards the ball contact phase. Compared with the less-skilled participant, the skilled participant did not flex the knee rapidly after the ball contact phase (based on the angle-angle plots in Figure 3) and knee extension was maintained until the end of the follow-through. Davids et al. (2000) proposed that, in producing a powerful and coordinated instep kick, the kicking leg is almost fully extended at the point of ball contact and remains extended throughout the early stages of follow through until the end, where the knee begins to flex. These actions enable the foot to reach high velocity, which is the main determinant of kicking a ball for power (Davids et al., 2000). Use of compression and textured materials appeared to produce some beneficial effects on knee-ankle intralimb coordination tendencies in less-skilled participants. With enhanced somatosensory feedback (in CSTI condition), ankle ROM values revealed greater plantar flexion during the ball contact phase compared to other insole and sock conditions.

Effects of enhanced somatosensory feedback on timing relationships between joints and segments

There were no significant differences between all insole and sock conditions for all relative kinematic variables (see Table I). Results suggested that the segmental sequencing of lower limb segments was similar in all insole and socks conditions in both groups, in agreement the findings reported by Chow et al. (2007)**. The intermediate and novice participants in their study shared similar skill level characteristics with the skilled and less-skilled participants in this study**. Results also showed that values for initiation time of knee extension relative to the instant of maximum hip angular velocity in the skilled participants were significantly higher than in less-skilled participants.

Effect of various insole and sock conditions on kicking movement patterns

In this study, effects of wearing clinical compression socks were more functional since data suggested significant changes in movement patterns **(i.e., greater hip ROM for greater ball impact)** among less-skilled participants. Due to our manipulations on somatosensory feedback, it is feasible that indentations on the socks might have allowed participants to exploit available “sensorimotor system noise” to constrain the emerging kicking actions. Wearing clinical compression socks might have enhanced the perception of somatosensory information from cutaneous mechanoreceptors among participants when performing this dynamic interceptive task. The compression socks in this study also provided a significant proportion of added texture to the plantar foot surface (Wheat et al., 2014) and to other areas of the foot (i.e., ankle and tibia bones) (Woo et al., 2014). With added compression on the textured socks, results implied that they might have provided greater stimulation to the lower leg mechanoreceptors, enhancing somatosensory system feedback to the performer.

Conclusions

Our findings suggested that wearing clinical compression socks seemed more adaptive than simply using textured insoles in supporting kicking performance, probably by providing augmented feedback information to enhance the functionality of movement patterns. The added texture and compression materials seemed to complement each other, especially benefiting the less-skilled participants in producing more functional levels of (i.e., greater) hip extension and flexion during instep kicking performance. It is recommended that footballers especially learners or developing athletes should wear compression socks to enhance kicking performance. Future investigations of the role of textured and compression materials need to extend the research on the functionality of movement organisation modes by examining the accuracy of instep kicking, comparing successful and less successful performance outcomes over an extended period of time.

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