Expertise-Related Differences in the Performance of Simple and Complex Tasks: an Event-Related Potential Evaluation of Futsal Players

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Abstract

In recent years, anecdotal evidence has pointed to the importance of futsal as a significant activity for the development of perceptual and technical skills, possibly due to the intensity of the game providing a multitude of different stimuli to the players. However, no scientific evidence to date exists regarding the processes that may underpin such benefits. The purpose of this study was to assess differences in electro-cortical activity and reaction time between expert and recreational futsal players. A two-group repeated measures design was used. Eleven expert and twelve recreational futsal players (mean age: 28.7 ± 4.9 years) performed congruent and incongruent trials of a modified Flanker task on a customised computer screen. Reaction time generated by an index-finger mouse press was recorded via a customised micro-processing system and electro-cortical activity was recorded by electroencephalography during task performance. There was a significant difference in reaction time and error rate in congruent and incongruent task performance, and difference in electro-cortical activity between groups in the performance of both congruent and incongruent tasks. Enhanced N1 ERP mean amplitude within the parietal region was demonstrated in the expert group compared to the recreational group. Similar to previous research, a greater level of expertise leads to recruitment of brain areas necessary for the efficient integration and processing of information required to produce the desired goal-directed behaviour.

Key words:

Congruency, EEG, N1, Event-related potential (ERP), expertise, futsal

Introduction

A constant challenge in elite sports is how to improve physical and mental competency to achieve peak performance. To this end, the relationship between goal-directed behaviour and the underlying neural processes have been examnined more recently. Particularly in the domains of perception, cognition and action (Park et al., 2015) and the sport-cognition relationship (Alves et al., 2013). Experts have been found to engage in advanced cue utilisation, making them more efficient at both predicting and anticipating other player's behaviour (Wimshurst et al., 2016). This was associated with enhanced activity within the action observation network in expert compared to novice badminton players, and stronger activation of the mirror neuron system, specifically activation of the inferior parietal cortex during the prediction of an opponent's action, in high compared to intermediate and low skilled soccer players (Bishop et al., 2013). These differences between groups are suggested to be a consequence of not only hours accumulated in practice and competition to achieve an elite status, but also the quality of their practice (Bishop et al., 2013). For the purpose of this research, the influence of sport-specific experience is of key interest, specifically within the evaluation of cognitive function (brain function) and the sport-cognition relationship between athletes of different ability levels.

There is an ongoing debate about the sport-cognition relationship, specifically within the context of the expert performance approach that enables the evaluation of sporting performance within a sport-specific context (field to laboratory transfer) and a component skills approach, which evaluates the relationship between non-specific cognitive skills and sporting expertise. Alves et al. (2013) used a component skills approach to evaluate the relationship between sport expertise and perceptual and cognitive skills, and found that in the performance of a modified Flanker task, elite female volleyball athletes in comparison to control group, displayed higher levels of executive control (e.g., processing speed) and visuospatial attention.

This evidence supports the use of a component skills based approach as it provides an informative means of capturing and characterising fundamental competitive sport-related cognitive skills (Alves et al., 2013, Voss et al., 2010). Furthermore, Voss et al., (2010) were optimistic in terms of the validity in using basic laboratory based tasks to evaluate the sport-cognition relationship, specificly in the context of the evaluation of processing speed (e.g., reaction time within interceptive sports), a measure of cognition that transcends sport context and spatial attention. For example: Ermutlu et al. (2015) showed differences in occilatory patterns of activation in fast-ball sport athletes compared to dancer and controls. They showed enhanced levels of anticipation and extraction of advanced sensory information (higher delta activation), and inhibitory processing and attentional processing, spatial navigation and working memory (higher theta activation) within the fast ball sports athletes compared to the other two groups. These enhanced patterns of electro-cortical activity are representative of neuroplastic adaptations resulting from the physical attributes and features of the athletes training. By acquiring domain-specific experience, highly-trained participants' cerebral function has adapted to the task demands and become more proficient at recruiting areas of the brain necessary for optimal performance, such as enhanced performance attributed to the capacity of expert athletes to engage in parallel processing in response to a sensory stimulus (Yarrow et al., 2009). This involves the parallel activation of areas of the brain responsible for sensory integration and areas associated with priming of an action, whereas in a novice only one area is activated at a time (Yarrow et al., 2009). This is of specific relevance in the context of sporting expertise as it relates to the enhanced ability to efficiently and accurately process the multiple sources of information within a game context and generate the desired goal-directed behaviour.

There is a comparatively small number of sports-related studies that have evaluated the influence of sporting expertise upon electro-cortical activity of the brain in context of perception, cognition and action (Bernardi et al., 2014, Naito and Hirose, 2014, Park et al., 2015, Reinecke et al., 2011). Of specific interest is the evaluation of the association between reaction time and the underlying electro-cortical activity during the performance of tasks of varying difficulty. For example: the modified Flanker task, which involves responding to a simple (congruent) or complex (incongruent) external stimulus. The purpose of this type of paradigm is primarily to evaluate the efficiency and accuracy of sensory integration, information processes and generation of time-stressed, goal-directed behaviour. The fundamental difference being that in a simple task where there is continuity in the presented stimulus, an incongruent task also incorporates distractor stimuli (Donkers and Van Boxtel, 2004, Yeung et al., 2004). Efficient and accurate decision making skills (e.g., initiation of appropriate and inhibition of incorrect actions) are of fundamental importance in many sporting contexts. This includes futsal, which is played in a highly-tactical environment that incorporates multiple sources of information and stimuli within a relative density of 100-125 m^2 per player (Barbero-Alvarez et al., 2008; Travassos et al., 2016).

To explore the influence of how different levels of expertise effect cognitive function, task-related differences in electro-cortical activity, specifically event-related potentials (ERPs) were examined in futsal players of differing skill levels. ERPs are of specific interest as they represent the time course (temporal resolution) of neural changes and patterns of activity in response to a specific sensory, cognitive or motor event (Luck, 2005, Luck and Kappenman, 2012). The main neural component of interest is that of the N1 ERP, specifically activity over posterior regions (i.e., parietal and occipital), which is reported to peak between 130 – 200 ms post stimulus onset (Luck and Kappenman, 2012, Vogel and Luck, 2000) and reflects the electro-cortical activity associated with discrimination processes within the focus of attention (Vogel and Luck, 2000), especially in tasks where the stimulus being attended to requires some form of discriminative response (Hopf et al., 2002, Mangun and Hillyard, 1991). To evaluate the influence of expertise on the underlying electro-cortical activity associated with the generation of time-stressed, goal-directed behaviour, expert and recreational futsal players were recruited. It was predicted that expertise-related differences would be found in both reaction time and electro-cortical activity, specifically: i) quicker reaction times in the expert compared to the recreational futsal players in the incongruent task; ii) shorter N1 peak latencies in the expert compared to the recreational futsal players in incongruent task performance; and iii) greater N1 mean amplitude overall in the expert compared to the recreational group.

Methods

A total of 23 males were recruited to participate in this study (age = 28.7 ± 4.9 y). Eleven players (age = 29.5 ± 4.9 y) were part of an expert European futsal team and were involved in professional competitions at the national and international level with both their club and their respective national teams. Their experience in team competition was 21.7 ± 4.7 years, and they were involved in 12-14 hours of weekly practice. The remaining 12 players (age = 27.9 ± 4.9 y) were involved in recreational futsal at the local level, and possessed 11.2 ± 8.4 years of experience and practiced 1-2 hours per week. Participants were excluded if they had reported any history of neurological conditions. The participants attended the lab on one occasion, where they were asked to undertake a modified Flanker test with continuous EEG recordings. The testing session was always conducted early in the morning, with a starting time between 07:00 and 09:00 AM, Participants were instructed to avoid the consumption any caffeinated products and to avoid the use of detergents applied to their hair for the 24h preceding the test. All participants provided written informed consent, were healthy and reported being free of any neurological disorders and medications that would influence central nervous system function. All procedures were conducted in accordance with the Declaration of Helsinki (http://www.wma.net) and were approved by Victoria University's Human Research Ethics Committee.

A modified Flanker task was employed (Pontifex and Hillman, 2007, Alves et al., 2013) which required participants to view and react to successive blocks of five arrows displayed on a screen, by reacting to the direction of the central arrow (left or right) and ignoring the direction of the two flanking arrows appearing on each side. The sequence comprised 160 blocks of equally-frequent congruent (i.e., all arrows pointing in the same direction) and incongruent (i.e. central arrow pointing in the opposite direction) combinations. The arrows (4.8 cm tall, 2.6 cm wide, and 90° angle) were generated by white LEDs on a black background within a custom made 19-inch computer screen. Within each block, a fixation dash was presented for 500 ms, followed by a blank screen for 200 ms, a five-dash pre-cue for 500 ms, and then a blank screen for 1500 ms. Then, the main stimuli (arrows) were presented for 200 ms followed by a blank screen for 1500 ms, before the commencement of the following block (see Figure 1). Reaction time (ms) generated by an index-finger mouse press was recorded via a customised micro processing system. The screen displaying the arrow blocks was placed on a 75-cm tall desk, at a distance of 1 m from the participant's forehead, with the test taking a total of 11.5 min to complete.

Please insert Figure 1 here

Continuous EEG data was recorded using 32 channel Ag-AgCl active electrodes, elastic ActiCap and PyCorder 1.0.7 software (Brain Products, GmbH). Electrodes were placed in accordance with the international 10/20 system (Klem et al., 1999, Pontifex and Hillman, 2007). A ground electrode was positioned above the forehead (Fpz), and all electrodes were referenced to Cz (central midline) during recording. Additional electrodes were placed above and below the left orbit and the outer canthus of each eye to monitor bipolar EOG activity. ECG electrodes were also placed below the collar bone on the mid and lateral aspect of the left side of the body on a 45 º angle to monitor for heart rate artefact. Data was recorded at a sampling rate of 1000 Hz and impedances were checked before and after each phase of testing and remained < 5 kΩ.

For the congruent and incongruent trials EEG data, on average 2 ± 1 were removed during the initial visual check of the raw data, resulting in 97% of all data being used for the overall analysis. Processing of EEG included: 1) Visual check of raw data; 2) Application of low and high cut-off filters (0.1 and 30 Hz respectively with a time constant of 1.59 s and a slope of 49 db/oct for each filter); 3) Ocular correction performed for vertical and horizontal eye movement (Gratton et al., 1983); 4) Data re-referenced to a global average reference; 5) Congruent and incongruent trials coded; 6) Congruent and incongruent trial segmentation of data with an epoch of -100 ms pre-stimulus onset to 600 ms post-stimulus onset; 7) Baseline correction of -100 pre-stimulus onset; 8) Data averaging; 9) Identification of the main time window and electrodes of interest relating to the latency and mean amplitude of the N1 ERP were performed using grand averaged computed data and topographical maps. This showed the most pronounced N1 related activity over parietal region electrodes (P3, P4 and Pz) within a time window of 150 – 250 ms post stimulus onset; 10) Peak identification for the N1 peak latencies for each participant (2 x conditions) and subsequent data exported for peak latency analysis; and 11) N1 ERP mean amplitude epoch (150 to 250 ms) for each participant (congruent and incongruent trials) exported for mean amplitude data analysis.

Please insert Figure 2 here

Please insert Figure 3 here

Analysis of reaction time (RT) and error rate were performed to determine the difference in congruent and incongruent trials between expert and recreational groups using 2 (group: recreational versus expert) x 2 (task: congruent versus incongruent) two-way ANOVA. Analysis of the N1 peak latency (ms) and mean amplitude (μV) between 150 - 250 ms, post stimulus onset was computed from parietal electrode sites using 2 (group: recreational versus expert) x 2 (task: congruent versus incongruent) x 3 (recording site: P3/P4 and Pz) within-subject repeated measures ANOVA. Only those main effect results showing large effect sizes (.14 = large) in reference to the partial eta squared (ηp2) measure of magnitude of a treatment effect (Cohen, , 1988), which are theoretically meaningful (Kayser et al., 2000) are reported. All data is presented as mean ± SD.

Results

ANOVA conducted on RT, showed a significant main effect of task (F(1,10) = 156.18; p < 001, η_p^2 = .94), but not group (F(1,10) = 0.33; p = .58, η_p^2 = .03) (see Figure 4). Although there was no significant interaction between group and task there was a large effect size (F(1,10) = 2.40; p= .15, η_p^2 = .19). Despite the lack of significance we conducted follow-up contrasts that revealed shorter RT in incongruent task performance for the expert compared to recreational group (575.14 ± 35.56 and 595.88 ± 70.36 ms respectively), but not for the congruent task (508.20 ± 33.11 and 518.13 ± 76.67 ms respectively). The ANOVA conducted on RT error rate, showed a significant main effect of task (F(1,10) = 18.89; p = .001, η_p^2 = .65), but not group (F(1,10) = 0.63; p = .45, η_p^2 = .06), showing the occurance of more errors in incongruent task performance compared to congruent (5.59 ± 1.22 and .55 ± .35 respectively). No interaction between group and task (F(1,10) = 0.03; p = .87, η_p^2 = .00) was observed.

ANOVA conducted on the N1 mean amplitude, showed a significant main effect of group (F(1,10) = 5.91; p = .04, η_p^2 = .37), showing larger overall mean amplitudes in the expert compared to recreational group (-1.82 ± .61 and .71 ± .89 µV respectively) (see Figure 5), and a non-significant main effect of task ($F(1,10) = 1.98$; $p = .19$, $\eta_p^2 = .17$), or interaction between group and task ($F(1,10) = 0.03$; $p = .86$, $\eta_p^2 = .00$). ANOVA conducted on the N1 latency were non-significant for group and task ($F(1,10) = 0.01$; $p = .92$, $\eta_p^2 = .00$ and $F(1,10) = 1.64$; $p = .23$, $\eta_p^2 = .14$ respectively) and no interaction between group and task ($F(1,10) = 1.75$; $p= .22$, $\eta_p^2 = .15$).

** Please insert Figure 4 here**

Please insert Figure 5 here

Discussion

The purpose of this study was to evaluate differences in RT and electro-cortical activity associated with the performance of both congruent and incongruent tasks between expert and recreational futsal players. As predicted, experts were quicker at performing incongruent tasks than recreational players and expertise-related differences in electro-cortical activity were identified in relation to the response to visuospatial information (N1 ERP).

The results relating to the RT data, show an increase in time to complete the incongruent compared to the congruent task and an increase in the occurance of incongruent task-related errors in both groups. The lack of a significant group effect, is confounded by the small sample size, however, this is suggested to be, not a lack of effect, but because of low power to detect a group effect (Voss et al., 2010). It is therefore suggested, that these findings are in line with a meta-analysis which found a task effect between athlete and non-athlete participants in visuospatial tasks (e.g., modified Flanker task) (Voss et al., 2010). Further, these RT results may provide provisional evidence of an enhanced inhibitory processing capacity within the expert compared to recreational futsal players. In other words, expert athletes have enhanced levels of executive control (e.g., processing speed) and visuospatial attention compared to recreational players (Alves et al., 2013).

The electro-cortical component examined was the later division of the N1 ERP component, which reflects activity associated with discrimination processes within the focus of attention (Vogel and Luck, 2000). It was predicted that there would be electro-cortical differences in task performance for each group, however, interestingly, although there was a RT task performance difference, this was not seen in the electro-cortical activity. Of importance, however, was the differences in overall task-related electro-cortical activity between groups within the parietal region (electrodes P3, P4 and Pz). This showed significantly different patterns of electro-cortical activity between groups. These findings are in line with the parallel interacting model of neural requirement (Yarrow et al., 2009). In other words, as can be seen in Figure 5, both expert and recreational players show electro-cortical activation within the occipital region, which is associated with attending to the presented stimulus and monitoring for the shape (format) of the presented stimulus to generate the goal-directed behaviour. However, in parallel, the expert compared to the recreational players also showed significantly enhanced electro-cortical activity within the parietal region, which is linked to processing of visual information, including preparation of potential responses. This difference in electro-cortical activity between groups is potentially evidence of enhanced sensory, cognitive, and motor processes (detection, evaluation and selection) that underpin skilled behaviour and play an important functional role in elite sporting performance (Park et al., 2015).

It is well established that sporting expertise is developed through a process of domain-specific experiences that engage the perceptual-cognitive skills of a player, to enable them to more efficiently determine an opponent’s actions, ball trajectories and positioning of fellow teammates (Jin et al., 2011). The acquisition of these perceptual-cognitive skills enables an enhanced capacity to recognise and classify events or a scenario more efficiently than a less skilled player and ultimately anticipate and perform the desired goal-directed behaviour (Jin et al., 2011). The results from this study are in line with previous findings using a component-skills approach, specifically, enhanced perceptual and cognitive skills in expert compared to recreational players (Alves et al., 2013). Furthermore, that these measures of cognition, transcend sport context, specifically the capacity to modulate and control allocation of attentional focus (Voss et al., 2010). It is further suggested, that these findings may represent enhanced activation of the action-observation network and mirror neuron system, specifically within the inferior parietal cortex during the perception, cognition and action phases of goal-directed behaviour, in the expert compared to recreational players (Bishop et al., 2013).

Although the task employed within this study is not sport specific, it is suggested that this component-skills based approach, provides evidence of enhanced perception-cognition processing and strengthens a sport-cognition relationship (Bernardi et al., 2014, Alves et al., 2013, Voss et al., 2010). This is in the specific context of recruitment of additional regions of the brain required for the integration and processing of information and generation of goal-directed behaviour (parallel neural activation). It appears that this advantage is not task-specific but also extends to tasks which have similar processing qualities. Growing our understanding of how expertise alters patterns of electro-cortical activity may in turn lead to the development of more specific training regimes that generate positive skill transfer. This may include the incorporation of a cognitive training component or manipulation of the physical parameters of training to promote a greater cognitive load to enhance the capacity to integrate and process the necessary information to generate efficient and effective goal-directed behaviour. While the current findings add to our understanding of underpinning processes supporting perceptual-cognitive expertise, the core limitation of a restricted sample size is suggested to have reduced the potential power of the results obtained. Further, within this study, evaluation of futsal players was used, it would have been beneficial to measure domain-specific task-related electro-cortical activity in both football and futsal players. Lastely, to evaluate perception, cognition and action in more real-world sporting contexts, employing an expert performance approach, mobile EEG technology could be utilised.

Conclusion and implications of findings

In conclusion, this study demonstrated that expert futsal players have an enhanced inhibitory processing capacity to successfully manage the performance of more complex tasks, and similar to previous research, a greater level of expertise leads to recruitment of brain areas necessary for the efficient integration and processing of information required to produce the desired goal-directed behaviour. The main implications of this study are that:

- A component skills based approach is an informative means of evaluating the sport-cognition relationship, specifically in relation to the evaluation of perceptual and cognitive function and expertise-related differences.
- Long-term futsal practice may lead to improved cognitive function, particularly enhanced integration and processing of sensory information and generation of goal-directed behaviour.

Acknowledgments

The authors would like to thank all participants for their important contribution to this study. The corresponding author received funding for this project from the Union of European Football Associations (UEFA).

Author contribution statement

F.S., R.P., D.F., and S.D. were involved in the conceptualisation of the project and study design. F.S., S.D., L.O., and C.B. participated in the data collection. S.D. wrote the main manuscript text, prepared all figures, and analysed the results. F.S., S.D., R.P., D.F., L.O., and C.B. participated in the manuscript review.

Competing financial interest statement

The authors declare no competing financial interests.

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Figure 1: Schematic of the key modified Flanker task segments and presentation times associated with each phase.

Figure 2: 32 Channel Montage with key channels examined.

Figure 3: ERP wave form comprising the key N1 ERP *mean amplitude* time window (150 – 250 ms) analysed comparing between group congruent and incongruent electro-cortical activity.

Figure 4: Reaction time data showing a meaningful difference between congruent and incongruent trials for both the expert and recreational futsal players (* denotes $p < .001$). Data is presented as Mean ± SD.

Figure 5: Topographical scalp map of the expert compared to recreational group comparison, showing a significant differene in the posterior distribution of the N1 electro-cortical mean activity (150 – 250 ms), specifically within the parietal region (* denotes $p = .04$).