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Effects of 15-mins of electroencephalographic neurofeedback on time perception and decision making in sport

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ABSTRACT

Our perception of time influences the critical decisions that we make on a daily basis. Time perception may also influence decision making and performance in sport. A lengthened perception of time, such as feeling that one is performing in slow-motion, may be associated with improved sport performance. This experiment reports the first examination of electroencephalographic (EEG) neurofeedback as an intervention designed to lengthen perceived time and improve decision making in sport. Thirty-one participants were randomly assigned to a neurofeedback group or a control group. They completed pre-test and post-test assessments of time perception and decision making in response to soccer penalty video clips played at a variety of speeds. In between, they underwent a 15-min neurofeedback intervention where they were trained to increase EEG theta and alpha power (neurofeedback group) or received sham training (control group). Results revealed that the neurofeedback intervention yielded a selective increase in EEG alpha power among members of the neurofeedback group. However, this had no effect on perception of time, and no beneficial effects on decision accuracy or decision response time. Several interpretations of the possible relationships between time perception, brainwaves and decision making in sport are discussed. Decision response time improved from pre-test to post-test for all participants, evidencing the potential of video-based training as a tool to enhance decision speed. Our findings also establish that just 15-mins of neurofeedback can produce significant changes in EEG alpha power. This highlights the potential of neurofeedback as a time-efficient means of modifying cortical activity for research and applied practice.

1. Introduction

Perception of time is the internal experience of the speed at which time passes, based on the use of an internal clock in the absence of cues from external clocks (Meck, 2005). Humans use an internal clock to perceive time throughout their activities of daily living, and time perception informs critical decisions (e.g., when to cross the road; when to move to evade a predator) that can ultimately determine whether an organism survives (Healy, McNally, Ruxton, Cooper, & Jackson, 2013). In fact, time perception might be so important that it has influenced the evolution of some species. For instance, research examining flicker fusion frequency, a measure of the rate that light is processed by the brain, implies that some types of bird and many types of fly may perceive time to pass by slowly, allowing them to experience the world in slow motion, and increase their chances of escaping life-threatening situations such as a fly swatter (Boström et al., 2016; Healy et al., 2013). Time perception may also be malleable within a species; several studies have evidenced interventions and experimental manipulations to alter perception of time in humans (e.g., Droit-Volet, Fanget, & Dambrun, 2015). Following the fly swatter example, it is tempting to speculate that interventions to lengthen perceived time in humans might be beneficial for performance in time-limited situations such as reactive sports. This experiment provides the first examination of whether electroencephalographic (EEG) neurofeedback can alter cortical activity to influence time perception and decision-making performance in sport.

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1.1. Time Perception and Sport

Time perception may have considerable importance in sport. For instance, athletes often report feeling as though the game is moving in slow motion when they are performing well, and at a faster pace when they are performing badly. Former world number one tennis player Martina Navratilova described being in the zone as an experience where everything seems to slow down, and she described everything moving at a fast pace during poor performances (Witt & Sugovic, 2010). Following such anecdotal reports, Witt and Sugovic (2010) experimentally investigated the relationship between time perception and sport performance. Participants varying in skill (beginners to experts) returned tennis balls from an automatic ball feeder, and completed a time perception task requiring them to hold the space bar on a keyboard to reproduce the time interval that they perceived between the ball leaving the feeder and striking their racquet. In support of their hypotheses, results revealed that participants estimated the intervals to be longer on successful trials (i.e., where the ball was successfully hit to a target zone; better performance) than during unsuccessful trials (i.e., shots that missed the target; worse performance). However, a separate analysis of perceived net height also revealed a significant relationship whereby players with more successful shots perceived the net as lower. Thus, the lengthening of perceived time may not have been the sole cause of good performance.

Studies of decision making in sport have also provided evidence to indicate a potential relationship between perceived time and performance. For example, Lorains, Ball, and MacMahon (2013a) examined participants' perception of the speed of a series of Australian Rules Football video clips. Elite and sub-elite footballers watched clips of football games at six different speeds (0.75, 1.0, 1.25, 1.5, 1.75 and 2.0 times the regular speed) and rated how each clip felt on a 1-7 Likert scale anchored with "too slow" (1), "very game-like" (4), and "too fast" (7). Results revealed that the 1.25 and the 1.5 speed video clips were perceived to be the most game-like, providing indirect evidence that experienced footballers had a lengthened perception of time when responding to the videos.[1] Subsequently, in an intervention study, Lorains, Ball, and MacMahon (2013b) indicated that footballers who trained their decision-making by viewing 1.5 speed video clips improved their decision accuracy more quickly than those who underwent the same training protocol but using normal 1.0 speed clips. Together, these findings provide indirect evidence to indicate that time perception in dynamic sport scenarios may lengthen with experience, and that training in conditions that may alter time perception (e.g., viewing 1.5 speeded videos) can help to accelerate the development of decision making expertise. Collectively, the findings of Witt and Sugovic (2010) and Lorains et al. (2013a; 2013b) provide some foundations for the idea that interventions designed to modify time perception could benefit sport performance.

This could be especially true for reactive sports where decisions must be made under time pressure. Time pressure is the "subjective feeling of having less time than is required (or perceived to be required) to complete a task" (Ordóñez, Benson, & Pittarello, 2015, p. 520). In reactive sport tasks, like receiving a serve in tennis, or facing a penalty kick as the goalkeeper in soccer, relevant information (e.g., body position of server/kicker) must be detected and processed, a decision has to be made (e.g., move left/right), and the motor response (e.g., initiate swing/dive) must be programmed in a matter of milliseconds (Gorgulu, Cooke, & Woodman, 2019; Johnson, 2006). Intuitively, one can speculate that any means of lengthening perceived time in such situations could provide the player with an important perceptual advantage that could facilitate more accurate decisions and better performance. Lorains et al. (2013b) provide evidence that speeded video training could benefit performance, but the rationale for that experiment was borne more from theories of automaticity than from time perception research, and it is not known whether changes in time perception contributed to the improved performance outcomes. In this experiment we sought to examine and assess an intervention that was specifically designed to benefit performance by lengthening perceived time for sport-based decisions.

1.2. Time Perception Interventions

Before constructing an intervention aimed at lengthening perceived time, it is important to first consider the mechanisms underpinning how time perception judgements are built. The dominant models in the time perception literature argue that the key determinant of perceived time is the amount of attention that is devoted to the so-called internal clock at a given moment (Zakay & Block, 1997). Perceived time is said to be governed by the number of pulses accumulated by an internal clock system between the start and the end of each event of interest (Gibbon, 1977). For example, in the case of Witt and Sugovic's (2010) tennis study described above, the event of interest was the ball flight, so perceived time would be governed by number of pulses registered from the point at which the ball was ejected from the feeder until the point at which it struck the racquet. The greater ones' awareness of the internal clock, the more pulses are said to be registered, and longer event durations are perceived (i.e., perceived time is lengthened) (Zakay & Block, 1997). In contrast, if attention is directed away from the internal clock, less pulses are registered, and perceived time is reduced.

Based on this theorizing, the psychological practice of mindfulness meditation, where individuals purposely direct their attention inwards and towards bodily sensations such as breathing, has been identified as an intervention to draw attention towards the internal clock and alter perceived time. For example, Droit-Volet and colleagues (2015) revealed that after daily mindfulness meditation practice (20 mins) over five-weeks, human time perception was significantly lengthened; a temporal bisection task revealed that participants overestimated the interval between auditory tones after mindfulness training. This provides evidence that human time perception is malleable and highlights

[1]The 1.25 and 1.5 clips were shorter in duration than the normal 1.0 clips (e.g., a 6s video at normal 1.0 speed would have been just 4s in duration when played at 1.5 speed), yet these 1.25 and 1.5 speed clips were perceived to be of the normal game-like duration. Put simply, the experienced participants appeared to perceive that the speeded clips were of a longer duration than they actually were.

mindfulness as a candidate intervention to modify perceived time and benefit human performance. However, Droit-Volet et al. (2015) also revealed that a shorter mindfulness intervention (i.e., single 10-min session) had little impact on perceived time, thereby implying the need for extensive meditation practice for time perception effects to be realized. This is unfortunate and reduces the appeal of mindfulness as an acute intervention during competitive sport, where athletes require very brief interventions if they are to be used in-game (e.g., incorporated into a pre-shot routine). Fortunately, EEG neurofeedback represents an intervention that may be able to replicate the attentional and neurophysiological characteristics of meditation and thereby influence time perception during a game, without the need for extensive training (Ring, Cooke, Kavussanu, McIntyre, & Masters, 2015). An introduction to neurofeedback and a more detailed overview of the neurophysiological effects of meditation and how they could impact perceived time is considered next.

1.3. Time Perception and Neurofeedback

Neurofeedback involves recording and displaying an individual's brain activity in real time, while encouraging them to develop strategies to control their brain activity levels. For example, computer software can be programmed to reward a participant by displaying a positive image or emitting a pleasant sound whenever a desired pattern of activation is achieved. In this way, individuals can learn to recognize and volitionally produce desired activation levels via the principals of operant conditioning (Skinner, 1963). Moreover, with relatively little neurofeedback training, participants can learn to produce the desired brain states in-game, during pre-performance routines (Ring et al., 2015).

The recipe for how neurofeedback might be employed (i.e., what aspects of brain activity should be fed back) to lengthen perceived time in sport can be derived from previous studies of brain activity during mindfulness meditation. Many mindfulness experiments have employed EEG, a brain imaging method that involves measuring electrical activity on the scalp (Harmon-Jones & Peterson, 2009), to shed light on the brainwaves that occur during meditative states. A recent systematic review of 56 EEG and mindfulness experiments revealed distinct effects of mindfulness principally characterised by an increase in EEG power in the theta (proportion of brainwaves oscillating between 4 and 7 Hz) and alpha (proportion of brainwaves oscillating between 8 and 12 Hz) frequency bands (Lomas, Ivtzan, & Fu, 2015). For example, Lagopoulos et al. (2009) compared EEG activity during 20 minutes of meditation with EEG activity during 20 minutes of quiet rest in a sample of 18 experienced meditators. Results revealed that there was a significant whole-brain increase in theta and alpha power during meditation compared to rest. EEG alpha power has an inhibitory function, with increases in alpha power said to inhibit activation, and decreases in alpha power said to increase cortical activation (Klimesch, Sauseng, & Hanslmayr, 2007). Increased alpha power has also been associated with the internalizing of attention (Cooper, Burgess, Croft, & Gruzelier, 2006). Increased tonic theta power may also associate with internalized attention and creative thinking, with theta waves characterizing the transition from wakefulness to sleep (Gruzelier, 2009; although note that the interpretation of theta remains a source of debate, see Klimesch, 1999). Accordingly, the increased theta and alpha power that are associated with mindfulness could explain how mindfulness meditation impacts our internal clock to modify perception of time. Specifically, the presence of increased EEG theta and alpha power during meditation could reflect more internalized attention towards the internal clock, thereby explaining how, in well-trained meditators, mindfulness can lengthen perceived time. These findings make a case for increased theta and alpha power being the targets for our EEG neurofeedback intervention.

Previous studies of neurofeedback in the motor performance domain have revealed that three hours of theta and alpha-based neurofeedback training was sufficient for golfers to learn to volitionally regulate these brainwaves during their pre-putt routine (Ring et al., 2015), while just 30 mins of alpha-based neurofeedback had a significant impact on subsequent motor performance (Sidhu & Cooke, 2020). This work demonstrates the potential of neurofeedback as an intervention that athletes can use to learn how to control their pre-performance brainwaves and potentially improve their performance in sport. However, no previous studies have examined the effects of neurofeedback on perceived time, and its subsequent effects on decision making, during reactive sports.

1.4. The Present Experiment

This experiment is designed to examine the effects of a brief EEG neurofeedback intervention to increase theta and alpha power on perception of time, and subsequent decision-making performance in reactive sport. Based on the research described above, we expected that: a) six 2.5 min neurofeedback sessions will be able to increase EEG theta and alpha power; b) this will lengthen perceived time viewing sport video clips; and c) this will improve sport-based decision making. To test these ideas, we adopted a mixed-model design where participants were assigned to either a neurofeedback group, or a control group, and completed a reactive soccer decision-making task and a time perception task either side of a 15-minute neurofeedback (or control) intervention. We hypothesized a series of interactions. First, we hypothesized group and session interactions for alpha and theta power; alpha and theta power were expected to be similar between the two groups at the start of the intervention before diverging over the six 2.5 min neurofeedback sessions (relative increase in power for the neurofeedback group). Second, we hypothesized a series of group and test interactions for time perception and decision-making variables. Specifically, we expected perceived time to be lengthened, decision accuracy to increase, and decision response time to decrease from pre-test to post-test to a greater extent in the neurofeedback than in the control group.

2. Methods

2.1. Participants

Thirty-one participants (15 male, 16 female; *M* age = 25.42, *SD* = 4.52 years) volunteered to take part in the experiment. We recruited participants via advertisement posters. All participants reported being free from illness and injury and were not taking any prescription medication (with the exception of the contraceptive pill) at the time of the experiment. All participants were familiar with the sport of soccer (i.e., had watched matches on television or live) and had varying levels of soccer playing experience (*M* soccer playing experience = 5.87, *SD* = 7.73 years; range = 0-23 years). We obtained informed consent from all participants. The experiment was approved by the University research ethics committee.

G*Power 3.1 power calculation software (Faul, Erdfelder, Buchner, & Lang, 2013) indicated that by adopting an alpha of .05 and a sample size of 31, the experiment was powered at .80 to detect between-within participant interactions for effect sizes exceeding f =.26 (i.e., medium-size effects) by mixed-model analysis of variance (ANOVA; Cohen, 1992). In a previous study of the effects of neurofeedback on motor performance, Cheng et al. (2015) reported a significant and large between-within participant interaction (η_p^2 = .26; performance improvement from pre- to post-intervention for neurofeedback group only). Accordingly, if similar effects were to emerge, our sample was adequately powered to detect them.

2.2. Design

We adopted a randomized placebo-controlled mixed-model design. The between-participant factor was Group. Participants were randomly assigned to either a Neurofeedback Group (*M* age = 26.25, SD = 4.41 years; *M* experience = 4.81, SD = 7.43 years) or a Control Group (*M* age = 24.53, SD = 4.63 years; *M* experience = 7.00, SD = 8.13 years)[2]. The within-participant factors were Test (i.e., pre-test, post-test), Video Speed (i.e., 0.75, 1.00, 1.25, 1.50, 1.75, 2.00), and Session (i.e., Baseline, Session 1, Session 2, Session 3, Session 4, Session 5, Session 6). All participants completed a soccer decision making task and a time perception task before (i.e., pre-test) and after (i.e., post-test) a 15-min neurofeedback (or control) intervention. The decision making and the time perception tests involved watching video clips of soccer penalties at six different speeds (i.e., 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00). The neurofeedback (or control) intervention involved a baseline EEG recording and then six 2.5-min neurofeedback sessions (i.e., Baseline, Session 1, Session 2, Session 3, Session 4, Session 5, Session 6). More details about each of these factors are provided in the following sections.

2.3. Decision Making Task

We developed a bespoke soccer decision making task, informed by previous sport decision making research (e.g., Lorains et al, 2013a). Participants sat at a computer and watched video clips of a soccer player striking penalty kicks, filmed from the perspective of the goalkeeper. Each clip was paused at the critical decision point, just before the ball was kicked (Figure 1), and the participant was asked to indicate where they anticipated the ball would go in relation to the goal posts by pressing one of four keys on the keyboard (Key "W"= top left corner; "X" = bottom left corner; "O" = top right corner; "M" = bottom right corner). The letters were labelled with yellow stickers on the keyboard. Participants were shown eight clips (two clips of each of the four corners) at each of the six speeds (0.75, 1.0, 1.25, 1.5, 1.75- and 2.0-times normal speed) (Lorains et al., 2013a) to make 48 trials in total. The sequence of the videos and speeds were randomly presented. Participants were told to make their decision as fast as possible and were given a maximum of six seconds to respond to each trial.

Figure 1: A frame from one of the video clips depicting the point at which the video was paused, and a decision was required

2.4. Time Perception Task

Immediately after indicating where they anticipated the ball would go in relation to the goal posts (see Decision Making Task section above), participants were asked to rate how they perceived the speed of the video clip they just watched using a seven-point likert scale anchored at 1 (too slow), 4 (very game like) and 7 (too fast). The same video clip speed rating scale has been used in previous sport decision making research (Lorains et al., 2013a). This task differs somewhat from traditional methods of assessing time perception. For example, time perception can be assessed by reproduction timing, such as in Witt and Sugovic's (2010) study where participants had to press and hold the space bar on the keyboard to reproduce the time interval they perceived between the previous ball release and racquet hit. Alternatively in a traditional temporal bisection task as employed by Droit-Volet et al. (2015), participants are presented with a short (e.g., tone sounding for 4 s) and a long (e.g., tone sounding for 8 s) interval standard, followed by comparison durations (e.g., 4.67-sec, 6-sec, 7.33-sec), and they judge whether each presented comparison was more similar to the short or the long interval standard (Grondin, 2010). However, parallels can be drawn to illustrate how our sport-specific task can be used to quantify sport-based time perception in the current study. For instance, in our task, the interval standard is drawn from memory, as the clips played in real time (i.e., 1.0 speed), since all participants were experienced in viewing televised soccer games at 1.0 speed. These clips are expected to be rated around 4 (i.e., very game like) on our 1-7

[2] Independent samples t-tests confirmed that the participant ages, $t(29) = -1.06$, $p = .30$ and experience, $t(29) = 0.78$, $p = .44$ did not differ between the neurofeedback group and the control group.

Likert scale.[3] Clips played at the other speeds are assumed to be less familiar as it is unlikely that participants are experienced in watching soccer clips at speeds other than 1.0, and hence, the 0.75, 1.25, 1.5, 1.75 and 2.0 speed clips can be considered a proxy for the comparison durations. We anticipate that it will be straightforward for participants to identify that, say, a 2.0 clip is shorter in duration than the 1.0 clips, and thereby give the 2.0 clip a higher score (e.g., 7 – too fast) on the rating scale. However, the key comparison on this metric is not the different ratings between clip speeds, but the changes in ratings at each speed from pre-test to post-test. If the neurofeedback intervention lengthens perceived time, we anticipate that all the clip speeds should receive lower speed ratings at post-test in members of the neurofeedback group. For example, if the 2.0 clips were rated at an average of 6.5 at pre-test, and 5.0 at post-test, this would indicate that time perception has been lengthened because these fast-paced short duration clips are perceived to be relatively slower and longer in duration at the post-test. We favoured this sport specific task over the more traditional reproduction or temporal bisection time perception paradigms because it allowed relatively seamless integration between the time perception and the decision-making tasks.

2.5. Neurofeedback Intervention

The decision making and time perception tasks described above were completed at pre-test and post-test, which were separated by the neurofeedback intervention. Participants received 15 minutes (six 2.5 min sessions) of genuine (neurofeedback group) or sham (control group) neurofeedback training. Cortical activity was recorded from the parietal midline of the scalp (i.e., Pz electrode site; Jasper, 1958) using an active electrode connected to a wireless 4-channel neurofeedback system (Brainquiry PET-4, Nijmegen, Netherlands). Additionally, an active electrode was placed over the orbicularis oculi muscle of the right eye to remove eyeblink artefacts, with reference and ground electrodes attached to the right and left mastoids (Ring et al. 2015). We focused our feedback on both theta (4-7 Hz) and alpha (8-12 Hz) power at the Pz site because increased power in these bands occurs during meditation, with the effects for alpha power being strongest over parietal areas (Lagopoulos et al., 2009). First, we measured baseline theta and alpha power. Participants were asked to fixate on a cross taped to the wall at eye level, for a period of five seconds while a computer running Bioexplorer software (Cyberevolution) extracted EEG theta (4-7 Hz) and alpha (8-12 Hz) power from the EEG signal. This process was repeated five times and the average of the recordings was used as their baseline theta and alpha power. Having established individual baselines, the procedure diverged for the neurofeedback group and the control group. For members of the neurofeedback group, a computer running Bioexplorer software extracted EEG theta and alpha power from the EEG signal and fed this back in the form of two bar graphs on a screen and an auditory tone (Ring et al., 2015). The graphs represented real-time theta and alpha power, with the bars moving up when power increased, and down when power decreased. Importantly, the tone was programmed to vary in pitch based on the level of alpha power and silence completely when both theta and alpha power were increased by 10% (neurofeedback sessions 1-3) or by 15% (neurofeedback sessions 4-6), relative to each participant's individual baseline. These thresholds were based on previous research documenting similar increases in EEG power during meditation (e.g., Cahn & Polich, 2006), and confirmed via pilot testing which established that they were achievable during our brief intervention. In addition to changing theta and alpha power by 10% (or 15%) the system also required <10 μV of 50Hz activity in the signal (i.e., low impedance) and the absence of eye-blinks, as detected by the electrode placed adjacent to the right eye, for the tone to silence. These control features helped ensure the signal was being regulated by cognitive processes and was not contaminated by muscular or eye-blink artefacts (Ring et al., 2015).

The neurofeedback was delivered to participants over six 2.5-min sessions, each separated by a 1-min break. Participants were seated, told that the graphs and the tone represented their brain activity, and told that their goal was to increase the size of both bar graphs to make the tone go silent. They were asked to try to recognize how to control the graphs and the tone with their thoughts. They were reassured that it should become easier with practice. Finally, they were told that the goal during each 2.5 min session was to increase the height of the bars in the two graphs and silence the tone as much as possible.

The procedure for members of the control group was identical except the graphs and tone supplied to them were not based on their brain activity. Instead, participants were played a recording of the graphs and tone from a matched participant from the neurofeedback group (Ring et al., 2015). Accordingly, unbeknownst to them, members of the control group received no systematic brain training.

2.6. Measures

2.6.1. Cortical Activity

Cortical activity was recorded during the neurofeedback intervention. Bioexplorer software applied bandpass filters to extract theta power (4-7 Hz) and alpha power (8-12 Hz) at a sample rate of 200 Hz. Power in the theta and alpha bands was then averaged for each of the 5s baselines, and for each of the 2.5 min neurofeedback sessions.

2.6.2. Decision Accuracy

Decision accuracy was measured by comparing participant's responses on the decision-making task (i.e., top left corner, bottom left corner, top right corner, bottom right corner) with the correct answer (i.e., the actual location the ball went in relation to the goal posts when each clip was played in full). Decision accuracy is expressed as a percentage. A score of 25% would be expected by chance, while scores greater than 25% reflect decision making above chance-level.

[3] We acknowledge that elite performers have been shown to rate clips at 1.25 to 1.5 speed as most game-like (Lorains et al., 2013a) when judging the clips against their real-game playing experience. However, the participants in the current study were not elite sport performers and had varied soccer playing experience. Therefore, we expect that most participants rated clips compared to how they recalled real-time soccer video clips (mostly consumed at 1.0 speed) rather than real-time soccer playing.

2.6.3. Decision Response Time

Decision response time was calculated as the time in milliseconds between the video pause and the button press response indicating which corner the participant expected the ball would go.

2.6.4. Speed Rating

We used speed rating on the time perception task as our proxy measure of perception of time. Reductions in speed rating scores on the time perception task from the pre-test to the post-test would indicate that videos were perceived as slower, and time perception was lengthened, after the interventions.

2.7. Procedure

Participants attended a single 75-min testing session. They were welcomed, briefed and gave their informed consent to take part, then demographic information was collected. All participants were then seated and fitted with a 4-channel wireless EEG neurofeedback system (PET-4, Brainquiry, The Netherlands). Active electrodes were placed at the parietal midline (i.e., Pz site, Jasper, 1958) of the scalp to record cortical activity, and over the orbicularis oculi muscle of the right eye to remove eyeblink artefacts, while reference and ground electrodes were attached to the right and left mastoids (Ring et al., 2015). We prepared the skin by lightly abrading over the mastoids and the right orbicularis oculi muscle with exfoliating paste, and with a blunt needle at the scalp site (Pz). The sites were then cleaned with an alcohol wipe, conductive gel was applied, and disposable spot electrodes (BlueSensor, Ambu) were placed and secured using tape and a lycra cap. The PET-4 wireless receiver was attached by an elastic and Velcro strap to the participant's right arm; this digitized the EEG signals at 24-bit resolution and transmitted them via Bluetooth at a sampling rate of 200 Hz to a laptop running Bioexplorer (Cyberevolution) software.

Following instrumentation, participants completed 24 practice trials of the decision making and time perception tasks to allow familiarisation with the task requirements. This was informed by pilot testing, which showed that a 24-trial familiarisation period allowed initially slow response times (as were typical in the first few trials) to stabilize, while not being so extensive as to induce fatigue. Participants were permitted a 2-min break after the familiarisation period. They then progressed to the Pre-Test, intervention, and Post-Test phases of the experiment. In the pre-test phase participants completed 48 trials of the decision making and time perception tasks as described above. After participants had made their decision making and speed rating responses at the end of each trial, a "get ready" prompt appeared on the screen, and the next trial automatically started after 2 s. E-prime software controlled the experiment and recorded all participant responses. On completion of the pre-test, participants underwent the neurofeedback (or control) intervention, as described above. Immediately after the intervention, participants completed the post-test phase, which was identical to the pre-test. Finally, the neurofeedback hardware was removed and participants were debriefed and thanked.

2.8. Statistical Analyses

2.8.1. Primary Analyses

We examined the effectiveness of our neurofeedback intervention by subjecting our measures of theta and alpha power to 2 Group (neurofeedback, control) × 7 Session (baseline, session 1, session 2, session 3, session 4, session 5, session 6) ANOVAs. Then, to examine our primary hypotheses concerning the effects of neurofeedback on time perception and decision making, we subjected our speed rating, decision accuracy and decision response time measures to 2 Group (neurofeedback, control) × 2 Test (pre-test, post-test) × 6 Video Speed (0.75, 1.00, 1.25, 1.50, 1.75, 2.00) ANOVAs. Significant effects were probed by polynomial trend analyses, and, in the case of 3-way interactions, by 2 Test × 6 Video Speed ANOVAs performed separately for each group.

2.8.2. Secondary Analyses

As a secondary aim, we also considered the effects of soccer playing experience on our key time perception and decision-making measures. While all our participants were experienced soccer spectators, 17 reported at least 1 year of regular soccer playing experience ($M = 10.71$, $SD = 7.55$ years), and 14 reported no soccer playing experience. Accordingly, separate from our main analyses of the effects of neurofeedback training, we examined the effects of soccer playing experience on speed ratings, decision accuracy and decision response time during the pre-test (i.e., before experimental grouping and interventions occurred) via 2 Experience (Yes, No) × 6 Video Speed (0.75, 1.00, 1.25, 1.50, 1.75, 2.00) ANOVAs for each measure. We also calculated the bivariate correlations between years of soccer playing experience and speed rating, and between speed rating and decision accuracy and decision response time at each video speed during the pre-test. Based on the research and our interpretation of the results of Lorains et al. (2013a; 2013b), our exploratory predictions were that the more experienced players would display lower speed ratings (indicating a longer perception of time) and better decision making performance (especially during higher speed clips). We also expected that speed ratings would display negative correlations with decision accuracy and positive correlations with decision response time (indicating longer perception of time correlating with better performance).

For both primary and secondary analyses the results of univariate tests are reported, with the Huynh-Feldt correction procedure applied for analyses that violated the sphericity of variance assumption. Due to software malfunction, speed ratings, decision accuracy and decision response time data were lost for one, two and three participants, respectively; occasional missing data are reflected in the reported degrees of freedom. Partial eta-squared is reported as a measure of effect size, with values of .02, .12 and .26 indicating relatively small, medium and large effect sizes, respectively (Cohen, 1992).

3. Results

3.1. Manipulation Check

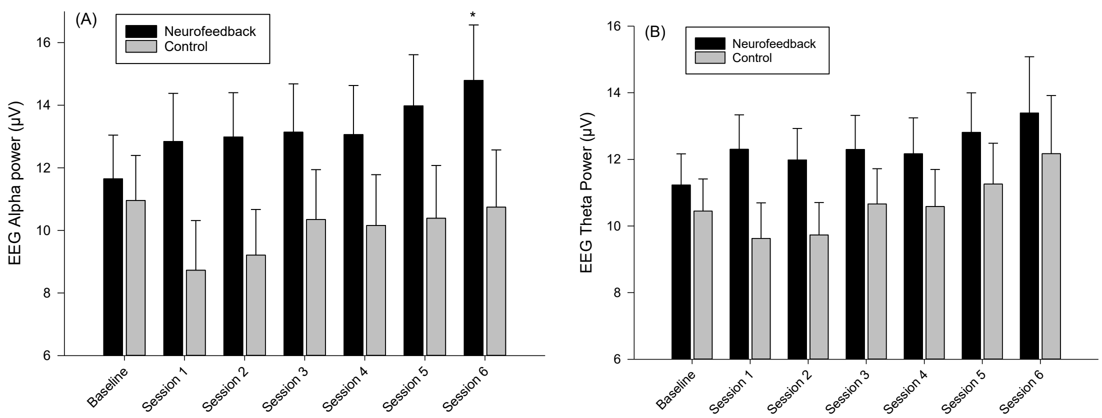

Figure 2: Alpha power (Panel A) and theta power (Panel B) as a function of Group and Session during the intervention phase of the experiment. Error bars indicate standard error of the means. * Indicates significant increasing linear trend for the Neurofeedback Group.

A 2 Group × 7 Session ANOVA for alpha power revealed no main effect for group, $F(1,29) = 2.22$, $p = .147$, $\eta_p^2 = .071$, a main effect for session, $F(4.51,130.68) = 2.69$, $p = .028$, $\eta_p^2 = .085$, $\varepsilon = .751$, and a marginal group × session interaction, $F(4.51,130.68) = 2.12$, $p = .074$, $\eta_p^2 = .068$, $\varepsilon = .751$. Polynomial trend analyses revealed that the main effect for session was characterised by an increasing linear trend, $F(1,29) = 5.69$, $p < .05$, $\eta_p^2 = .164$; alpha power increased from baseline to the final neurofeedback session. They also revealed that the marginal group × session interaction was characterised by a difference in the linear trend; the linear increase in alpha power across sessions was significant for the neurofeedback group, $F(1,15) = 5.83$, $p = .029$, $\eta_p^2 = .280$, and not significant for the control group, $F(1,14) = 0.76$, $p = .400$, $\eta_p^2 = .051$.

A 2 Group × 7 Session ANOVA for theta power revealed no main effect for group, $F(1,29) = 1.41$, $p = .245$, $\eta_p^2 = .046$, no main effect for session, $F(2.73,79.27) = 2.32$, $p = .087$, $\eta_p^2 = .074$, $\varepsilon = .456$, and no group × session interaction, $F(2.73,79.27) = .446$, $p = .703$, $\eta_p^2 = .015$, $\varepsilon = .456$. The effects of alpha and theta power are illustrated in Figure 2.

3.2. Speed Rating

A 2 Group × 2 Test × 6 Video Speed ANOVA for speed rating revealed no main effect for group, $F(1,28) = 0.56$, $p = .461$, $\eta_p^2 = .020$, or test, $F(1,28) = 0.10$, $p = .759$, $\eta_p^2 = .003$, but there was a main effect for video speed, $F(1.87,52.43) = 153.44$, $p < .001$, $\eta_p^2 = .846$, $\varepsilon = .374$. There was also a group × video speed interaction, $F(1.87,52.43) = 4.22$, $p = .022$, $\eta_p^2 = .131$, $\varepsilon = .374$. The hypothesized group × test interaction was non-significant, $F(1,28) = 0.00$, $p = .972$, $\eta_p^2 = .000$. No other significant effects emerged. Polynomial trend analyses revealed that the main effect for video speed was characterised by an increasing linear trend, $F(1,28) = 207.21$, $p < .001$, $\eta_p^2 = .881$; speed ratings increased from the 0.75 speed clips to the 2.00 speed clips. They also revealed that the group × video speed interaction was characterised by a difference in the linear trend, which was slightly stronger for the neurofeedback group, $F(1,14) = 163.96$, $p < .001$, $\eta_p^2 = .921$, than for the control group, $F(1,14) = 63.12$, $p < .001$, $\eta_p^2 = .818$. This shows that participants correctly rated the slower videos as "too slow" and the faster videos as "too fast" and the effect was highly significant for both groups. The means are illustrated in Table 1. Note that the 1.0 and the 1.25 speed clips yielded mean ratings closest to 4 and were thereby considered the most game-like.

3.3. Decision Accuracy

A 2 Group × 2 Test × 6 Video Speed ANOVA for decision accuracy revealed no main effect for group, $F(1,27) = 0.29$, $p = .593$, $\eta_p^2 = .011$, no main effect for test, $F(1,27) = 0.78$, $p = .386$, $\eta_p^2 = .028$, and no main effect for video speed, $F(5,135) = 1.05$, $p = .390$, $\eta_p^2 = .037$. The hypothesized group × test interaction was non-significant, $F(1,27) = 1.86$, $p = .183$, $\eta_p^2 = .064$, but there was a significant group × test × video speed interaction, $F(5,135) = 2.95$, $p = .015$, $\eta_p^2 = .098$. Separate 2 Test × 6 Video Speed ANOVAs were conducted for each group to decompose the 3-way interaction. They revealed that the test × video speed interactions were non-significant, but the effect size was marginally greater for the neurofeedback group, $F(5,65) = 2.17$, $p = .069$, $\eta_p^2 = .143$ than for the control group, $F(5,70) = 1.86$, $p = .113$, $\eta_p^2 = .117$. The means are displayed in Table 1.

3.4. Decision Response Time

A 2 Group × 2 Test × 6 Video Speed ANOVA for decision response time revealed no main effect for group, $F(1,26) = 0.50$, $p = .486$, $\eta_p^2 = .019$, a main effect for test, $F(1,26) = 5.10$, $p = .033$, $\eta_p^2 = .164$, and a main effect for video speed, $F(4.18,108.78) = 6.52$, $p < .001$, $\eta_p^2 = .200$, $\varepsilon = .837$. The hypothesized group × test interaction was non-significant, $F(1,26) = 1.45$, $p = .239$, $\eta_p^2 = .053$. No other significant effects emerged. Polynomial trend analyses revealed that the main effect for video speed was characterised by an increasing linear trend, $F(1,26) = 13.15$, $p < .05$, $\eta_p^2 = .336$; participants were generally able to respond to the slower videos more quickly than they responded to the faster videos. The main effect for test confirmed that participants were faster at making decisions in the post-test ($M = 1028.89$, $SD = 757.91$ ms) than in the pre-test ($M = 1235.08$, $SD = 774.39$ ms). The means are presented in Table 1.

Table 1: Mean speed ratings and decision-making performance as a function of Group, Test and Video Speed.

	Pre-Test						**Post-Test**					
Speed rating (1-7)	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**
Neurofeedback Group	2.20	$3.48_{\dagger}$	$4.03_{\dagger}$	$4.88_{\dagger}$	$5.41_{\dagger}$	$5.83_{\dagger}$	2.48	$3.48_{\dagger}$	$4.06_{\dagger}$	$4.77_{\dagger}$	$5.28_{\dagger}$	$5.67_{\dagger}$
Control Group	2.91	$3.89_{\dagger}$	$4.41_{\dagger}$	$4.80_{\dagger}$	$5.29_{\dagger}$	$5.41_{\dagger}$	2.91	$3.98_{\dagger}$	$4.35_{\dagger}$	$4.77_{\dagger}$	$5.13_{\dagger}$	$5.43_{\dagger}$

	Pre-Test						**Post-Test**					
Decision accuracy (%)	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**
Neurofeedback Group	46.42	51.79	50.00	55.36	53.57	56.25	50.89	46.43	55.36	$41.96_{a\dagger}$	48.21	47.32
Control Group	45.00	45.83	52.50	44.17	40.83	50.00	49.17	53.33	43.33	50.83_{a}	39.18	47.50

	Pre-Test						**Post-Test$_{a}$**					
Decision response time (ms)	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**
Neurofeedback Group	914.87	1071.42	1062.96	1107.27	1052.50	$1320.50_{\dagger}$	855.84	$1013.89_{\dagger}$	$897.41_{\dagger}$	1034.99	1015.06	1135.42
Control Group	1162.72	1406.42	1456.79	1419.36	1357.46	1488.71	981.81	1073.69	1136.14	1036.87_{a}	1018.47	1147.10

Note: $_{a}$ indicates significant change ($p < .05$) from the pre-test. $_{\dagger}$ indicates significant change ($p < .05$) from the previous video speed.

3.5. Secondary Analyses

To explore the secondary aim concerning the effects of soccer playing experience on our key time perception and decision-making measures we conducted 2 Experience × 6 Video Speed ANOVAs on the pre-test speed ratings, decision accuracy and decision response times. Analyses confirmed the previously described main effects of video speed on speed rating and decision response time (F's > 3.72, p's < .001, η_p^2's > .12); speed ratings and response times both increased from the slowest (0.75) to the fastest (2.00) video clips. There was no main effect of video speed on decision accuracy, $F(5,135) = 1.05$, $p = .39$, $\eta_p^2 = .04$, there was no main effect of experience on any of the variables, F's < 0.64, p's > .43, η_p^2's = .02, and there were no interaction effects, F's < 0.56, p's > .56, η_p^2's = .02. Means are presented in Table 2. Correlation analyses performed at each clip speed yielded non-significant positive correlations between experience and speed rating (r's = .01 - .20, p's = .29 – .98), non-significant and mixed positive and negative correlations between speed rating and decision accuracy (r's = -.19 - .26, p's = .19 – .97), and non-significant positive correlations between speed rating and decision response time (r's = .06 - .26, p's = .17 – .77). In sum, experience did not correlate with speed rating, and speed rating did not correlate with decision making performance. Those who had some soccer playing experience tended to perform a little better on the decision-making variables than their non-soccer playing counterparts (Table 2), but this was not statistically meaningful. The overall consensus is that experience appeared to have little bearing on the results of this experiment.

4. Discussion

This experiment was designed to examine the effects of a brief EEG neurofeedback intervention on brainwaves, time perception and decision making in sport. We expected that: a) six 2.5 min neurofeedback sessions would increase EEG theta and alpha power; b) this would lengthen perceived time viewing sport video clips; and c) this would improve sport-based decision making. Our results as they pertain to each of these predictions are discussed in the following sections.

4.1. Neurofeedback Manipulation Check

To establish the effectiveness of our brief neurofeedback intervention in modifying EEG theta and alpha power, we expected to reveal group and session interactions characterised by a selective increase in EEG theta and alpha power over the course of the intervention for the neurofeedback group only. We revealed partial support for our hypothesis. Specifically, there was a marginal group and session interaction for EEG alpha power, and follow-up planned polynomial contrasts confirmed that there was a significant increase in alpha power across the intervention sessions for members of the neurofeedback group only. This provides encouraging evidence that brief neurofeedback interventions can reliably modify brainwaves and replicate the pattern of increased alpha power that occurs during mindfulness in trained meditators, but in a more time-efficient manner (cf. Droit-Volet et al., 2015). By increasing alpha power, we can speculate that members of our neurofeedback group should have been able to inhibit the processing of environmental stimuli and experience a progressively more internalized state over the course of their neurofeedback intervention (Cooper et al., 2006; Klimesch et al., 2007), potentially drawing greater attention to their internal clock (Zakay & Block, 1997).

However, in contrast with our hypothesis, there was no group and session interaction for EEG theta power. While the effects of mindfulness on EEG theta power are widespread, they tend to be strongest over frontal regions, but we focused our neurofeedback on the parietal midline because that was revealed as the key location for meditation effects on alpha power (Lagopoulos et al., 2009). This could explain why our results failed to support our hypothesis for theta power. It would be interesting to replicate this experiment with two neurofeedback sites (i.e., parietal alpha and frontal theta) to optimize the feedback for both frequency bands. Notwithstanding, it is encouraging to note that such an acute intervention did deliver the expected alpha power effects, and the fact that theta power was also higher (albeit non-significantly – Figure 2B), does allow some confidence that the manipulation worked, and members of the neurofeedback group were in a different brain state than members of the control group ahead of the time perception and decision-making post-tests.

Table 2: Mean speed rating and decision-making performance as a function of soccer playing experience.

Experience Level	**Pre-Test**					
	0.75	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**
Speed rating (1-7)						
Experienced	2.74	3.71†	4.29†	4.82†	5.40†	5.65
Inexperienced	2.32	3.65†	4.14†	4.88†	5.28†	5.57
Decision accuracy (%)						
Experienced	50.00	50.78	53.91	53.13	46.09	53.91
Inexperienced	40.35	46.15	48.08	45.19	48.08	51.92
Decision response time (ms)						
Experienced	908.74	1086.38	1191.22	1099.17	1060.35	1300.89†
Inexperienced	1158.86	1369.57	1280.38	1410.84	1321.01	1452.24

Note: † indicates significant change (p < .05) from the previous video speed.

4.2. Effects of Neurofeedback on Time Perception

We hypothesized that our neurofeedback intervention would lengthen perceived time, characterised by the neurofeedback group reporting lower speed ratings for the video clips than their control group counterparts during the post-test. This prediction was not supported as there was no group and test interaction for speed ratings. Our finding suggests that increase alpha and theta neurofeedback training has no impact on time perception. We chose increase alpha and theta as the targets for our neurofeedback intervention based on previous research demonstrating that these frequencies characterise mindfulness meditation (Lomas et al., 2015), and that mindfulness meditation can lengthen perceived time (Droit-Volet et al., 2015). It is possible that other aspects of mindfulness (e.g., reduced heart rate) are more important than brainwaves for mediating the effects of mindfulness on perception of time. This could be examined by future research.

Reassuringly, we did reveal a main effect for video speed. As would be expected, all participants accurately rated the 0.75 speed videos as the slowest, and the 2.00 speed videos as the fastest. We also revealed a group and video speed interaction where the neurofeedback group tended to rate the 0.75 videos as slightly slower and the 2.00 speed videos as slightly faster than the control participants. However, the difference between the linear trends displayed by the two groups was very small (control group η_p^2 = 82; neurofeedback group $\eta_p^2 = .92$) and was independent of the test factor so cannot be attributed to the neurofeedback intervention. Instead, this effect could be a result of random variation that may dissipate in a larger sample.

4.3. Effects of Neurofeedback on Decision Making

We hypothesized that decision accuracy and decision response time would improve from pre-test to post-test to a greater extent among members of the neurofeedback group than members of the control group. These hypotheses were not supported as there was no group and test interaction for either of these variables. There was a main effect of video speed for decision response time. As would be expected, participants were faster at making decisions in response to the clips at the slower video speeds than in response to clips at the faster video speeds. This is likely due to the extra time afforded to information processing during the slow-motion clips (Land & McLeod, 2000). There was also a main effect of test for decision response time. As would be expected, participants were faster at making decisions during the post-test, showing that decision making speed improves with practice (Mori, Ohtani, & Imanaka, 2002).

Interestingly, for decision accuracy, there was a three-way interaction effect showing that, if anything, decision accuracy decreased from pre-test to post-test, but only at the faster video speeds (especially the 1.5 speed) and for members of the neurofeedback group (Table 1). Thus, rather than the expected enhancement of decision making, it appears that there was a slight tendency for our neurofeedback intervention to prompt less accurate decisions during the faster video clips. While this observation clearly opposes our hypothesis, it must be noted that our performance-based hypotheses (i.e., neurofeedback would improve decision making) were contingent on support for our earlier hypothesis (i.e., neurofeedback would lengthen perceived time). Seeing as increased theta and alpha neurofeedback failed to impact time perception, we can reformulate our expectations concerning decision making. Specifically, our data show that members of the neurofeedback group entered the post-test with significantly increased EEG alpha power compared to the controls, possibly reflecting a more internally focused state (Cooper et al., 2006). The lack of time perception effects suggest that this was not focused on the internal clock. Instead, it may have primed decision reinvestment, where an internal self-focus may de-automate the decision-making process leading to inferior decision-making performance (Kinrade, Jackson, & Ashford, 2015). Alternatively, as reinvestment might be considered more likely to occur during slower than faster clips, a second possibility is that our alpha enhancing neurofeedback reduced cortical activity and encouraged a deepened state of relaxation (Nowlis & Kamiya, 1970). If members of the neurofeedback group were too relaxed at the post-test, this could have impaired their ability to concentrate, extract information, and make accurate decisions after the high-speed video clips.

In sum, had we ignored the enticing suggestion that increase theta and alpha power neurofeedback would lengthen perceived time, we could have formulated a different neurofeedback intervention specifically focused upon decision making and motor performance. For instance, previous studies have trained participants to decrease theta and/or alpha power prior to motor performance (e.g., Kao, Huang, & Hung, 2014; Ring et al., 2015) on the premise that these states may be associated with increased concentration, improved motor response programming, and an external focus of attention (Cooke, 2013; Cooke et al., 2014; Cooke et al., 2015). The demands of the task should be a very important consideration when formulating neurofeedback interventions; different protocols are typically prescribed for motor compared to cognitive tasks, and sometimes even within different classes of motor task (for review see Cooke, Bellomo, Gallicchio, & Ring, 2018). As the primary task here was a button press response, decreased alpha neurofeedback training to increase cortical excitability may have been the most obvious intervention to increase accuracy and decrease response times had our theorizing about time perception been put to one side. It would be interesting for future research to replicate and extend this experiment with a longer neurofeedback intervention and an additional decrease alpha and theta neurofeedback group to investigate this line of thinking.

4.4. Effects of Experience on Time Perception and Decision-Making

As an aside from our primary investigation into the effects of neurofeedback on time perception and decision making, our secondary analyses briefly considered the impact of soccer playing experience on our outcome measures. Lorains et al. (2013a) found that elite and sub-elite Australian rules football players responded differently to the speeded video paradigm, with elite players displaying improved decision accuracy and sub-elite players showing impaired decision accuracy with increasing video speeds. Novice players displayed lower decision accuracy scores throughout and were relatively unaffected by the changes in speed. The participants of the current study could not be classified based on their performance level, but we were able to dichotomize those with some soccer playing experience from those with no experience at all. Results revealed no main or interaction effects involving the experience factor in the current study. We did observe a main effect for decision response time, providing some evidence that performance of all participants was impaired with increasing video speeds. However, this effect did not manifest for decision accuracy meaning our performers most closely resembled the novice group from Lorains et al. (2013a) on the decision accuracy measure. Subtle differences in the decision and the response time recording methods employed here versus those employed by Lorains et al. (2013a) could explain why we revealed effects for decision time but not for decision accuracy, and why Lorains et al. (2013a) revealed the opposite pattern. Our decision accuracy measure was a forced choice between one correct and three incorrect options, whereas Lorains et al. (2013a) gave participants a relatively free choice of response and employed a points-based scoring system based on response quality. This may have rendered their accuracy measure more sensitive than ours. On the other hand, our response time measure required a simple button press whereas Lorains et al.'s (2013a) measure required participants to move and click a mouse, potentially involving different locations and movement times across trials. We may have benefited from lower between-trial variability and thereby higher sensitivity to temporal effects via our simple button press response. Irrespective of these methodological nuances, the pattern of stable accuracy and impaired decision response times at faster video speeds indicate that our participants more closely resembled those at the lower end of the skill acquisition continuum than elite athletes. Most importantly, this pattern occurred regardless of whether our participants reported having soccer playing experience or not, indicating that even our experienced participants may have been of a relatively low skill level. In future studies it would be advantageous to record soccer playing level (e.g., novice, sub-elite, elite) as well as experience as per Lorains et al. (2013a).

Our final set of analyses involving experience employed correlations to examine the prediction that experience would correlate with time perception, and the subsequent prediction that time perception would associate with performance. Results provided little evidence to suggest that experience on a task (in this case, soccer) serves to lengthen perceived time on that task. There were no significant correlations between experience and speed ratings at any video clip speed. There were also no correlations between speed ratings and either of the decision-making variables, providing little evidence to support our assertions that lower speed ratings, potentially indicating a lengthened perception of time, would be beneficial for performance. It is possible that lengthened time perception may come as a consequence of high-level performance rather than being something that causes high-level performance. For instance, the literature on embodied cognition and perception shows that participants in a rich vein of form demonstrate perception differences due to their superior form (Gray, 2014). The distance between the posts was perceived wider by American football kickers, and the size of the hole was perceived bigger by golfers, after (but not before) successful compared to unsuccessful performances (e.g., Witt, Linkenauger, Bakdash, & Proffitt, 2008; Witt & Dorsch, 2009). We previously described Witt and Sugovic's (2010) tennis study and speculated that the lengthened time perception that occurred after successful shots in that experiment may have contributed to the successful performance outcomes. However, it is possible that the direction of this relation was the other way around. Future research could conduct mediational analyses to probe the directionality of relations between expertise, performance outcome, and perception.

4.5. Limitations

The results of this experiment should be considered in light of some limitations. First, we did not measure EEG activity during the decision making and time perception tasks. Accordingly, although the EEG alpha data recorded during the neurofeedback intervention provide some evidence that cortical activity was different between the neurofeedback and the control groups at the end of the intervention, we do not know if these differences persisted throughout the post-test. Previous research has evidenced that changes in theta and alpha power induced during neurofeedback training can persist during post-training retention tests (e.g., Ring et al., 2015), but future research should measure cortical activity during post-tests to verify this assumption. Second, while we believe that parallels can be drawn between the sport-based speeded video paradigm that we employed to measure time perception, and the traditional temporal bisection task used by Driot-Volet et al. (2015) (see explanation in Methods section), we concede that our time perception measure remains somewhat atypical. Future research could adopt a range of reproduction or comparison timing measures to afford a more comprehensive assessment of perceived time in sport (Grondin, 2010). Finally, we recognise that our key prediction that lengthened time perception should benefit decision making is worthy of future scrutiny. Our prediction was based on evolutionary evidence showing that some species have developed a longer perception of time to provide a competitive advantage (Healy et al., 2013), and sport evidence suggesting that when time perception was longer, performance was better (Witt & Sugovic, 2010). However, there may be other factors to explain those previous results (e.g., Gray, 2014). For instance, while Lorains et al.'s (2013b) finding that speeded video training improved sport-based decisions may owe something to altered time perception, the performance benefits of the intervention were not attributed to changes in perceived time by the authors. Instead, Lorains et al. (2013b) argued that training with faster clips was beneficial because it permitted less time for information processing, and this was of benefit because it forced automatic decisions. In accord with this interpretation, Spitz, Moors, Wagemans and Helsen (2018) recently argued that watching clips in slow-motion can, in some cases, impair decision making. Interventions designed to modify perceived time may be considered in a different class of intervention to speeded video training. Time perception interventions like the one used here aim to instil a psychological strategy in training that, when learned, may transfer to match play to help participants cope with real game time pressure. In contrast, speeded video training appears more focused on promoting overreaching and adaption to more challenging conditions in training than one would routinely face in a game, potentially making real games feel easier. Future research could directly compare these two intervention types and explore whether time perception mechanisms underlie any performance benefits.

4.6. Conclusion

In conclusion, our experiment provides new evidence that just 15-mins of neurofeedback training can increase EEG alpha power and mimic the EEG alpha effects of mindfulness meditation. Accordingly, EEG neurofeedback could be of use as an alternative or supplemental method of replicating some of the effects of mindfulness in situations where there is insufficient time for a regular meditation session. However, neurofeedback had no impact on perception of time, and thereby failed to deliver any benefits for decision making during reactive sport. It remains for future research to further clarify the relationships between perceived time, decision making, and performance in sport. It is critical for neurofeedback interventions to be precisely tailored to the demands of the task at hand. While neurofeedback did not impact perceived time here, research is continually providing improved understanding of the brain states for optimized decision making, and thereby opening more avenues for new neurofeedback interventions targeted at improving sport performance. It is clear that neurofeedback can change brainwaves, and if the correct neurofeedback recipe can be programmed, we see considerable potential for neurofeedback as a valuable tool in the arsenal of skill acquisition practitioners in the years to come.

Conflict of Interest

The authors declare no conflict of interests.

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