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Research article

Chasing the zone: Reduced beta power predicts baseball batting performance

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ABSTRACT

Mental state prior to sports skill execution is related to subsequent performance. For example, relationships between pre-performance electroencephalogram (EEG) power and subsequent movement outcomes in golf putting, pistol shooting, and basketball free throw shooting have been previously reported. With that said, the existing body of research examining the pre-performance EEG – performance relationship has been focused on the execution of internally as opposed to externally-paced motor skills. Given that the execution of internally and externally-paced movements are dependent on different neural pathways, in the present study we examined whether or not pre-performance EEG power predicted ensuing performance of an externally-paced motor skill – baseball batting. Sixty-seven baseball players had EEG data recorded for 120 s prior to batting practice. Performance was assessed by three expert coaches and the accuracy of coach performance ratings was verified via Generalizability Theory. An analysis of our data revealed an inverse relationship between frontal EEG power in the beta range and subsequent batting performance - reduced beta power was associated with better batting performance whereas increased beta power was associated with worse batting performance. Our results are in line with prior research that has demonstrated a relationship between increased EEG power in the beta range and the subsequent commitment of motor errors in addition to the aforementioned work examining pre-performance EEG and the execution of internally-paced motor skills.

1. Introduction

In sports, both players and coaches believe in “the zone” – a mental state purportedly associated with superior performance. Seminal work by Hanin [1–5] proposed the Individual Zones of Optimal Functioning Model (IZOF). The IZOF framework posits that individually specific levels of anxiety correspond with optimal performance. Support for the IZOF model comes from research that demonstrates that level of pre-competition anxiety predicts subsequent performance [6]. Another explanation of “the zone” by Csikszentmihalyi relates it to flow state – a state in which thought is limited, movement comes easily and effortlessly, and time seems to slow for an athlete [7]. Whether one subscribes to Hanin’s and/or Csikszentmihalyi’s theories, there seems to be little doubt that optimal performance is associated with a specific mental state. Framing this from a neuroscience perspective, one would predict a specific pattern of neural activity that is associated with subsequent optimal performance.

Studies using electroencephalography (EEG) have indeed provided evidence that patterns of neural activity prior to sport performance are correlated with motor outcomes [8,9]. In one of the first studies to use EEG to investigate neural activity during the pre-shot period – the period of time immediately prior to the execution of a discrete motor skill – Loze et al. [10] found that successful air-shooting performance was associated with increased alpha power (oscillations between 8 and 12 Hz) relative to unsuccessful air-shooting performance. Conversely, Babiloni et al. [8] examined the EEG spectra prior to putting a golf ball and found that there was a correlation between reduced alpha power and the magnitude of missed putts. In two follow up experiments Babiloni and colleagues [11,12] examined coherence in alpha power between electrode sites and its relationship with skill performance. In these studies, they found that expert performance was associated with greater alpha coherence between central and parietal electrode sites – a result they attributed to increased neural efficiency (see also Del Percio et al. [13] for pistol shooting).

In addition to alpha power and coherence, other patterns of EEG activity have also been observed prior to sport performance. Chuang

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and colleagues [14] recorded EEG data prior to attempted basketball free throws and found that successful free throw attempts were associated with greater frontal theta power than unsuccessful free throw attempts. In other work examining expert-novice differences Cooke et al. [15] found decreased activity in the theta, alpha, and beta EEG bands prior to successful performance by experienced golfers. In yet another study, Di Fronso et al. [16] found a different result – successful shooting performance was associated with increased event-related synchronization between the theta, low alpha, and high alpha bands. In summary then, the body of work examining EEG activity prior to sports skill execution is far from consistent, likely owing to methodological and task variations.

In the present study we sought to examine whether or not EEG data recorded before baseball batting would predict subsequent performance. Differing from previous work, in the present study we recorded EEG data before batters went up to swing and not immediately before skill execution (i.e., the pre-shot period). Further, to the best of our knowledge, all of the prior work examining EEG prediction efficacy has focused solely on internally-paced motor skills [17] - tasks wherein stereotyped execution is ideal and no externally driven adaptation is required for success. As such, and given that the execution of externally-paced motor skills are reliant upon different neural pathways [18], here we sought to extend the existing body of work by focusing on pre-performance EEG and the execution of a subsequent externally-paced motor skill. In line with previous work (e.g., Babiloni et al. [8]) we hypothesized a correlation between alpha power and subsequent batting performance. Specifically, we hypothesized that reductions in alpha power would be associated with better batting performance. Given other prior work (e.g., Cooke et al. [15]), we also sought to examine the relationship between reductions in theta and beta power and batting performance.

2. Methods

2.1. Participants

Sixty-seven participants were recruited from high performance baseball teams in Vancouver and Victoria, British Columbia, Canada and were males between 15 and 21 years of age (mean = 18.2, SD ± 1.5). All participants had no known neurological impairments, volunteered for the study, and provided informed consent approved by the Human Research Ethics Board at the University of Victoria. Additionally, the study followed ethical standards as prescribed in the 1964 Declaration of Helsinki.

2.2. EEG data collection

EEG data were collected with a MUSE EEG headband with pre-set collection parameters (500 Hz sampling rate, no onboard data processing: InteraXon, Ontario, Canada; see Krigolson et al. [20] for validation of the MUSE). The MUSE EEG headband has five electrodes (AF7, AF8, Fpz, TP9, TP10) with electrode Fpz being utilized as the reference. Data from the MUSE EEG system was streamed to an 11″ MacBook Air (Apple Inc., California, U.S.A.) via Bluetooth and was recorded within the MATLAB programming environment (see Krigolson et al. [20] for full technical details). Signal quality was determined by computing the variance per second of the incoming EEG data and was kept below 200 μV/s at all times. After setup, and immediately prior to batting, 120 s of continuous EEG data were collected from each participant. Participants were instructed to sit quietly and stare at a centrally presented fixation cross that appeared on an otherwise blank screen on the recording computer (with the recording software running in the background) while the first 60 s of EEG data were recorded. Following this, participants were instructed to silently count down from 1000 by 7′s while again staring at the fixation cross and another 60 s of EEG data were recorded. While the EEG data was collected participants were instructed to sit still at all times and to avoid blinking if possible.

2.3. Batting performance

Immediately following EEG data collection participants took part in batting practice thrown by a coach. The coach throwing the batting practice was instructed to deliver pitches to the batter the same way that they would during a normal batting practice. The coach was instructed that each pitch should be straight and close to the batter's "strike zone." Due to performance variability, batters were asked to only swing at balls thrown within the strike zone. Only pitches that were swung at counted towards the batter's total number of swings and were analyzed. Each player was tested until they completed 24 swings. Batters were not provided with any feedback before or during their testing rounds from any of their coaches or their teammates.

2.4. Batting performance analysis

Batting performance was evaluated by three coaches who rated the batter in terms of: 1) ability to recognize if the pitch is in the strike zone, 2) the batter's form, 3) power displayed upon contact and 4) ability to contact the pitch, with coaches rating each of these factors on a range from 1 (poor) to 10 (exceptional). Prior to each batting session, the coaches reviewed the criteria and came to agreement on what type of performance constituted the low and high ends of the scale. Specifically, the criteria were:

1) Batter's ability to recognize whether or not the pitch was in the strike zone before swinging. A score of 10 meant that the batter only swung at balls in the strike zone and they lost points for each pitch they swung at outside of the zone;
2) Form related to the batters perceived batting technique. A score of a 10 meant that the batter swung without any perceived flaws;
3) Power reflected the perceived rate of speed at which the batted ball left the bat following contact. A score of 10 meant that the batter contacted the ball with power such that the ball exited at a high rate of speed, on a line or well hit in the air, on every at bat; and,
4) Contact was defined as a hit that led to the batted ball landing in "fair territory".

All of the coaches rating players were qualified to a minimum standard of the National Coaching Certification Program (NCCP) of Canada.

2.5. EEG data analysis

The EEG data were recorded in MATLAB and converted for offline processing using a custom MATLAB script into a format that was importable into Brain Vision Analyzer 2 software (Version 2.1.1, Brainproducts, GmbH, Munich, Germany) using methods previously employed by the Neuroeconomics Laboratory (see http://www.neuroeconlab.com/data-analysis.html). Preprocessing of the EEG data began with the application of a zero-phase shift Butterworth filter with a passband of 0.1 Hz to 30 Hz in addition to a 60 Hz notch filter. Next, the frontal EEG channels (AF7, AF8) were re-referenced to an average of the posterior channels (TP9, TP10) given the proximity of the physical reference at Fpz. Note, channels TP9 and TP10 were not re-referenced as they were already distal to the physical reference of Fpz. Given a preliminary analysis of the data in which hemispheric differences were not observed, we pooled the two frontal electrodes (AF7, AF8) and the two posterior electrodes (TP9, TP10). Next, data were divided into smaller 2000 ms epochs using an overlap for each segment of 1900 ms. An artifact rejection algorithm was conducted on each epoch, and epochs with gradients of greater than 10μV/ms and /or an absolute difference of more than 150μV were discarded. The artifact rejection procedure resulted in the removal of three participants from further analysis due to an unacceptable percentage of artifacts in their data (> 30%).

A Fast Fourier Transformation (FFT) was conducted on each epoch using maximum resolution, power, non-complex output on the full spectrum with a Hanning Window with a 10% taper and a resolution of 0.48 Hz. Epochs were zero-padded for a length of 2048 ms generating 1024 points. From this, power was extracted for each epoch and averaged across epochs for each frequency (1–30 Hz) for each participant. Finally, average power was computed for each frequency band (delta: 1–3 Hz, theta: 4–7 Hz, alpha: 8–12 Hz, beta: 13–30 Hz) for each channel (pooled frontal, pooled posterior), condition (not counting, counting), and participant.

2.6. Statistical analysis

Descriptive statistics on coaches score are reported and Generalizability Theory (g-theory) was used to analyze and calculate the reliability of coaching scores, inter-rater reliability and the inter-item correlation [19]. Since all coaches rated all players on all items, this was a fully crossed generalizability theory design with the following facets: players (67), coaches (3), items (4). To assess the relationship between coaching score and EEG Pearson correlations (r) were computed between each of the four batting performance ratings (form, contact, power, pitch recognition) and each of the four EEG frequency bands of interest (delta, theta, alpha, beta). The statistical assumptions of correlation analysis were tested and met. Cook's D plots were examined to determine if there were any influential data points; no data were found to have enough leverage to warrant exclusion based on these analyses.

3. Results

3.1. Reliability of coach performance evaluations

The average score for pitch recognition was 6.43 (SD ± 0.82). The mean score for batter's form was 6.41 (SD ± 0.98). The average score for power was 5.98 (SD ± 1.12). The average score for contact was 6.41 (SD ± 0.93). The overall reliability of the coaching scores was 0.81, the inter-rater reliability was 0.68, and the inter-item correlation was 0.70 [19]. This analysis also revealed that the majority of the variance was between players (48.4%) whereas there was little to no difference between coaches (less than 1%). Overall therefore, these analyses demonstrate that there was strong agreement between the coaches in terms of their performance ratings.

3.2. Relationship between rated performance and the EEG power spectra

Pearson r correlations between each of the four batting performance ratings (form, contact, power, pitch recognition) and each of the four EEG frequency bands of interest (delta, theta, alpha, beta; see Table 1 and Fig. 1) for the average of the frontal electrodes and the posterior electrodes revealed that there were no significant correlations between power in the delta, theta, and alpha frequency bands and any of the batting performance ratings (form, contact, power, pitch recognition: all p's > .05, see Table 1). However, we did find that power in the beta band correlated with all four of the batting performance ratings (form [$r = -0.33$, $p = .009$], contact [$r = -0.48$, $p < .001$], power [$r = -0.33$, $p = .008$], and pitch recognition [$r = -0.36$, $p = .003$] (see Fig. 2). Interestingly, we did not observe a correlation between batting performance ratings and EEG power in any frequency bands for posterior electrode sites or for either the front and back electrodes during performance of the counting task. In sum, these results reveal that batting performance was better if observed beta EEG power during quiet rest was reduced at frontal electrodes prior to baseball batting.

Table 1
Pearson correlation of the frontal fixation task – frequencies vs evaluation criteria.

	Form	Contact	Power	Recognition
Delta	−0.10	0.08	−0.02	0.12
Theta	0.03	0.02	0.13	0.14
Alpha	−0.10	−0.17	−0.05	−0.13
Beta	−0.33**	−0.48***	−0.33**	−0.36**

Two tailed significance: *p < .05. **p < .01. ***p < .001.

4. Discussion

In the present study we sought to examine the relationship between EEG data recorded prior to baseball batting and subsequent batting performance. Specifically, our data demonstrated an inverse relationship between pre-performance frontal EEG beta power and batting performance – better batting was associated with lower pre-performance frontal beta EEG power whereas poorer batting was associated with greater pre-performance frontal beta EEG power. We observed no relationship between pre-performance frontal EEG power in the delta, theta, and alpha bands nor posterior EEG power in any spectra and subsequent batting performance.

Our results are notably inconsistent with previous work examining the relationship between power in pre-performance EEG spectra and subsequent performance. Indeed, the general trend in previous work examining pre-performance EEG has shown that successful performance is associated with reductions in alpha power prior to skill execution [13,15]. With that said, it is worth noting again that a variety of differing patterns of results have been observed. For example, work by Chuang and colleagues [14] found that increased theta power was associated with successful basketball free throw shooting and Cheng et al. [21] found that increased power in the low-beta range was associated with more accurate air pistol shooting. As such, given the diverse findings to date one can only conclude that there is no common pattern of neural activity prior to successful performance across all sport skills. Indeed, our results here attribute successful batting performance with a reduced level of frontal beta EEG power but unlike previous work here we examined an externally-paced as opposed to an internally-paced motor skill [17]. Another point worth noting is that the sample size examined here was considerably larger than previous studies.

One still must wonder why a reduction in frontal beta EEG power would be associated with successful baseball batting performance. In general, previous work has shown that reductions in frontal beta power are observed with the onset of voluntary movement [22]. However, in our study we only examined performance when the players actually swung the bat (i.e., only swings were scored), thus a reduction in beta power would be expected in all instances, and further – we recorded our EEG data well in advance of skill execution. With that said, Koelewijn and colleagues [23] observed an increase in beta power following the observation of incorrect motor responses. Similarly, and perhaps most pertinent to the findings presented here, Ruiz et al. [24] observed an increase in beta power prior to errors made by pianists playing piano. In other words, Ruiz et al. [24] found that response errors were associated with increased beta power prior to the actual error being committed. With this in mind, our results could be explained similarly – poor batting performance could be reflective of errorful performance by the motor system which is associated with an overall increase in pre-performance frontal beta EEG power.

Our results might also be explained in terms of arousal and/or motivation theory. High-levels of anxiety have been associated with greater beta EEG power whereas low-levels of anxiety have been associated with lower beta EEG power [25]. As such, and in line with the IZOF framework [1–5], poor baseball batting performance in our task may also have been due to greater athlete anxiety as evidenced by greater beta EEG power. Another explanation of our results could be that participants with lower beta EEG power prior to batting were more

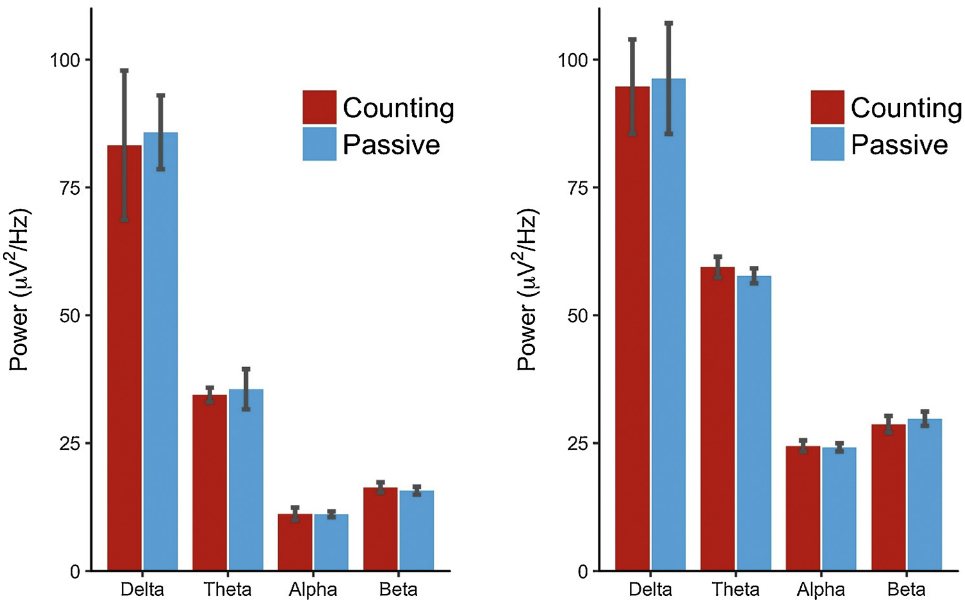

Fig. 1. Mean power in the EEG spectra for frontal (left) and posterior (right) electrodes for the non-counting and counting EEG recording periods. Error bars reflect 95% confidence intervals.

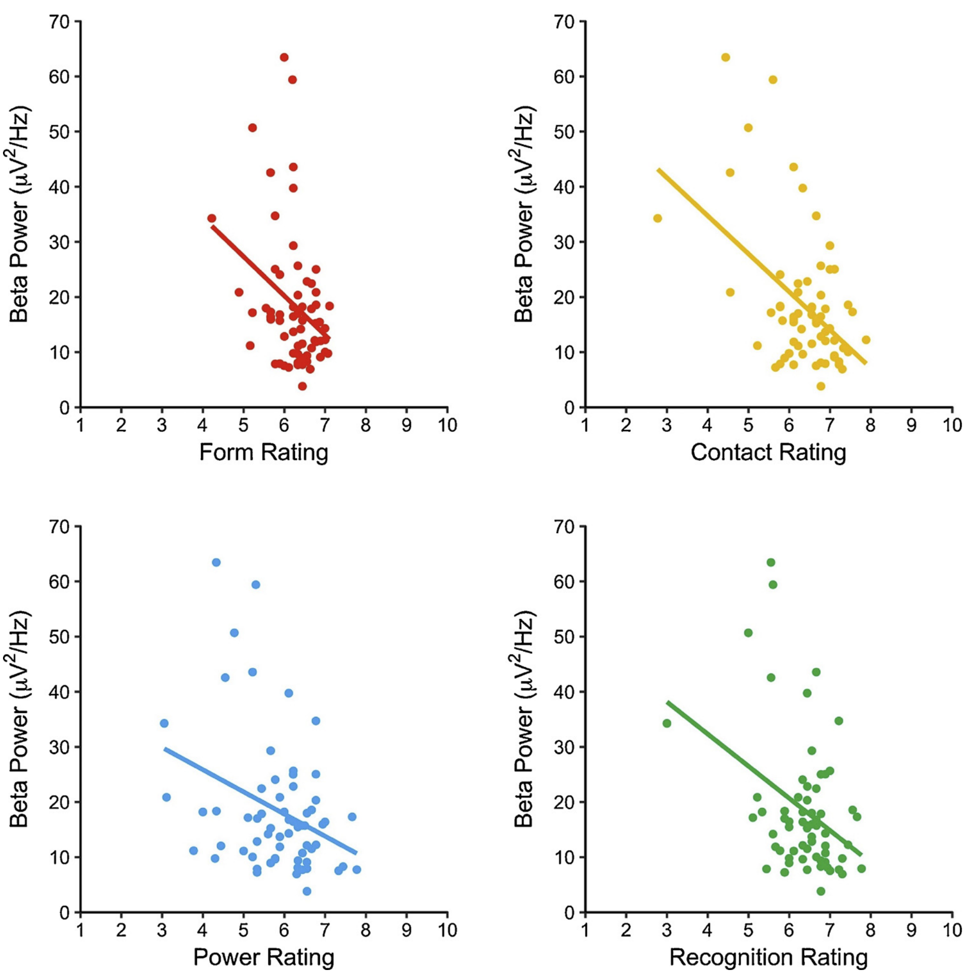

Fig. 2. Correlations between the four batting performance measures (form, contact, power, recognition) and frontal beta power.

motivated than participants with greater beta EEG power prior to batting. Supporting this, Threadgill and Gable [26] recently demonstrated a relationship between beta EEG power and motivation that impacted motor-action preparation. Given that in our study the pre-performance “brain state” of athletes predicted subsequent overall performance, an anxiety or motivational account of our results is feasible.

5. Conclusions

Here we demonstrate that successful baseball batting performance was associated with reduced power in the beta EEG band relative to unsuccessful performance which was associated with increased power in the beta EEG band. While our findings differ from an existing body of work demonstrating relationships between theta and alpha power and performance, our results are in line with previous work that found that increased beta power predicted subsequent motor errors. Overall, the body of work examining pre-performance EEG and performance suggests that it is potentially possible to use this methodology to predict performance.

Contributions

Anthony Pluta contributed to the design of the study, collected and analyzed the data, and assisted with manuscript preparation. Chad Williams provided technical support and assisted with manuscript preparation. Gordon Binsted and Kent Hecker contributed their expertise to assist with experimental design and data analysis. Olave Krigolson was the senior author and designed the study, provided mentorship, technical training, and supervised the implementation of the project.

Conflict of interest

The authors have no conflict of interest to report.

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References

[1] Y.L. Hanin, A study of anxiety in sports, in: W.F. Straub (Ed.), Sport Psychol. An Anal. Athl. Behav, Mouvement Publications, NY, 1980, pp. 236–249.
[2] Y.L. Hanin, STAI in sport: problems and perspectives, in: E. Apitzsch (Ed.), Anxiety Sport, Magglingen, FEPSAC, 1983, pp. 129–141.
[3] Y.L. Hanin, State-trait anxiety research on sports in the USSR, in: C.D. Spielberger, R. Diaz-Guerrero (Eds.), Cross-Culturul Anxiety, Hemisphere Publishing, Washingtong, DC, 1986, pp. 45–64.
[4] Y.L. Hanin, Interpersonal and intragroup anxiety in sports, in: D. Hackfort, C.D. Spielberger (Eds.), Anxiety Sport. An Int. Perspect, Hemisphere Publishing, NY, New York, 1989, pp. 19–28.
[5] Y.L. Hanin, Individual zones of optimal functioning (IZOF) model: an idiographic approach to performance anxiety, in: W. Straub, K. Henshen (Eds.), Sport Psychol. An Anal. Athl. Behav. 3rd ed., Mouvement Publications, Ithica, NY, 1994, pp. 250–292.
[6] S. Salminen, J. Liukkonen, Y. Hanin, A. Hyvönen, Anxiety and athletic performance of finnish athletes: Application of the zone of optimal functioning model, Pers. Individ. Dif. 19 (1995) 725–729, https://doi.org/10.1016/0191-8869(95)00096-O.
[7] M. Csikszentmihalyim, Flow: The Psychology of Optimal Experience, Harper Collins Publishers, CA, 1990.
[8] C. Babiloni, C. Del Percio, M. Iacoboni, F. Infarinato, R. Lizio, N. Marzano, G. Crespi, F. Dassù, M. Pirritano, M. Gallamini, F. Eusebi, Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms, J. Physiol. 586 (2008) 131–139, https://doi.org/10.1113/jphysiol.2007.141630.
[9] J.L. Park, M.M. Fairweather, D.I. Donaldson, Making the case for mobile cognition: EEG and sports performance, Neurosci. Biobehav. Rev. 52 (2015) 117–130, https://doi.org/10.1016/j.neubiorev.2015.02.014.
[10] G.M. Loze, D. Collins, P.S. Holmes, Pre-shot EEG alpha-power reactivity during expert air-pistol shooting: a comparison of best and worst shots, J. Sports Sci. 19 (2001) 727–733, https://doi.org/10.1080/02640410152475856.
[11] C. Babiloni, C. Del Percio, P.M. Rossini, N. Marzano, M. Iacoboni, F. Infarinato, R. Lizio, M. Piazza, M. Pirritano, G. Berlutti, G. Cibelli, F. Eusebi, Judgment of actions in experts: a high-resolution EEG study in elite athletes, Neuroimage 45 (2009) 512–521, https://doi.org/10.1016/j.neuroimage.2008.11.035.
[12] C. Babiloni, F. Infarinato, N. Marzano, M. Iacoboni, F. Dassù, A. Soricelli, P.M. Rossini, C. Limatola, C. Del Percio, Intra-hemispheric functional coupling of alpha rhythms is related to golfer’s performance: a coherence EEG study, Int. J. Psychophysiol. 82 (2011) 260–268, https://doi.org/10.1016/j.ijpsycho.2011.09.008.
[13] C. Del Percio, M. Iacoboni, R. Lizio, N. Marzano, F. Infarinato, F. Vecchio, M. Bertollo, C. Robazza, S. Comani, C. Limatola, C. Babiloni, Functional coupling of parietal alpha rhythms is enhanced in athletes before visuomotor performance: A coherence electroencephalographic study, Neuroscience 175 (2011) 198–211, https://doi.org/10.1016/j.neuroscience.2010.11.031.
[14] L.Y. Chuang, C.J. Huang, T.M. Hung, The differences in frontal midline theta power between successful and unsuccessful basketball free throws of elite basketball players, Int. J. Psychophysiol. 90 (2013) 321–328, https://doi.org/10.1016/j.ijpsycho.2013.10.002.
[15] A. Cooke, M. Kavussanu, G. Gallicchio, A. Willoughby, D. Mcintyre, C. Ring, Preparation for action: psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure, Psychophysiology 51 (2014) 374–384, https://doi.org/10.1111/psyp.12182.
[16] S. di Fronso, E. Filho, S. Conforto, M. Schmid, L. Bortoli, S. Comani, C. Robazza, M. Bertollo, Proficient brain for optimal performance: the MAP model perspective, PeerJ 4 (2016) e2082, https://doi.org/10.7717/peerj.2082.
[17] A.M. Gentile, A working model of skill acquisition with application to teaching, Quest 17 (1972) 3–23.
[18] M. Ito, Neural design of the cerebellar motor control system, Brain Res. 40 (1972) 81–84, https://doi.org/10.1016/0006-8993(72)90110-2.
[19] R.L. Brennan, Generalizability Theory, Springer-Verlag, New York, New York, 2001.
[20] O.E. Krigolson, C.C. Williams, F.L. Colino, Using Portable EEG to Assess Human Visual Attention, (2017), https://doi.org/10.1007/978-3-319-58628-1_5.
[21] M.Y. Cheng, K.P. Wang, C.L. Hung, Y.L. Tu, C.J. Huang, D. Koester, T. Schack, T.M. Hung, Higher power of sensorimotor rhythm is associated with better performance in skilled air-pistol shooters, Psychol. Sport Exerc. 32 (2017) 47–53, https://doi.org/10.1016/j.psychsport.2017.05.007.
[22] A.K. Engel, P. Fries, Beta-band oscillations-signalling the status quo? Curr. Opin. Neurobiol. 20 (2010) 156–165, https://doi.org/10.1016/j.conb.2010.02.015.
[23] T. Koelewijn, H.T. van Schie, H. Bekkering, R. Oostenveld, O. Jensen, Motor-cortical beta oscillations are modulated by correctness of observed action, Neuroimage 40 (2008) 767–775, https://doi.org/10.1016/j.neuroimage.2007.12.018.
[24] M.H. Ruiz, F. Strübing, H.C. Jabusch, E. Altenmüller, EEG oscillatory patterns are associated with error prediction during music performance and are altered in musician’s dystonia, Neuroimage 55 (2011) 1791–1803, https://doi.org/10.1016/j.neuroimage.2010.12.050.
[25] G.G. Knyazev, A.N. Savostyanov, E.A. Levin, Uncertainty, anxiety, and brain oscillations, Neurosci. Lett. 387 (2005) 121–125, https://doi.org/10.1016/j.neulet.2005.06.016.
[26] A.H. Threadgill, P.A. Gable, Resting beta activation and trait motivation: neurophysiological markers of motivated motor-action preparation, Int. J. Psychophysiol. 127 (2018) 46–51, https://doi.org/10.1016/j.ijpsycho.2018.03.002.