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Integrating technology in psychological skills training for performance optimization in elite athletes: A systematic review

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ABSTRACT

Objectives: The aim of the current study was to systematically review the literature on the integration of technology in psychological skills training (PST) to optimize elite athletes' performance.
Design: Systematic review.
Method: Published English, Italian, and Russian language articles were identified using electronic databases. Eighteen articles (out of 3753 records) fulfilled the inclusion criteria, and their quality was assessed using the Mixed Method Appraisal Tool (MMAT). Six papers were judged to be excellent and four to be high quality. There were significant methodological inconsistencies across eight studies. An overall score of quality assessment ranged from 20% to 100%.
Results: The included studies implemented various technologies, in combination with PST, to identify, monitor and/or have an intervention aimed at optimizing elite athletes' performance. The results suggested that the integration covered different meanings, i.e., functional integration, integration between technologies and measures, integration between technology, theoretical framework, and psychological skills training. There was no distinct consistency between the studies with regards to the theory or model used.
Conclusions: Technology and mental training should not be viewed as interchangeable facets of performance enhancement, but rather as complementary ones – where technology integrated in psychological skills training can lead to identify and monitor optimal performance and to implement more effective interventions.

In elite athletes' performance optimization is the ultimate stage which finalizes the process of performance enhancement. Performance enhancement refers to helping athletes prevent underperformance and/or find strategies to reach and maintain a peak performance, intended as an optimal or outstanding achievement which include peak experiences (characterized by feelings of happiness and fulfillment) and/or flow (typified by a total absorption in a rewarding experience) (Kimiecik & Jackson, 2002). To this purpose, sport psychologists focus on optimizing athletic performance via the application of psychological techniques, an approach often referred to as psychological skills training (PST), mental skills training, or simply as mental training (Terry et al., 2020; Weinberg & Gould, 2010; Williams & Krane, 2020). In PST, we must keep in mind also the difference between psychological skills that reflect expected outcomes (e.g., improved attentional focus) and psychological techniques (Vealey, 2007). These techniques encompass, for example, goal setting, relaxation, concentration, imagery, self-talk or self-regulation of behavioral and psychophysiological states (e.g., heart rate or muscle activity indexing arousal/emotions) underpinning peak performance (e.g., Dupee et al., 2015; Hanin, 2007; Hanin & Hanina, 2009; Williams & Krane, 2020). On the elite level (i.e., international and/or national competitive level), PST is crucial in teaching athletes how to recognize, constantly achieve and maintain behavioral states, and how to regulate psychophysiological processes underlying optimal performance. However, as Harmison (2011) suggested, there is a very limited number of applied sport psychology experimental studies, so performing interventions in the absence of supportive research is not an easy task for sport psychology practitioners. Therefore, searching for more effective methods and reliable tools that could be integrated in psychological training and interventions seems understandable and necessary (Harmison, 2011). One promising approach is the integration of technology

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in elite sport settings, which has been explored recently by many researchers and practitioners.

By technology, we mean methods, techniques, systems, and devices which are the result of scientific knowledge being used for practical reasons (e.g., to solve a problem, to achieve a goal) (Kool & Agraval, 2016; Collins English Dictionary). The present review provides insight into how and which technology can be adopted to increase the effectiveness of PST aimed at elite athletes' performance optimization.

1. Technology aimed at sport performance optimization

The scientific literature about elite "sport performance and technology" has increased greatly in the 21st century, with an exponential growth rate and innovative technologies are dominating also the sport psychology context (Giblin et al., 2016; Schack et al., 2020; Watson & Coker-Cranney, 2019). For instance, the following technologies are now available: physiological sensors and mobile applications that allow real-time identification of optimal performance and movement errors, to track the workload of the athlete and presumably to minimize the potential for injuries (Seshardi et al., 2019a); video systems and wearable technology (e.g., body temperature measure) for monitoring athletes' movement and real-time reactions on physiological, biomechanical and neurological levels during training and competition (Kiely et al., 2019; di Fronso et al., 2019; Seshardi et al., 2019b); and innovative technologies such as physiological sensors embedded in textiles used for optimizing performance by sharing real-time analysis data with athletes and surrounding professionals (Aroganam et al., 2019; Marinho et al., 2019; Ye et al., 2020).

Thus, there is great evidence of the rapid development of technologies used for identifying and monitoring behavioral states and psychophysiological processes that underlie optimal performance, and for implementing performance optimizing interventions (Marinho, 2018).

1.1. Technology for identification and monitoring of optimal performance

To understand the features of excellent performance in sport it is mandatory to identify the psychophysiological and behavioral states associated with optimal performance (e.g., flow, clutch; Swann et al., 2017; Holmes & Wright, 2017). These states fluctuate a lot during training and competition and are extremely idiosyncratic, and therefore monitoring their temporal dynamics is a key factor for supporting elite athletes (Calmeiro & Tenenbaum, 2007; Bertollo et al., 2012).

Among the vast number of technologies, electroencephalography (EEG) represents a useful technique to identify and monitor athlete's behavioral states and the psychophysiological processes underlying optimal performance. EEG, previously relegated only to the research labs, now is one of the most promising psychophysiological techniques in applied sport psychology (Bertollo et al., 2020; di Fronso et al., 2019; di Fronso et al., 2020). EEG monitors electrical activity in the athlete's central nervous system (CNS) and allows us to evaluate – even in real-time – psychological states and brain functioning.

In this vein other technologies such as electromyography (EMG) or electrocardiography (ECG) can be used. In detail, EMG is a technique that, using surface electrodes, examines muscular signals generated by physiological changes in the state of the muscle membranes. On the other hand, ECG measures the electrical signal of the heart and provides autonomic indices such as heart rate (HR) and heart rate variability (HRV). In order to simplify the use of these measures, HR and HRV can also be collected through tools (e.g., chest strain wireless data assessed with the use of a computer) and biosensors placed on the finger of a hand (e.g., plethysmography). Specific biosensors are also used to assess electrodermal activity (EDA, i.e., skin conductance level and/or response). Moreover, tools such as strain gauges placed below the chest cage are generally adopted to examine respiratory rhythm and breathing alterations usually associated with poor performance and influenced by anxiety and stress (di Fronso et al., 2017; Wilson & Somers, 2011).

According to one of the latest reviews (Sayem et al., 2020), athletes can also benefit from technical features of the available smart electro-clothing systems (SeCSs), covering both textile and electronic components. SeCS sensors are highly and selectively sensitive to bioelectrical signals of the body (e.g., heart, brain, muscle) or other targeted markers and represent a noninvasive way of capturing and measuring biosignals. Additionally, the development of wireless and Bluetooth technologies, as well as dry electrodes, greatly improved the use of these biosignals and technological tools in sport settings during actual practice (di Fronso et al., 2019).

Additionally, GPS technology and motion tracking systems allow us to measure players' position, velocity, and movement patterns, and are often combined with accelerometers. They permit measurement of energy expenditure, enable classification of postures and movement and analyze gait and balance control (Camomilla et al., 2018; Rago et al., 2020).

1.2. Technology for supporting interventions aimed at performance optimization

A noninvasive technology commonly used in sports for interventions (e.g., self-regulation), aimed at optimizing performance is biofeedback (Blumenstein & Hung, 2016). This tool allows athletes to become aware of and regulate, when needed, their physiological activity by displaying their activity measures in real-time (Smolianov et al., 2018). Biofeedback training usually utilizes five modalities: EMG, EDA, peripheral body temperature, HR and respiration (Blumenstein & Orbach, 2014). The latter two modalities are the most used and provide information about the rate and depth of breathing and HRV (di Fronso et al., 2020).

Another example is neurofeedback. Neurofeedback is a type of biofeedback (i.e., EEG biofeedback) that can be utilized in modifying human brain oscillations and in developing skills of self-regulation of brain activity (Cheng & Hung, 2020). For instance, it can be used to teach athletes to regulate brain activity within a frequency band to enhance performance (Mirifar et al., 2017). More precisely, neurofeedback training enables the individual to effectively manage their central nervous system by teaching them how to (a) recover mentally (e.g., increasing alpha power); (b) use a narrow focus (e.g., increasing low beta power, and decreasing theta and high beta power); and (c) develop the ability to switch between these two states (di Fronso et al., 2020; Ros et al., 2020).

At the brain level, other technologies that can be used for interventions aimed at optimizing performance consist of transcranial stimulation techniques. More precisely, transcranial stimulation influences neurological activity either electrically (e.g., transcranial direct current stimulation, tDCS) or magnetically (e.g., transcranial magnetic stimulation, TMS). Transcranial stimulation is supposed to excite neurons and thereby make them more receptive to acquiring a new skill (Bilalić, 2017). In tDCS, the applied current partly penetrates the brain and alters spontaneous neural activity and excitability (Prete et al., 2020).

1.3. Optimal performance and person-task-environment interaction

Following the suggestion by Bertollo et al. (2020), in the performance optimization context, technology can also be used to observe the complex interaction between the person-task-environment constellation (Hackfort, 2017). For instance, this interaction can be detected using eye tracking, GPS and motion analysis, or simulating the constraints and features of the interaction using virtual reality (VR; Frank, 2020). Specifically, eye tracking is a technology that records the location, duration, and sequence of athletes' visual fixations when they inspect a given scene and has been used to measure the quiet eye and implement cognitive training in sports (Moran et al., 2018). Additionally, VR allows the individual to interact with an environment that can be controlled and manipulated in specific and reproducible ways. VR can complement the imagery practice, symbolic learning that is taught to athletes by many sport psychologists (Marinho, 2018). Moreover, VR research in sport psychology and mental training, in particular, has yielded promising results for questions related to anxiety/pressure, attentional focus, relaxation, observation, and imagery (Frank, 2020). The research findings to date indicate that VR can be a promising adjunct to existing real-world training and participation in sports (Neumann et al., 2018).

1.4. *Purpose of the study*

With the growing interest in the application of technology in sports, the number of reviews on how the use of technology – directly or indirectly – can influence athletes' performance is also increasing. One category of literature reviews embraces studies with interventions that require the use of technology and are related to different measurements of sport performance. As a good example could serve a meta-analysis of randomized controlled trials aimed at assessing the effect of neurofeedback training (NFT) on sport performance and EEG power (Xiang et al., 2018). Participants represented different skill levels and sport domains. The analysis revealed significant effects of NFT on EEG power and sport performance. These and other investigations in the applied fields of sport, exercise, and performance have improved our knowledge of mind-body dynamics during actual performance (Kimura, Mochida, Ijiri, & Kashino, 2014; Bertollo et al., in press). Moreover, the adoption of ecological tasks and the use of brain-body technologies in practice helped to further elucidate the processing involved in performance execution (Bertollo et al., 2020).

Another category of literature review focuses on the integration of different technologies. For example, Cummins et al. (2013) conducted a systematic review of the application of GPS and microtechnology measures within team sports. They highlight that GPS technology has been used more often in football than across other team sports and that work rate pattern activities are most often reported, while impact data, which require the use of microtechnology sensors, are least reported. Likewise, Dellasera et al. (2014) provided a narrative-qualitative overview of the emerging impact of integrated technology in sports settings. The authors examined how the combination of GPS, accelerometer, and HR technology can contribute to significant improvements in the preparation, training, and recovery aspects of field-based team sports.

Coaches, athletes, researchers, and applied sport scientists – including sport psychologists – can improve methods of data collection, processing, and feedback to optimize sport performance. In recent systematic reviews, the usefulness and effectiveness of technology in the sport performance context have been evaluated, however no review focusing on the integration of technologies in PST has been found during our literature review (see Appendix 1 for the search algorithm). Integration is meant as the process of coordinating and connecting different elements (i.e., technology and PST) in order to obtain better quality (e.g., optimal performance) (Reber, 2000). Integration pertains to the internal process of performance enhancement and supports the training environment. Appropriate integration improves both performance efficacy (e.g., coordination, outcome, results) and processing efficiency (e.g., energy consumption, cardiac or cortical activity) (Bertollo et al., 2016). On the other hand, using technology independently (e.g., to collect data during athletes' performance) does not exemplify integration.

Tools and technologies are at the forefront regarding the effectiveness in sport performance optimization. Thus, a systematic review of evidence-based studies on the integration of these tools and technologies could substantially contribute to the present state of the art. For this reason, the main goal of the current review is to provide clear insight into the contribution of technology to PST to optimize elite athletes' sport performance. Therefore, the main research questions of the current review of the literature are: (1) which are the technologies that can be integrated in PST for the identification and monitoring of behavioral and psychophysiological indices of optimal performance and for the implementation of interventions aimed at achieving peak performance, and (2) how sport psychologists (and coaches) can integrate them in their practice to optimize performance in elite athletes.

2. Method

2.1. *Design and search strategy*

This systematic review is reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA; Moher et al., 2009; see Fig. 1). We searched four electronic databases [SCOPUS, Web of Science all databases (e.g., KCI—Korean Journal Database, MEDLINE, Web of Science Core Collection), SportDiscus and EBSCO] from their inception until July 2020. Two researchers (ZSB and MB) conducted the searches in all databases. The search strategy (see Appendix 1) was developed using PICO (population, intervention, comparator, outcome) elements and was adapted for each database. Relevant systematic reviews identified by the structured search, prominent authors' publications, and reference lists of all selected papers were manually searched for other potentially eligible papers.

2.2. *Study selection*

All electronic search results were imported to EndNote software for analyses. Records identified through the structured and hand searches were also imported into the EndNote software database of possibly eligible studies. Eligible studies were identified following a three-step process. First, the results from the searches were merged, duplicate records were removed (ZSB), and the final list was randomly divided among three researchers (MS, SdiF, and ZSB).

Then, as the second step, based on the screening of the title and abstract, we excluded publications that were clearly irrelevant to the topic under review. Possibly eligible abstracts were included in one of the following subcategories based on their goals regarding performance enhancement: "outcome goals", "performance goals", and "mixed". This categorization was based on the theory of goal setting (Gould, 2010), and the reason for this division was the existence of considerable differences in indicators of performance enhancement. At this stage we made an ad-hoc decision about adding another inclusion criterion (see Table 1) that we considered necessary for providing relevant information on the performance of elite athletes. Specifically, studies were included only if they integrated technology to identify optimal performance, monitor changes, and progress or optimize performance, with performance-related measures completed on field (training or competition) or in sport-related situations. We performed a second possibly eligible abstract check, and we retained only those studies that also satisfied this criterion. In case of uncertainty about exclusion, the studies were taken to the next step. At this stage, the full texts of potentially relevant studies were retrieved, and three authors (MS, SdiF, and ZSB) independently examined them for eligibility. Any uncertainty regarding the final inclusion-exclusion status was discussed until an agreement was reached between all three researchers involved in the selection process.

2.3. *Data Extraction*

Data extraction was completed by three authors with scheduled meetings. The accuracy of the coding was checked with two coauthors (JB and MB). Extracted information included bibliographic details of the papers (i.e., author and year); study design; participant characteristics [sample size, female (number), average age and sport discipline]; characteristics of the intervention, measurements, outcomes/indices, devices utilized and findings. In case of missing data the authors of the reviewed studies were contacted by one of the reviewers. Data are summarized in Table 2, as explained in the Results section.

The integration of technology is applicable not only to elite athletes.

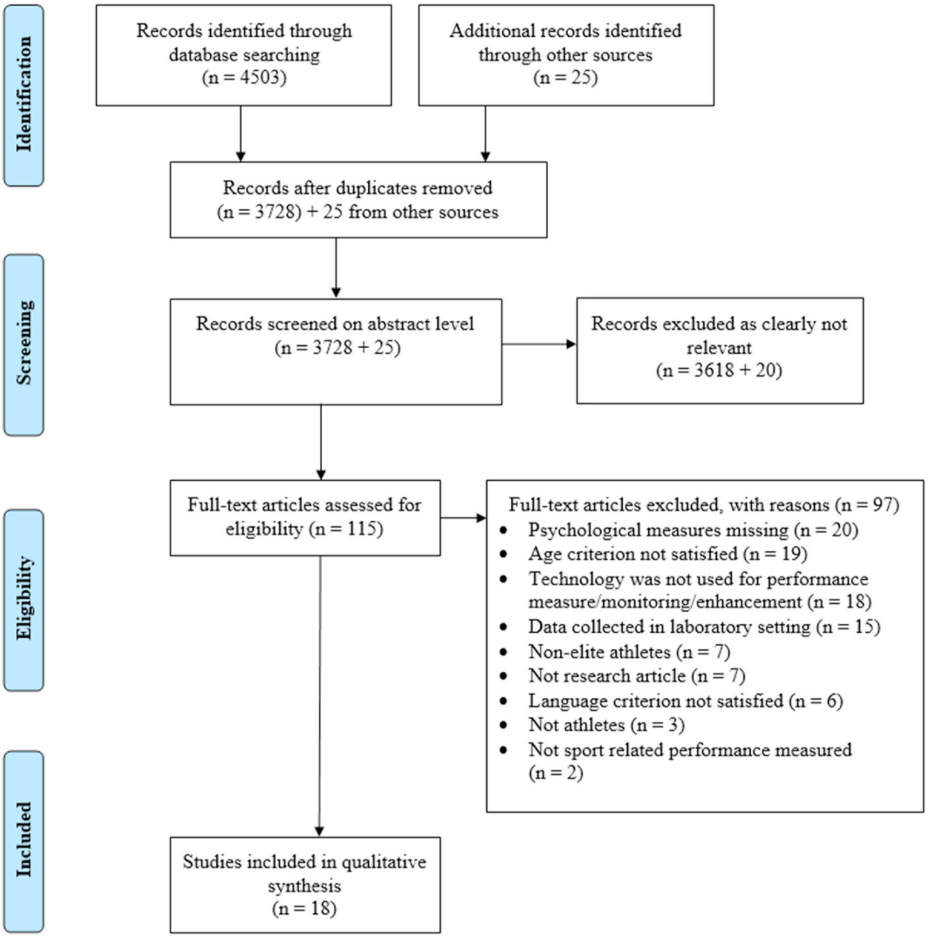

Fig. 1. Flow diagram adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement (Moher et al., 2009).

Table 1
Systematic review criteria.

Inclusion and exclusion criteria
Inclusion criteria:
- Conference papers and peer-reviewed articles
- Competitive elite level athletes with mean age above 18 years or in case of specific sports (e.g. gymnastics) elite athletes with the age under 18 who compete on senior-level
- Full-text available in English, Italian or Russian
- Interventions including psychological measures and technologies (general – e.g. ECG, EEG, eye tracking; sport specific – e.g. SCATT in shooting)
- Sport related performance measured on field (training or competition) or in sport-related situations[a]
- Technology was used with the purpose of performance enhancement
Exclusion criteria:
- Conference abstracts, notes
- Paralympics

[a] Criterion added after the first round of abstract check

Technology integration in PST can also improve the performance of ordinary athletes (i.e., not elite or amateurs). However, research in disciplines spanning from sports psychology to neuroscience show that expert athletes differ consistently from amateurs regarding a variety of perceptual, cognitive and strategic aspects of behavior (Swann et al., 2015). Moreover, since there has been considerable inconsistency and confusion in the definition of elite/expert athletes in sport psychology research, to identify elite athletes, we referred to classification of characteristics associated with expert performance by Swann et al. (2015; see Fig. 1 Summary of Findings and Models for Classifying the Validity of Expert Samples in Sport Psychology Research). We took into account two categories (out of four) as athletes' highest standard of performance and identified study participants as "absolute elite" (A4) or "relative elite" (A3). An "absolute elite" athlete can be described as a person who competes on international senior level (A4), while a "relative elite" athlete is someone whose highest competition is on a national level (A3) (see Table 3). Additionally, we presented information about two other within-sport characteristics: (B) success at the athlete's highest level (B3 – infrequent or B4 – sustained success in major international competition) and (C) experience at the athlete's highest level (C2 – 2–5 years, C3 – 5–8 years, C4 – 8+ years). These attributes were described only for studies that reported such information about within-sport characteristics.

2.4. Risk of bias assessment of articles

To investigate the possible sources of bias, the Mixed Methods Appraisal Tool (MMAT; Hong et al., 2018) was used. Three independent reviewers (MS, SdiF, and ZSB) appraised the eligible articles on the MMAT checklist that is applicable for evaluating the methodological quality of both qualitative and quantitative studies. Importantly, none of the studies was excluded based on the appraisal of methodology quality, but the scores obtained by each reviewed article were reported to ensure that readers can contrast the quality of these papers (see Table 4). Conflicts in the grading were resolved by a consensus meeting among all

Table 2
Main characteristics of the included studies.

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
Bird (1987)	**Population:** 1 elite male shooter (M_{age}=23 years) **Study Design:** case report **Duration:** one-time measure during mock competition (10 serials, of 10 shots with a 5-minute break between each serial and a 30-minute rest period after the 5th serial, during which the subject employed progressive muscle relaxation PMR) **Aim: Identification/ Monitoring/Intervention -** to examine physiological intraindividual variability of an elite shooter across his best and poorer shots, and also the psychological traits and states in areas pertinent to shooting performance were examined.	Questionnaires: 1. Test of Attentional and Interpersonal Style (TAIS) 2. Autonomic Perception Questionnaire (APQ) 3. Present Affect Reactions Questionnaire (PARQ) And 4. EEG 5. EMG 6. Skin temperature	1. Attentional and interpersonal style 2. Autonomic perception 3. The present affect reactions 4. Left hemisphere EEG frequency 5. Muscle activity (left flexor digitorum profundus) 6. Left facial skin temperature – tonic autonomic activation level	EEG system not specified using ASI sponge electrodes EMG system not specified using silver-silver chloride 7mm surface electrodes Autogen 200b Autogenic Systems, Inc. equipment	Physiological patterns associated with the 15 highest and 15 lowest scoring shots indicated that superior performance was related to the ability to achieve relatively low levels of autonomic and cortical activation. No extreme scores were found in TAIS
Jürimäe et al. (2001)	**Population:** 14 national-level male rowers; M_{age}=18.6 years **Study Design:** longitudinal case series **Duration:** six-day training period of increased training load (12 training sessions) **Aim: Identification/ Monitoring/Intervention/ -** to investigate whether a short-term overreaching state in rowers, as indicated by a decrease in performance parameters, is reflected by similar changes in different mood state parameters	1. Cardiovascular activity 2.Body mass 3.Rowing performance 4.Respiratory activity 5.Blood lactate 6.Mood state	1. Mean HR & 2. Body mass were recorded daily, early morning 3. Maximal 2000 m rowing ergometer test (time, average workload) – before and after training period 4.VO_{2max} 5. Finger-tip capillary blood sampled 5 min after the completion of the test and determined enzymatically 6. Subjective ratings of fatigue, stress, muscle soreness, sleep quality were recorded daily on 7 points scale	Polar Vantage NV (Kempele Finland); TrueMax 2400 Metabolic Measurement System, Parvo Medics, USA	Pre- vs. post-test: Significant higher rowing performance time Significant lower mean power, mean maximal HR, blood lactate concentration No significant change in $VO_{2max.}$, morning HR, body mass Significant higher rating of fatigue, muscle soreness
Del Percio et al. (2009)	**Population:** 18 athletes (8 women) air pistol shooters and 10 non-athletes (5 women). Elite athletes regularly competing in national and international tournaments; practicing shooting > 8 years, 5 x week at least; M_{age}=29.2 (SE ±1.6), (21-45 years;) Non-athletes M_{age}=33.1 SE±2.3, (22-46 years). **Study Design**: experiment with a comparison group (elite athletes and non-athletes) and comparison of high vs. low performance. **Duration:** one-time measure. **Aim: Identification/ Monitoring/Intervention** - to test 2 hypotheses: (1) compared with non-athletes, elite athletes are characterized by a reduced cortical activation during the preparation of precise visuo-motor performance; (2) in elite athletes, an optimal visuo-motor performance is related to a low cortical activation	1.Visuo-motor performance 2.EEG and EOG	1.Actual shooting score of 120 air-pistol shots in six separate recording blocks. Interblocks interval of about 5 min. 2.Power decrease/ increase of alpha rhythms during the pre-shot period indexed the cortical activation/deactivation (event-related desynchronization/ synchronization, ERD/ERS)	Electronic Scoring Targets EST; Optical shooting simulator unit (SCATT company, Russia) A device based on acoustic technologies (cardio microphone connected to Powerlab© 16/30 Adinstruments, Australia); EEG - 56-channels EB-Neuro Be Plus© (Firenze, Italy)	Behavioral data (shots) significantly higher in athletes' group. In elite athletes (experts), visuo-motor performance is related to a global decrease of cortical activity, as a possible index of spatially selective cortical processes ("neural efficiency")
Del Percio et al. (2011)[a]	**Population:** 18 athletes (8 women) air pistol shooters and 10 non-athletes (5	1. Visuo-motor performance 2. EEG	1. Actual shooting score of 120 pistol shots in six separate recording blocks.	Electronic Scoring Targets EST and Optical shooting simulator unit (SCATT	"Neural efficiency" of elite athletes is associated with a stabilization of a

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	women). Elite athletes regularly competing in national and international tournaments; practicing shooting > 8 years, 5 x week at least; M_{age}=29.2 (21-45 years;) Non-athletes M_{age}=33.1 (22-46 years). **Study Design**: experiment with a comparison group (elite athletes vs. non-athletes). **Duration:** one-time measure. **Aim: Identification/ Monitoring/Intervention -** to test the hypothesis that "neural efficiency" processes are associated with an enhanced functional coupling of posterior cortical regions involved in task-relevant attentional processes and visuo-motor transformations (120 shots in six separate recording blocks).		Interblocks interval of about 5 min. 2. The functional coupling of the preparatory alpha rhythms in the contralateral and ipsilateral hemispheres, as revealed by spectral coherence between electrode pairs of interest.	company, Russia) A device based on acoustic technologies (cardio microphone Powerlab© 16/30 Adinstruments, Australia); EEG - 56-channels EB-Neuro Be Plus © (Firenze, Italy).	functional coupling of preparatory EEG rhythms between "visuo-spatial" parietal area and other posterior cortical areas.
Neumann and Thomas (2011)	**Population:** 16 elite golfers (6 women), 18 novice golfers (6 women), 16 experienced golfers (5 women); M_{age}=23.38 years **Study Design:** the mixed factorial designs included group, putting condition, and epoch **Duration:** five measurements (five experimental conditions) **Aim: Identification/ Monitoring/Intervention:** to examine measures of cardiac and respiratory activity when participants at different levels of skill development performed a golf putting task under attentional focus instructions. Participants attempted 2.4 m straight putts under a baseline (no instruction) condition and when instructed to focus attention on a process goal, a performance goal, an outcome goal, or to trust the body to perform the skill.	1. ECG 2. Respiratory effort 3. Putting performance 4. Focus of attention	1. HRV in the LF and HF bands, HR change before and after putt onset, 2. Respiratory frequency 3. Photographic records to calculate the distance of the ball from the hole 4. Self-reported type of attentional focus	PowerLab (ADInstruments, Sydney) Model 4/20 Disposable ADInstruments MLA 1010B Ag/AgCl electrodes applied over the manubrium, xiphoid process, and 6th rib (ground)1132 Piezo Respiratory Belt Transducer	Reduced HR, greater HRV, pronounced HR deceleration prior to the putt, and a greater tendency to exhale prior to the putt in experienced and elite golfers Better performance in experienced and elite golfers
Bertollo et al. (2012)	**Population**: 8 elite air-pistol shooters (2 women); M_{age}=29.2 years **Study design:** case series **Duration:** during pre-Olympic tournament **Aim: Identification/ Monitoring/Intervention**: to examine the value of the probabilistic approach in the assessment of the time course of physiological indicators of arousal/activation and vigilance during the period preceding the shot, in comparison with the performance-based method; athletes were required to execute the same number of	1.Behavioral data - shooting performance 2.Physiological data – ANS and cardiac activity 3.Psychological data - a modified 11-point Borg scale	1. Shooting score (optimal, moderate, and poor performance) 2. HR & SC level 3. Affective states intensity and hedonic tone were measured before each shooting phase	Electronic Scoring Targets EST and optical shooting simulator unit (SCATT company, Russia) Two Ag/AgCl electrodes and a piezoelectric pulse transducer directly connected to the acquisition system (PowerLab 16/30, ADInstruments, Australia). A device based on acoustic technologies (cardio microphone and PowerLabVC 16/30)	Higher effectiveness of the probabilistic method to analyze physiological parameters (SC, HR) and to describe the physiological mechanisms associated with shooters' performance

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	shots as in a competitive event (60 shots in 2 sessions)				
Oudejans (2012)	**Population:** 21 elite female basketball players; M_{age}=18.3 years **Study Design**: quasi-experiment with two comparison groups. First CG (M_{age}= 19.3 years) - 8 players performed shooting drills; because of violating scientific procedures a second CG (M_{age}=17.7 years) was included **Duration:** pretest and posttest (after 10-12 weeks) **Aim: Identification/ Monitoring/ Intervention**: sessions of visual control training once or twice a week during regular training sessions (50 three-point shots with the goggles/session). Players were forced to use information about the position of the rim as late as possible, which was the aim of intervention and which was shown to be necessary and sufficient for expert shooting in earlier studies. The manipulation educated the attention of the player to use relevant information at the relevant time with the aim of improving shooting performance.	Three-point shooting test (star-drill)	Shooting percentage, execution time	Plato liquid crystal (LC) goggles; Goggles with wireless control (XBee Pro, Digi International Inc., Minnetonka, USA)	After intervention experimental group significantly improved shooting percentages (8% on average) while two control groups did not. In EG and CG 1 the 50 shots on the posttest were executed significantly faster than on the pretest.
Dekker et al. (2014)	**Population**: 13 participants recruited from the national gymnastics center. Group A – experimental training group; Group B – control group. Eventually, 6 gymnasts participated in group A (2 females; M_{age}=22 years) and 6 in group B (2 females; M_{age}=23.8 years). **Study Design:** double-blind and placebo control experiment. **Duration:** pre-training measurement, 10 training sessions (one lasted 50 min), post-training measurement; follow up measurement after 2 months; 1 week later a "simulated competition day". **Aim: Identification/ Monitoring/Intervention:** Group A- alpha power training and 2 cognitive tasks (Mental Rotation and Stroop task); Group B – random beta power training	1.EEG 2. N-back task 3. Questionnaires: - Perceived Stress State (PSS) - Profile of Mood State (POMS) - Pittsburg Sleep Quality (PSQ) Index - Eysenck Personality Questionnaire (EPQ) 4. Assessment of training session experience: - Being in Shape Questionnaire - Stress Arousal Check List	1.comparison of cortical activity among three conditions: eye closed, eye open and cognitive task 2. working memory 3. Behavioral measures of mental capacities: perceived stress, mood state, sleep quality, social desirability 4. Four domains assessed before every training session: physical shape, rest, mental shape, eating behavior Six feelings assessed after each phase of the training (at the entrance, before exercise, after exercise, and at the end.): relaxed, tired, satisfied, active, energetic, insecure.	BioSemi→ ActiveTwo amplifier system – a head cap with 32 actively shielded electrodes (Amsterdam, The Netherlands)	Group A shows an overall alpha power positive change from pre- to post-training measurement, although not significantly different from group B. Small improvements in sleep quality, mental and physical shape
Wolf et al. (2014)	**Population:** 44 of 60 recruited table tennis athletes met inclusion criteria - 14 elite (5 women) M_{age}= 23.8 years, 15 young elite (6 women; M_{age}= 14.9 years), and 15 amateurs (4 women; Mage = 22.8 years) **Study Design**: comparison of different skill level groups from the same discipline.	1. EEG 2. Self-Assessment Mannequin System 3. Objective performance 4. Self-rating scale of motor imagination 5. Self-rating scales of commitment 6. Self-rating scale of expertise	1.With reference to a baseline period, power decrease/increase of the sensorimotor rhythm (SMR) during the pre -task and task period indexed the cortical activation/deactivation ERD/ERS 2.Level of arousal (9-point scale) 3.Rankings by the	Nexus 32, Mind Media B.V., Herten, Holland (21 electrodes using a 32-channel system); Brain Vision Analyzer (Brain Products, Gilching, Germany);	EG vs. CGs: 8–10 Hz SMR ERD was stronger in elite athletes than in amateurs with an intermediate ERD in young elite athletes in the motor cortex EG one-time measure: No correlation between ERD/ERS in the motor

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	Duration: one time measure **Aim: Identification/ Monitoring/Intervention**: to test 2 hypotheses – (1) compared with amateurs and young elite, experts are characterized by enhanced cortical activation in the motor and fronto-parietal cortex during motor imagery in response to table tennis videos; (2) in elite athletes, worlds rank points are associated with stronger cortical activation. All subjects watched videos of a serve and imagined themselves responding with a specific table tennis stroke in a real-like situation (experiencing mental pressure in competition situation)		International Table Tennis Federation 4. Quality and intensity of motor imagination 5.Motivation, interest in the study, professionalism of the researchers, perceived relevance of the research project 6. Perceived expertise i.e. ability of their own forehand topspin.		cortex and world rank points in elite experts, but a weaker ERD in the fronto-parietal cortex was associated with higher world rank points.
Wolf et al. (2015)[b]	**Population:** 29 of 35 recruited table tennis athletes met inclusion criteria - 14 elite (5 women) M_{age}= 23.8 years, and 15 amateurs (4 women; M_{age}= 22.8 years) **Study Design**: comparison of different skill level groups from the same discipline. **Duration:** one-time measure **Aim: Identification/ Monitoring/Intervention:** to test 4 hypotheses – (1) Experts rely more on visual-attentional motor than on verbal-analytical cortical processes; (2) Experts show less involvement of verbal-analytic processes in motor planning; (3) More world rank points are correlated with lower relative left temporal activity; (4) More flow-experience is correlated with lower relative left temporal activity in all athletes. All subjects watched videos of a serve and imagined themselves responding with a specific table tennis stroke in a real-like situation (experiencing mental pressure in competition situation)	1.EEG 2. Self-Assessment Mannequin System 3. Objective performance 4. Self-rating scale of motor imagination 5. Self-rating scales of commitment 6. Self-rating scale of expertise 7.The “Flow Kurz Skala”	1. Alpha asymmetry, Theta coherence 2. Level of arousal along a 9-point scale 3. Rankings by the International Table Tennis Federation 4. Quality and intensity of motor imagination 5. Motivation, interest in the study, professionalism of the researchers, perceived relevance of the research project 6. Perceived expertise i.e. ability of their own forehand topspin. 7. Self-rating scale of experience of flow	Nexus 32, Mind Media B.V., Herten, Holland (21 electrodes using a 32-channel system); Brain Vision Analyzer (Brain Products, Gilching, Germany)	EG vs. CG (amateur): Significantly stronger shift towards lower relative left-temporal brain activity in EG Significantly stronger right temporal-premotor coherence in EG Lower relative left temporal activity in EG correlated with more world rank points Lower relative left-temporal brain activity in EG associated with more flow-experience
Bertollo et al. (2016)	**Population:**10 elite shooters (4 women) M_{age}= 22.8 years **Study Design:** case series **Duration:** one-time measure **Aim: Identification/ Monitoring/Intervention:** to explore theta and alpha ERD/ERS activity during shooting performance (optimal automated and optimal-controlled performances across 120 pistol shots)	1.Interview 2.Shooting performance 3. Borg Scale (0-11) 4.EEG	1.Core components of the “chain of action”, essential for optimal performance 2.Perceived shooting score (0-10.9) and actual shooting score (of 120 shots) recorded automatically 3. Perceived control level on a core component 4.ERD/ERS	Electronic Scoring Targets (HS 10 Hybridscore, SIUS, Effreticon, Switzerland); A mobile EEG device i.e. 32-channel and waveguard cap by ANT (Advanced Neuro technology, Enshede, The Netherlands) A device based on acoustic technologies (cardio microphone and PowerLabVC 16/30)	ERS was mainly associated with optimal-automatic performance, in agreement with the “neural efficiency hypothesis”. ERD was mainly associated with optimal-controlled performance in conditions of “neural adaptability’’ and proficient use of cortical resources.
di Fronso et al. (2016)	**Population**: 1 male elite pistol-shooter; M_{age}= 30 years **Study design:** case report	1.Interview 2.Shooting performance 3. Modified Borg Scale. 4.EEG	1.Core components of the “chain of action”, essential for optimal performance 2. Actual shooting score (of	32-channel eegosport^{TM} amplifier (ANT, Enschede, Netherlands). and waveguard	Optimal-automatic performance experiences were characterized by a global synchronization of

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	Duration: one-time measure **Aim: Identification/ Monitoring/Intervention**: to identify the neural markers (in low, high alpha and theta bands) underlying optimal and suboptimal performance experiences of a pistol-shooter, across 120 pistol shots		120 shots) recorded automatically 3. Perceived hedonic tone prior to each shot, control level on aiming, accuracy level on the execution of the core component 4.ERD/ERS	cap by ANT (Advanced Neuro technology) +	cortical arousal associated with the shooting task Suboptimal controlled states were underpinned by high cortical activity levels in the attentional brain network.
Dupee et al. (2016)	**Population:** 5 elite canoeists (Olympic level athletes) (2 women); M_{age}= 25.2 years **Study Design:** qualitative exploratory study (constructivist epistemology) **Duration:** one year **Aim: Identification/ Monitoring /Intervention:** to explore the perceived outcomes of a biofeedback and neurofeedback training intervention; 9-stage psychophysiological stress assessment; 20 sessions (1 h/session)	1. Psychological measures - Semi-structured interview on three main areas: - experience of the biofeedback and neurofeedback training intervention; - transfer of skills learned in the lab to the sport environment; - overall learning about the self (self-awareness, self-regulation, perceived benefits at the end of the intervention digitally audio-recorded 2. Biofeedback data (respiratory, cardiovascular, neuromuscular, autonomic 3. Neurofeedback data (EEG)	1. Three main themes revealed based on thematic analysis 2. RR, HR, HRV, muscle tension, SC, Peripheral body temperature 3. Focusing ratio (theta/beta), intensity ratio (high alpha/intensity), rumination ratio (busy brain/SMR)	ProComp Infinity equipment from Thought Technology Ltd. (measures in seven physiological areas);	Pre- vs. post-intervention: Greater Self-Awareness (recognition that physical & mental states can be managed; Ability to identify and differentiate between physical and mental states; Understanding the mind-body connection) Enhanced Self-Regulation (Sustaining a state; Managing distractions; Breathing as a key component; Feeling 'in control' when performing) Perceived Benefits (Greater understanding and appreciation for sport psychology; In-depth understanding of techniques for stress management) Biofeedback data (during recovery): lower RR, HR, muscle tension, SC; higher HRV, hand temperature Neurofeedback data: lower focusing ratio (theta/beta), intensity ratio (high alpha/intensity), rumination ratio (busy brain/SMR)
Rijken et al. (2016)	**Population**: Group A: 11 professional soccer players (M_{age}=21 years), Group B: 10 Elite sprinters and hurdlers (M_{age}=18 years) **Study Design:** Pilot study with two distinct cohorts **Duration:** 5 weeks & 5-week follow-up **Aim: identification/ Monitoring/Intervention:** to study the effects of an intervention (four 2.5-hour sessions/group) consisting of mental coaching combined with either HRV feedback (A) or EEG alpha power feedback (B) on HRV or EEG outcomes and self-reported to stress, performance, recovery and sleep quality	1.ECG 2.EEG 3.Performance 4.Sports Improvement Measurement (SIM)-60 5.Pittsburgh Sleep Quality Index (PSQI) 6.Recovery-Stress Questionnaire-Sport (RESTQ)	1.HRV (RMSSD) 2.IAF on the P3 location 3.Numeric self-rating scale of performance (0-worst, 10-best performance) 4.Physical wellbeing, concentration capacity, coping and emotional stability 5.Subjective sleep quality, latency, duration, disturbances, habitual sleep efficiency, use of sleep medication, daytime disfunction over the last month (0-21 score) 6.General and sport specific stress/recovery states	The InnerBalance application developed by Heartmath TMSi 16 channel porti-system Quickcap and 7 water electrode recordings 24 bit A/D converter on a MobiMini portable device (Twente Medical Systems International, Oldenzaal, The Netherlands)	Group A pre- vs. post-test: Significant increase in SIM-60: emotional stability & concentration Significant increase in HRV LF/HF ratio Significant increase in EEG alpha power on C3, C4, OZ, P3 and P4 Group A follow-up: NO significant declines in any outcomes Group B pre- vs. post-test: Significant increase in HRV LF power Significant increase in RESTQ Group B follow-up: NO significant declines in any outcomes
Rusciano et al. (2017)	**Population**: 20 professional soccer players **Study Design:** RCT **Duration:** The experiment was conducted during preseason camp; Physiological response was measured during baseline,	1.Psychophysiological stress profile (ANS, respiratory activity, cardiovascular activity, neuromuscular activity) 2.Resilience 3.Visual search task 4.Injury prevention	1.Skin conductance level SCL, respiration rate RR, blood volume pulse BVP (LF-HRV), surface EMG, temperature response 2.Physiological response during three periods: baseline, cognitive stress	Nexus 10 Mark II hardware and Biotrace+ commercial software (Mind Media, Herten, The Netherlands) (the same apparatus was used to assess the psychophysiological stress	Significant interaction between treatment and session on SCL, HR, RR No significant interaction between treatment and session on BVP EG vs. CG: EG showed enhanced

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	cognitive stress, and recovery; Resilience and selective attention was assessed 2 weeks before and 2 weeks after treatment; Injury prevention was assessed during the sport season after treatment. **Aim: Identification/ Monitoring/Intervention:** to evaluate the biofeedback training method called Neuroplus and assess resilience, visual attention, and injury prevention. Experimental group: 10 players (M_{age}=30 years) - Neuroplus individual biofeedback sessions (HRV, RR, SCL, surface EMG, temperature responses) 15 sessions x 30 min/session, two sessions/week. Control group:10 players (Ma_{ge}=30.7 years.). 15 motivational music and video clips sessions, 30 min/ session.		(Stroop test), and recovery 3.Cognitive effects (selective attention, visual control) 4.Effects on injury prevention – number of training days	profile and to provide biofeedback	recovery after stress, slower respiration at rest, increased resting LF-HRV, indicating improved sympathetic and cardiovascular control and more efficient respiration
Chu et al. (2018)	**Population**: 12 male taekwondo athletes (M_{age}=21,7 years, SD=0.83). **Study design**: an exploration study in training experiences and a comparison of different competition performance level groups from the same discipline **Duration**: Each of three courses started at 9 am and only one course was performed each day. After the completion of the training models, the simulation competition was conducted. **Aim: Identification/ Monitoring/Intervention**: to investigate the correlation of brainwaves of TKD athletes in training experiences and competition performance. Brainwave activities recorded before performing each course of the training model, then recorded during the three courses of training models: physical, technical, tactical; Simulation games – brainwave signals collected 1 min before 3 rounds of competitions. After competition participants were divided into winner and the loser group according to the results of the game.	1.EEG 2.Trainig model: 2.1.Physical training course - The test method used incremental exercises with moderate intensity 2.2.Technical training course 2.3.Tactical training course 2.4.Simulation competition model	1.The changes of brainwaves were recorded during the whole trainings (2.1, 2.2, 2.3) and before 1st, 2nd, 3rd round of competition 2.1. The running speed was fixed and the slope adjustment was used to increase intensity; the max HR was calculated. 2.2. The specified kicking attacks (8 types) to the speed target; each course of movements was executed for 3 min. 2.3. Watching TKD competition films (and then a discussion of the film with the coach) and watching cartoons (to measure brainwaves in resting status). 2.4. The differences of brainwaves frequencies between the winner and the loser were compared	NeuroSky Zigbee multiplayer synchronous brainwaves analyzer to measure EEG (RS232-DTE-3.0, Alchemy Technology Co., Ltd., Taiwan). The electrical treadmills were used as physical training tools The polar heart rate meter was used to record heart rate	The β-wave was significantly increased when the heart rate of the participant was >120 min^{-1} compared to the resting state. The γ-wave was significantly decreased during foot kicking modalities. The γ-wave was significantly increased while watching competition films when compared to that in the resting state. EEG signals were significantly different during the training experiences versus the simulated game of TKD
Fernandez-villarino et al. (2018)	**Population:**7 rhythmic gymnasts competing on a national level, representing the same club; M_{age}=15.7 ± 1.2 years. Practicing for an average of 8.7 ± 1.2 years. **Study design:** single-group study (case series) **Duration**: The study was completed over 10 sessions during the competitive	**The dependent variable**: 1. Performance data in competition exercises **The independent variables:** 2. Cardiovascular activity 3. The CR-10 scale (Foster et al., 2001) 4.Apparatus 5.Competitive exercises 6.Training sessions	1.The score achieved in the competition exercise executed in the main part of the training session - SCORE). Performance data evaluated by 4 international judges 2. Average HR (AHR). 3. Subjective rate of perceived exertion (RPE). 4.Number of apparatus 1÷4 (NA) – ball,	"Polar Vantage NTV" monitors for recording heart rate; The official records of the competition exercises JVC digital cameras (GR-DVL820EA) to record the training sessions	A decrease in the perceived exertion and the average score of the exercises were observed at the end of the competitive period An increase in HR and in the perceived exertion has a positive impact on the total final score The variables of heart

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Table 2 (*continued*)

First author & year	Methodology	Measurements	Outcomes/indices	Devices	Findings
	period. Each training season consisted of a 35-minute warm-up, 60-minute technical training, 35-minute simulated competition, and 15-minute cool-down. **Aim: Identification/ Monitoring/Intervention**: to identify the training variables that can determine the score in elite rhythmic gymnasts; RPE data were collected during the main part of the session, and HR of each gymnast was monitored throughout of the session		hoop, clubs, ribbon. 5. Number of competitive exercises (NE). 6.Number of training sessions (NS)		rate and subjective rate of perceived exertion are significant to control the effects of training on the performance of individual rhythmic gymnasts
Goh et al. (2018)	**Population:** national squad of bowlers (11) M_{age}=21.4 ±3.3 years, and 10 sub-elite (M_{age}=13.7 ±2 years). **Study design**: experiment (two groups and 2 different conditions that were counterbalanced between participants). **Duration:** one-time measure (10 shots). **Aim: Identification/ Monitoring/Intervention**: to investigate the pre-movement and during movement visual search behavior VSB and quiet eye QE of elite vs sub-elite ten-pin bowlers, performing under high anxiety HA and low anxiety LA conditions.	1.Mental Readiness Form-3 (MRF-3) 2.Cardiovascular activity 3. VSB - Pre-movement and during movement QE	1.Individual anxiety level – self-confidence, cognitive and somatic anxieties - recorded at the end of 5th bowl, and at the end of 10th bowl (after HA or LA performance conditions). 2. Baseline HR and recorded at the end of 5th bowl, and at the end of 10th bowl. 3.A total number of fixations, mean number of fixations per area of interest (AOI) and mean fixation duration per AOI	HR - S810i and T61 electrode belt, Polar Electro, Kempele, Finland; QE - A Dikablis mobile eye tracker (Ergoneers GmbH); Four video cameras	Pre-movement and independent of expertise, bowlers had more fixations and directed them to more locations when performing under HA. Elite bowlers fixated at more locations closer to the pins in pre-movement than during-movement, with pre-movement QE occurring mostly at 2 AOI - the breakpoint and middle arrows. During movement bowlers fixated closer to AOI Elite bowlers recorded longer QE durations during movement rather than pre-movement

Note. Aims are related to the function of technology, i.e., identification, monitoring, intervention. The underlined function is the aim of the study.

[a] Some procedures (i.e. experimental design, EEG recordings and preliminary data analysis) of the current investigation have been previously described (Del Percio et al., 2009) in the context of a study with a completely different aim.

[b] Here is presented a reanalysis of the EEG data for expert and amateur table tennis players (Wolf et al., 2014).

coauthors.

3. Results

3.1. Identification and selection of studies

The results of the literature search are presented in a PRISMA flow diagram in Fig. 1. The literature search identified 4503 records, with 3728 remaining after removing duplicates through the structured procedure available in EndNote and individual checks. After the first screening at the title and abstract level, 380 articles were found as possibly eligible ("Outcome goals": 254 records; "Performance goals": 21 records, "Mixed": 96 records). These records were screened again, taking into account the additional eligibility criterion, namely, if the technology was used with the purpose of performance enhancement and/or optimization. One hundred fifteen studies were identified as potentially relevant and examined at the full-text level. Twenty-five additional articles were identified through manual search as potentially eligible, and five of them were examined at the full-text level. Following the full-text screening, 18 studies were found to be eligible for our literature review, of which one article was identified through manual search. Ninety-seven articles did not meet the inclusion criteria. Most of the studies excluded after full-text review reported the use of technology for performance optimization without performing psychological measures or assessed performance in a laboratory setting with no specific sport performance-related measures. The list of excluded articles on full-text level is available in the Supplemental material.

3.2. Study characteristics

The main characteristics of the included studies are summarized in Table 2. With regard to the type of sport, six studies investigated shooting (Bird, 1987; Del Percio et al., 2009; Del Percio et al., 2011; Bertollo et al., 2012; Bertollo et al., 2016; di Fronso, 2016), two soccer (Rijken et al., 2016; Rusciano et al., 2017), two table tennis (Wolf et al., 2014; Wolf et al., 2015), one basketball (Oudejans, 2012), one rowing (Jürimäe et al., 2001), one canoeing (Dupee et al., 2016), one golf (Neumann & Thomas, 2011), one gymnastics (Dekker et al., 2014), one rhythmic gymnastics (Fernandez-Villarino et al., 2018), one sprint & hurdles (Rijken et al., 2016), one taekwondo (Chu et al., 2018), and one bowling (Goh et al., 2018). One study reported data from two different sports (Rijken et al., 2016). As for the number of participants, across all 12 sports investigated, the total sample included 217 elite athletes (68 women), with a mean age ranging from 15.7 years (rhythmic gymnasts) to 30.7 years (soccer players). The participants from Del Percio et al. (2009, 2011) and Wolf et al. (2014, 2015) have been counted twice as observations. Regarding the athletes' level, all studies reported data collected from elite athletes. However, six studies also reported data from non-athletes (Del Percio et al., 2009; Del Percio et al., 2011) or non-elite samples (Neumann & Thomas, 2011; Wolf et al., 2014; Wolf et al., 2015; Goh et al., 2018). Two studies were based on the same samples. In one study (Del Percio et al., 2011) some procedures (i.e.,

Table 3
Theoretical frameworks and psychological characteristics of the studies.

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
Bird (1987)	shooting - fine, discrete & closed skill	global performance	A 3 B no info C no info	Before, during, and after the competition	Attentional and Interpersonal Style – direction (internal-external) & breadth (narrow-wide) of attention	**Psychophysiological** aspects: levels of autonomic and cortical activation **Cognition**: the focus of attention, concentration **Affect**: anxiety (cognitive), displeasure with scores **Behavior:** control of breathing	Integration between mind-body systems of the athlete Integration between different technologies and psychological measurements in the actual field of practice	"It may be that the strategies evolved by experience, through trial and error, are not optimal and that the need for new, and superior, psychophysiological control methods will become apparent … the success of intervention techniques to introduce control over physiological activity might be assessed by the reduction of distractibility".
Jürimäe et al. (2001)	rowing – continuous self-paced & skill gross	global performance	A 3 B no info C 2	During training sessions	Not reported	**Psychophysiological** indices of short-term overreaching (e.g., muscles soreness) **Affect:** mood state parameters (i.e., perceived training stress, fatigue, sleep quality) **Behavior:** time of performance	Integration between different technologies and psychological measurements in the actual field of practice	"It appears that conscientious self-analysis by the athlete who trains with high training loads are the most efficient method of monitoring possible short-term overreaching. Long term daily records of self-analysis can be kept with relative ease and compared with the more sophisticated physiological methods when necessary."
Del Percio et al. (2009)	shooting - fine, discrete & closed skill	global performance	A 4 B no info C 4	All subjects performed shots according to the international shooting competition rule	Neural efficiency hypothesis	**Cognition:** global attentive readiness, elaboration of sensorimotor or semantic information, suppression of cognitive processes while performing a trained motor task, stimulus encoding, working memory, memory retrieval processes, visuo-spatial information processing, spatial attention to visual target. **Behavior**: precise visuo-motor performance, intentional visual behavior	Integration between mind-body systems of the athlete	"In future studies, cortical alpha rhythms may be trained to produce a low event-related desynchronization (strong event-related synchronization) during the execution of shots, with the aim of improving motor control of subjects suffering from motor deficits. Such training could be performed by alpha neuro-feedback during computer simulation of motor performances (i.e., video games, virtual reality) After the training, alpha rhythms and motor performance could be measured again".
Del Percio et al. (2011)	shooting - fine, discrete & closed skill	global performance	A 4 B no info C 4	All subjects performed shots according to the international shooting	The hypothesis of "neural efficiency" in a brain functional	**Cognition**: task-relevant attentional processes, visuo-motor transformations, global attention and readiness, elaboration	Integration between mind-body systems of the athlete	"The increase of parietal-occipital alpha coherence in elite athletes could suggest an improvement of eye-

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Table 3 (*continued*)

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
				competition rule	organization in experts	of sensorimotor or semantic information, causal top-down control of spatial attention **Behavior**: eye-hand coordination (sensorimotor integration)		hand coordination … we could not ascertain how many seconds before the pistol shot started the stabilization of the functional coupling of alpha rhythms in the athletes. This is a matter for future studies on this interesting phenomenon".
Neumann and Thomas (2011)	golf – discrete, closed & self-paced skill	a specific part of the performance (putting task)	A 3 B 3 C 3	The participants were tested outdoors on a level synthetic grass surface. They completed the putting task under 5 conditions.	Theories of skill acquisition, i.e., the role of external attentional focus in performance, level of expertise and focus of attention, effects of goal setting strategies on performance, interactions between goal type and attentional processes	**Psychophysiological** aspects: cardiac activity **Cognition**: focus of attention	Integration between different technologies and psychological skills in the actual field of practice	"The relationship between goal setting and cardiac activity observed in the present experiment suggests that any such biofeedback program would be best served by teaching the attentional processes that lead to the appropriate cardiac responses, rather than teaching the athlete to modify their cardiac response *per se* … The present results encourage the use of cardiovascular measures during a training program in golf".
Bertollo et al. (2012)	shooting - fine, discrete & closed skill	global performance	A 4 B no info C 4	All subjects performed shots according to the international shooting competition rule. "The motivational level during training was high because of the internal competition to qualify for the Olympic Games	Individual Zones of Optimal Functioning (IZOF) theory; performance-based and probabilistic method	**Psychophysiological** aspects: indicators of arousal/activation and vigilance **Cognition**: the focus of attention, kinesthetic imagery, decision-making **Affect**: current emotion intensity, perceived affectivity (i.e., pleasantness – hedonic tone) **Behavior:** control of coordination between postural activity and arm rising	Integration between mind-body systems of the athlete	"From an applied perspective, athletes should become aware of effects on the performance of the different SC intensities, and maintain a specific level of activation in order to be more effective … Remarkable cardiac deceleration implies attentional focus directed towards bodily and proprioceptive symptoms for postural balance and motor control, whereas small cardiac decelerations are related to attention that is more focused on the external stimuli, namely on the target".
Oudejans (2012)	basketball - discrete, closed & self-paced skill	a specific part of the performance (three-point shots)	A 3 B no info C 2	Test and training sessions took place in the regular training facilities	Assumptions of the visual training intervention (visual control training)	**Cognition**: visual control, concentration, and focus, perception (vision) **Behavior:** gaze behavior	Integration of technology in visual control training	"Special visual control training performed on the field with wirelessly controlled LC goggles seems to hold promise, both

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Table 3 (*continued*)

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
								with regard to the applicability in the actual sports setting and with regard to the potential to improve performance."
Dekker et al. (2014)	gymnastics - gross, serial & closed skill	global performance	A 3 B no info C no info	During training sessions and a "simulated competition day" in the gymnastics hall (before the upcoming National Championship)	Concept of mental toughness (mental capacities). Efficiency in information processing; Superior performance and neural efficiency processes	**Cognition**: attention control, concentration, attentional focus, attentional processes, selective attention (associated with processes of neural inhibition), cognitive performance, self-confidence, control of thoughts **Affect:** mood **Behavior**: stress and sleep (by behavioral measures)	Integration between technologies and psychological measurements	"… the eyes open alpha power training could act as a valuable contributor in a mixture of mental interventions for athletes".
Wolf et al. (2014)	table tennis - discrete, open & externally paced skill	a specific part of the performance (participants had to imagine the score to be 10:10 in the last set of an important match and react to the serve with a specific table tennis stroke: a forehand top spin	A 3 B no info C no info	Data was collected at a training center during simulated competition situation (pseudo competition)	Motor imagery paradigm (kinesthetic motor imagery). Motor efficiency. Neural efficiency hypothesis	**Psychophysiological** aspects: self-rated level of arousal, multisensory integration. **Cognition:** imagination, motor attentional processes, perception, visual attention **Affect:** motivation and commitment	Integration between mind-body systems of the athlete Integration between technologies and psychological measurements	"… a weaker 8–10 Hz ERD in the frontoparietal cortex is associated with more world rank points in experts. These results suggest that high motor skills in table tennis are associated with focused excitability of the motor cortex during the reaction, movements planning, and execution with high attentional demands. Among elite experts, however, less activation of the frontoparietal attention network may be necessary to become a world champion".
Wolf et al. (2015)	table tennis - discrete, open & externally paced skill	a specific part of the performance (participants had to imagine the score to be 10:10 in the last set of an important match and react to the serve with a specific table tennis stroke: a forehand top spin	A 3 B no info C no info	Data was collected at a training center during simulated competition situation (pseudo competition)	Motor imagery paradigm, Motor efficiency, Flow experience, Choking under pressure. Skill acquisition model (motor skill learning, motor planning and somatosensory and visuo-motor integration) Approach-withdrawal model Neural efficiency hypothesis	**Psychophysiological** aspects: self-rated level of arousal, multisensory integration **Cognition:** focus, attention, verbal-analytical processes (self-instruction and disturbing thoughts), superior visuo-spatial attentional skills, attentional shift, exterior attention, top-down attentional processes, motor imagery **Affect:** motivation and commitment **Behavior**: a decline in performance (motor disruptions and errors)	Integration between mind-body systems of the athlete. Integration between technologies and psychological measurements	"Skilled psycho-motor performance in elite table tennis players probably reflect less interference of irrelevant communication of verbal-analytical with motor-control mechanisms, which implies flow-experience and predicts world rank experts … Optimal psycho-motor performance implies the suppression of irrelevant cognitive processes (self-reference, motor monitoring, disturbing thoughts) and enhanced attention to skill-specific cues, which

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Table 3 (*continued*)

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
								at the phenomenological level are key phenomena of the flow -experience".
Bertollo et al. (2016)	shooting - fine, discrete & closed skill	global performance	A 4 B 4 C 4	All subjects performed shots according to the international shooting competition rule.	Multi-action plan (MAP) model embedded with the IZOF framework, Neural efficiency hypothesis Attentional control theory (ACT) Flow-like experience, Dual-process theories in sport and motor performance Reinvestment theory	**Psychophysiological** aspects: arousal and vigilance **Cognition**: working memory capacity, attentional control, the focus of attention, the encoding of new information in the episodic memory, sustained attention, top-down processing, task-related attention, processing of visuospatial information, verbal semantic processes, anticipatory attention **Affect**: anxiety **Behavior: a** degree of automaticity, behavioral markers (e.g., kinematic patterns), core components of "chain of action."	Integration between mind-body systems of the athlete	"From an applied point of view, our findings can address neurofeedback training to enhance performance in closed skills sport … The MAP model can be used as a framework to develop performance enhancement strategies based on cognitive and neurofeedback techniques".
di Fronso et al. (2016)	shooting - fine, discrete & closed skill	global performance	A 4 B 4 C 4	The participant performed shots according to the international shooting competition rule	MAP model embedded with the IZOF framework, Neural efficiency hypothesis Reinvestment theory Flow-like state	**Psychophysiological** aspects: arousal & arousal regulation strategies **Cognition**: attentional control, excessive conscious control of movement execution, the focus of attention, attentional engagement, goal-relevant attentional focus, the transmission and retrieval of sensorimotor and cognitive information, attention regulation strategies **Affect**: competitive anxiety and fatigue, level of involvement, interest, energy, emotional regulation, emotion regulation strategies hedonic tone, emotion regulation strategies **Behavior:** a degree of automaticity, behavioral markers (e.g., kinematic patterns), core components of "chain of action," movement coordination	Integration between mind-body systems of the athlete Integration between technologies and psychological measurements	"… focusing attention on idiosyncratic core components of action can improve performance in a distressful situation, whereas directing attention to the execution of automated actions can hamper the control processes that naturally regulate movement coordination. Conversely, focusing on a core component of the action can benefit performance … Pre-performance routines may benefit the athlete's control of attentional resources prior to movement execution … an athlete may benefit from arousal, attention, and emotion regulation strategies to increase Theta activity and modulate low and high Alpha activity … a task-relevant focus on the core components of the action can enable the athlete to recover from suboptimal performance levels."
Dupee et al. (2016)								

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Table 3 (*continued*)

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
	canoeing – gross, continuous & self-paced skill	global performance	A 4 B 3 & 4 C 3	In the lab and during training sessions, and when competing in at various international competition and the Olympic Games	The neurovisceral integration model -A comprehensive model of self-regulation which embraces a complex mix of cognitive, behavioral, affective and physiological components. Self-awareness as a crucial skill in recognizing psychological state required for peak performance	**Psychophysiological** aspects: arousal/activation management **Cognition**: focusing ability, attentional control, self-awareness (including body awareness), self-appraisal, attentional regulation **Affect**: emotional control, emotional state, anxiety level **Behavior**: automaticity, muscle tension/relaxation, sustaining a state, shifting states between focus and recovery, breathing for re-focusing	Integration between mind-body systems of the athlete Integration between different technologies and psychological skills	"… biofeedback and neurofeedback training may well be a useful technique for developing the skills required for optimal performance in high-performance sport."
Rijken et al. (2016)	soccer - serial, open & externally paced skill; sprint and hurdles -continuous, closed, & self-paced skill	global performance	A 3 B no info C no info	During training sessions with an experienced, licensed, mental coach, and at home in a calm environment, and during measurement sessions in a dimly lit and quiet room	Mental stress and psychological well-being and their influence on sports performance Peak performance program (mental coaching)	**Psychophysiological** aspects: heart and brain indices (alpha power, HRV parameters) **Cognition:** cognitive performance, attention, concentration capacity, intuition, and creativity **Affect:** emotional stability, social well-being **Behavior**: stress limiting behaviors, motivation observed by coaches, sleep & recovery	Integration between mind-body systems of the athlete Integration between technologies and psychological measurements	"A combination of peak performance training and biofeedback reinforces the positive effects of either intervention … a mental coaching program combined with either HRV or EEG alpha power feedback may increase HRV and alpha power and may lead to better performance-related outcomes and stress reduction."
Rusciano et al. (2017)	soccer - serial, open & externally paced skill	global performance	A 3 B no info C 2 (at least)	During training sessions (the preseason camp)	A neurovisceral integration model of self-regulation. An approach based on improved self-regulation that progressively combines intense autonomic biofeedback with cognitive and physiological stressors to enhance key performance abilities (i.e., resilience, visual selective attention, injury prevention)	**Psychophysiological** aspects: arousal, psychophysiological stress profile, physiological adaptability **Cognition**: visual selective attention and its top-down control, executive cognitive skills (planning, anticipation, decision-making), the efficiency of selective attention and executive control **Affect**: emotional and motivational pressures **Behavior**: visual search behaviors (i.e., flexible visual search strategies, periods of fixations on informative visual cues); breathing (different breathing pattern, e.g., slow-paced breathing), preparatory routines; presence/absence at training sessions during the entire post-treatment sport season	Integration between mind-body systems of the athlete Integration between technologies and psychological skills	"… results are highly promising in the domain of sports because efficient visuospatial selective attention and cognitive processes are crucial for obtaining improvements in peak performance … the method can easily be integrated into classical training programs to yield practical competitive advantages for the players and their teams".

(*continued on next page*)

Table 3 (*continued*)

Article	Sport discipline and skill classification[a]	Task[b]	Expertise level[c]	Data collection strategy	Theoretical frameworks, concepts, and models	Psychological variables researchers refer to	Types of integration	Recommendations for PST[d]
Chu et al. (2018)	taekwondo – gross, open & externally-paced skill	global performance - combat a match (winning vs. losing); **a specific part of the performance** - physical component incremental running test - a technical sequence of kicking attacks (left vs. right leg) - tactical watching film of tactical competition)	A 3 B 3 C no info	During training practice and simulated competition (3 rounds of the match)	Not reported – only general information on the relationship between brainwaves and sports performance is mentioned	**Psychophysiological** aspects: arousal **Cognition**: attention, concentration, speed of information processes, **Behavior:** stability of movements	Integration between mind-body systems of the athlete in different types of the actual field of practice	"The results of this experiment indicated that before the beginning of the next round TKD competition, the coach should quickly prepare the strategic plan based on the opponent's habits and give the order, and the contestants should maintain a status of stable emotion … In conclusion, we reported factors affecting the results of TKD competition, which can help coaches build up strategic plans for training".
Fernandez-Villarino et al. (2018)	rhythmic gymnastics -gross, serial & closed skill	global performance	A 3 B no info C 3 & 4	During training sessions and simulated competition	Not reported. Authors mention physiological and psychological parameters of training load in gymnastics	**Psychophysiological** aspects: intensity during training **Affect:** subjective perceived exertion **Behavior:** competitive exercises and routines evaluated by judges	Integration between technologies and psychological measurements	"It is important that coaches learn to utilize load control strategies that would give adequate feedback on training adaptation … The findings can contribute to improving the effectiveness of training programs in rhythmic gymnastics."
Goh et al. (2018)	bowling -discrete, closed & self-paced skill	global performance – 10 shots	A 3 B no info C 3 &4	During simulated competition	The ecological psychology perspective & the Attentional Control Theory (ACT)	**Cognition**: attentional control, focus, perceptual processing, stimulus-driven attentional control **Affect:** anxiety (cognitive and somatic) **Behavior**: quiet eye and visual search behavior	Integration between technologies and psychological measurements in different task demands	"Considering that visual search may be more pertinent to performance during movement, bowlers could focus on regulating anxiety levels during the pre-movement state with less emphasis on visual search … Such a strategy may allow bowlers to invest their perceptual resources at a more optimum time so that their movements can be calibrated for a successful performance."

Note.

[a] Schmidt R. A., Lee T. D., Winstein, C., Wulf G., and Zelaznik. H. N. Motor Control and Learning: A Behavioral Emphasis. 2018. Human Kinetics.

[b] Some tasks in the studies constitute part (e.g., putting in golf) or all of the sports performance (e.g., shooting).

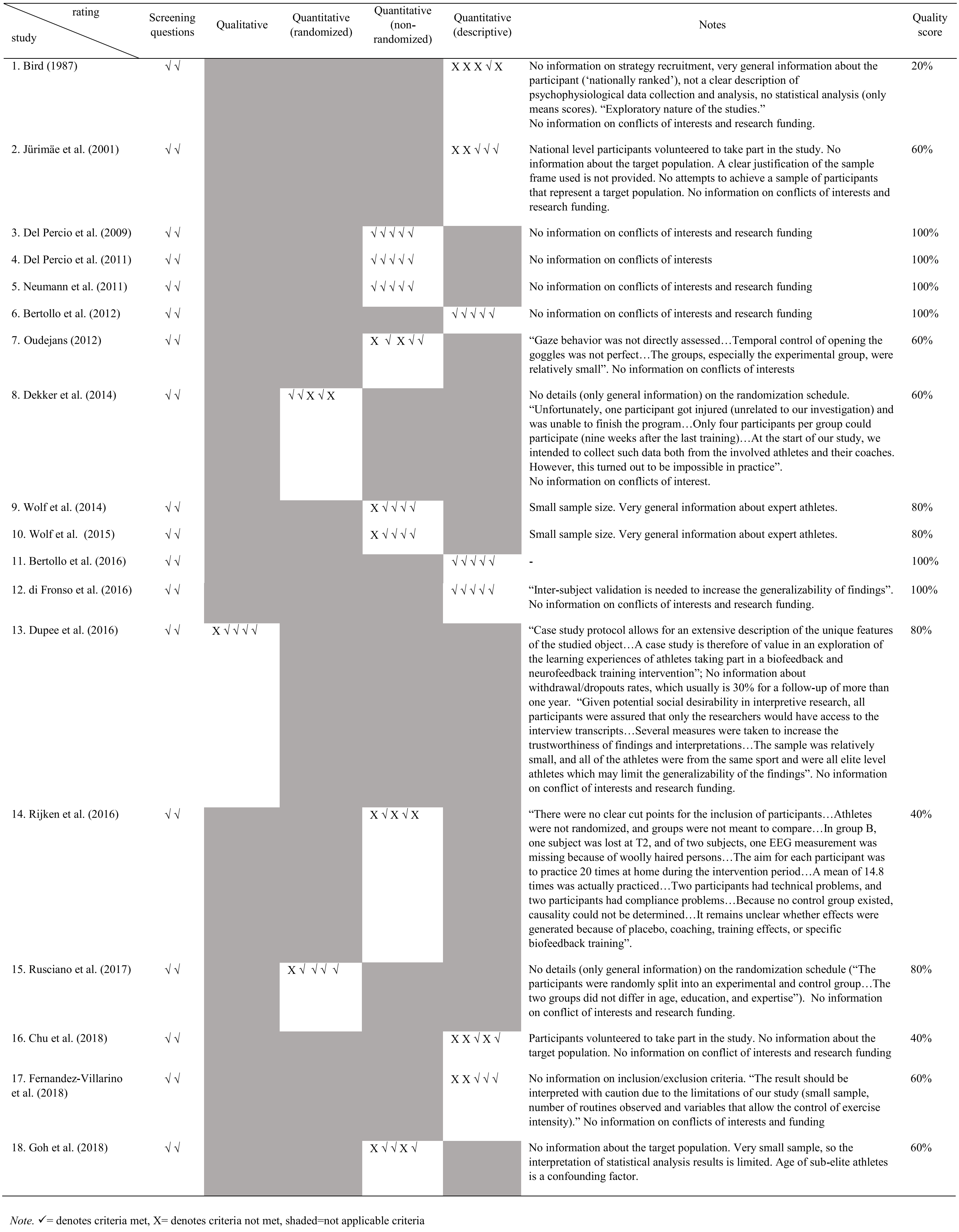
[c] A - Athlete's highest standard of performance; B - Success at the athlete's highest level; C - Experience at the athlete's highest level. More information in Data Extraction. See also Swann et al., 2015.

[d] PST – psychological skills training

experimental design, EEG recordings and preliminary data analysis) of the investigation had been previously described in the context of a study with a completely different aim (see Del Percio et al., 2009). The second study (Wolf et al., 2015) presents a reanalysis of the EEG data – for experts and amateur players – previously reported (Wolf et al., 2014).

According to the inclusion criterion of research procedure and organization, all data were collected in the field (see Table 3). In nine studies, data were collected in competition or simulated competition situations (Bird et al., 1987; Del Percio et al., 2009; Del Percio et al., 2011; Bertollo et al., 2012; Wolf et al., 2014; Wolf et al., 2015; Bertollo et al., 2016; di Fronso et al., 2016; Goh et al., 2018). In five studies, data were collected during training sessions (Jürimäe et al., 2001; Neumann

Table 4
Study quality appraisal.



rating study	Screening questions	Qualitative	Quantitative (randomized)	Quantitative (non-randomized)	Quantitative (descriptive)	Notes	Quality score
1. Bird (1987)	√ √				X X X √ X	No information on strategy recruitment, very general information about the participant ('nationally ranked'), not a clear description of psychophysiological data collection and analysis, no statistical analysis (only means scores). "Exploratory nature of the studies." No information on conflicts of interests and research funding.	20%
2. Jürimäe et al. (2001)	√ √				X X √ √ √	National level participants volunteered to take part in the study. No information about the target population. A clear justification of the sample frame used is not provided. No attempts to achieve a sample of participants that represent a target population. No information on conflicts of interests and research funding.	60%
3. Del Percio et al. (2009)	√ √			√ √ √ √ √		No information on conflicts of interests and research funding	100%
4. Del Percio et al. (2011)	√ √			√ √ √ √ √		No information on conflicts of interests	100%
5. Neumann et al. (2011)	√ √			√ √ √ √ √		No information on conflicts of interests and research funding	100%
6. Bertollo et al. (2012)	√ √				√ √ √ √ √	No information on conflicts of interests and research funding	100%
7. Oudejans (2012)	√ √			X √ X √ √		"Gaze behavior was not directly assessed…Temporal control of opening the goggles was not perfect…The groups, especially the experimental group, were relatively small". No information on conflicts of interests	60%
8. Dekker et al. (2014)	√ √		√ √ X √ X			No details (only general information) on the randomization schedule. "Unfortunately, one participant got injured (unrelated to our investigation) and was unable to finish the program…Only four participants per group could participate (nine weeks after the last training)…At the start of our study, we intended to collect such data both from the involved athletes and their coaches. However, this turned out to be impossible in practice". No information on conflicts of interest.	60%
9. Wolf et al. (2014)	√ √			X √ √ √ √		Small sample size. Very general information about expert athletes.	80%
10. Wolf et al. (2015)	√ √			X √ √ √ √		Small sample size. Very general information about expert athletes.	80%
11. Bertollo et al. (2016)	√ √				√ √ √ √ √	-	100%
12. di Fronso et al. (2016)	√ √				√ √ √ √ √	"Inter-subject validation is needed to increase the generalizability of findings". No information on conflicts of interests and research funding.	100%
13. Dupee et al. (2016)	√ √	X √ √ √ √				"Case study protocol allows for an extensive description of the unique features of the studied object…A case study is therefore of value in an exploration of the learning experiences of athletes taking part in a biofeedback and neurofeedback training intervention"; No information about withdrawal/dropouts rates, which usually is 30% for a follow-up of more than one year. "Given potential social desirability in interpretive research, all participants were assured that only the researchers would have access to the interview transcripts…Several measures were taken to increase the trustworthiness of findings and interpretations…The sample was relatively small, and all of the athletes were from the same sport and were all elite level athletes which may limit the generalizability of the findings". No information on conflict of interests and research funding.	80%
14. Rijken et al. (2016)	√ √			X √ X √ X		"There were no clear cut points for the inclusion of participants…Athletes were not randomized, and groups were not meant to compare…In group B, one subject was lost at T2, and of two subjects, one EEG measurement was missing because of woolly haired persons…The aim for each participant was to practice 20 times at home during the intervention period…A mean of 14.8 times was actually practiced…Two participants had technical problems, and two participants had compliance problems…Because no control group existed, causality could not be determined…It remains unclear whether effects were generated because of placebo, coaching, training effects, or specific biofeedback training".	40%
15. Rusciano et al. (2017)	√ √		X √ √ √ √			No details (only general information) on the randomization schedule ("The participants were randomly split into an experimental and control group…The two groups did not differ in age, education, and expertise"). No information on conflict of interests and research funding.	80%
16. Chu et al. (2018)	√ √				X X √ X √	Participants volunteered to take part in the study. No information about the target population. No information on conflict of interests and research funding	40%
17. Fernandez-Villarino et al. (2018)	√ √				X X √ √ √	No information on inclusion/exclusion criteria. "The result should be interpreted with caution due to the limitations of our study (small sample, number of routines observed and variables that allow the control of exercise intensity)." No information on conflicts of interests and funding	60%
18. Goh et al. (2018)	√ √			X √ √ X √		No information about the target population. Very small sample, so the interpretation of statistical analysis results is limited. Age of sub-elite athletes is a confounding factor.	60%

Note. ✓= denotes criteria met, X= denotes criteria not met, shaded=not applicable criteria

Note. ✓ = denotes criteria met, X = denotes criteria not met, shaded = not applicable criteria

& Thomas, 2011; Oudejans, 2012; Rijken et al., 2016; Rusciano et al., 2017), and in four studies, data were collected during both competition and training sessions (Dekker et al., 2014; Dupee et al., 2016; Chu et al., 2018; Fernandez-Villarino et al., 2018). With regard to the type of task, most studies (13 out 18) encompassed the whole performance (e.g., shooting, canoeing, rowing, soccer). Four studies covered a part of the performance (e.g., a forehand top spin in table tennis, putting in golf), and one study referred to both global performance (i.e., taekwondo match) and specific parts of training (e.g., running test) (see Table 3). In four studies, researchers modified task instruction to create specific psychological conditions, such as different attentional focuses (Neumann & Thomas, 2011), increased mental pressure (Wolf et al., 2014; Wolf et al., 2015), and low vs. high levels of anxiety (Goh et al., 2018) (see Table 2).

3.3. Methodological quality

Given the heterogeneity of the included study designs, all studies were appraised for reporting quality based on the standards of the MMAT (Hong et al., 2018). After the first general screening (i.e., assessment of the clarity of research question and the relationship between collected data and research question), all of the studies were considered of adequate quality and, after being assigned to one of four categories, were subjected to further appraisal (see Table 4). All of the studies were appraised against five criteria appropriate to the category of study design. For example, for randomized controlled trials, one of the questions was: Are the groups comparable at baseline? For quantitative description: Is the sample representative of the target population? The studies were also given a percentage quality of 20% for each criterion. Six papers were judged to be excellent (100%) and four to be high quality (80%), five studies scored 60%, two studies scored 40%, and one study scored 20% (Table 4). Since excluding studies with low methodological quality is discouraged (see Hong et al., 2018, p. 1), in Table 4 a more detailed presentation of the ratings of each criterion was provided to better illustrate the quality of the included studies.

3.4. Characteristics of technology used in the included studies – modalities and measurement indices

Technological devices used in the included studies (see Table 2) referred to general or sport-specific measurements. General measurements (e.g., ECG, EEG, eye tracking) can also be used in other contexts (e.g., health care), while the sport-specific measurements are meant specifically for sport (e.g., SCATT in shooting).

General measurements were related to the following modalities: cardiovascular, respiratory, neuromuscular, electrodermal, skin temperature, and central nervous system. Cardiovascular activity encompassed average HR (Dupee et al., 2016; Fernandez-Villarino et al., 2018; Goh et al., 2018; Jürimäe et al., 2001), optimal HR (Bertollo et al., 2012), heart rate variability (Neumann & Thomas, 2011; Dupee et al., 2016; Rijken et al., 2016), blood volume pulse (Rusciano et al., 2017), and max HR (Chu et al., 2018). Respiratory modality refers to expired gas (Jürimäe et al., 2001) and respiratory rate (Neumann & Thomas, 2011; Dupee et al., 2016; Rusciano et al., 2017). Muscular measurements encompassed surface EMG (Bird, 1987; Dupee et al., 2016). Electrodermal modality included skin conductance level (Bertollo et al., 2012; Dupee et al., 2016). Skin temperature encompassed facial skin temperature (Bird, 1987) and peripheral skin temperature (Dupee et al., 2016). Measurements related to CNS were most often presented in the included studies (11 out of 18). Brain activity was monitored using EEG or neurofeedback technology. Moreover, the included studies used sport-specific technologies: (1) to measure athletes' outcome, i.e., shooting score, shooting time (Del Percio et al., 2009; Del Percio et al., 2011; Bertollo et al., 2012; Bertollo et al., 2012; di Fronso et al., 2016) and the distance of the ball from the hole in golf (Neumann & Thomas, 2011); (2) to record athletes' behavior during task execution, i.e., trajectories of the pistol on the target during the pointing phase (Bertollo et al., 2012; Del Percio et al., 2009; Del Percio et al., 2011); training sessions in rhythmic gymnastics (Fernandez-Villarino et al., 2018), bowling action, quiet eye and visual search behavior in bowling (Goh et al., 2018); and (3) for training and practice, i.e., learning attentional skills and improving shooting in basketball (Oudejans, 2012), and physical training tests (Chu et al., 2018).

3.5. Functions of technology in the included studies

Studies included in the review referred to elite athletes, and researchers used technology in at least one of the following functions integrated in PST: *identification, monitoring,* and *intervention* aimed at performance optimization. In the present review, eight studies were focused on identification, thirteen were aimed at monitoring, and six were based on intervention. Five studies took into account both identification and monitoring. Three studies included monitoring and intervention (see Table 2).

3.6. Identification

Identification refers to psychological and/or psychophysiological states during optimal performance. Researchers addressed questions: What are the psychophysiological features that determine the optimal performance state? What are the technological advancements that help us to identify psychophysiological features of optimal performance?

All studies that aimed at the identification investigated precise sports, and participants' tasks were based on discrete skills (see Tables 2 & 3). The majority of studies (6 out of 8) investigated shooting. All but one study were rated high in quality scoring (see Table 4).

In the included studies, the optimal performance was either defined as the highest score (Bird, 1987; Del Percio et al., 2009; Del Percio et al., 2011; Neumann & Thomas, 2011) or was based on the multimodal assessment approach, which goes beyond the result achieved. The approach takes into account, e.g., the athlete's awareness of the subtle variations occurring in their psychophysical states during the preparatory period preceding the shot and not only the shot release (Bertollo 2012), the athlete's ability to reach and maintain a flow-like state (Wolf et al., 2015), optimal-automatic performance typified by an effective, minimal conscious control level matching task demands, and cortical activity synchronized with the shot (Bertollo et al., 2016; di Fronso et al., 2016). To identify optimal performance, the researchers used two strategies: (1) analysis of intraindividual (Bird, 1987; di Fronso et al., 2016) or intragroup differences between the best and poorer performance (Bertollo et al., 2012; Bertollo et al., 2016; Del Percio et al., 2009); and (2) analysis of differences between elite athletes' and a comparison group performance (Del Percio et al., 2009; Del Percio et al., 2011; Neumann & Thomas, 2011; Wolf et al., 2015). Detailed results are presented in Table 2.

3.7. Monitoring

Monitoring means that technology was focused on a process and was applied in observing, controlling, following, or describing athletes' states and/or behaviors that can potentially influence (enhance) their performance. The main questions were as follows: How can technology be useful to monitor changes related to performance state? How can different technologies be integrated to achieve peak performance in elite athletes?

Studies aimed at monitoring are based either on (1) one-time measures of intraindividual/intragroup variability across different phases and types of performance during simulated or real competition (Bertollo et al., 2012; Bird, 1987; Chu et al., 2018; Del Percio et al., 2009; Goh et al., 2018; Neumann & Thomas, 2011; Wolf et al., 2014; Wolf et al., 2015) or (2) multiple measures during training sessions and follow-up measurements (Jürimäe et al., 2001; Dupee et al., 2016; Rijken et al., 2016; Rusciano et al., 2017; Fernandez-Villarino et al., 2018), which ranged from six days (Jürimäe et al., 2001) to one year (Dupee et al., 2016) (see Table 2 & 3). Researchers were interested in changes in and the course of performance-related psychological characteristics and psychophysiological states. Psychological characteristics encompassed cognition (e.g., the focus of attention, attentional control), affect (e.g., mood, anxiety), and behavior (e.g., time of performance, visual behavior). Psychophysiological aspects were related mainly to the level of arousal and arousal regulation (see Table 3).

3.8. Intervention

Intervention refers to using technology for performance optimization. Researchers were searching for answers to questions such as: What are the technologies that help sport psychologists improve performance in elite athletes? How can technologies be combined with PST to optimize performance?

There were two types of interventions and none of the studies identified was suitable to be included in both. The first consisted of a simple manipulation that directly influenced performance by creating different conditions during sports task execution (Goh et al., 2018; Oudejans, 2012). The results that were obtained in this way were measured. The technology was used either to carry out interventions (Oudejans, 2012) or to register players' behaviors during task execution in various psychological conditions (Goh et al., 2018). In the other type of intervention, the influence of manipulation on performance enhancement was indirect (Dekker et al., 2014; Dupee et al., 2016; Rijken et al., 2016; Rusciano et al., 2017). The effects and their transferability were measured using self-report measures and psychophysiological indicators. The technology was used to conduct training sessions aimed at (1) developing skills, e.g., physical & mental state management, managing distractions, coping with stress (Dupee et al., 2016) or (2) achieving specific psychophysiological states, e.g., sleep quality, mental and physical shape (Dekker et al., 2014; Rijken et al., 2016), self-awareness and understanding the mind-body connection, feeling 'in control' when performing (Dupee et al., 2016), emotional stability and concentration (Rijken et al., 2016).

3.9. Theoretical frameworks and models

There was no distinct consistency between the studies with regard to the theory used; however, the Individual Zones of Optimal Functioning (IZOF), with the multi-action plan (MAP) model embedded in it, was observed to be the recurring framework (Bertollo et al., 2012; Bertollo et al., 2016; di Fronso et al., 2016). We also found some recurring concepts across the studies, e.g., the concept of "neural efficiency", used (as the main reference or mentioned) in seven studies. Moreover, two studies were based on the neurovisceral integration model (Dupee et al., 2016; Rusciano et al., 2017). Three studies were based on general assumptions of the skill acquisition model and combined it with other concepts, i.e., the focus of attention and goal setting (Neumann & Thomas, 2011) and the motor imagery paradigm (Wolf et al., 2014; Wolf et al., 2015). Two studies (Bird, 1987; Goh et al., 2018) focused on one theoretical concept concerning attention. However, in both cases, psychological concepts only partially explained the obtained results. Three studies addressed "applied-oriented" assumptions of visual control training (Oudejans, 2012), mental toughness and mental capacities (Dekker et al., 2014), mental stress and psychological well-being (Rijken et al., 2016). In three of the included studies, researchers did not report a theoretical framework (Jürimäe et al., 2001; Chu et al., 2018; Fernandez-Villarino et al., 2018) (see Table 3).

4. Discussion

The aim of the current study was to systematically review the literature on the integration of technology in PST to optimize elite athletes' performance. More precisely, we were interested in which technologies were integrated in PST for the identification and monitoring of behavioral and psychophysiological indices of optimal performance and for the implementation of the interventions aimed at achieving peak performance (see Table 2), and how scholars integrated them in their studies to optimize performance in elite athletes (see Table 3).

We reviewed eighteen studies that implemented various technologies in PST. These were related to the use of biosensors to detect mind-body interaction (e.g., EEG, EMG, ECG, EDA) and other assessing perception-action coupling in person-task-environment dynamic (e.g., eye tracking, SCATT, GPS). These technologies were integrated into sport psychology-based protocols, and we found that this integration covers different meanings, i.e., functional integration, integration between technologies and measures, integration between technology, theoretical framework and psychological interventions. The three meanings can be also related to the general aim of integration that is to form an organized whole that functions more effectively and with minimal effort or without conflict, in order to coordinate parts into a totality (see APA Dictionary of Psychology, definition of Integration).

4.1. Functional integration

Functional integration in elite athletes covers operational aspects, such as *identification, monitoring,* and *intervention* aimed at performance optimization in the actual field of practice.

The outcomes of the studies confirm that superior performance is related to the ability to achieve specific levels of autonomic and central activity before and during performance (Hatfield, 2018). That ability is associated with the level of expertise and is based on self-regulation strategies and particularly on attentional and emotional regulation.

Thanks to technological advancements in measurements, the psychophysiological features underpinning athletes' behavior can be more easily elucidated. Various psychophysiological parameters were identified by the reviewed studies. For instance, cardiac and respiratory activity measures displayed some of those physiological features that could allow the development of psychological training programs aimed at optimizing elite athletes' performance based on individual patterning and tailoring idiosyncratic programs (Bird et al., 1987; Del Percio et al., 2009; Del Percio et al., 2011; Neumann & Thomas, 2011; Bertollo et al., 2012; Wolf et al., 2015; Bertollo et al., 2016; di Fronso et al., 2016).

Technology used for monitoring can be integrated into PST in three ways. First, the usefulness and reliability of psychological tools (based on self-report data) that are relatively easy to use on a daily basis can be tested (Bird et al., 1987; Jürimäe et al., 2001; Rijken et al., 2016). Second, technology may be useful for developing self-awareness (Neumann & Thomas, 2011; Bertollo et al., 2012; Wolf et al., 2015; Dupee et al., 2016; Rusciano et al., 2017) and self-analysis skills (Jürimäe et al., 2001). Finally, technology can be used to integrate phases of training and task execution. For instance, technology can be adopted to check the effects of training for a given motor task by monitoring brain/cardiac activity changes and showing differences that occurred from the pre-to post training phases or in the course of task execution and the role of the preparatory period (Bertollo et al., 2012; Chu et al., 2018; Del Percio et al., 2009; Fernandez-Villarino et al., 2018; Goh et al., 2018; Neumann & Thomas, 2011; Wolf et al., 2014; Wolf et al., 2015).

The results of interventions presented in some of the included studies show that technology can be integrated in psychological training to improve or develop skills related to sport performance, such as effective visual control (Oudejans, 2012), self-regulatory skills (Dupee et al., 2016; Rusciano, et al., 2017), stress management techniques (Dekker et al., 2014; Dupee et al., 2016; Rijken et al., 2016) and anxiety level regulation (Goh et al., 2018). Technology can also be integrated into training aimed at mental toughness and recovery enhancement (Dekker et al., 2014; Rijken et al., 2016) (see Tables 2 & 3).

4.2. *Integration between technologies and measurements*

The integration between different technologies and measurements is aimed at optimizing PST. Most studies (14 out 18) included in the review integrate different measurements (quantitative and subjective) and different technological devices (10 out of 18 studies) (see Tables 2 & 3). The main goal of this integration is to test the reliability of the self-report measure to achieve the synergistic effect of technology and PST on performance outcomes.

Authors of the papers included in our review suggest different intervention techniques for performance optimization. For example, the intervention aimed at controlling physiological activity might be combined with the control of the direction and the width of attention and then assessed by the level of distractibility (Bird, 1987). Another promising way to improve visuomotor attention is monitoring alpha waves (Del Percio et al., 2009). Using cardiac measures as a part of a biofeedback training program and combining it with teaching athletes' attentional processes that lead to appropriate cardiac response can be another effective approach (Neumann & Thomas, 2011). Based on the study's findings, integrating alpha power training with mental skill training could improve responses on cognitive, affective and behavioral levels, such as focus and attentional control, self-confidence, mood, stress response, and sleep quality (Dekker et al., 2014). The researchers also suggest developing performance enhancement strategies based on cognitive and neurofeedback techniques and choosing the proper areas to apply transcranial electrical stimulation that allows the brain to dynamically integrate, coordinate, and respond to internal and external stimuli across multiple time scales (Bertollo et al., 2016). Based on the findings, it also seems reasonable to use pre-performance routines for better control of attentional resources prior to movement execution and to use arousal, attention and emotion regulation strategies to increase athletes' theta activity and modulate low and high alpha activity (di Fronso et al., 2016). The roles of various components of optimal performance (cognitive, affective, behavioral, and psychophysiological) also merit consideration; we can help athletes improve their ability to self-regulate through combined biofeedback and neurofeedback training (Dupee et al., 2016). To improve performance-related outcomes and to reduce stress levels, PST could be integrated with either HRV or EEG alpha power feedback to modulate HRV and alpha power (Rijken et al., 2016). Another suggestion would be to combine an intensive biofeedback training method with a classical training program to improve performance, resilience, and injury prevention and to enhance self-regulation and executive control (Rusciano et al., 2017). Moreover, the researchers recommend that the following factors be taken into account: HR, rating of perceived exertion, and a number of competitive exercise repetitions to control the impact of training sessions on the performance of rhythmic gymnasts (Fernandez-Villarino et al., 2018). Finally, they proposed adjusting elite bowler training programs aimed at anxiety regulation and effective visual search to make them more targeted within each phase of their performance (Goh et al., 2018) (see Table 3).

Summarizing, the most promising approach that seems to be supported by the identified studies is the aid of technologies in measuring self-regulation skills and attention abilities in order to monitor and optimize athletes' performance.

4.3. *Theoretical frameworks and models*

The understanding of the integration of technology in PST needs to be addressed by theoretical frameworks, which lead the research and applied practice. For instance, recently, a Grand Unified Theory of sport performance has been acclaimed as a comprehensive theory to integrate different perspectives and approaches in sport science (Glazier, 2017). In our review, we have found various frameworks, models and concepts inspiring the investigation of the applied researchers; however, there is no comprehensive theory that could offer a holistic key to understanding the integration of technology in PST for performance optimization.

One of the recurring frameworks in the reviewed studies - The Individual Zone of Optimal Functioning (IZOF) – provides a comprehensive conceptualization of psycho-biosocial states related to performance (Hanin, 2007; Hanin & Hanina, 2009). A model that stood behind the integration of technology in PST in some of the reviewed articles is the multi-action plan (MAP) model. The MAP intervention model is embedded within the IZOF framework and encompasses four performance states, in which unique psychophysiological states underlie distinct performance-related experiences (Bertollo et al., 2016). The MAP model fits well with the central tenet of a recurring theory, the attentional control theory (ACT). According to ACT, anxiety will typically impair processing efficiency more than performance effectiveness (Bertollo et al., 2016). Thus, athletes should have the ability to control attention and stay focused under elevated anxiety to perform at the highest levels (Goh et al., 2018).

In addition, the neurovisceral integration model appeared in some of the studies (Dupee et al., 2016; Rusciano et al., 2017) as the theoretical framework behind the understanding of the integration of technology in PST, specifically in the improvement of athletes' ability to self-regulate. This theoretical framework deriving from the field of psychophysiology recognizes self-regulation as a complex mix of cognitive, affective, behavioral, and physiological components (Thayer & Lane, 2000, 2009). Notably, both the neurovisceral integration model and biofeedback and neurofeedback training, also used in some of the reviewed studies, utilize the central autonomic network (Benarroch, 1993) as the structural basis for self-regulation.

Furthermore, a hypothesis of human intelligence – the neural efficiency hypothesis – recurred across many of the reviewed studies. It was in part generated by the same groups of authors publishing different papers on the same subject (Del Percio et al., 2009; Del Percio et al., 2011; Wolf et al., 2014; Wolf et al., 2015; Dekker et al., 2014, Bertollo et al., 2016; di Fronso et al., 2016) (see Table 3). According to the neural efficiency hypothesis, elite athletes require "less" and more focalized brain activation (weaker event-related desynchronization) in task-relevant brain areas compared to novices (Del Percio et al., 2008). The hypothesis refers to both motor and cognitive tasks, e.g., the better the performance of the athlete, the fewer attentional resources they require for motor tasks with high attentional demands. The neural efficiency hypothesis concurs very well with the psychomotor efficiency theory postulated by Hatfield many years ago (see for review, Hatfield, 2018). Summarizing, there were two effective frameworks, IZOF and Neural efficiency, that emerged from the identified studies for integrating technologies in performance optimization. Both are devoted to looking at the features of the athletes when "in the zone", and the MAP model combines the two frameworks for an optimal and proficient performance (Bertollo et al., 2020).

4.4. *Limitations*

In this section we discuss the limitations at study and outcome level, and at review-level.

Although we found two main theoretical frameworks (i.e., IZOF and neural efficiency) leading the experimental studies it is clear there is no general framework that can lead intervention for performance optimization through the integration of technology and PST. To integrate technology in PST for athletes, we need to provide a rigorous scientific- or evidence-based approach for integrating the subdisciplines of sport science in applied sport science support. For instance, a Grand Unified Theory of sports performance could guide the integration of technology in mental training programs using the specific information derived from sport science subfields related to the person-environment-task interaction to optimize performance. Only when the scientific or applied evidence are established, high-performance agencies and national governing bodies can adopt these programs for various sport disciplines (Glazier, 2017).

Issues identified through quality appraisal represent another group of limitations of the reviewed studies. First, several studies provided little or no information about the target population and sampling strategy; thus, we do not know if the participants represent their population. Second, due to the inherent challenges accessing and executing controlled designs with elite athlete populations, the study samples are quite small, and implementation of fully randomized and controlled experiments is the exception, not the rule. Third, there are many studies with elite athletes conducted in the lab, but few studies met our inclusion criteria related to the setting of the study (i.e., data collected in the field). Fourth, although some technologies, such as eye tracking, are used in practice with athletes, we have found only one experimental study that met our inclusion criteria.

Another limitation refers to the discrepancy between the use of technology applied in team sports (3 studies) and individual sports (15 studies). Although using technology in a specific context (i.e., competitive or real-life scenarios) is a big challenge for scholars, there are some limitations that could be overcome by organizing ecological paradigms using simulation (see Filho et al., 2015).

One additional limitation of the reviewed studies is the evidence behind the use of technology in the elite sport setting. Recently, literature reviews focused on wearable technology (e.g., Li et al., 2016; Luczak et al., 2019; Seshardi et al., 2019), and authors highlighted that wearable devices are valuable tools for the optimization of sport performance, but supporting evidence for the use of these devices in professional sports is still limited. Gathering data on the same topic through a variety of means (e.g., technological devices and psychological tools) and from different perspectives (e.g., athlete evaluation, coach observation, and technologies used as an objective measure) might be a way of validating research findings through triangulation.

A potential limitation of the current systematic review is the lack of protocol registration, which is recommended by various guidelines to increase transparency and reproducibility of a systematic review. To diminish this potential bias, we highlighted throughout the manuscript any ad-hoc decision or changes that have been made to the initial protocol.

The fact that the review is focused on a specific population, could be perceived as a limitation. Technology serves as a performance-enhancing means not only in elite sport settings. Also, those who are engaged in different activities (e.g., other performers or amateur athletes) can integrate technology into their practice. It seems thus reasonable to ask whether different levels or sport practice/expertise may lead to different usages of technological tools and techniques. On the other hand, the insights collected from the elite athletes might be useful to design tools addressing amateurs, when the aim is to increase their sport competences (i.e., combination of knowledge, skills, and abilities) and to help them use technology as performance *enhancer* rather than stressor or distractor (see Rapp & Tirabeni, 2020).

4.5. Integration of technology in elite sport settings: ethical considerations

Technological innovations are producing a broad array of tools and techniques, each of which offers benefits while posing ethical challenges (Wallach, 2017). For example, they can cause a shift in responsibility from the athletes to "external expert systems" (see Murray & Chuan, 2017), and threaten athletes' status as free, informed and responsible moral agents (Loland, 2009).

Moreover, the assumption that biometric data reduce error over other methods carries with it the risks of overdetermination of the results and of subsequent harms to some players, including pushing them too hard or wrongly assuming that they are fatigued or are unfit to compete (Karkazis & Fishman, 2017).

The particular ethical concerns arise with the implementation of technologies for optimizing the performance of professional athletes and the access to the biometric data for the stakeholders (e.g., coaches, team owners, agents etc.) These concerns encompass: (1) validity and interpretation of data; (2) increased surveillance and threats to privacy; (3) risks to confidentiality and concerns regarding data security; (4) conflicts of interest; and (5) coercion (Arnold & Sade, 2017; Karkazis & Fishman, 2017).

Although the focus of our paper was not related to ethical issues about the integration of technology in elite sport, we consider it important to highlight that there still is the need of critical reflection upon the use of technology in sport, particularly in elite sport settings (Loland, 2009; Pugh & Pugh, 2020). Further studies should consider the risks of integrating technology in sport settings and whether technological innovation poses any threats to the spirit of sport (see World Anti-Doping Agency, 2019).

5. Conclusions

From a theoretical point of view this review provides evidence that there is a need of a clear framework, supported by a Grand Unified Theory of Performance, on the integration of technologies in PST to support optimal performance in athletes. This framework could be found in the description of the technologies devoted to the analysis of the person-task-environment interaction for performance optimization (see Bertollo et. al, 2020). Moreover, to reliably evaluate the aid of technologies in applied practice, it is recommended to take into account the strength of evidence and its effectiveness (see Peake et al., 2018). Through assessing study quality (Table 4) and synthesizing the available results (Table 2), it is apparent that there is supported evidence for the usefulness of technology in identification of optimal performance, promising evidence for monitoring athletes' performance, and emerging evidence for planning intervention to optimize performance.

From a methodological point of view the results of research conducted with the use of new technologies facilitate the development of new techniques in mental training for athletes, e.g., various forms of biofeedback and neurofeedback. These techniques enhance self-awareness and self-regulation and foster athletes' beliefs that the mind could and should be trained. They might also be promising in psychological support and useful for psychosomatic recovery, resilience, and injury prevention (see Rijken et al., 2016; Rusciano, 2017), which often have key importance in high-performance sports. Nevertheless, there is still a need for studies aimed at psychological interventions for performance optimization in elite athletes, with real-life tasks transferable to real-world benefits. Moreover, specific protocols combining technology and PST should be defined for testing each psychological skill useful for performance optimization.

From an applied point of view, the results of the present review provide insights into the technology that can be used to help athletes optimally self-regulate their mental states and modulate the underpinning psychophysiological processes to perform at their potential more effectively. However, an emphasis should be placed on technology as a useful tool and not the driver. Increased technology literacy among sport psychology professionals might provide the key to more effective strategies for performance optimization (Luczak et al., 2019) and protect them from the detrimental effects of information overload (see Edmunds & Morris, 2000). In addition, since we live in the "era of technology" (see Watson & Coker-Cranney, 2019), not only sport psychologists but also current and future athletes might easily embrace the integration of technology in PST. Knowledge on how to integrate technology in PST for performance optimization in elite athletes can help reduce errors, biases and uncertainty in measurement, and protect from the risk of overdetermination of the biometric data. The integration supports both subjective and objective perspective in the training process.

In summary, technology plays an increasingly important role in performance optimization in sports. Nevertheless, technology and PST should not be viewed as interchangeable facets of performance enhancement but rather as complementary faces of the same coin – where technology integrated in psychological skills training can lead to identifying, monitoring and optimizing athlete performance more effectively. Further studies should investigate how each specific new technology can be implemented in PST and what is the added value it can provide in the framework of person-task-environment interaction perspective for optimal performance.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2021.102008.

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