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Coaching with virtual reality, intelligent glasses and neurofeedback: The potential impact of new technologies

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The last decades have seen new sport technologies become increasingly important for recording, analyzing, and optimizing athletic performances. Combined with valid and defined diagnostic methods, these techniques have opened new perspectives and opportunities for an individualized and context-sensitive action support for training, competition, daily living management and communication. New technologies do not only allow athletes to reach better training results in a less amount of time, but also allow coaches to get more insights on training processes with more effectiveness. This contribution provides an overview of recent technological advancements in sport psychology and highlights their key characteristics as well as useful applications. Techniques that enrich the physical environment of athletes, such as virtual, augmented, and mixed realities are described with modern and mobile output devices like intelligent glasses. Additionally, explanations on attentional, auditory, and brain-related technologies such as neurofeedback that can help improve the cognitive processes of athletes, and serve as diagnostic and training tools are provided. The contribution concludes with a discussion on the ethical and practical implications of these new technological approaches for sport psychology from a broader perspective.

Key words: Artificial Intelligence; Augmented-Virtual Reality; Intelligent Glasses; Neurofeedback; New Technologies; Sport Psychology.

The recent trends in information and communication technologies (such as Internet of Things, IoT) as well as the continuing miniaturization of tech-

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nical devices have started to increasingly pervade and influence many different areas in sports. New sport technologies have become increasingly important for recording, analyzing, and optimizing athletic performances. This trend is even more reinforced by the advent of efficient Artificial Intelligence (AI) methods, allowing for a proper automatic analysis and interpretation of the recorded large multi-modal data sets. Combined with classical and modern sport psychological diagnostic methods these techniques allow for a generation of individualized and context sensitive action support, which can be presented in different feedback formats (such as audio or visual) for the athlete using modern mobile output devices, such as Augmented Reality (AR) Glasses. In this manner new technologies do not only allow athletes to reach better training results in a lower amount of time but also trainers it to get more insights on the training process and effectiveness as well as on athletes' individual weaknesses in different sport situations.

Sports and technology date back to antiquity and have always demonstrated a symbiotic association. Notably, the Greeks' ancient Olympic games were characterized by the use of simple but useful devices (e.g., discus, javelin; Coakley, 2001). Drawing from the past, modern games and competitions have seen the introduction of basic devices (e.g., bats, balls, gloves) and complex equipment (e.g., skates, skis, swimming and cycling gadgets) that have become increasingly popular. The current sport generation has seen the advent of technologies that have provided diverse equipment (e.g., joysticks, dance pads, portable controllers) to transform games and competitions in contemporary society (Murphy, 2009) and makes use of new information platforms and communication devices (e.g., internet, smart phones).

Research has shown that most of our activities in sport require that we plan, execute, and control our interaction with the environment and other people in a skillful manner (e.g. Vickers, 2016; Williams & Ward, 2007). Via motor actions, we are not only able to interact with particular sport tools within the environment but with individual opponents and teams. As in sporting contexts, our movements are purposeful and aim at achieving particular action goals. Such goal-directed interactions require that we integrate task-relevant information about the current context from the environment via sensory inputs, and consider relevant cues and mental representation stored in our memory for motor planning (Schack & Hackfort, 2007; Schack et al., 2014; Schack & Ritter, 2013). In order for people to learn new sports skills and successfully access them under different environmental conditions, they need multi-year goal-oriented training (Deliberate Practice; Ericsson, Krampe, & Tesch-Romer, 1993). This goal-oriented training includes challenging new learning exercises, informative feedback as well as opportunities for repetition and error correction (cf. Ericsson, Krampe, & Tesch-Römer, 1993). Feedback is of fundamental importance, especially in sports because of the complexity and variety of movements. It is divided into sensory or intrinsic feedback (sensoric feedback) and extrinsic feedback (augmented feedback; external feedback) (see Magill & Anderson, 2012). Via intrinsic feedback, which is provided during or after movement execution via the sensory receptors, the learner can understand a target-actual comparison between the sensory movement information and the anticipated action goal (cf. a child immediately hears and feels whether it has caught a ball or not). In spite of the significant improvement in identifying the mechanisms and attributes necessary for improved sport psychology consulting from both athletes' and coaches' perspectives, researchers and consultants are still probing for effective ways to improve scientific knowledge, skills and techniques needed to meet professional needs (Sharp & Hodge, 2011; Schack, 2020; Tod, Hutter & Eubank, 2017). Thanks to technical advances (such as sensorics, Virtual- and Augmented Reality (VR, AR) and eye tracking, ingestible computers, intelligent clothes, neurotechnology for monitoring and improving mental skills, and 3D body scanners that analyze body geometry and kinematics) it is now possible to not only record multimodal performance and perception behavior of athletes in lab and field studies, but also to analyze this data for generating extrinsic feedback and training techniques which can be used in sports practice. Such modern recording and feedback systems have great potential to improve athletes' athletic performance, facilitate motor learning of sports skills and optimize performance analysis for coaches and athletes (see Bideau, Kulpa, Vignais, Brault, Multon & Craig, 2010; Schack, Bertollo, Koester, Maycock, & Essig, 2014). The literature has long referred to the need for inexpensive, robust and easy-to-use feedback systems for coaches and sports clubs (cf. Baca & Kornfeind, 2006). However, the purchase of VR, AR and eye tracking systems is still associated with high costs (see Kulpa, Multon, & Argelaguet, 2015; Miles et al., 2012). This is particularly a problem for sports associations and sports clubs that have a low budget (cf. Baca & Kornfeind, 2006). The current devices for mobile eye tracking also lack robustness (see Discombe & Cotterill, 2015). For this reason, they have so far mainly been used in studies in which closed sports skills (e.g. free throws in basketball) but no open sports skills (for an overview, see Vickers, 2016). This is justified by the fact that the head does not move back and forth too much during closed sports skills (e.g. basketball free throw) and more valid data can thus be recorded for the evaluation (cf. Discombe & Cotterill, 2015). Another problem with modern technologies is how to make sense out of all the data recorded during field research and sports training – not only for an offline but also for real time processing in game play. Particularly, recent progresses in AI offers perspectives to process the highly unstructured and unsegmented data, which is too cumbersome using existing approaches.

Although the advent of new technologies has significantly fostered interactions in sport and the progression of sporting achievements at different levels across professional boundaries, sport psychology consultants have not so far made enough use of these techniques and their available opportunities (Hagan Jr., Schack, & Koester, 2018). Therefore, this article provides an overview about actual and future technical developments in Sport Psychology, as well as how these techniques can be used in order to realize trainers' demands on the recoding of comprehensive performance data, as well as new forms of individualized feedback, coaching and training success monitoring for Athletes. We are addressing in this contribution some chosen technological advancements in sport psychology which have been developed in the last 50 years but mainly established in the new (21st) century and highlight their key characteristics as well as useful applications. Mainly, we are characterizing technological approaches that could enrich the physical environment of athletes (such as VR and AR). Additionally, explanations on attentional and brain-related technologies like eye tracking and intelligent glasses are provided. Further, neurofeedback-technologies and EEG measures are presented on how these advancements can help improve the cognitive processes of athletes, and serve as diagnostic and training tools. We will look at the advantages and disadvantages but also point out future trends on how these techniques can become more and more unobtrusive and affordable, as well as on trends in AI for sports analysis. Since future technologies are able to measure and record sensitive data about athletes' perception and action behavior and they interact closely with the human performer, we will also address ethical, legal and social implications (ELSI), as well as usability and technological acceptance issues from a broader perspective (see Schack et al., 2020; Strenge & Schack, 2019).

Coaching in Virtual and Augmented Reality (VR/AR)

VR is a visual based computer simulation which can reproduce a realistic and controlled environment (Akbas et al., 2019). Aukstakalnis and Blatner (1992) define VR as "a way for humans to visualize, manipulate, and interact with computers and extremely complex data" (p. 7). Whereas AR is defined as overlaying real perceived scenes with computer-generated images in order to display important additional information or digital content such as texts, images or videos in the human field of vision (see Nischwitz et al., 2011).

VR offer several advantages for sports: 1.) More repetitions are possible than with physical practice; 2.) Increased motivation as a result of a higher level of engagement / presence; 3.) Rare events (e.g., curved free kick in soccer) can be experienced more often; 4.) individualized training of technical and tactical as well as motor abilities regardless of the time and place, against a chosen opponent; 5.) Practicing of motor imagery and managing physiological stress in game play; 6.) Research and diagnostics in sports. Disadvantages of VR are: 1.) Action - perception decoupling; 2.) Can perceptual information be correctly simulated?; 3.) Even small discrepancies (e.g., in timing) have an impact; 4.) VR is not mobile and people react in an artificial world without relation to the real game; 5.) VR-headsets are quite heavy (Düking et al. 2018; Gray, 2017). The environment can be a simulation of the real world or an imaginary world (Figure 1), providing an interactive and immersive experience in a simulated autonomous world (Burdea & Coiffet, 2003; Zeltzer,

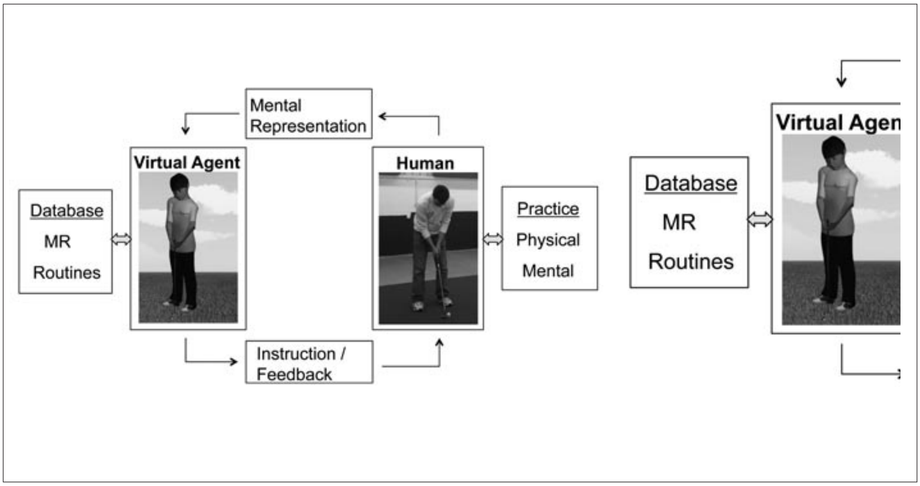

Fig. 1. - Left: Basic principle of an individualized and adaptive coaching scenario based on the measurement of mental action representations. Mental representations are evaluated by particular methods (e.g., SDA-M) and provided to a the virtual coach (in that case "Billy" created by the Social Cognitive Systems Group, CITEC, Bielefeld University, Germany). The virtual coach (or rather the system architecture) extracts relevant information from human memory (mental representation) and is providing individualized instructions. Right: The virtual coach supervises the acquisition of action sequences (in that case: squat) by verbally instructing a participant based on evaluated mental representation or motion tracking during motor skill learning to provide feedback. The movement is modeled by the virtual agent and the trainee can observe his own movements furthermore in a virtual mirror. Photo CITEC. Reproduced with permission of Thomas Schack.

1992). This process can be achieved via computer generation of sensory impressions that are delivered to the human senses. The type and quality of these impressions determine the level of immersion and the extent to which the participant feels 'present' in the virtual setting. Additionally, the environment itself must provide realistic responses to the user's actions so that users can act in the same way as they would in a real environment, and without the need to adjust behavior significantly to interface effectively. From a technological standpoint, VR/AR systems are complex and require additional input/output (IO)-hardware devices, special drivers, and software. In general, input devices (e.g., body and eye-tracking systems, data gloves, 3D mice and bats, space balls) are responsible for interaction, whilst output devices (e.g., 3D glasses, surround- or head-mounted displays (HMD)) are responsible for the feeling of immersion. Software is responsible for control and synchronization of the whole environment. Simulations may include additional sensory information such as sound, proprioceptive, or tactile feedback.

Sport-action related wireless virtual environments with full body capture and mobile eye tracking only became possible in the past 25 years. Becker and Pentland (1996) built a Tai Chi trainer using a hidden Markov Model to interpret the user's gestures. Jacky, Leung, Tang, and Komura (2011) proposed a new dance training system based on the motion capture and VR technologies where a subject has to imitate a motion demonstrated by a virtual teacher. An evaluation study revealed that the system can successfully guide students to improve their motor skills and motivates them to learn, although with a small number of participants. This intervention is more a mimicking of the optimal movement than a real coaching process and the user must be able to recognize the difference between both movements. Additionally, in previous work, the systems compared the movements just by pointing out differences in the velocity, timing, and joint angles. This form of assessment may not be adequate on different expertise levels which require a much finer evaluation and feedback procedure for the motion structure. To offer additional improvements, using changes in gaze behavior and mental representation structures may provide a better method to evaluate the actual learning process through interviews and questionnaires (see Figure 1). VR has been used across a range of sports including rugby, handball, soccer, and table tennis (Bideau, Kulpa, Vignais, Brault, Multon, & Craig, 2010). For recent overview studies on application fields and acceptance studies see Dücking, Holmbach, and Sperlich (2018); Gradl et al. (2016). There is also research on the transferability of skills from the virtual to the real world, although this still has to be proved scientifically (Tirp et al., 2015). On a few occasions, VR has been used to create a complete coach-athlete interaction although in many cases, VR-scenarios are not well evaluated (see Schack, et al., 2020).

Sport psychologists can use, test, and modify these technologies to make empirical and applied aspects of sport psychology more visible and attractive for athletes, other disciplines (e.g., business), and institutional investors. Based on available research evidence, the application of these technological tools in applied sport psychology should be embedded for a better conceptual understanding of action and mental coaching in sports (see Schack et al., 2020). VR and AR can be used to provide various perceptual (e.g., visual, auditory and/ or tactile) information as additional sources of feedback in motor learning (Hagan, Schack, & Koester, 2018). In such a context, it is helpful to check in how far such VR- or AR technologies are creating or enriching task-person-environment related factors of action in sport (Schack & Hackfort, 2007; Schack, Bertollo, Essig, & Maycock, 2014).

Over the last few years, advances have been made in *AR* for application in domains such as robotics, telemanipulation, and the military (Milgram, Takemura, Utsumi, & Kishino, 1994). The most common definition of AR is that of Azuma (1997), who stated that AR systems have the following three characteristics: (1) Combine real and virtual environments; (2) Are interactive in real time; and (3) Are registered in 3D. AR systems overlay digital computer-generated data such as audio, visual and tactile information on top of a live, direct or indirect view of a physical and real-world environment (Duh & Billinghurst, 2008). In AR sport environments, athletes' data are retrieved from multisensory components; audio-visual aids, actuators (i.e., types of motors used for moving or controlling mechanisms), and virtual actors. These measurements are logged at varied degrees and harmonized to offer valuable information on athletes' movement dimensions to achieve realistic adaptations to athletes' movements and thus enhance motor experience (see Figure 1).

With the help of advanced AR technology, information about the surrounding real world becomes interactive and digitally manipulable. Thus, AR makes the environment richer in terms of feedback and creates a mixed reality between our environment and movement-related computer-generated feedback. In contrast to VR, in which the user is often completely embedded in an artificial world, AR is on a continuum between reality and virtuality (Milgram et al., 1994). AR techniques hold potential when training for game situations, when practicing techniques, and for the provision of real time performance feedback, with research suggesting that AR use improves athletes' performance (Bideau et al., 2010).

In a new research direction using the Cognitive Architecture Approach

(CAA [Schack et al., 2014; Schack, 2020]), Hülsmann, Frank, Schack, Kopp, and Botsch (2016) used a multi-modal approach and developed a multilevel architecture for an augmented sport coaching device, called Intelligent Coaching Space (ICSpace). Besides the capturing of motion data, the authors use mainly biofeedback data and mental representation structures (i.e., cognitive components) to inform the virtual coach about the recent learning stage of the subject (see Figure 1). From this perspective, the research on mental action representation as a scaffold for learning (Schack & Ritter, 2013; Schack, 2020) became a main building block of the interaction with a virtual coach.

This multilevel approach of ICSpace (Hülsmann et al., 2016) allows the virtual coach to be pointed towards task and context relevant information, to tailor the coaching process to those movement phases that need particular and context sensitive training, as well as to handle expertise-dependent analysis, dialogue, and feedback components. Therefore, the virtual coach can identify particular deficits in users' movement execution on several expertise levels (see Figure 2). This is in contrast with existing systems, where the user has to compare his own movements with those of a virtual teacher, requiring movements' knowledge and trained observation skills in order to recognize the differences between the displayed movements and adopt his or her own movement repertoire adequately.

Providing helpful assistance to human users is one of the most promising applications of interactive technology in rehabilitation and sport psychology. In coaching, one can best observe how far trainees are capable of responding to an expert's assistance, and whether the coaching system is able to activate the users' learning potential. Coaching a trainee at different interaction levels while practicing and learning a motor task is an interesting scenario not only to support motor learning processes but also to understand in how far we know the basic principles of coaching. By addressing mental representation in sport (Schack & Mechsner, 2006, Schack & Hackfort, 2007), we are investigating in how far the interaction in coaching not only in reality but in VR settings could become more individualized and adaptive. To facilitate smooth interactions with humans, a virtual avatar should be able to establish and maintain a shared focus of attention with its human partner or instructor (see Figure 1). Furthermore, it should be able to react to commands delivered in a "natural" way, such as speech, gestures, and demonstration. To this extent, it is clearly advantageous for a real or a virtual coach to know how mental structures form, stabilize, and change in sport action. A coach who possesses such knowledge is better able to address the individual athlete on his or her current level of learning, and shape instructions to maximize training and performance.

Eye-tracking devices

The term eye tracking denotes the process of monitoring and recording participants' gaze positions when they look at 2D or 3D stimuli. Researchers are interested in exacting gaze positions measured in 2D or 3D coordinates and therefore assess spatial-temporal scan paths (Holmqvist et al., 2011). Fully mobile, head-mounted eye-tracking systems allow participants to move in an unlimited working range and to grasp, touch, and manipulate objects of interest. This is especially important for dynamic environments, such as sports. There is a spatial and functional relationship between eye movements and whole body movements or movements of body segments. For example, to achieve good hand-eye coordination, both parts must work together in smooth and efficient patterns. In goal-directed movements, the selection of task-relevant objects and locations is determined by the goals of the moving person. Hollands, Patla, and Vickers (2002) found that prior to changing the direction of walking, participants aligned their gaze with the endpoint of the required travel path, thus suggesting that eye movements are related to movement goals. Similarly, Heinen, Jeraj, Vinken, and Velentzas (2012) found a relationship between gaze behavior and movement in a complex gymnastic skill, namely the backward salto performed as a dismount on the uneven bars. Essig, Prinzhorn, Maycock, Ritter, and Schack (2012) implemented an interface between a monocular mobile eye tracking and a motion tracking system to further investigate the spatial and functional relationship between eye and whole body/body segment movements. This interface may prove useful for investigating the amount of information required for successful motion execution, or the way athletes react in unusual playing situations.

In order to investigate visual perception processes, eye-tracking studies have been applied in sport settings beginning in the early1980s (Vickers, 2007). Tydelsley, Bootsma, and Bomhoff (1982), for example, investigated the eye movements of experienced and inexperienced players looking at a right-footed soccer player taking a penalty kick in a static slide presentation. Their results revealed experienced players' fixations were restricted to the right side of the body and the shooting leg, neither the supporting leg nor the left side were scanned. Additionally, the fixation duration for the inexperienced players was longer than for the experienced counterparts, revealing their problems to pick up relevant scene information. In contrast, in the studies of Williams and Davis (1998), where participants stood in front of a life-size video projection viewing video tapes of tactical plays and had to response to soccer defensive plays (1v1, 3v3, 11v11) by pressing pressure-sensitive pads found, experts made more fixations of shorter durations on tactical important areas and the hip-region, whereas novices looked at the ball and spend longer times to fixate the player in possession of the ball. The discrepancy in the results of the two studies may be due to different task constraints portrayed in the visual-search stimuli used (Vickers, 2007). In a more recent study, Frank, Land and Schack (2016) investigated the changes of perceptual-cognitive components over the course of motor learning. Participants training the golf-putting mentally and physically had longer quiet eye periods and better mental representation structures than those participants receiving physical practice only. The quiet eye is defined as the final fixation or tracking gaze that is located on a specific location or object in the visuo-motor workspace within 3o of visual angle for a minimum of 100 ms (Vickers, 2007). Elite performer's quiet-eye onset is invariably earlier and longer than that of near-elite or lower skilled performers, i.e. near-elite players see critical information earlier and process the visual information longer than less-skilled athletes. All in all, eye tracking offers several possibilities to investigate athletes' gaze and perception behavior in lab and field studies as well as to compare the results among players of different expertise. Additionally, it can be used to monitor if players follow the visual gaze strategies or corrective feedback provided by the coach, or if the focus is on irrelevant cues (for an overview see Hüttermann, Noël and Memmert, 2018).

Intelligent AR-Glasses

Computer-assisted sports training is a recently evolving development that caught broad attention in both research and applied work in sport psychology (Chen et al., 2015). The concept of bimodal visuo-spatial interface termed "intelligent glasses (IG)" designed to provide assistance on daily tasks such as access to information and mobility (Sottilare & LaViola, 2015). The IG provides adaptive training where an instruction is personalized to provide specific needs of an individual learner or a team of learners (Sottilare et al., 2013).

Employing a vision-based golf training system using IG, termed "Improve My Golf Swing, Chen et al. (2015) proposed a training system that implemented computation-efficient image processing methods to examine a golfer's posture targeted at improving the golfer's swing skill. Three routinely created feature lines that were stimulated from the "Tiger Lines" of the "Tiger Woods: My Swing" app, were used to appraise whether the golfer's body is accurately aligned. Using the IG, which was used as a wearable displayer, permitted the golfer to watch his own body posture amplified with the feature lines from a side view during a golf swing. Remarkably, varied audio alerts were incorporated to provide what forms of potential postural faults were discovered, instantly drawing the golfer's attention to the incorrect body posture (s). According to Chen and associates, this training system could provide immediate directives for postural modification in a more instinctive and unmistakable way. Other target shooting or far aiming sport (e.g., pistil or rifle shooting, darts throwing, archery) could take advantage of these novelty approaches.

In another research direction, which could be interesting for anticipation in sport and medicine, researchers tried to support anticipation by seeing the world through assistive glasses. This project, called ADAMAAS (i.e., Adaptive and Mobile Action Assistance in Daily Living Activities), focuses on the development of a mobile adaptive assistance system in the form of intelligent glasses that provide unobtrusive, anticipative, and intuitive sup-

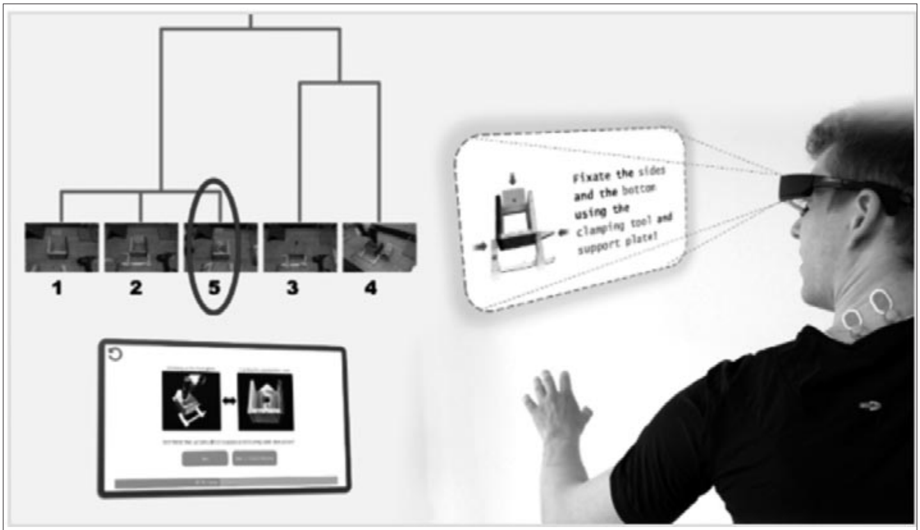

Fig. 2. - The basic idea behind the cognitive ADAMAAS-Glasses: Mental representations are evaluated in advance with the help of the SDA-M diagnostic on a tablet PC (left). A particular computational algorithm is then estimating the probability of failures in different steps of a particular action (e.g., building a nesting box). Relevant and individualized prompts are provided in time in the AR component of the glasses to support anticipative processing of the user (right). Photo: CITEC. Reproduced with permission of Thomas Schack.

port in everyday situations (Essig, Strenge, & Schack, 2016). The system is able to identify problems in ongoing action processes, react to mistakes, and provide context-related assistance in textual, pictorial, or avatar-based formats superimposed on a transparent virtual display. This project integrates mental representation analysis, eye tracking, physiological measures (e.g., pulse, heart rate), computer vision (i.e., object and action recognition), and augmented reality with modern diagnostics and corrective intervention techniques (see Figure 2). The major perspective that distinguishes ADAMAAS from stationary diagnostic systems and conventional head-mounted displays is its ability to react to errors in real-time as well as provide individualized feedback for action support, and learn from expert models, including the individual behavior of the user (see Figure 3).

The Intelligent AR Glasses can be used to provide athlete and sport sensitive feedback, for remote observation or assistance (e.g. the video can be transferred to the trainer or the trainer can use a red pointer to help the athlete to focus on the relevant cue), as well as new trainingforms, such as displaying distractive stimuli in the glasses in order to simulate different training conditions or environments (see Figure 3).

Neurotechnologies for sport performance

Neurotechnologies (NT) are used to monitor and improve performance based on information about individuals' neurocognitive status assessed via

Fig. 3. - Based on the measurement of mental representation, it is possible to learn about the expertise stage of the user and to provide individualized feedback (e.g. in a bakery or golf putting example). Photos: CITEC. Reproduced with permission of Thomas Schack.

cognitive or neurophysiological measurements. NTs are a set of procedures, methods, tools, and devices that affect human understanding of the brain and various aspects of consciousness, thoughts, and higher order activities in the brain and motor memory. These scientific techniques include technologies that are designed to monitor, improve, and treat brain function, and it allows researchers and clinicians to visualize and stimulate brain and memory structures and functions.

Several neuroimaging techniques have been applied to sport science and coaching domains for the purposes of monitoring activity and improving performance (Yarrow, Brown, & Krakauer, 2009; Hillmann, Erickson, & Kramer, 2008). Determining the best method depends on the setting, the research question, and the intended purpose. For instance, Positron-Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI) are useful in laboratory or clinical settings where the body posture is not of critical relevance, because participants must lie still in the recording device (Tashiro et al., 2008). PET and fMRI are particularly suitable for investigating the neural correlates of imagery skills in athletes (Holmes & Calmels, 2008), for exploring subcortical structures, such as basal ganglia during coordination task (De Luca, Jantzen, Comani, Bertollo, & Kelso, 2010), and for aiding rehabilitation after concussion or injuries (Pulsipher, Campbell, Thoma, & King, 2011). Electroencephalography (EEG) and Magnetoencephalography (MEG) are particularly suited for investigating rapid processes such as visuo-spatial attention required for aiming and shooting (Del Percio et al., 2009). EEG has successfully been used to monitor motor learning and enhance performance in golf putting (Pitto et al., 2011). A general disadvantage of some methods, however, is the low temporal resolution when investigating cognitive processes. Consequently, other methods such as EEG and MEG are better suited for measuring rapid (cognitive) processes, particularly during training (see Hatfield & Kerick, 2007).

EEG and MEG both externally monitor brain activity via electrodes placed on the scalp. EEG records changes in electrical fields due to neuronal activity (slow post-synaptic potentials), whilst MEG captures changes in the magnetic field that are associated with electric activity. Brain activity that can be captured by either technique is largely limited to the cortex, the outer part of the brain. The most prominent advantage of these two methods is their high temporal resolution. That is, brain functions that support cognitive functions can be recorded in real time. Also, these measures do not require overt responses from participants. Another advantage of EEG is that, it is less expensive than PET or MRI scans and is essentially a mobile technique (Thompson, Steffert, Ros, Leach, & Gruzelier, 2008). It is possible to bring the equipment into field settings, although participants' movements can still pose a challenge as they can evoke muscle artifacts.

Within sports, EEG can be used to train athletes by altering brainwaves through on board computer screen display. Two recent research investigations measured how patterns of cortical activity influenced successful golf putts. Findings provided empirical baseline for new neurofeedback interventions. Patterns of EEG activity following holes' putts and missed putts were compared among expert and novice golfers. Cooke et al.'s (2014) findings showed that expert golfers experienced a greater reduction in high EEG alpha power than novices, and that holes' putts provided less high-alpha power than missed putts at frontal and central sites (e.g., Fz, F3, F4, Cz) in two seconds before movement (see Cooke et al., 2014). Similarly, Leocani et al. (1997) found in other self-paced voluntary movements investigations where EEG power was minimized in both hemispheres of the brain during bimanual tasks. Therefore, EEG in conjunction with biofeedback serve as a powerful tool to reduce attention related problems, anxiety and anger experienced by elite athletes.

A more comprehensive overview in literature suggest that neurofeedback training (NFT) has reportedly been explored in diverse sports: soccer (Wilson et al., 2006), short-track speed skaters (Beauchamp et al., 2012), gymnasts (Shaw et al., 2012a), golf (Sherlin et al., 2015), tennis (Gracz et al., 2007), and rifle shooting (Harkness, 2009) to enhance sport performance and affective outcomes through self-regulation skills in athletes (e.g., relaxation and concentration skills, [Beckmann & Elbe, 2015]). According to Kao et al. (2014), sport performance involves continuous top-down alteration of continuous attention often characterized by specific cortical activation, hence NFT is one practical technique that can help adjust brain activity supportive of continual attention for enhanced sport performance. Specifically, NFT offers insightful understanding of the useful links between brain activation and performance in motor task by activating brain's right hemisphere connected with visual-spatial processing and decrease activation in the left temporal lobe. This decrease in activation in the left temporal areas (e.g., in verbal-analytic areas) is associated with the suppression of task irrelevant information (Mirifar et al., 2017) required for optimal performance. Significantly, many professionals and researchers are exploring alternative opportunities that provide better understanding on how to enhance athletes' performance. Therefore, NFT effectiveness offers that essential alternate route that could help promote applied practice in sports.

Artificial Intelligence (AI) and Machine Learning (ML) Techniques in Sport

The application of new technologies goes along with the recording of large multi-modal data sets which have to be automatically analysed and interpreted. Recently, AI and ML are making their way into a number of sport applications. For example, Novatch and Barca (2013) show how AI can be used for assessing the quality of weight lifting exercises and to assist the athletes and the coaches regarding training optimization and prevention purposes. On one hand, AI is applied in sport industries, such as chat bots to response to fan inquiries, to identify racing cars in images with reduced quality, as well as to automate journalism (e.g. by translating number-based sports stats into natural language) (Kumba, 2019). On the other hand, AI in combination with computational intelligence, data mining, IoT devices (such as wearable tech), affects also the way how we watch and perceive sports and how we optimize training and performance. More and more IoT sensors, cameras, smart algorithms and systems are deployed in sports training. Smart Sport Training (SST) describes new sport training forms which make use of various wearable IoT devices combined with intelligent data analysis methods and tools to improve training performances with a simultaneous reduction of workload. SST comprises a huge spectrum, ranging from basic usage of wearables in training up to artificial coaches providing training and individualized feedback for the athletes in different sports (Rajšp & Fister, 2020). For athletes and trainers, the goals are: better training results in a lower amount of time; more insights on the training processes and effectiveness; insights into athletes' individual weaknesses in different sport situations and a partially automatization of the coaching routine. Deep learning methods using Recurrent Neural Networks (RNN) with Long-Short Term Memory cells (LSTM) are a promising approach for real time Human Action -Recognition, -prediction and performance analysis in sports (Foc, Chan, & Chen, 2018). RNNs are artificial neural networks that can learn the temporal dynamics of input data over time. LSTM is an extension to RNN that allows RNN to model long-term temporal correlations in data streams. (Hochreiter & Schmidhuber, 1997). For example, Zhao et al. (2018) use bidirectional LSTM to predict basketball trajectories, helping coaches and players during training. LSTM found its application in table tennis coaching, extracting useful, low dimensional latent information from wearable sensors. Also open-source realtime systems are available for multi-person 2D pose detection, including body, foot, hand, and facial keypoints, such as OpenPose (Cao et al., 2018). Rajšp and Fister (2020) provide an overview on different intelligent data analysis methods used in various domains of sport training.

Data privacy, technical acceptance, usability and ELSI aspects

Despite the all the new possibilities opened up by the application of new technologies in Sport science there are also many challenges which have to be considered: New technologies allow the recording and storage of detailed user-specific data. Therefore data privacy, as well as ethical, legal and social implications (ELSI) are becoming more and more important and are seen as important considerations with respect to technological developments. Strenge and Schack (2019) propose an innovative approach to incorporate ethically relevant criteria during agile development processes through a flexibly applicable methodology called Agile Worth-Oriented Systems Engineering (AWOSE). First, a predefined model for the ethical evaluation of technical systems is used to assess ethical issues according to different dimensions. To ensure that ethical issues are not only identified, but also systematically considered during system design, the second part of AWOSE integrates the findings with approaches from worth-centered development into a process model compatible with agile methodologies. The authors improved artifacts of worth-centered development called Worth Maps to guide the prioritization of development tasks as well as choices among design alternatives with respect to ethical implications. Furthermore, the improved Worth Maps facilitate the identification of suitable criteria for system evaluations in association to ethical concerns and desired positive outcomes of system usage. According to the *Technology Acceptance Model* (TAM; Davis, Bagozzi, & Warshaw, 1989), for an information system theory that models how users come to accept and use technology, there are at least two primary factors that influence the acceptance of new technologies: (1) the degree to which people believe that using particular systems enhance their performance (perceived usefulness), and (2) the degree to which people believe that the use of particular systems is free of effort (perceived ease-of-use). A reliable and simple use is a prerequisite for a broad acceptance of new technologies in sports. Techniques that do not work properly or that restrict athletes during movement are unlikely to be accepted. Therefore, aesthetics, 'joy-of-use' and positive sensations athletes and researchers get when using products are important design considerations. In addition to acceptability, another factor to consider is user experience, the way sport psychologists and athletes feel about using a product, system or service, and their confidence in the product. *Usability* describes the extent to which a product can be used by sport psychologists and athletes to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context. Only when all these factors are considered in the relevant sporting context, will new technologies be accepted and widely used. Ongoing considerations include ensuring that technologies in sport are useful and easier to interact with than those of the past, whereby future technologies need to progress alongside our evolving human needs.

Conclusions

The rate at which sport professionals, researchers, athletes and other persons embrace new technologies may provide the foundation for growth in the field. Regardless of how easy or efficient a new technology may be, not everyone within the field of sport psychology and other cognate fields will embrace the new paradigm. There are persons who may be interested in the new approaches, excited about the prospects of new ideas and are willing to accept the risk of uncertainty. Other people may be skeptical about the innovations and are likely to resist and hold on to the conventional approaches familiar to them. Knowing these dynamics can help practitioners understand their clients' decision making process as they contemplate about the usage of new technologies being promoted. To enhance the process of introduction, clear protocols or guidelines that are less intrusive for users, advantages and disadvantages should be articulated very well to potential users so that the element of uncertainty would be minimized. While acknowledging that the new technological advancements in contemporary sport psychology research and practice are vital, these new approaches are connected with ethical as well as usability issues and potential risks that should not be underestimated (Schack et al. 2020). Sport psychology as a profession across professional boundaries ought to provide strict ethical guidelines for all empirically acquired data in the foreseeable future.

The application of these evidence-based tools for research and consulting may help provide different conceptual frameworks for psychological skills interventions for the field's numerous clients. Sport psychology consultants, athletes and coaches should consider utilizing varied scientific information to improve their awareness on valid procedures currently available to them. By recognizing these integrative approaches in different situations and even among individuals with whom they work, performance and long term behaviour changes in sports could be improved using more inclusive scientific perspectives. The challenge though may be how, when and where to comprehensively capture these useful scientific information for effective sport psychology consulting (Hagan, Schack & Koester, 2018). But also coaches are looking for inexpensive and unobstrusive new technological solutions to improve and monitor training. Existing solutions are too complicated, expensive and not mature enough except for a few working examples, such as running apps and fitness armbands. The future will be on multi-modal and light cognitive systems – combining classical methods from Sport Science with modern AI analysis methods realized on inexpensive hardware for individual training and performance analysis as well as maintaining health, fitness and safety.

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