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Augmented reality tools for sports education and training.

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Abstract

Augmented reality (AR) provides additional information to the reality of sportpeople, and might offer supplementary advantages compared to other technologies. The goals of this study were to characterize and understand the benefits of AR in sports education and training. We reviewed Pubmed, Scopus, Web of Science, and SportDiscus databases, and discussed the results according to their role in sport (practitioner, spectator, and customer). Our results showed that different AR approaches might be used for learning and providing feedback. New rules could be introduced for reducing the gap between players with different experience levels. Additional information could also be added to improve the audience experience. We also explored the limitations of current AR systems and their efficacy in training, and provided suggestions for designing training scenarios.

Keywords: Augmented and virtual reality; Review; Human-computer interface; Sport; Mobile learning.

Executive summary

Limitations of previous systems
Video: Inability to consider depth which is necessary for attentional focus and reaction time.
VR: No visual references to surrounding, systems are either basic or expensive and sophisticated, physiological discomfort
Benefits of AR systems
Learning sports skills, providing additional information, providing additional feedback, stimulating practice, introducing new rules and creating new sports, interacting with sports events, enhancing customers' choice.
Targeted sports
basketball, rock climbing, football, dodgeball, Pokemon GO, air hockey, judo, table tennis, baseball, ball activities, billiard, cycling, fitness, golf, hado, ice skating, running, shooting, ski, table football, and tennis.
Targeted sportspeople
AR systems mainly target practionners and spectators, while some AR developments are marginaly designed for coaches and customers.

Introduction

Physical educators may use technology to add more value to their teaching, and to improve athletes' capabilities. Computers play growing roles in simulating the dynamics of sports in gaming environments. Wearable sensors have also received interest over the past years due to their promise for monitoring the users' health, fitness, and their surroundings. Additionally, virtual environments provide opportunities for practicing sports in remote places (Sánchez Pato & Davis Remilllard, 2018), and might allow transferring behaviors to real situations. Augmented reality (AR) comprises a view of the real-world merged with computer-generated elements such as audio, video, graphics, or location data (Milgram, Takemura, Utsumi, & Kishino, 1995; Sourin, 2017). While virtual reality (VR) replaces the real-world with computer-generated elements, AR works in tandem with the physical world, for enhancing users' perception of the surrounding environment (Wiederhold, 2019).

The ideology behind AR is to expand the organizational space for enhancing the environment and situations, and to offer perceptually rich experiences (Sánchez Pato & Davis Remilllard, 2018). With the help of AR, the surrounding world becomes interactive and digitally manipulatable. Additionally, by improving users' capabilities to detect, recognize, and process objects and situations, AR allows adding, removing, or changing aspects of the real-world more efficiently. AR technologies are also used in media, office productivity, phobia treatments, pedagogy, and human-robot interaction (Brito & Stoyanova, 2018). Overall, AR is more than just visuals and is about augmenting our world with digital assets.

Before 2010, most AR applications were complex and expensive systems that restricted their accessibility and adoption. In recent years, the integration of AR systems into mobile devices increased the number of AR applications. For example, mobile games might contribute to increased sedentary times, location-based AR games might encourage players to be active and to interact with other players (Finco, Rocha, Fão, & Santos, 2017). Few sports coaches have experience with AR technologies to recognize their benefits and applications in their practice. Therefore, the goal of this study was to provide an overview of AR applications in sports education and training. Specifically, we wanted to answer the following questions: (1) What are the characteristics of available AR systems? and (2) what are the benefits of using AR compared to other applications?

Methods

Search strategy and selection criteria

Although AR and sports concepts might look clear at first, their definitions are strongly debated. Azuma (1997) mentioned that "*… with AR, 3D virtual objects are integrated into a 3D real environment in real-time*." This definition appears to be restrictive and the following examples can militate in this direction. Regarding "*3D virtual objects*," although some see-through glasses are usually considered as AR displays, they either display 2D objects, without any perspective, or they display virtual objects monocularly. The "*real-time*" part of Azuma's definition may also be limited in situations where AR systems allow spectators to watch a delayed TV broadcast for perceiving offside position in soccer. Therefore, Azuma's definition should be modified to provide a complete overview of AR systems. Rather than focusing on a definition, Milgram and

Kishino (1994) focused on “*real-virtual continuum*,” that provides a large spectrum inside which different immersive systems are regrouped within a mixed reality concept. AR systems can also resort to different technologies to display virtual elements, including see-through head-mounted displays (HMD) and glasses, video-based systems that form the virtual elements in the video flow, and spatial systems that video project virtual elements on the real ones, and mobile AR systems that are video-based systems embedded in mobile phones. After 15 years of debate, Hugues, Fuchs, and Nannipieri (2011) suggested a revised AR taxonomy. Within their definition, alternative classifications of AR systems were proposed according to functional criteria, such as rendering quality and user’s mobility. These features rate AR systems based on their technical criteria, and sort them according to their visualization, tracking capabilities, and composite criteria (Mallem & Roussel, 2019; Parveau & Adda, 2018). In addition, AR systems can be understood as systems that improve user’s perception and execution performance (Dubois, Nigay, & Troccaz, 2000). In this paper we define AR systems as new types of human-machine interfaces that allow “*augmented interactions*” (Rekimoto & Nagao, 1995).

Sport definition has also fueled debates (Augustin, 2011; Defrance, 2011). Sport is not limited to the diciplines exhibited during the Olympic games, and can be deprogramed or introduced in gaming events with time. Moreover, it does not consider the new branches of sports, that are not recognized by the big organizations like the Olympic games. Efforts in sports classifications have been made based on their potential risk on health (contact and non-contacts sports; Rice, 2008), or based on games spaces, as suggested by French sociologists. However, such classifications exclude emerging sports, such as Techno Sport and eSport. With a review focusing on AR and sports, even restricting sport to “*what people do when they think they're playing sports*,” limits the field to players and might exclude sport spectators. Putting these thoughts in perspective, we propose the following criteria for including papers: (1) The material should be a new type of human-machine interface and not described as VR; (2) The targeted users could be sports practitioners (practicing or coaching sports, leisure, or non-sedentary casual games), spectators (viewing sports events), or customers (buying sports equipment); (3) The environment must deal with sports; and (4) The interaction with the real environment can encompass past, present, or future events related to sports. Due to the novelty of the topic, we did not set any criteria on the experimental design of the included studies, but restricted our search to the English language.

Data course and study search

For this review, Pubmed, Scopus, Web of Science, and SportDiscus databases were searched from 1964 until March 3, 2019. We used the following search terms and Boolean operators: (head display” OR augment* reality OR goggle OR phone) AND (“sport”). We also hand searched the reference lists of all eligible studies to identify additional records.

Outcomes

Information about the name of the prototype, sport, benefits of AR for sport, type of AR and augmentation, human experiment protocol, and the outcomes were extracted from the included records.

Data extraction

Each author reviewed the titles and abstracts of selected references independently. The full-text of the articles that appeared relevant, and those without obvious relevance was retrieved. The full-text of the records were read, and their eligibility was screened with the inclusion criteria. Any disagreement was resolved by mutual discussion.

Data analysis

As our research questions are descriptive and most of the articles were conceptual, and did not report enough statistical data for a meta-analysis, we used a qualitative content analysis that focused on the relationship between the content and context. We used a summative approach of content analysis where we compared and contrasted the articles based on our research questions (Hsieh & Shannon, 2005). Both authors classified and coded the articles and reviewed the summaries with each other. After mutual discussions and approval, we synthesized and reported the results in different domains.

Results

Figure 1 unfolds our experimental method. The search strategy initially yielded a total of 995 articles. A careful review of all the abstracts resulted in 52 pertinent articles selected for this review. Of these 52 articles, there were 14 journal articles, 34 conference articles, and 4 book chapters. We also introduced sub-categories according to each research question. These categories helped us to group studies based on their shared characteristics.

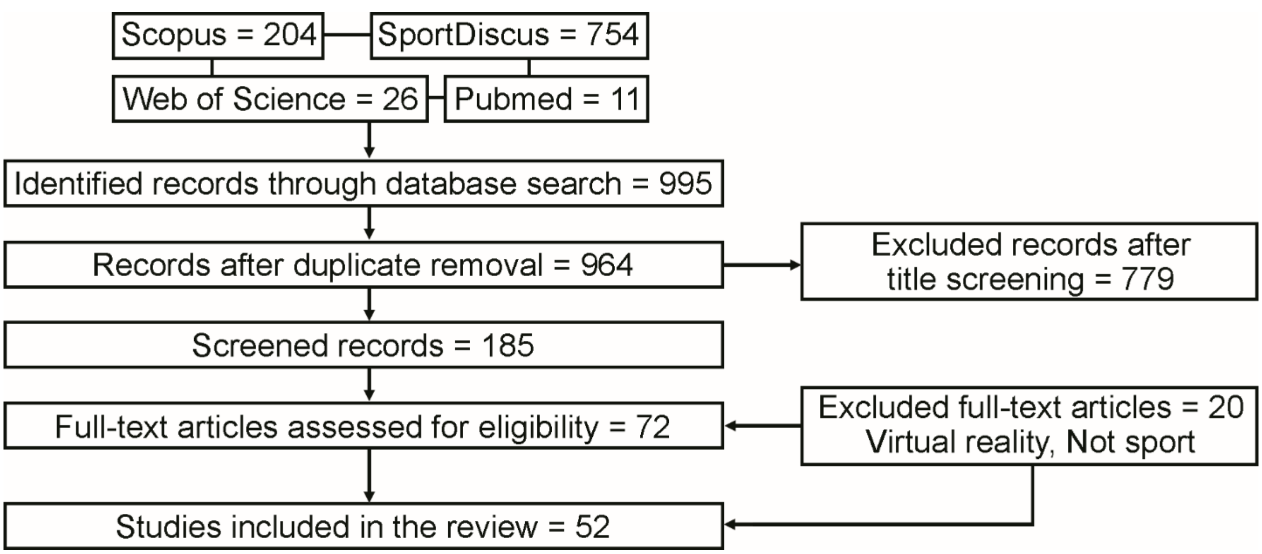

Figure 1: Flowchart of the search strategy.

Figure 2 shows that the AR systems mainly target practitioners and spectators, while some AR developments are marginally designed for coaches and customers. Summer Olympic games widely offer support for AR developments but Techno Sports, like Dodgeball, and casual games, like billiard and foosball table, also receive attention.

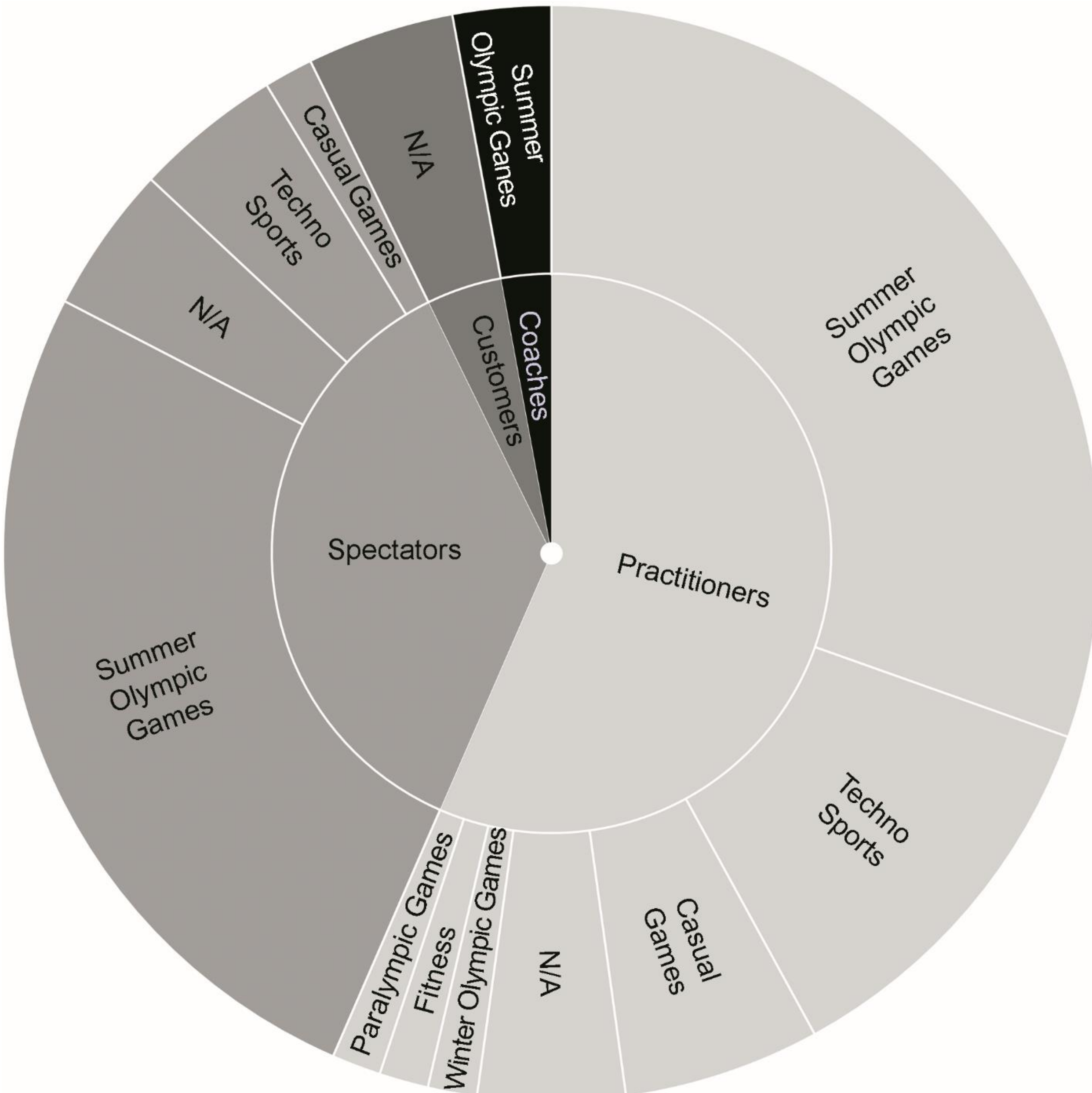

Figure 2: Distribution of the papers based on the roles of sportspeople (practitioners, coaches, spectators, and consumers), and the sports categories (Summer/Winter Olympic games, Techno Sports, and casual games) targeted by AR developments.

When focusing more precisely on sports, Figure 3 shows that basketball and rock climbing contexts provide the most fruitful frameworks for developing AR. AR inclusion for basketball may be explained by the possibility for enhancing practionners' environment and spectators' viewing experience. Basketball also provides a context for anchoring AR games in our everyday environment through mobile phones. Concerning rock climbing, one can first interpret this from a technical view-point, because bouldering surfaces have small areas and offer fixed hold-supporting calibration. The area is ideal for projecting virtual elements suchs as hold, path, etc. Second, from a perceptual-motor view-point, bouldering activity requires visual observation of holds and climbers, and allow displaying different form of guidance. Third, from a social view-point, AR displays can serve to motivate and stimulate climbers to go into an indoor gymanisium alone. Figure 3 shows that ball sports, such as football and baseball, can also benefit from AR developpments, partly due to advantages of AR layers for broadcasting and its ability to balance games and to enhance ball trajectories. Finally, Techno Sports, like Dodgeball or the Pokemon GO killer app, are well represented. Dodgeball is a basic ball game with simple rules that can easily benefit from the addition of an augmented layer. Therefore, it is easy to display and understand for both spectators and practitioners. Finally, Pokemon GO provides a nice excuse to investigate how AR can generate physical activity (PA).

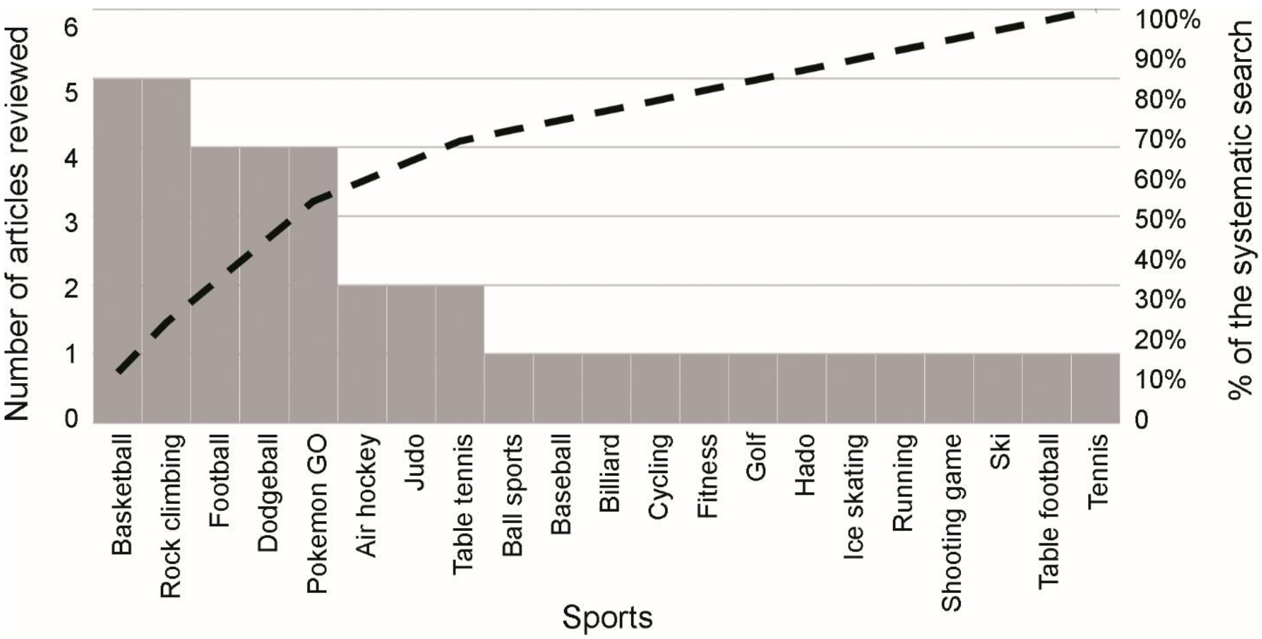

Figure 3: Pareto diagram showing sports that benefit from AR developments.

1. What are the charactrisctics of AR systems?

Limitations with video- and VR-based systems

In the past, video-based sports training methods received great attention, and their effectiveness in assisting visual-perceptual sports training was widely argued. For example, it has been shown that baseball players perform significantly better when training with life-sized video-based simulation than when training with real-world scenarios (Hopwood, Mann, Farrow, & Nielsen, 2011). Additionally, Yang and Lee (2016) showed that coaches' instructions concerning the defensive position of handball goalkeepers could benefit from the analysis of real videotaped matches. On the other hand, the impoverishment of informational content of 2D visual scenarios was found to be the major drawback of video-based methods because attentional focus and reaction time are also influenced by depth (Lee et al., 2013). With these limitations, players may not be able to pick up key information, such as parallax, and may not be able to interact with the system realistically (Aglioti, Cesari, Romani, & Urgesi, 2008).

VR-based training methods were recently introduced and offer several advantages for sports training over video-based methods (Craig, 2013; Miles, Pop, Watt, Lawrence, & John, 2012). For instance, Vignais et al. (2009) showed that goalkeepers' performance is better with VR simulator than with video clips. Such advantages can be attributed to the availability of stereoscopic information and viewpoint enslavement provided by VR. Additionally, VR could offer opportunities to design realistic scenarios for teaching and practicing real sports. It is possible to isolate one visual parameter while others are being controlled and modified. However, VR closes users off the real-world to enter a virtual one (Milgram & Kishino, 1994). When wearing a fully occluding HMD, users may have no visual reference relative to their surroundings and own body (Salisbury, Keshav, Sossong, & Sahin, 2018; Soltani, 2019). Moreover, the reproduction of the real-world in VR results either in too basic and unrealistic, or too expensive and sophisticated systems (Vignais et al., 2009). Finally, physiological discomfort such as VR sickness, head compression, and sweat, have also been reported while wearing VR headsets.

Characteristics of AR systems

AR hardware components include sensors, input devices, processors, and displays. Several technical solutions for merging real and virtual views have been proposed. Earlier versions of spatial augmentation relied on projecting information on un-instrumented surfaces for providing extra stimulation to the users. For example, Sodhi, Benko, and Wilson (2012) used human body parts to project information for completing the desired movement. As an alternative and not a very convenient solution to video-projection systems, a see-through video HMD captures the real-world view using one or two video cameras mounted on the HMD. The images collected by the cameras are then combined with computer-generated information and displayed for the user. Handheld displays are based on the same video AR principle but use a small screen that can fit in the user's hands. Recent smartphones usually contain AR components, but users have to hold them at their eye sights. Finally, head-up displays (HUD) typically use projector units, such as combiners, viewing glasses, and video generating computers. Eyewear based AR displays such as Google Glass are one of the most well-known headsets, but lacked eye-tracking and did not allow virtual objects to overlay real-environment. Microsoft HoloLens is currently the most diffused see-through HUD, and provides wireless solutions with high computing powers, positional and rotational tracking, gesture recognition, and spatial mapping. Users can interact with their surroundings using gestures, gaze, and voice. HoloLens also integrates the 3D virtual objects over the real environment, and anchors holograms to certain objects in the environment (Stropnik, Babuder, Crmelj, Vizintin, & Pogacnik, 2018). Additionally, AR contact lenses are currently under development and might project computer graphics directly into the eyes (Perry, 2020).

Table 1: Summary of reviewed papers evidencing the benefits of using AR in sport.

Reference	Name of the prototype	Sport	Benefits of AR for sport	Type of AR & augmentation	Human experiment protocol and outcomes
Baumeister et al. (2017)	N/A	No sport applicat ion	N/A	Spatial AR, Optical See-Through AR, Video See-Through AR & Visual Tags	Response times during a button-press procedural task; Learning cognitive load model increased performance and reduced cognitive load; Low FOV increased cognitive load
Godbout and Boyd (2012)	Corrective feedback & Awareness Feedback Training	Speed skating	Improving the skating periodic movements through learning, synchronizing the movements of a subject against the movements of a skater model	Audio AR & Interactive auditory feedback conveying information related to the matching between the subject and the model behavior	Kinematic analysis shows correcting movement upon training match that of the model
Itoh, Orlosky, Kiyokawa, and Klinker (2016)	Laplacian vision	Tennis	Assisting in predicting future trajectory of the ball bouncing on the floor	Optical See-Through AR & Visual overlay of the trajectory and the kinematics of bouncing balls	Judgments show that errors in judging ball motion can be reduced by AR, providing a correct angle of vision and full trajectory is not available
Jebara, Eyster, Weaver, Starner, and Pentland (1997)	Augmenting the billiards experience with probabilistic vision and wearable computers	Billiard	Enhancing the game of billiards	Optical See-Through AR & Visual overlays of primitives to suggest shots and assist targeting	Observation shows latency approximatively equal to 100 ms requiring smooth, slow head motion of the observer that must occasionally wait for the system's output
Kajastila, Holsti, and Hämäläinen (2016)	Augmented climbing wall	Boulder Rock-climbin g	Increasing diversity of movements; Enabling user-created contents; Enabling procedurally generate content	Projection AR & Visual overlay of hold composing rock-climbing routes	Survey showed interactive augmented visuals can increase the diversity of movements and challenges, e.g., timing of moves in an otherwise strength-centric sport ; Digital malleable content layer can empower users to become content creators with low risk compared to allowing users to actually modify the physical environment ; Digital content can be procedurally generated, which is useful especially for endurance training sessions of non-predetermined duration ; Increased spectator-athlete interaction and users forgetting their fear of heights
Kálmán, Baczó, Livadas, and Csielka (2015)	BlindTrack	Runnin g	Guiding blind runners along the running track	Haptic AR & Location and strength of the vibro-motors of a tactile belt indicates the correct direction	N/A

Kelly and O'Connor (2012)	N/A	Tennis	Improving amateurs' tennis swing by allowing direct technique comparison with elite movements between dedicated one-to-one coaching sessions	Video overlay on video playback & Visual overlay of elite athlete poses depicted as virtual 3D avatar on amateur video playback	N/A
Kuramoto, Nishimura, Yamamoto, Shibuya, and Tsujino (2013)	Augmented practice mirror	N/A	Improve learning	Mirror AR & Overlay the image of the learner's motion onto the teacher and enhance differences between them Visualize velocity and acceleration of the teacher' s motion	Survey showed no significant differences between the system, with and without visualization of velocity and acceleration
Mueller, Cole, O'Brien, and Walmink (2006)	Airhockey over a distance	Air Hockey	Creating social interaction by video conference hockey	Mechanical AR & Concealed mechanics on each table allow a physical puck to be shot back and forth between the two locations, creating a perceived physical shared space	N/A
Rogers et al. (2018)	KickAR	Table Football	Balancing players' skill levels by game or players triggers	Projection AR & Visual overlay of icons allowing changing game rules (boost or handicaps) in real time; Visual overlay of the path of the ball after goals; LED strips showing the scoring team	Survey showed skill-based control is preferred to game balancing; Perceived fairness of game balancing does not impact player experience; The visual design of game balancing, affects negatively players' perceived competence
Page and Vande Moere (2007)	TeamAwear	Basketb all	Enhancing awareness of game-related information	Individual Scoreboard & Jerseys depicting individual fouls, scores, and time alerts with electroluminescent wires and surfaces	Survey showed very limited influence of the displays on the players game decisions due to the fastpace and highly demanding cognitive load of the game itself ; Influence of the displays on players' self confidence level ; Positive influence of the displays on the game awareness for referees (more efficient decision), coaches (understand the game more profoundly) and spectators (make the game more enjoyable to watch)

Salisbury et al. (2018)	N/A	Contact sports	Measuring balance stability with smartglasses	N/A & N/A	Kinematics show head-based measurement produces similar results to waist-based measurement
Sano, Sato, Shiraishi, and Otsuki (2016)	Sport support system	Soccer	Improving beginner players skills to recognize what they should do next; Balancing players' skill levels during a game	Projection AR & Visual overlay of predicted ball trajectory and velocity + enhancement of the player positions in the field	Kinematics analysis showed improved reaction time in catching ball pass for players unable to predict ball-path and in the case of passing the ball from out of view
Sieluzycki et al. (2016)	N/A	Judo standing techniq ues	Training high-precision standing techniques	Mirror AR & Training avatar indicating optimal posture and 2D indicators depicting spatial deviations from model	N/A
Sodhi et al. (2012)	LightGuide	Martial arts, fitness	Directing the users toward optimal reach of the arm; Avoiding detrimental arm positions	Projection AR & Visual overlay of guidance information on hands for accurate movements information projection; Projection of information on the body and movement tracking	Kinematics analysis of hand trajectories showed movement accuracy (deviation and shape) and movement time (self-guided time and distance ahead/behind paths) better with projected AR compared to video
Sörös, Daiber, and Weller (2013)	Cyclo	Cycling	Assisting biking an allowing collaborative training	Optical See-Through AR & Embedded windows with video, track overview and map notification	Survey showed performance measurements and physiological sensors are important for bikers; Users want to compare their performance with other users
Wiehr, Daiber, Kosmalla, and Krüger (2016)	betaCube	Rock Climbin g	Enabling a life-sized video replay and climbing route creation	Projection AR & Visual overlay of the replay of a shadow climber, position of holds	N/A

Witkowski et al. (2016)	N/A	Judo	Training Judo without the need for a partner with feedbacks	Optical See-Through AR, Projection AR & Visual overlay of virtual models on actual image of an athlete performing a throw or other judo techniques; Icon or projected background color showing the deviation from the adopted model	N/A

N/A: Information not available; AR: Augmented reality; FOV: Field of view.

2. What are the benefits of Using AR in Sport?

In this part, we present the main benefits of using AR in sport. We outline the use of AR for learning sports skills, providing additional information, providing additional feedback, stimulating practice, as well as, introducing new rules and creating new sports. Table 1 summarizes the reviewed articles.

Learning sports skills

Previous review articles have identified some of the AR features for improving learning, including increased content understanding through AR compared to other types of media, long-term memory retention, improved physical task performance, and improved collaboration (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018; Radu, 2014). While some of these areas of general learning overlap with sports, others are unique to sports education and training. Within sports contexts, learning visual cues could inform players about the dynamics underlying sports movements (Fery & Ponserre, 2001). AR systems could fuel players' sensory modalities with augmented information to help them understand their real environment. Earlier versions of sports vision training showed inconsistent results, which leads to questioning the effectiveness of such training methods. For example, video analysis lacks real-time feedback, and performers have to try different movements over and over. Recent approaches are including perceptual learning methods to create more specific and robust training. Learners are exposed to several situations, allowing them to develop knowledge of different domains, which could lead to faster decisions (Fery & Ponserre, 2001). Although visual displays play the dominant role in communicating information to the user, they might be limited to providing stimuli related to features and events occurring in the direction that users are facing. Audio cues could provide additional information about the surrounding environment to the user. Tactile sensorial feedback such as texture, temperature, and vibrations may also serve as mechanical interfaces between our bodies and the physical world.

By using AR, both skill training and naturalistic sports scenarios might be executable at the same time. Technological augmentation could also reduce the focus on natural human abilities, and could emphasize the skills and abilities for harmonizing with technology (Chernyshov, Ragozin, Chen, & Kunze, 2018). It also considers the players' competitiveness, PA, and entertainment. Fery and Ponserre (2001) used an example of golf, and showed a positive skill transfer from digital games to the real sport. Witting (2010) also showed that it may not be necessary to include all the real sports actions into the gaming scenario, and athletes can still benefit from the gaming only by observation. Baumeister et al. (2017) mentioned that limited fields of view (FOV) could increase cognitive load requirements, and special AR displays could increase performance and reduce cognitive load.

Providing additional information

The central aspect of using AR for imrproving sports skills relies on the possibility to provide additional information for helping users to decide and regulate their behaviors. In this case, artificial information is overlayed on the real situation to enhance the user's understanding and knowledge. It has been shown that offering additional information, especially to novice players (player balancing), might improve their experience, enjoyment, and immersion (Denisova & Cairns, 2015; Rogers et al., 2018). For example, Sano et al. (2016) projected players' positions to help beginners to improve their decision-making skills in football (Figure 4). Rogers et al. (2018) projected icons, indicating boosts and handicaps, over table foosball to influence the game play and to adjust for different player skill levels. Kelly and O'Connor (2012) developed a visualization tool for tennis that augmented information about technique, timing, and body posture. Players' movements were aligned and compared with an experienced player, and the results were projected on players' video recordings. However, no experimental evidence of the benefits offered by this tool was provided. Sodhi et al. (2012) created a real-time guiding system that projected the hints directly on the users' hands. They showed that the participants could perform movements more accurately compared to guidance by video.

AR can also help coaches to explain complicated sports concepts such as orientation-specific knowledge. In a rock climbing context, Wiehr et al. (2016) used a self-calibrating projection system that acted like an experienced climber, and allowed life-size video-replay and climbing-route creation. The climber could choose between two display modalities; During the offline modality, the climber's performance was recorded and analyzed. This modality could be used to explain difficult parts of a route using video and supportive materials. During the shadow-climbing display modality, the climber follows a previously completed climb, displayed on the climbing route. It allows the climbers to precisely adjusting their body posture to those performed by other climbers. The system could also be used with telepresence, which offers a powerful interaction when climbing with other climbers.

The complementary information capabilities of AR systems can be useful in various sports activities. With the help of wearables and external tracking systems, AR applications may be used to calculate the speed and the accuracy of moving objects. Itoh et al. (2016) used a vision augmentation system that could estimate objects' trajectories and predict their future positions. They showed that players' accuracy in estimating the future ball landing position increased by three times when using their system. Additionally, the span of sports applications transcends traditional ball sports. For example, Jebara et al. (1997) displayed hits for billiard players to enhance the learning experience. When appropriately designed, augmented feedback might also motivate and guide motor learning better and faster than video playback or coach feedback (Kajastila et al., 2016).

Sport-specific information can be added to AR systems to improve skills. For instance, Sörös et al. (2013) developed a personal assistant for bike training and imported the relevant parameters by conducting surveys. They showed that performance measurements, such as current and average speed, distance, stopwatch, and burnt calories, as well as, performance comparison to other athletes, navigation, assistive notifications, video recording, virtual trainer, communication, interaction, and durability are important for bikers who used their system. In the case of track and field, speed measurements, trajectory highlights, and comparative display of various attempts, are interesting to be included in the training scenario. The ability to navigate freely within the scenery and replay options are also important for the athletes (Demiris, 2014). In ball sports, relevant additional information has also been studied. Page and Vande Moere (2007) mentioned that individual fouls, scores, and time alerts are important in basketball. They also showed that displaying such game-related information to the players in real-time, increases their awareness and would positively influence in-game decisions. Additionally, Hebbel-Seeger (2015) mentioned elements that could be implemented in a basketball AR game. Distance from the rim, current and highest score, and time countdown could be included in the training. The application had a mere symbolic adaptation of basketball, which was swiping for shooting instead of throwing. However, the authors anticipated an action transfer based on the moments of similarity between virtual and real-world schemes. Individual sports also need customized additional information. Smith and Loschner (2002) used a biomechanical analysis of rowing, to identify the variables that are linked to boat speed. These variables could be shown on water or simultaneously on video after the event. Kálmán et al. (2015) also developed AR glasses that provided controlled light and contrast levels and allowed selectable features on players' FOV. They also developed a guiding system that used wireless localization and provided haptic feedback at the belt level for blind runners.

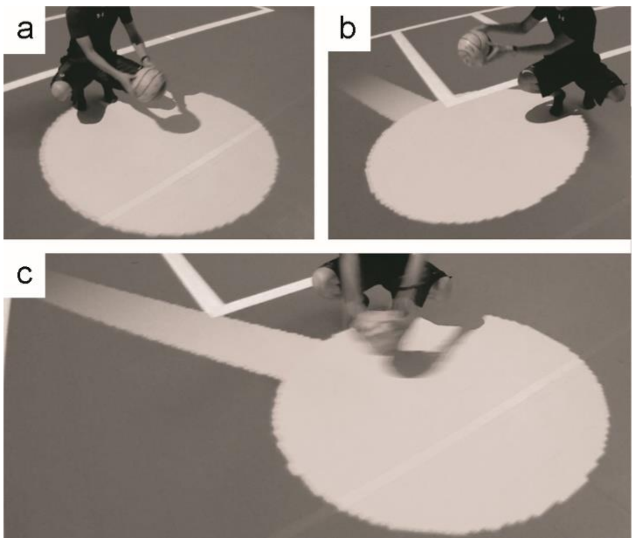

Figure 4 : Providing additional information might improve players' decision-making and action regulation. Here, the projected additional information shows the predicted path of a ball (a) stopping, (b) moving slowly, and (c) moving quickly (figure was aquired from Sano et al., 2016).

Providing additional feedback

Performing the correct movements in sports is important to achieve certain goals and to avoid injuries. AR systems may allow accessing additional feedback about performance and behavior. Frequent terminal (after task execution) and concurrent (during task execution) feedback are crucial for learning simple motor tasks, and could be supportive for complex tasks. Sigrist, Rauter, Riener, and Wolf (2013) compared different visual, auditory, and haptic feedback while learning a complex rowing task. They showed that terminal visual feedback is important in the internalization of task-relevant aspects. On the other hand, concurrent feedback helps to correct errors that might hinder learning. Additionally, concurrent visual and haptic feedback had better effects compared to auditory feedback. It seems that a combination of concurrent and terminal feedback would be most effective when the feedback strategy is adapted to players' preferences and skill levels. For effective verbal and visual feedback, Jeraj, Veit, Heinen, and Raab (2015) developed a heuristic model of error correction, to identify six feedback factors of visual perspective, visual experience (visual gaze strategies when observing and judging the movements), motor experience, personal coach-athlete relationship, methodological knowledge, and biomechanical knowledge that might influence the error-correction process in gymnastics.

AR feedback capabilities could also be used for visualizing the experience, and for revealing a "before and after" state. Gradl, Eskofier, Eskofier, Mutschler, and Otto (2016) showed that 43% of the athletes think that using AR could improve their performance. Athletes may wear unobtrusive AR headset and receive individualized feedback from their coaches. This allows for faster integration of new players or reduces the time required for the entire team to improve their positioning and learn new tactics (Gradl et al., 2016). AR devices might also provide real-time feedback to correct balance instability during movement (Salisbury et al., 2018). It has been shown that immediate verbal feedback increases swimming stroke length and velocity (Zatoń & Szczepan, 2014). Additionally, Kuramoto et al. (2013) used a special interactive video mirror system that overlaps teacher's movements with the learners'. They used colors to show changes in the velocity of the limbs and arrows to show the changes in acceleration.

Stimulating practice

By increasing diversity of the movements and challenges, and enabling personalized content creation, digital augmentation can contribute to the improvement of sports performance. Previous research has shown that intentional use of some AR games can accumulate the recommended levels of daily/weekly PA (Fountaine, Springer, & Sward, 2018). Additionally, Hsiao (2013) developed an AR learning system that combined learning activities with physical fitness, and showed improvements in players' academic lessons. Ryan and Duckworth (2017) used commentary, crowd sounds, and music in a basketball entertainment augmentation, and showed that it could amplify the reality experience in urban play spaces. Principles of game design could be implemented in AR applications for motivational reasons and to make the experience challenging (Dunleavy, 2014; Santoso, 2018). Novice learners usually mimic experienced players' movements by watching recorded videos. Based on this observation, Soga, Nishino, and Taki (2011) developed a self-training system for archery with an expert's body animation. Similarly, Mishima, Okamoto, and Matsubara (2014) proposed a skill learning support method, where the player imitates a previously recorded model virtual instructor. They showed possible skill acquisition at lower speeds for novice players. Godbout and Boyd (2012) synchronized the periodic movements of players against a model using corrective auditory feedback in real-time. Both experienced and novice players showed improved stride rates within a few training sessions. Finally, sports training with AR could be repeated individually or with a distant partner (Rebane, Shijo, Schewe, Jiang, & Nojima, 2018; Witkowski et al., 2016).

Introducing new rules and creating new sports

AR systems may benefit users in introducing new rules to the games (Table 2). AR allows introducing an additional virtual layer that is managed and updated in relation to the actions in the physical world. In this case, the game itself does not change, but the virtual layer induces changes in players' strategies. Introducing parameters in the virtual layer allows compensation for disequilibrium between players' real physical abilities and skills. When the virtual elements are overlayed onto the physical worlds, they can help balancing players' differences in technical abilities. For instance, Sano et al. (2016) visualized the ball velocity and trajectory to help novice soccer players. They suggested that their system can improve reaction times in passing and receiving the ball for beginners compared to more skilled ones.

Implementing video games elements, such as game controller, scoreboard, and soundboard, into a physical setting, might transform the experience of social sports (Storebjerg et al., 2016). For example, players began to play defensively when they were ahead in the score and more offensively when they were about to lose. In augmented sports, physical events of real sports are also used to create virtual parameters in forms of points and powers, to reduce the gap between the players (Nojima et al., 2018). AR allows playing with real rules while a real part of the game is missing. For example, Baudisch et al. (2014) created new game dynamics that mimicked real basketball, including physical exertion and social interaction between players, with no visible ball. Players learned about the ball position from other players' actions and occasional auditory feedback. Here, the original game rules did not change, but since sport equipment, or ball, was missing, the gameplay was more focusing on players' collective displacements than on individual throwing skills. Another example is a collaborative AirHockey, in which players used a virtual puck while sharing the physical game environment (Ohshima, Satoh, Yamamoto, & Tamura, 1998). Finally, in augmented dodgeball, the original game rules do not change despite the fact that the opponent is physically missing (Rebane et al., 2018). By emulating the puck with realistic physics and projecting the other player onto a screen, AR systems compensates the missing opponent. The fast-moving puck between players creates a social game experience that could contribute to social interactions and an increased sense of connectedness.

AR systems can be used as roots for designing new sorts of games. For instance, sport and AR technology were used to create "Hado," in which virtual energetic balls are thrown with real movements to smash opponents, while a virtual shield allows preventing from opponent's attacks (Araki et al., 2018). A Hado World Cup is organized since 2016, with players from different countries, allowing them to win upto $120000. Similar to Hado, Techno Sports or Super Human Sports promise to recruit more and more practitioners with their developments, including partnerships with the Olympic movement (Kegeleers et al., 2018). We can also exploit other features of AR technology to create new games. For instance, the perception of the real world can be diminished, while maintaining the physical elements of the games, such as balls (Sakai, Yanase, Matayoshi, & Inami, 2018). This can allow practitioners to develop the use of sensory cues.

Table 2: Advances in AR for promoting physical activity, changing rules, and balancing players experience.

Reference	Name of the Prototype	Sport	Benefits of AR for sport	Type of AR & augmentation
Baudisch et al. (2014)	Imaginary Reality Basketball	Basketball	Maintaining many properties of the physical sport while introducing game elements from video-games; Creating a new game dynamic around the notion of an invisible ball	Audio AR & Ball position deduced from sounds
Chernyshov et al. (2018)	DubHap: a sensory substitution-based Super Human Sport	Collective Battle game	Augmenting the human abilities using technology in order to give players certain "superpowers" that can balance the skills levels of the players	Haptic AR & The sensing of the projectile is purely haptic
Escaravajal-Rodríguez (2018)	Pokemon GO	-	Contributing to PA, social relations, and discovery of the city and nature	Video See-Through AR with mobile phone & Overlaying virtual elements
Fountaine, Springer, Sward, 2018	Pokemon GO	-	Contributing to PA	Video See-Through AR with mobile phone & Overlaying virtual elements
Kegeleers et al. (2018)	Superhuman Training in Augmented Reality (STAR)	Shooting adventure game	Promoting PA through a collaborative immersive experience that augment superhuman abilities	Optical See-Through AR & Overlaying virtual elements, such as robots, laser beams, and paths
H. Kim, Lee, Cho, Kim, and Hwang (2018)	Pokemon GO	-	Contributing to PA with an unconscious motivation	Video See-Through AR with mobile phone & Overlaying virtual elements
Nojima et al. (2018)	N/A	Dodgeball	Motivating people to become physically active; Improving spectators' enjoyment	Optical See-Through AR & Scoreboard + wearable parameter indicator consisting of four LED bars that allow checking the actual game situation and virtual parameters simultaneously; Overlay players' role icons and current life point on HMD

Rebane et al. (2018)	Augmented DodgeBall	Dodgeball	Balancing physical skills with virtual powers to induce a more strategical game and to avoid relying solely on the physical skills of the player	Scoreboard & Player's information
Ohshima et al. (1998)	AR²Hockey: Augmented Reality Air Hockey	Air Hockey	Sharing physical game elements but interacting with a virtual puck	Optical See-Through AR & Overlaying the virtual puck on the physical table
Sakai et al. (2018)	D-Ball: Ballgames that use diminished reality technology	Collective Physical Ball Game	Experiencing ballgame as if they were in a video game from the 70s; Engaging players with different skills and sport experience; Viewing the game from various level of diminishment	Diminished reality with Video See-Through mobile phone & Watching only specific colored objects and features from the real environment, including balls, lines, and markers attached to players that have similar color

PA: Physical activity; N/A: Information not available.

Interacting with sports events

Recent advances in AR systems could also improve sports events viewing experience (Table 3). Live events organizers are competing for new ways to attract visitors through integrating sensors, cameras, and digital signs. Passive ways of sports content consumption have been replaced by interacting with related content and social sharing (Thompson & Potter, 2017). Sports broadcasting is an ideal case for adding interactive scenarios and providing additional information about the event to the viewers (Figure 5). For example, S. Lee, Ahn, Hwang, and Kim (2011) implemented a vision-based AR system that displayed supplementary information about the position of each player during the baseball game. Such algorithms could identify players during matches and address the comments to them during debrief sessions (Mahmood et al., 2017).

Figure 5: Adding information using virtual elements might improve viewers' experience. On the left part, virtual elements overlayed on the live transmission, allow displaying statistics about the two American football teams. On the right part, virtual elements are displayed on a match replay and provide information on ball trajectory and match state (score and time), and allow viewers to see the match from desired viewpoints.

A merge of AR and live sports broadcasting may also lead to a better comprehension of sports events. The Hawk-Eye system is the most recognized example of AR systems that is no longer limited to electronic line-calling feature, and has been extended to be used for coaching tennis or cricket. Therefore, augmented broadcasting technology allows viewers to see relevant content and match information (S. Kim, Choi, Jeong, Hong, & Kim, 2014). In this line, Monji-Azad, Kasaei, and Eftekhari-Moghadam (2014) proposed an AR method for adding information to sports scenes from a single moving camera. Such algorithms are useful for match summarization, match analysis, and referee assistance (Figure 6). Such tools can also help coaches and players to generate individual profiles of the players, teammates' coordination, and thus, to evaluate physical and tactical performances. These tools can also be used to prepare competitions by characterizing the future opponents' playing styles.

Figure 6: Providing additional information to sports scenes might improve viewers' experience and help the referee's decision-making.

AR platforms might also provide sharing, collaborative training, and social features to create, share, communicate, and define goals and challenges for the participants (Daiber, Kosmalla, & Krüger, 2013; Kajastila et al., 2016; Ohshima et al., 1998). With AR, users may be encouraged to take more risks as a measure of progress (Tiator et al., 2018). Users can also benefit from AR to increase their awareness of hazards. For instance, Fedosov et al. (2016) developed a wearable ski AR system that allowed skiers to share personal contents and maps of the routes taken, to improve decision making, and to avoid hazards when going off the track.

Enhancing customers' choice

Advances in AR can finally benefit sports customers as the technology can help practionners to project themselves in sport gears. Current works focus on the best way to shop sports shoes and look more suitable for meeting the fashion expectations of customers (Brito & Stoyanova, 2018; Eisert, Fechteler, & Rurainsky, 2008; Eisert, Rurainsky, & Fechteler, 2007). One can imagine that in the near future, such features can help outdoor practionners to choose the filters of their sunglasses to understand whether they are suitable for marine navigation. It can also help customers to choose their ski by watching the expected carving trajectories of a specific model.

Table 3: Advances in AR for enhancing sport broadcasting.

Reference	Sport	Benefits of AR for sport	Type of AR & augmentation
Daiber et al. (2013)	Boulder Rock-climbing	Supporting collaborative sports training by creating, sharing, and defining goals and challenges together with friends	Video See-Through AR with mobile phone & Visual overlay of hold composing rock-climbing routes
Fedosov et al. (2016)	Ski and snowboarding	Allowing groups of skiers and snowboarders to share and review personalized content, such as pictures, tracks, hazards, and POIs	Video See-Through AR with mobile phone & Overlayed content on a printed panoramic resort map
Kajastila et al. (2016)	Boulder Rock-climbing	Increasing the diversity of movements and enabling user-created and procedurally generated contents	Projection AR & Visual overlay of hold composing rock-climbing routes
S. Lee et al. (2011)	Baseball	Augmenting meaningful information on each player's position during a game using homography-based algorithm	Video See-Through AR with mobile phone & Tags with name, team, positions, and statistics of players and the game
Mahmood et al. (2017)	Sport ball	Improving the accuracy of the players and face detection and recognition using image enhancement technique to display useful players' statistics on captured images of a sports game	Video See-Through AR with mobile phone & Image tag
Monji-Azad et al. (2014)	Football	Inserting virtual content in video, independently of the camera FOV, through homography-based algorithm so that it appears as a part of the original scene	Video overlay on video playback & N/A
Thompson and Potter (2017)	Stadium sports	Enhancing live-sport experience through gamification and social sharing (share and see emotional reactions and predictive plays)	Icons overlay on video playback & representing primary emotions

Stropnik et al. (2018)	Football	Augmenting the viewing experience of a sports match by displaying statistical sport data provided by Sportradar	Optical See-Through AR & Separate virtual panels displayed on each side of the screen; Information include names of teams, number of fouls, off target attempts and red cards, as well as the team formations, amount of (virtual) money the spectators wish to bet

AR: Augmented reality; POI: Point of interest; FOV: Field of view; N/A: Information not available

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Discussion

Summary

Because of limitations of current video-based and VR systems, AR could offer alternative scenarios for sports education and training. This includes visual, auditory, and haptic feedback for learning and exploring abstract concepts. It may not be necessary to include all elements of real sports inside the system, and players can still benefit from the gaming scenarios, only by observing. Providing additional information, especially to novice players, may improve their experience. It may also help coaches to explain complicated concepts. Different feedback modalities, during and after task execution, could provide information and advice on players' performances and behaviors. New rules could be added to the existing games, and could reduce the gap between different players. By augmenting relevant information, AR systems could also improve viewers' experiences. Additionally, by increasing the diversity of movements and challenges, and by allowing personalized content, AR training might contribute to the improvement of performance (Figure 7). On the other hand, systems are still under development and evaluation for commercial and professional use. Issues related to tracking, display, latency, as well as content, ergonomics, and design issues, should be addressed.

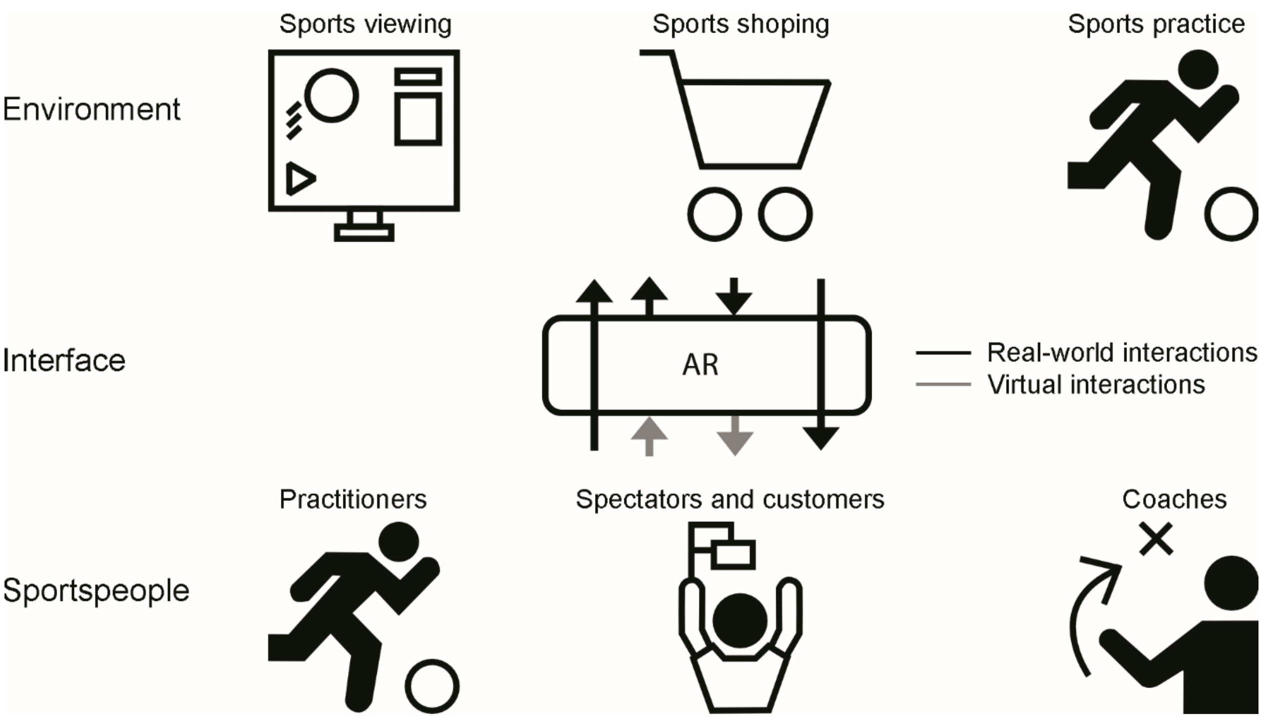

Figure 7: Sketch of using AR systems in sports. Practitioners, coaches, spectators, and customers can benefit from AR to improve learning, to enhance event watching, and to project themselves into shopping (figure adapted from Rekimoto, & Nagao, 1995).

Designing AR systems for sports

Designing systems for sports AR experiences requires overcoming various challenges. Before following specific guidelines that are more relevant to sports training and education, AR designers have to be up to date with other domains of AR application, including the industry and defense. Several ergonomics recommendations that have been developed to translate information into HUD, may be applicable only to a limited range of sports, such as mechanical sports or cycling. However, in the historical domain of AR application, the user-centered design approach has promoted specific tools, such as Work Domain Analysis, as well as procedures, such as Ecological Interface Design. These processes provide additional virtual contents in accordance to the needs of the users. Second, AR designers must consider the specifications of sports practice from the action and perception perspective. From an action viewpoint, sports impose complex interlimb synergies, with wide amplitude movements. Using miniature devices has to be promoted to prevent tearing sensors or displays. For example, improving basketball throw by displaying ideal ball trajectory into bulky see-through glasses will disturb the natural inter-limb coordination, as the ball and hands pass close to the eyes. Sports also require high-velocity movements, and therefore, high acquisition frequencies of sensors and high refresh rates of displays must be used. This prevents visual augmentation slip and decalage between virtual objects and real images. From a perception perspective, sports rely on finely-tuned perceptual-motor strategies. The content of the additional AR information must rely on the knowledge of information picked-up for a given level of expertise. The timing of the additional AR information must be rooted in established modelized perception-action coupling processes. Finally, the availability of the additional information during learning has to follow guidelines that have emerged from the distribution of feedback during sport-skills acquisition.

We targeted some specific perceptual, social, and technical recommendations for illustrative purpose. Kajastila et al. (2016) mentioned that climbers should be aware of their bodies in space and in relation to the projected graphics. This means that they should be able to observe the whole scene, but interact with a part. The systems should prevent cheating by adding goals, intrinsic motivation, robustness, and adaptability to real-life conditions. To improve the predictive capabilities of AR applications, a combination of object tracking, trajectory prediction, spatial calibration, delay compensation, and rendering techniques is needed (Itoh et al., 2016). For example, Park, Kim, and Yoon (2006) showed that for an enjoyable and social experience, physics and speed could still be chosen randomly. Reference models of sports techniques should be adapted to the basic features of the player, such as weight, height, age, and training experience. Depending on the device, feedback, deviation from the model, and command to correct, given motor activity should be provided continuously (Witkowski et al., 2016). Additionally, Kosmalla, Daiber, Wiehr, and Krüger (2017) compared different feedback methods for demonstrating climbing techniques. They showed that neither augmented third-person video, nor full-size video of the instructor on the wall, could offer an overall solution for in-situ video feedback for climbing. They suggested that a hybrid approach might be viable in other sports. Human-computer interaction issues, such as natural and intuitive interaction, ergonomics, appearance, and social compatibility, as well as cost, weight, and power consumption, should also be addressed (Stephanidis & Kaasinen, 2015). Sharing information about other players, such as heart rate, could improve the richness of the interactions between the players, but might also increase the stress levels (Frey, 2016). Finally, creating motivating scenarios to keep players active is more important than the current limitations of AR hardware (Kegeleers et al., 2018).

Systems technical limitations

For efficient operation of AR systems, a combination of calibration, tracking, registration, and display is necessary. Despite the commercial availability of AR systems, many custom arrangements of tracking, computing, and display devices are still experimented in parallel. Like VR, we can arrange AR systems with tracking devices that can enslave the virtual elements to the real-world view. These systems could use real-time 3D software to render the images to the user's eyes. Facing a wide range of technologies, several AR taxonomies had been proposed (Hugues et al., 2011; Milgram & Colquhoun, 1999; Milgram & Kishino, 1994; Milgram et al., 1995). In the next paragraphs, we reviewed the major concerns regarding the tracking, display, and software.

First, we must address tracking according to the sports activities. Earlier AR sports applications used tabletop approaches that required printed markers, and may not be applicable to action sports, where players have to run, jump, or shoot (Santoso, 2018). Newer AR engines allow markerless setups where space and objects are computer generated, and players can have more realistic experiences. Demiris (2014) argued that markerless tracking, real-time human motion calculation, and realistic merging of real and computerized objects in augmented views, play a central role in players' acceptance. The Microsoft Kinect is probably the pioneer emblematic low-cost markerless tracking system, which can be used for calibrating AR displays (Kosmalla et al., 2017). However, Kinect's limited application for complex movements, such as standing techniques in Judo stems from its inability to see the body parts in the optical shade (Sieluzycki et al., 2016). This limitation can be resolved with machine learning and computer vision algorithms that could be used to improve the accuracy of such systems (Mahmood et al., 2017). In any case, the accuracy of AR systems must be tested since the human visual system can detect slight shifts between the virtual image and the targeted actual display location. Therefore, AR applications are less tolerant to tracking errors than VR applications (McLellan, 2004). Additionally, sensors' FOV and depth measurement noise are increased with distance. Therefore, users' anthropometrical properties, such as children's small hands, may not be detected correctly leading to extra noise. Sakai et al. (2018) mentioned that changing the size of the playing area, allows adjusting the offensive and defensive movements. The greater width of the field results in easier scoring, and a higher length of the field results in a longer stay of the ball in the defense field.

Second, displays have to be carefully selected to avoid detrimental effects. When using VR technologies for viewing sports activities, the user's ability to interact with others is limited (Stropnik et al., 2018). On the other hand, users observing an avatar with AR gears, sense a lower level of co-presence compared to VR tools. That might be because of uncomfortable and heavy motion capture suits and smart glasses (Koskela et al., 2018). The poor and narrow FOV may also contribute to lower co-presence. Although Microsoft is now proposing a larger FOV for the Hololens 2, the limited FOV of most AR devices (e.g., 30 × 17.5° for the HoloLens, 43 × 29° for the HoloLens 2, 40 × 30° for the Magic Leap One, and 50 × 18° for the ODG R-9) could be compensated by keeping the virtual components at a relevant height (Kegeleers et al., 2018). Additionally, multiplayer and speed of movement should be adjusted according to the capabilities of the AR devices (Kegeleers et al., 2018). Finally, biomechanical constraints induced by the HMD on the player's neck have to be evaluated (Chihara & Seo, 2018; Cometti, Païzis, Casteleira, Pons, & Babault, 2018).

Third, when arranging tracking, computing, and display systems, attention must be given to latency or the time lag between the player's actions and system responses. Latency is the primary factor that detracts players from the sense of presence. It interrupts the proprioceptive cues of the player and the visual stimuli shown on the display (Buker, Vincenzi, & Deaton, 2012). Latency depends on the process, transport, and synchronization delays of the components, and can affect the performance and usability of AR systems (Papadakis, Mania, & Koutroulis, 2011). As computers are getting more powerful, the time to complete each process could be decreased, and the latency could get closer to zero. Additionally, humans can adapt to the latency with learning (Morice, Siegler, Bardy, & Warren, 2007). However, the latency should be processed carefully when using AR systems because the delayed visual movements of mixed virtual objects can be compared with the resulting behavior of the actual scene.

Efficacy and perceptual concerns

As shown in the previous section, the primary focus of the AR was on technology, and content was an afterthought. However, AR is no longer about technology, but about defining how we want to design meaningful scenarios to help sports performance. Kim et al. (2018) suggested that AR games may not increase self-efficacy. However, by increasing enjoyment and attitudes, these games could lead to increased intentions of use. Earlier versions of AR were limited by input devices, such as cheap video cameras. For example, it was only possible to track the human gestures and not the paddle in table tennis games (Park et al., 2006). Natural perspectives, shading, and infinite depths of field were also absent when using 2D displays, causing various perceptual issues. For example, Jakl (2004) showed that missing, unrealistic, or wrong shadows relative to virtual objects, led to the error of depth perception in basic catching tasks. By manipulating the position of virtual objects in depth, Binetti et al. (2019) showed that users might be less capable of extracting behaviorally relevant information, that is signaled by users' gaze behaviors. Additionally, Pascoal and Guerreiro (2017) mentioned that AR might lose its purpose and disperse user's attention, if too much contextual information is presented.

Risk of injury, insufficient warning, and adaptability to the rules of the existing sports may also arise. Escaravajal-Rodríguez (2018) reported that about 10% of his participants suffered from accidents with other objects while playing an AR game. Psychophysiological impacts such as nausea, simulator sickness, cyber sickness, visual motion sickness, eye strain, disorientation, and perceptual illusions can cause a range of symptoms that can last from several minutes to several hours (Ling, Nefs, Brinkman, Qu, & Heynderickx, 2013). Moon et al. (2015) showed that the players' lower body movements were increased in a ski AR simulator, and may contribute to increased muscle fatigue. Converting and fitting digital data to the visual field, negative marketing, and privacy issues have also been mentioned among the limitations of AR systems (Bhakar & Bhatt, 2018). Sigrist, Rauter, Marchal-Crespo, Riener, and Wolf (2015) compared augmented visual, auditory, haptic, and multimodal feedback in motor learning. They showed that although online visual feedback is more effective in complex tasks, the performance gain is lost during the retention tests. Kajastila et al. (2016) and Sigrist et al. (2013) also showed that such continuous access to information, builds up a dependency upon feedback.

Future research

Future research should consider the development of AR technology. As AR is enabled in modern phones, users can start to understand and interact with this technology. AR systems could act like bridging devices for a large part of the sports communities, such as children, educators, coaches, and parents, as we make the shift to other technologies. Future systems should be lighter, less intrusive, more integrated, and with stable and standard interfaces. With bulky optics of current VR displays, the industry might shift away from the flat panel and fixed focus HMDs, towards multi-purpose augmenting displays. Additionally, hardware improvements could allow communicating more information with voice and hand gestures. However, the ultimate success of AR systems will be based on disruptive content and innovative applications. To rethink and redesign present sports and to adapt them to the new age, several levels of philosophy, engineering, visual and game design, as well as marketing and entertainment should be considered. Game rules and core mechanics could be adjusted based on certain abilities and affordances that are offered by technological tools (Chernyshov et al., 2018). Additionally, if an idea is better served with video or VR, we should direct athletes to those mediums. There should be a careful balance between dreaming about possibilities and finding how we can deliver real practical value.

Future research should also explore how adding extra information, affects players' communication styles and timing of their actions. Adding more digital elements, such as replay function for augmenting social sports, could be explored further. The misconception of AR being just visual is still true today; However, audio and other senses may create transportive and transformative experiences, and their effects on performance and interaction are to be explored. Reliance on technology, and how it affects sports skills is to be answered; Especially when real life might seem dull without digital augmentation. Negative side effects such as constant access to information could lead to shorter attention span and memory problems. The effects of diminished reality could be explored further as information fatigue becomes more prevalent.

Conclusions

In this article, we reviewed conceptual and empirical studies on using AR for sports education and training. We proposed different systems for receiving, processing, and displaying the information. We showed the possibility of AR systems for learning sports skills, providing additional information and feedback, stimulating practice, introducing new rules, and creating new sports.

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