Journal of Physical Education and Sport ® (JPES), Vol 19 (Supplement issue 5) Art 254 pp 1740 – 1747, 2019
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

ICTs for exercise and sport science: focus on augmented reality

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Published online: October 22, 2019
(Accepted for publication: October 15, 2019)
DOI:10.7752/jpes.2019.s5254

Abstract:
Nowadays, Virtual Reality, Mixed Reality and Augmented Reality are providing users with new and innovative forms of interaction with computer systems. Their applications cover a wide range of possible domains like business, architecture, videogames, marketing, healthcare, and so on. Among the aforementioned domains, it is possible to recognize also that of Exercise and Sport Science. In particular, in the last years, the goal of applying such technologies to sport is moving from improving the experience of audiences (broadcasting, merchandising, etc.) to aiding more effective and efficient training methods. Moreover, also the assessment of athletes could benefit from the application of such kind of technologies. In this context, it is crucial to design and deliver learning activities (also in e-learning) aimed at improving knowledge and skills related to these three technologies in sport scenarios. In particular, Virtual Reality and Mixed Reality are already exploited by consoles for videogaming and can be also considered tools for sport training, whilst Augmented Reality represents, today, a new frontier and can play an important role for training if it is finalized to improve the performance of athletes but also their abilities related to technical and tactical aspects. Furthermore, Augmented Reality is a very important enabler for giving the chance, to sport persons, to observe, analyze and correlate their data during the training session in a way to exploit the advantages of situated training. In this field, computer scientists can provide an important contribution to all the phases related to data management, from data gathering to data processing and data visualization.
Key words: augmented reality, sport sciences, training, education, situation awareness, granular computing.

Introduction

More and more, Information and Communication Technologies (ICT) are playing a main role in educational activities and sports. The ICT impact on physical education is mainly recognized on its capability to assist teachers in motivating students. In fact, in the past decade, time-motion analysis systems (e.g., video recording, hand notation) have been used to determine physiological measures and, of course, to improve athletes' performance. Thus, research activities have been focused, especially, on characterizing the locomotors demands of team sports given that the majority of sports asked for them. Today, a shift has been realized thanks to the diffusion of wearable devices able to identify sport-specific movements to better assess the demands of sports and to support physical preparation, injury prevention and technical analysis (Hirsh, 2018). A key challenge to this technology remains the need for better levels of efficiency, accuracy and (non)invasiveness. Wearable sensors can deal with measurements like hearth rate, blood pressure, stress, strain, force, steps per day, burned calories, velocity, acceleration/deceleration, total distance traveled, but also with the identification and quantification, in a nonintrusive manner, of biomarkers like, for instance, electrolytes (sodium, chloride, potassium, and calcium), metabolites (lactate, creatinine, glucose, and uric acid), small molecules (amino acids, DHEA, and cortisol), and proteins (interleukins, tumor necrosis factors, and neuropeptides). These aspects have a great impact on the capability of understanding how physical activity and exertion are related to fatigue and can be used to minimize sport-related injuries and to help providing a thorough recovery. Furthermore, global positioning system (GPS) plays an instrumental role in performance (related to sport) analysis by allowing coaches, physicians, and trainers to better understand the physical demands made on an athlete in real time. GPS combined with accelerometers help objectively record both physical activities conducted at different times of the day and individual positions (on the field) in a team (Seshadri et al., 2017).

Therefore, many professional sport teams are investing in ICT. An important example of the aforementioned teams is represented by FC Barcelona that created the *Barça Innovation Hub*. Barça Innovation Hub is divided into seven cross-sectional work areas which are related to each other: team sports, athletic performance, sports analysis and technology, health and wellness, fan engagement and big data, smart facilities and social innovation. In particular, the area *analysis and sports technology* is committed to compete in several challenges like artificial intelligence (for recognizing emerging tactical patterns), automated video editing (for improving the quality of tactical analysis), computer vision (for recognizing new variables in individual and

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group behavior, as well as in emotions), data integration and improvements to tracking precision (for the integration and correlation of performance, tactical and personal data for athletes and the ball in both competition and training), virtual and augmented reality (for improving contextualization of the game using video analysis with virtual and augmented reality) and gamification (for developing gamification-based solutions to incentivize a healthy lifestyle in athletes).

In this context, technologies for Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR) are explored more and more in order to provide sports people with tools for improving training activities.

Virtual, Mixed and Augmented Reality

The authors of (Drascic et al., 1996) discuss the Milgram's Continuum in which the spectrum of MR (MR refers to the class of all displays in which there is some combination of a real environment and digital technologies) lies between the extremes of real life and Virtual Reality and where views of the real world are combined in some proportion with views of a virtual (digital) environment (see Fig.1 where DV means direct view, SV means stereoscopic video and SG means stereoscopic graphics). In particular, VR is a computer-generated simulation of a realistic experience. Typically, VR blocks out the real world (reality) and replaces it with a fully virtual (digital) world. The virtual world may be generated by a computer, or by interactively playing back recorded media. AR does not block out reality but it adds computer-generated content onto the real-world experience (Mann, 2018).

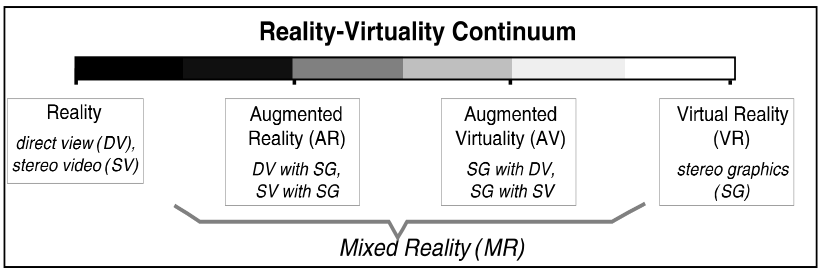

Fig.1. Reality-Virtuality Continuum (Drascic et al., 1996)

The most known definition of AR comes from Azuma (Azuma, 1997) who affirms that *"AR is an immersive experience that superimposes virtual 3D objects upon a user's direct view of the surrounding real environment, generating the illusion that those virtual objects exist in that space. While VR completely replaces the user's view of the real world, AR supplements it"*.

As already asserted, technologies for VR, AR and MR (sometimes called XR) represent interesting solutions for Exercise and Sport Science.

The present work provides both a discussion on the three forms of XR applied in sport contexts and goes in details by focusing on Augmented Reality and on how it could be integrated with cognitive approaches (Granular Computing and Situation Awareness) to define effective methodologies for supporting training activities by using AR technologies.

From the computer science perspective, the main computational tools enabling AR are computer vision, specific devices capable of handling heavy computations, and intuitive interfaces to provide the user with a natural and easy-to-use way to interact with the AR system. Computer vision is employed when it is needed to render 3D virtual objects from the same viewpoint from which the images of the real scene are being captured by the tracking cameras. Thus, the computer vision methods for AR are usually divided into two stages: *tracking* and *reconstructing/recognizing*. During *tracking*, fiducial markers, optical images, or interest points are detected in the camera images using several processing techniques such as feature detection or edge detection. The *reconstructing/recognizing* stage makes use of the data obtained during the first stage to reconstruct the real-world coordinate system. More in details, in order to enable the augmentation of the real-world it is possible to employ two different approaches: *marker-based AR* and *markerless AR*.

Image recognition is an imperative component of augmented reality systems. By use of identifying visual markers already embedded within the system, physical world objects are detected for superimposition of virtual elements. In order for an AR application to estimate the orientation and position of a camera with respect to the real-world frame, most applications employ a tracking technique known as marker based augmented reality.

On the other side, markerless AR solutions identify the position and rotation of objects which have to be added to the real-world scene by using GPS coordinates, spatial maps, camera orientation, etc.

Clearly, the correct type of AR and the most effective algorithms to be employed for tracking and reconstructing/recognizing phases should be selected after having analyzed the scenario to realize.

Lastly, with respect to the implementation view, it is important to describe the development stack for implementing AR Apps. In particular, we need to remember to classes of tools: the application development environment (enriched with libraries to deal with 3D graphics and user interactions) and the AR engine (providing the APIs for tracking and reconstructing/recognizing). The first class is typically covered by software like Unity or lower level IDE like Android Studio and XCode. For the second class, well-known AR engines are represented by Vuforia, Wikitude, etc. or by lower level libraries like ARCore (for Android devices) and ARKit (for IOS).

Applications of VR, MR and AR to Sports

Even if VR, AR and MR, in general, are not based on the same technological solutions (in particular, they need different devices), they can have in common the same development environment and, in some cases, similar software libraries. The idea, again, is to correctly analyze the scenario to be implemented and then select the correct technological stack. First of all, it is possible to make some considerations on the usefulness of VR, AR and MR in specific scenarios.

VR is especially adopted for sport simulations addressing physical, technical, tactical and psychological training. Such simulations are immersed in fully virtual worlds and are executed in sporting contexts in order to help athletes to develop necessary skills that can be transferred into competition, thus improving the proficiency of skill execution and reducing error (Farley, 2019). Because training is only as good as the sense of immersion it can imparts and the closer a simulation approximates real life conditions, the more an athlete can learn from it. Moreover, the VR simulation environments can be customized for the athlete to address specific skills but it can be also configured in a way to reproduce the behavior of the next opponent of the athlete. The repetition of the aforementioned scenarios would give an athlete the upper hand over competitors by helping to reduce errors through improvements to mental, perceptual (visual awareness), and physical coordination, as well as reaction times.

Fig. 2. STRIVR: the VR Training Platform for American Football
(https://www.roadtovr.com/nfl-refs-using-strivrs-vr-training-platform-prepare-new-season/ - image courtesy STRIVR)

An existing ready to use solution is the system provided by STRIVR Labs (A Silicon Valley-based VR startup) that is working with NFL and college football teams to train their athletes virtually, using a headset to help athletes experience game scenarios the same way they do on the field without physically jeopardizing their bodies (see Fig. **2**).

AR is mainly used for improving live sessions in which athletes observe their data (and the analysis results on this data) during the traditional training. AR enables to overlay the various data, graphs, information onto the real world lived by the athlete during the training session. Such digital elements are visualized in a way that is coherent with the current situation in which the athlete is involved. Only the relevant information pops up on the screen (and are registered on those real-world objects focused by the athlete or that should be focused by her/him) as-and-when required during each step of the training session. Through the augmented reality sports training program, the sportsmen can get information on every hit and miss, jump, push, throw or distance ran etc. in real-time. This helps them to change or correct their action and take better decisions with regards to their training and performance.

An existing AR solution is PuttView that transforms the golfing world with the latest cutting-edge AR glasses and help players to better analyze the course so that they can plan their game in a better way (see Fig. **3**).

Fig. 3. PuttView
(https://19thholemag.com/golf-meets-sci-fi/gear-the-puttview-glasses-augmented-reality-glasses-3/)

Lastly, the usages of MR include the assessment of athletes or rehabilitation session for them after injuries. MR gives the chance for the athlete to interact with physical objects or environments and receive the biofeedback by using a virtual (digital) representation of the world. For instance, the solution Riablo, from Corehab, allows patients or athletes to work on specific physical behaviors in a way that improves their capabilities of reducing errors and, in this way, improving training sessions with a feedback mechanism.

Fig. 4. Riablo: a MR solution
(Corehab communication material)

Sports, videogames and XR

The idea of using VR and MR in the sport context is not completely new. In fact, the vendors of consoles for videogaming like Sony, Microsoft and Nintendo have already exploited such concept for implementing innovative videogames and, in particular, sport simulations. Sony introduced a set of VR devices for its PlayStation 4. Nintendo produced Wii, a console with MR controllers natively included in it. Lastly, Microsoft, for its console Xbox, provided Kinect, i.e., a device for capturing human gestures in order to provide a new MR experience.

Such existing systems have been also associated with the possibility to allow students to execute practical activities in e-learning mode in the context of Sport and Exercise Science courses (D'Elia, 2019). This context is going to be even more strengthened by the new trend in videogaming, the *cloud gaming services* (CGS). By means of CGS it will be possible to play with videogames in streaming modality. In the sense that, the videogame is executed in the cloud and is streamed towards the clients that can be represented by any common device like smart tv, smartphone, tablet, PC, etc. Users play such games by using low-cost (around 130 euros) special controllers. The first real CGS is Google Stadia that will be released in the next months.

Therefore, CGS provide innovative platforms for realizing those remote practical activities for the aforementioned online courses related to Sport and Exercise Science.

Focus on Augmented Reality: technologies and approaches for AR in Sports

In this section and in the next ones, the focus will be on AR because we are convinced that it has a greater development potential than VR and MR in specific scenario we will investigate after. In particular, the application of AR for sport contexts has been explored in different ways along several tries to find the right set of technologies and approaches for its application. In a sort of historical path for AR, the work of (Bozyer, 2015) proposes several significant applications of AR for sports. In particular, one of the first of these is represented by *PingPongPlus* (Ishii, 1999) that aims at enriching the experience of the players by analyzing and visualizing, during the game situations, data related to the game itself.

More in details, eight microphones are installed under the table and the point, to where the ball strikes, is determined through the time in which the sound waves reach to each microphone. Such data are gathered and transferred to the computer and the point to where the ball strikes on the table was reflected via a projector located on the table. Information regarding the points to where the ball is sent at most and, at the same time, the tactics of players are visualized during the game situations by projecting circular shapes on the tables (see Figure 5). The radius of the shapes informs on how frequently the balls fall into areas pointed out by the circular shapes. This form of augmentation is a useful support for improving training of athletes in terms of performance, technique and tactics.

Another example of application of AR to sport contexts is represented by the work of Kajastila and Hämäläinen (Kajastila et al., 2014). Such work had the objective to improve the performance of a climber by projecting, directly on the wall, the next move, the route information and others (see Figure 5). Also, the idea underlying the aforementioned system has a great potential, in fact it could be considered a kind of tutor able to guide the climber with more or less support and to provide tasks with different level of difficulty basing on the Zone of Proximal Development (Fenza et al., 2017).

Fig. 5. PingPongPlus (Ishii, 1999; AR-based application for climbing, Kajastila et al., 2014)

Definitely, the applications of AR to sport contexts are numerous and heterogeneous, in the sense that they are targeted to different aims: audience experience, sports broadcasting, training experience (as we already have discussed), coaching/tutoring, marketing, merchandising, and so on.

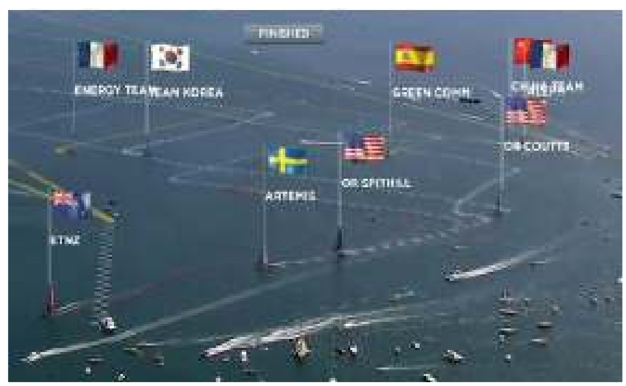

Fig. 6. Example of AR for improving sport audience experience (Sportvision)

Certainly, it is clear that for applying AR to sports it is needed to select a device able to support the real-world scenarios (to be realized) in effective and efficient ways. At the moment the market offers a number of devices that can be classified in two main categories: handheld devices and wearable devices. A third category is represented by projectors (adopted in the two sample applications discussed above in this section). For AR, handheld devices are mainly represented by smartphones and tablets, whilst wearable devices are represented by head-mounted displays like Microsoft HoloLens, Magic Leap and by smart glasses like Google Glasses, Vuzix Blade, and so on. The last two are less invasive with respect the device from Microsoft and Magic Leap.

The choice of the right device is driven by the analysis AR scenario to be realized. In fact, it is needed to consider the environment in which the device must be used, the task in which the user is involved, the digital content needed to augment the real-world scene, the interaction capabilities needed for the application, specific type of AR to support (marker-based or markerless) and so on.

For instance, if it is needed to apply AR to football training we can exclude handheld devices and also heavy-weight devices like HoloLens for usability reasons before considering also the specific features provided by the devices.

Currently, the market provides, among the others, three main AR devices specialized for sports: *Kopin Solos*[1], *Everysight Raptor* and *Ride On*. The first one is specialized for cycling but it can be also used by runners and triathletes. The second is targeted to cycling. The third one is specific for ski/snowboard. All these three devices provide features for improving the experience of the athletes in several way. Kopin Solos provides 360-degreees tracking and visualizes in real-time the athlete's performance (elapsed time, speed, and heart rate) in order to allow her/him to self-regulate and improve the her/his training. Moreover, this device is able to handle routes and help to follow the right roads. Lastly, it allows communication among team members in order to support also training relating to tactical aspects. Everysight Raptor is used to visualize heart rate and cadence. It offers also a set of sharing functionalities among the members of the same team (routes, photos, etc.). Such device is equipped with a positional tracker and a built-in front camera. RideOn helps snowboarders to navigate the mountain slopes by using the virtual maps and highlight points of interest. RideOn indicates also the position of friends around the user. The aforementioned three devices become useful training tools when integrated with wearable sensors for physiological signals and software like Strava and Training Peaks to handle personalized training sessions.

Can Granular Computing and Situation Awareness help?

The aim of this section is to propose a vision concerning the application of AR technologies to sport sciences.

Starting from the considerations provided in the previous sections, it seems that AR can be considered as an effective tool for situational data visualization and the availability of the first AR devices specialized for sports, in some sense, certifies this commitment.

The idea is that athletes, during their training sessions, can gathered huge amount of heterogeneous data mostly coming from wearable sensors but also from "external" sources like cameras or the ball (if you consider sports like football, basketball, etc.). This data is useful to improve their performances with respect to their physical capabilities and physiological data, technical and tactical aspects and so on. Until now, such huge quantity of data is analyzed outside the training session, during "debriefing" activities where the athlete reviews her/his performance data, compares such data against historical one and tries to adapt and improve her/his behavior. Moreover, coaches and trainers can aggregate this data to analyze team performance for improving the whole team behavior.

In this context, non-invasive AR devices can allow athletes to watch their data during their training session in the situation in which they are producing such data. In this way, the training activity and the debriefing activity, merged together and with a specific game situation, can improve significantly the positive effect for the athlete. Using non-invasive AR devices allows athletes to receive communications by coaches/trainers and also, in team sports, information about tactical aspects related, for instance, to team movements, awareness of the field positions, and so on. The considered situation is not only the macro-situation related to a training session but it will be possible to consider also micro-situations like game situations in which athletes could be involved. This aspect is crucial for an athlete that can learn how to improve to react to all possible situations during a play.

Now, the question is: *is AR already ready to support such scenarios?* Unfortunately, no. AR is great chance to be exploited in order to realize the aforementioned scenarios but it is not enough. Effective and efficient approaches to data processing must be considered.

In particular, this work is aimed at proposing ideas for building a framework regarding the adoption of AR for sport training sessions and, in general, for sport sciences.

More in details, in order to define the aforementioned framework, firstly, it is needed to employ a cognitive approach to process data coming from different and heterogeneous sources in a way that it will be possible to provide multiple-views on such data and a mechanism to switch from one view to another by considering different levels of details (more or less details) and also different perspectives (tactical, technical, psychological, physiological, combiations of them, etc.).

Granular Computing seems to be a cognitive approach able to represent a solution for the aforementioned issues. Granular Computing (GrC) is focused on representing, reasoning and processing basic chunks of information, namely granules. Zadeh (Zadeh, 1997) defines a granule as a clump of points (objects) drawn together by indistinguishability, similarity, proximity or functionality. As a mechanism for information processing, GrC is focused on creation and processing of granules. The creation of granules is usually referred to as granulation. Granulation of information is a human activity, that we employ whenever we need to better understand a problem. Granulation serves as a vehicle to divide a problem into a series of well-defined subproblems in order to reduce our cognitive and computational effort. Moreover, it serves as an abstraction mechanism to comprehend a problem and offer a better insight into it rather than get buried in all unnecessary details.

An information granule may be built at different levels of abstraction and, by changing the size of the granules, it is possible to hide or reveal a certain amount of details. Granules can be defined in different formal settings: set theory, interval calculus, fuzzy sets, rough sets, shadowed sets, probabilistic granules. In each of these environments, granules and granulation are defined in different ways however, in all cases, granules can be organized in more complex Granular Structures.

Secondly, in order to realize the framework, it is needed a methodology to organize data in a way that is functional for Granular Computing processing and for supporting the situated nature of the AR-based data visualization. This methodology is the Goal-Directed Task Analysis (GDTA) that follows the principles of the so-called Situation Awareness.

Endsley (Endsley, 1995) defines Situation Awareness (SA) as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The SA model proposed by Endsley is shown in Fig. **7**.

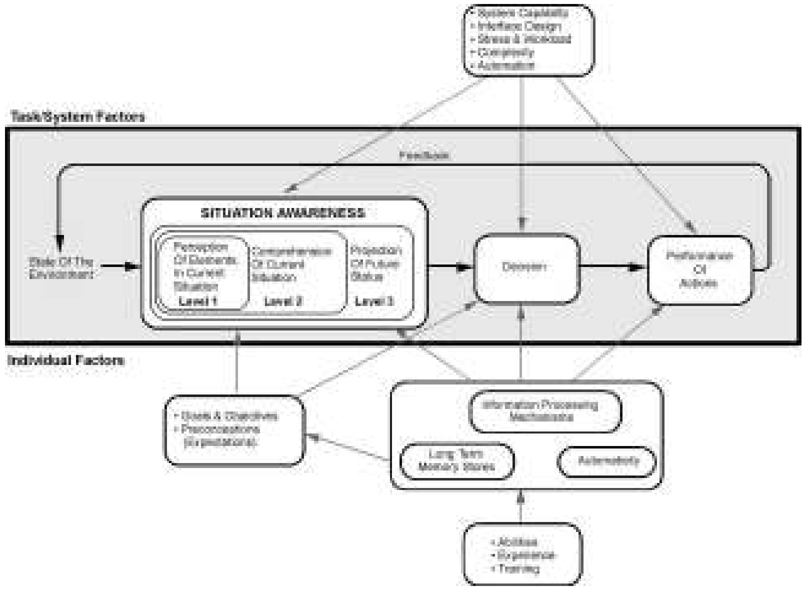

Fig. 7. SA Model by Endsley (Endsley, 1995)

The model has three levels: i) perception, which involves the capability to perceive the status, attributes and dynamics of the relevant elements of the environment, ii) comprehension, which refers to the understanding of what data and cues perceived mean in relation to goals and objectives, and iii) projection, which relates to the capability of projecting in near future the elements recognized. Endsley's model is not linear but iterative, with understanding driving the search for new data and new data coming together to feed understanding. Furthermore, it must not be understood as a pure data-driven process since factors such as goals, mental models, attention, working memory and expectations play a pivotal role in SA.

An approach to identify the users' goals for an appropriate design of the system is the Goal-Directed Task Analysis (GDTA) (Bolstad et al., 2002). GDTA can be considered a kind of requirement analysis process and a form cognitive task analysis which allows system designers to identify, in a systematic way, the goals the human operator must achieve and the information requirements that are needed to make appropriate decisions. GDTA adopts different requirement analysis techniques to identify the SA requirements, like for instance structured interviews, observations of opera- tors performing their tasks, analysis of documentation. The general steps to conducting a GDTA include identifying the users' major goals, identifying sub-goals to support major goals, identifying operational tasks to achieve the sub-goals, identifying questions as part of decision-making in task performance, and developing information requirements to answer these questions. The final results of a GDTA process are usually represented as a hierarchical structure of goals and SA requirements (see Fig. **8**).

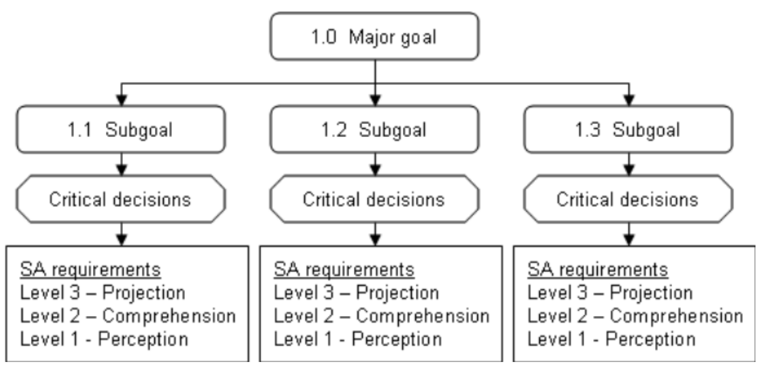

Fig. 8. Goal-Directed Task Analysis generic hierarchical structure

GDTA can be adopted in combination with GrC in order to define the initial information table on which the data processing techniques can be applied following the information fusion criteria driven by the SA analysis results. Altogether, AR technologies, Granular Computing, Situation Awareness, Goal-Directed Task Analysis and deep knowledge on motor, sports science, competences related to training methods, etc. represent the building blocks on which it will be possible to design the framework.

Conclusion

This work proposes a discussion on the applications of XR technologies in the context of sports also associated with the possibility to allow students to execute practical activities in e-learning mode in the context of Sport and Exercise Science University courses. Then, the discussion mainly focuses on past and present of AR solutions (software and hardware) applied to sports and shares some ideas on why and how applying Granular Computing and Situation Awareness to process and organize data coming from heterogeneous sources to augment the live training session of athletes. In this vision, the AR technologies enables to merge training sessions with data-driven debriefing activities in order to provide a kind of augmented training session for improving athletes' performance. A sample scenario to which is possible to apply AR technologies in combination with GrC and SA is represented by specific training activities executed by a football team for improving the individual capability of single players to move in the field considering the positions of her/his teammates, the positions of the opponents and the position of the ball. In this case, during training, AR devices could provide individual players with the needed information to improve their position during the play. Therefore, in this context, it is crucial to adopt a multidisciplinary approach and exploit heterogeneous competences to analyze, design, implement and evaluate effective tools for AR-based training sessions.

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