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The role of visuospatial abilities in memorizing animations among soccer players

<https://doi.org/10.1515/jirspa-2020-0002>

Received January 14, 2020; accepted November 3, 2020;

published online November 13, 2020

Abstract

Objectives: The use of dynamic media such as animations for educational purposes in the sport field keeps growing. However, not adapting these information-enriched supports to learners' prerequisites can diminish their learning efficiency. In this paper, we studied the effect of visuospatial abilities (VSA) on the memorization of a dynamic tactical scene among soccer players.

Methods: Participants (N=48) performed a multitask VSA test (control test) to distinguish people with "high" and "low" VSA. Then, they were required to memorize and reproduce a dynamic sequence (main test).

Results: Results indicate a learning enhancer effect of VSA. Players with high VSA were more efficient in memorizing the sequence than those with low VSA.

Conclusion: Results suggest considering VSA in order to optimize learning from dynamic presentations even if participants belong to the same group. In addition, VSA training for athletes is recommended in order to enhance their learning of dynamic visual content.

Keywords: animation; memorization; prior knowledge; soccer; visuospatial abilities.

Over the past three decades, sports researchers largely invested in computer sciences. Many systems were developed to improve coaching and/or athletes' performance. For example, animation, video and virtual reality (VR) trainings were conceived to improve athletes' technical

and/or tactical learning (Cha et al., 2015; Lopes et al., 2009; Schorer, Schapschröer, Fischer, Habben, & Baker, 2018; Tsai, 2018). In some cases, researchers used tactical animations as visual aids to compensate for hearing issues among elite athletes (Kozina et al., 2016). Likewise, these tools were utilized to improve players' accuracy and anticipation skills to help them manage high-pressure situations in the real world better (Murgia et al., 2014; Stinson & Bowman, 2014). Dynamic presentations were also developed in order to enhance assistant referees' decision-making skills (Put, Wagemans, Spitz, Williams, & Helsen, 2016). This technological progress has favored the use of animations in sports. The advantage of dynamic presentations lies in the exposure of the different interactions and transitions of the scene's elements. That is the reason why trainers use dynamic media to explain different game strategies through time and space and to acquire in-depth knowledge.

Previous studies have shown that soccer players are more efficient at memorizing tactical schemes when information is dynamic (Khacharem, Zoudji, & Ripoll, 2013; Zoudji, Khacharem, & Porter, 2015). Indeed, athletes possess dynamic knowledge structures (Ripoll, Zoudji, & Lluçia, 2009) that enable them to understand the different states of a dynamic sequence and to anticipate sequences close to the real game logic. Even though athletes develop specific knowledge during their experience, other learner characteristics such as VisuoSpatial Abilities (VSA) may differ from one another and influence the memorization process. VSA are a well-studied cognitive factor. Their importance in acquiring new knowledge from multimedia supports is well-documented in several areas such as anatomy (Berney, Bétrancourt, Molinari, & Hoyek, 2015), earth science (Black, 2005), technology, engineering and mathematics (Uttal, Miller, & Newcombe, 2013). However, its effect on the memorization of tactical scenes in team sports has not been studied yet and has often been overlooked.

The present study aimed at investigating the effect of VSA on the memorization of a dynamic tactical scene among soccer players. A major part of this aim was to verify whether the contribution of VSA in memorizing new information was as effective as their specific prior knowledge.

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Animation memorization process

For athletes, the main goal of memorizing a new tactical scene is to create a clear and structured mental model of the presented content. This process requires the integration of new external information based on Working Memory (WM) treatments and, then, the creation of links with their prior knowledge stored in Long-Term Memory (LTM) (the knowledge construction view of learning, Mayer, 2012).

Dynamic presentations, such as animations, have the educational advantage of explicitly displaying changes in action through time and space, which facilitates the creation of a precise mental model. However, this type of presentation can induce a high cognitive load caused by its transient nature. In other words, animations always display new information over time (transient information effect: Leahy & Sweller, 2011; Sweller, Ayres, & Kalyuga, 2011). In such situations, learners must both process current information and retain previous ones at the same time, which can cause interference between them and inhibit learning (Kacharem et al., 2013). Indeed, the memorization process is disturbed when the presentation requires high attentional demands and exceed the limited retention capacity of the WM (7 ± 2 information; Baddeley, 2001, 2002; Miller, 1956). According to the cognitive load theory (CLT: Choi, van Merriënboer, & Paas, 2014; Sweller, Ayres, & Kalyuga, 2011; Sweller, van Merriënboer, & Paas, 2019), the WM is exposed to two types of cognitive load while processing animations. On the one hand, the intrinsic cognitive load depends on the number of elements and their interactivities, and, on the other hand, the extrinsic cognitive load depends on the design of the presentation. Depending on learners' characteristics, the cognitive load intensity varies and affects the memorization process differently.

Indeed, for professional players, when information to memorize is related to their specific domain, a part of their LTM is activated as a WM (long-term working memory: Ericsson & Kintsch, 1995) in order to access their prior knowledge and recover all needed information. This process can reduce the cognitive load and enable better learning (Paas, Renkl, & Sweller, 2003). According to the Animation Processing Model theory (APM: Lowe & Bouchéix, 2008, 2011, 2017) learning from animation goes through several cognitive stages ranging from animation decomposition into event units to composition and building of a mental model. Professionals can reach the final learning phases and create an adequate mental model based on their prior knowledge. Their top-down

attentional processes contribute to guiding their attention in searching and assimilating information based on their pre-existing patterns (Kriz & Hegarty, 2007). The skilled memory theory (Ericsson & Kintsch, 1995) sustains that experienced people select relevant indicators in the WM and easily access their specific knowledge in the LTM to recover needed information and respond to a particular situation. These high-level athletes' mechanisms represent a major advantage in memorizing and/or learning dynamic presentations. However, other features such as VSA may interfere and influence the memorization process.

Visuospatial abilities

VSA are defined as the ability to recall, generate, represent and transform symbolic and non-linguistic information (Linn & Petersen, 1985; Toivainen et al., 2018; Yılmaz, 2017). According to Peck, Yuksel, Harrison, Ottley, and Chang (2012), VSA are a cognitive trait that varies among individuals and affects learning performance when using visualizations.

Currently, two divergent theories treat the interactions between VSA and learning from dynamic media. On the one hand, the ability-as-enhancer hypothesis (Brucker et al., 2014; Hegarty, 2005; Hegarty & Sims, 1994; Huk, 2006) states that individuals with high visuospatial abilities (HSA) are better equipped to handle dynamic visualizations (e.g. animation, video) because they possess more cognitive and attentional resources to support learning from these complex presentations (Çöltekin, Francelet, Richter, Thoresen, & Fabrikant, 2018). Previous studies such as Mayer and Sims (1994) have examined the effect of VSA on multimedia learning and found that VSA impact the understanding of dynamic phenomena. Specifically, HSA learned better from animations than people with low spatial abilities (LSA). Brucker, Scheiter, and Gerjets (2014) also examined the effect of VSA on learning biological movement from dynamic presentations. Results indicate a better recognition performance from realistic presentations of HSA over LSA. Furthermore, medical researchers (Berny, Bétrancourt, Molinari, & Hoyek, 2015; Garg, Norman, & Sperotable, 2001; Loftus, Jacobsen, & Wilson, 2018) revealed that VSA are crucial in learning human anatomy. On the other hand, the ability-as-compensator hypothesis (Hays, 1996; Höffler & Leutner, 2011) stipulates that dynamic visualizations act as a cognitive prosthesis for LSA (Hegarty & Kriz, 2008) since it provides them with an explicit external representation of

the system, which reduces their need for mental manipulations. Two meta-analytical reviews of the literature (Höffler, 2010; Kaushal & Panda, 2019) admit that animations enable LSA to be as efficient as HSA when learning from dynamic presentations.

Even though the effect of VSA in processing dynamic presentations is well-documented, to our knowledge, no study has tested their effect on memorizing tactical game patterns in team sports such as soccer yet. Indeed, the main issue is that most coaches, trainers and/or teachers conceive external visualizations in a “one-size-fits-all” manner. However, not adapting external visualizations to learners’ aptitudes may put some at a disadvantage. Understanding individuals’ specific abilities is crucial to provide educators with guidelines on how to adjust interactions between learners and computerized visualization systems. As far as we know, Souriac-Poirier, Thon, and Cadopi (2008) wrote the only study examining the effect of VSA on athlete’s memory in individual sports. It aimed at testing the effect of VSA on the motor recall of dance sequences. In this study, learners’ mental imagery was assessed using the Movement Imagery Questionnaire (Hall & Pongrac, 1983) and the mental rotation ability using the S test (Thurstone & Thurstone, 1967). These tests were followed by the memorization of a dynamic sequence and its reproduction on the field. Results did not show a significant effect of VSA on the memorization of dynamic motor scenes. The lack of influence may be due to the use of a unique objective task to measure VSA instead of using multiple tasks that measure different spatial dimensions (D’Oliveira, 2004).

The purpose of this study was to investigate the effect of VSA on the memorization of a tactical soccer scene among soccer players. We hypothesized that people with high spatial abilities would be more efficient in memorizing the animation than those with low spatial abilities.

Method

Participants

The experiment was conducted on 48 male soccer players aged between 18 and 39 ($M_{\text{age}}=24.85$, $SD=5.55$) with 17.1 ± 4.7 years of practice and 7.3 ± 1 h of practice per week. All participants answered a questionnaire concerning their soccer practice. According to Swann, Moran, and Piggott (2015), the chosen participants were competitive elite players, that is to say, they often compete at the highest level in their sport (e.g. the best divisions or leagues), but do not prevail at this

level (e.g. winning events or medals). Subjects had no vision-problems, otherwise, it was corrected with glasses or lenses. Also, participants affirmed it was the first time they were doing this kind of experience. Finally, they volunteered to participate and provided informed consent. Approval for this project was granted by the local ethics committee.

Materials

Two tests were computerized and displayed on a TOSHIBA L755-1GL laptop with a 15.6-inch screen. The control test contained three tasks to measure subjects’ VSA. The main test consisted in memorizing a tactical soccer scene and reproducing it on a sheet of paper.

Control test: Three tasks were programmed with the Unreal Engine 4 (software) of the American Epic Games studio written in C++. Each task was designed to measure a subfactor based on the taxonomy of Linn and Peterson (1985).

The first task, Water level task (Piaget & Inhelder, 1956), aimed at measuring subjects’ spatial perception which is the ability to estimate spatial relationships according to the orientation of their bodies. This task consisted in identifying the horizontal line of water among four tilted glasses. Each individual had 3 min to respond to eight situations by clicking on the corresponding icon to the chosen glass. The angle of inclination differed for each situation to avoid repetition. The final score was rated on eight points.

The second task, Vandenberg and Kuse mental rotation task (Vandenberg & Kuse, 1978), aimed at measuring subjects’ mental rotation ability which represents the ability to mentally rotate images and figures in two or three dimensions. During this task, an initial cubic figure (x) and four rotated propositions were presented. Subjects had to identify among four propositions the two figures that referred to the initial one. Each individual had 6 min to respond to a total of 20 situations by clicking on the corresponding icon to the chosen figure. One point was awarded for the choice of only one correct answer, two points for the choice of the two correct answers and none for the choice of a good and a wrong answer or two wrong answers. The final score was rated on 40 points.

The third task, Paper Folding task (Ekstrom, French, Harman, & Dermen, 1976), aimed at measuring subjects’ spatial visualization which is the ability to deal with complex spatial forms involving multiple dynamic operations (e.g. combining spatial perception and mental rotation). During this task, participants were shown an initial figure (x), which was a drawing on a sheet of paper, and four propositions, which were suggestions of the initial figure after folding. Subjects had to identify the figures that referred to the initial one among the four propositions. Each individual had 6 min to click on the icon corresponding to their chosen figure for the 20 proposed situations. The final score was rated on 20 points.

Main test: The main test consisted in memorizing a dynamic soccer scene created with the software “tacticalpad” developed by the Temma Software company. The sequence showed a counter-attack tactic drill made by five players. Nine actions, divided into player movements and ball passes, were presented (see Figure 1).

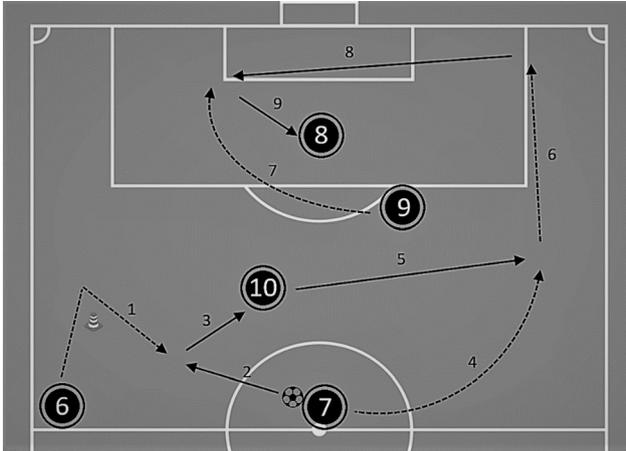


Figure 1: Representative diagram of the dynamic scene to memorize.

Procedure

The experiment was carried out individually in a quiet place. The entire test lasted for about 40 min. Five to ten minutes were dedicated to answering the questionnaire and explaining tasks, 15 min to measuring VSA (control test) and 15 min to memorizing the scene (main test). Every participant was given instructions, explanations and eventually a familiarization trial before performing each task to make sure he understood what to do.

First, participants performed three VSA tasks (control test) and proceeded then to the main test (memorization test) which contained two phases. During the first phase, participants repeated the animation as many times as they wanted in order to memorize it (study phase). Once they reported they memorized it, the broadcasting was stopped, the laptop was shut down and they started the reproduction phase (test phase). Participants performed two successive tasks. First, they evaluated the mental effort invested in the memorization with a 9-point subjective Likert rating scale, ranging from 1 (very low) to 9 (very high) mental effort. This self-report measure is widely accepted as a valid and noninvasive method of estimating cognitive load (e.g. Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Pass & Van Merriënboer, 1993; Pass, Van Merriënboer, & Adam, 1994). Second, they reproduced the scene. They were given a sheet of paper with the same field and starting positions of players drawn on it. They had to draw discontinuous arrows to show movements and continuous arrows to show passes (memorizing items). Also, they were required to number the actions to check if they remembered the chronology of the scene (memorizing information serial order). A point was given only if the subject succeeded in illustrating the right type of action in the right order.

Data analyses

First, participants were ranked according to their average score of the control test. Then we used a median split to divide them into two groups: players with High Spatial Abilities (HSA) and players with Low Spatial Abilities (LSA).

To evaluate the participant's ability to memorize the sequence, we analyzed the number of repetitions needed, the perceived mental

effort during the main test, and the recall scores. Based on these three variables, we calculated the learning efficiency using the three-dimensional formula elaborated by Tuovinen and Paas (2004). For the purpose of the present study, the number of repetitions was used instead of the study time (Khacharem et al., 2013). The formula consists in standardizing (z-transformation) the raw values obtained for each of the three variables.

$$\text{Learning efficiency} = (\text{zRecall} - \text{zMental Effort} - \text{zRepetitions}) / \sqrt{3}$$

This formula was also used to estimate people's efficiency in learning from the presentation. For each dependent variable, individual means and standard deviations were calculated. Levene test was used to assess Homoscedasticity and Kolmogorov-Smirnov test for distribution normality. For the control test, a univariate analysis of variance (ANOVA) was used to compare the level of spatial abilities and individual averages in the memorization test for the two groups (HSA and LSA). The significance level (α) was set at 0.05 in all analyses and effect sizes were expressed by partial eta-squared (η^2). Partial eta squared values of 0.20, 0.50, and 0.80 represent small, moderate, and large effect sizes, respectively (e.g. Sechrest & Yeaton, 1982).

Results

Control test

Descriptive data for the control test are presented in Table 1. The univariate ANOVA for the control test showed a significant difference between groups [$F(4,64)=101.5$, $p<0.001$, $\eta^2=0.68$, and Power=1.00]. The HSA group performed better ($M=15.47$, $SD=1.64$) than the LSA group ($M=9.2$, $SD=2.56$).

Main test

Repetition

Univariate ANOVA for the number of repetitions revealed a significant effect for group [$F(1,52)=30,26$, $p<0.001$, $\eta^2=0.39$; Power=0.90]. Participants with HSA ($M=3.16$, $SD=0.91$) repeated the dynamic scene less than participants with LSA ($M=5.12$, $SD=1.48$) in order to memorize it.

Table 1: Descriptive table of the control test (VSA).

Participants	Group	WLT	MRT	PFT	Average score
Soccer players (n=48)	HSA	7.45	12.12	15.66	15.47
	(n=24)	(0.97)	(2.6)	(2.63)	(1.64)
	LSA	4.16	5.91	11.29	9.2
	(n=24)	(2.16)	(2.76)	(3.16)	(2.56)

WLT, water level task; MRT, mental rotation task; PFT, paper folding task.

Mental effort

Univariate ANOVA for mental effort showed a significant effect for group [$F(1,4)=15.23$, $p<0.001$, $\eta^2=0.24$; Power=1.00] indicating that the HSA group ($M=2.29$, $SD=1.32$) invested less mental effort in memorizing the dynamic sequence than the LSA group ($M=3.62$, $SD=1.01$).

Recall accuracy

Univariate ANOVA for the recall accuracy revealed a significant effect for group [$F(1,78)=20.73$, $p<0.001$, $\eta^2=0.21$; Power=1.00], participants with HSA ($M=8.7$, $SD=1.12$) had higher recall scores than those with LSA ($M=7$, $SD=1.38$).

Learning efficiency

Univariate ANOVA for learning efficiency showed a significant effect for group [$F(1,78)=40.48$, $p<0.001$, $\eta^2=0.34$; Power=1.00], Participants with HSA ($M=0.99$, $SD=0.85$) were more efficient in memorizing animation than participants with LSA ($M=-0.99$, $SD=0.91$). The data are illustrated in Figure 2.

Discussion

In this study, we analyzed the effect of VSA on the memorization of a tactical soccer scene among soccer players. After dividing participants according to the control test, results confirmed the superiority of HSA over LSA in terms of VSA. Based on these results, differences observed between the two groups in the memorization test will be attributed to VSA.

Even though the chosen participants in this study were all professional soccer players, differences in terms of memorization were observed. Results of the main test showed that players with HSA achieved better learning efficiency scores than those with LSA. Specifically, with fewer repetitions, HSA remembered the scene better than LSA and invested less mental effort for the retention and the reproduction of the scene. The differences between elite soccer players could be explained by the ability-as-enhancer hypothesis (Brucker et al., 2014; Hegarty & Sims, 1994; Hegarty, 2005; Huk, 2006). Indeed, when treating and/or memorizing the tactical animation, players with HSA were able to devote more cognitive resources to be more performant (Isaak & Just, 1995; Mayer & Sim, 1994). These resources prevented the WM overload and enabled faster memorization as VSA impact visual information's processing and encoding speed (Hegarty & Kriz, 2008;

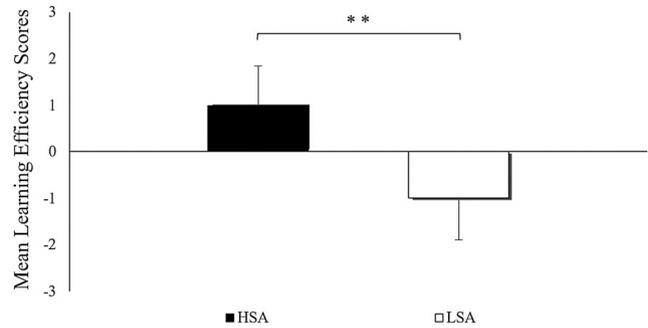


Figure 2: Mean scores of learning efficiency of the two groups. Bars represent the standard deviation of the associated mean values.

Salthouse, 1996). On the contrary, LSA found difficulties in managing the transient nature of the dynamic content which caused the loss of information and led to more repetitions. Our study illustrates this phenomenon as players with LSA repeated the animation about five times on average whereas those with HSA repeated it only about 3 times on average before judging they had completely memorized the scene.

In addition, previous studies in sports (Farrow, Reid, Buszard, & Kovalchik, 2018; Wood, Vine, & Wilson, 2016) admitted that a larger WM improved learning. Furthermore, according to Miyake et al. (2001), VSA are related to WM. That is to say, when the task requests WM treatments such as memorizing new visual information, HSA will be more efficient than LSA. The present study argues that HSA are able to mobilize almost all the storage capacity of the WM, unlike LSA who cannot mobilize it entirely (WM capacity: 7 ± 2 units of information; Miller, 1956). This difference was observed between the two groups in terms of recall scores. HSA remembered on average 8.7 pieces of information whereas LSA remembered only 7 pieces of information on average. This original finding yielded to a main questioning: is prior knowledge sufficient to define an athlete's memorization performance?

Unlike previous studies which considered that prior knowledge was elites' main quality (Khacharem, Zoudji, Kalyuga, & Ripoll, 2013; Khacharem et al., 2014; Zoudji et al., 2015), our study demonstrates that VSA are another essential factor that influences their memorization process. Even though information to memorize came from their specific domain field, LSA found difficulties to maintain all information of the dynamic support. Indeed, LSA can only manage the intrinsic cognitive load, because they only rely on their skilled memory (Ericsson & Kintsch, 1995) that helps them constructing mental representations based on chunks and/or patterns stored in LTM (Kalyuga, 2009). However, they are not able to manage the extrinsic

cognitive load because their VSA are not sufficient to handle the ephemeral nature of dynamic support. This may explain the higher judgment of mental effort for LSA compared to HSA. Furthermore, in some cases, incomplete and inconsistent prior knowledge in a domain may lead to wrong conclusions and harm future learning (Simonsmeier, Flaig, Deiglmayr, & Schalk, 2018). In our situation, we suppose that LSA were affected by some wrong information previously acquired due to their low VSA. Subsequently, LSA generated errors during the recall even if they took all the needed time to memorize the animation. It has notably been demonstrated that VSA help managing high-constraining situations (e.g. simultaneous processing and/or cognitive overload conditions) and thus avoiding the adoption of erroneous information (Isaak & Just, 1995).

The present research offers answers on learner's characteristics that need to be considered when memorizing animations. We also admit that a high level of prior knowledge is not enough to define elite players' memorization performance. This finding presents important implications for developing coaching and learning from dynamic presentations. From a practical point of view, we advise sports stakeholders (e.g. players, trainers, coaches and referees) with LSA to perform visuospatial training to improve their VSA and thus their tactical expertise. Indeed, studies in science, technology, engineering and mathematics found mental rotation and spatial visualization training had a positive impact on performance (Cheng & Mix, 2014; Dimitriu, 2015; Lowrie, Logan, & Ramful, 2017; Sorby, 2009). Some authors proposed additional techniques such as visual guidance to optimize VSA training (Roach, Fraser, Kryklywy, Mitchell, & Wilson, 2019). In sport, training VSA could improve athletes' tactical expertise with learning offensive and defensive patterns (Lopes et al., 2009; Schorer et al., 2018; Tsai, 2018) and/or perceptual skills such as anticipating penalty kicks for goalkeepers (Murgia et al., 2014; Stinson & Bowman, 2014). In addition, coaches could group players according to their playing positions to optimize video training by targeting a specific goal for each session. Then, VSA could improve decision-making skills in time-poor processes such as tactical game changes for coaches and/or offside decisions for assistant referees (Put et al., 2016).

Even though this study yielded some original initial findings, some limitations should be acknowledged. First, this research was conducted on elite players. However, beginners are also concerned about learning from dynamic presentations. It is important to include beginners in future research in order to verify the intervention of VSA according to the level of expertise. Second, there are several types of dynamic presentations, and it is important to include

other presentation conditions with different levels of realism, such as video and virtual reality. This research will aim at determining the appropriate combination between learners' and presentations' characteristics to provide optimal learning conditions. In addition, it could also be useful to test visuospatial training on LSA players in order to verify their effectiveness among athletes and provide training methods.

To conclude, dynamic visualizations such as animation have strong properties that stimulate attention and learning processes. However, our research shows that with higher VSA these technologies can be capitalized more fully in sport settings. This finding implies that VSA should be taken into account and even be trained to benefit from the instructional advantages of dynamic presentations and improve athletes' performance on field.

Research funding: None declared.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: Authors state no conflict of interest.

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