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LEARNING HOW TO PREPARE ATHLETES FOR PEAK PERFORMANCE: USE OF MENTAL IMAGERY TRAINING AS A PSYCHOLOGICAL STRATEGY TO ENHANCING MOTOR LEARNING, RETENTION, AND TRANSFER OF SPORT RIFLE MARKSMANSHIP

Taktek K[1*], Zinsser N[2], Corbari G[2], Miller S[2], Fielitz L[3], St. John R[4]

[1] *School of Education (École des sciences de l'éducation, ÉSÉ), Faculty of Education, Laurentian University, Ontario, Canada*

[2] *United States Military Academy, Center for Enhanced Performance, West Point, New York*

[3] *United States Military Academy, Department of Physical Education, West Point, New York*

[4] *Department of Military Psychology & Leadership, Royal Military College of Canada, Kingston, Ontario, Canada*

ABSTRACT

PURPOSES: This article is intended (a) to compare the effects of mental imagery and physical practice only on the learning and transfer of an open motor skill; (b) to identify the mental imagery modality (visual, kinesthetic, or temporal) which is most efficient for sport rifle marksmanship; and (c) to determine the relationship between movement image vividness and motor performance. **METHODS**: Seventy students from the United States Military Academy, West Point, New York, participated in this study. They used their dominant hand to shoot (live-fire shooting) rotating targets. This study comprised four principal phases, namely the pretest, treatment, posttest (retention) and transfer. **RESULTS**: The results demonstrated that the retention performance obtained by each group using mental imagery combined with physical practice was equivalent to that produced by physical practice only group. Furthermore, during the transfer, each group using visual or kinesthetic mental imagery combined with physical practice showed significantly superior performance than that obtained by physical practice only group. **CONCLUSION**: These results may be explained by three evidences for functional equivalence between mental imagery and physical practice, namely behavioural, central and peripheral (Feltz & Landers, 2007; Holmes & Collins, 2001; Taktek, 2012; Taktek, Zinsser, & St-John, 2008).

Keywords: mental imagery, motor performance, visual imagery, kinesthetic imagery, retention and transfer

INTRODUCTION

Mental imagery, as a process of mental representation, mental practice, mental rehearsal, mental repetition, visualization (Taktek, 2004), or even motor imagery (Collet, Guillot, Lebon, MacIntyre, & Moran, 2011; Holmes & Collins, 2001; Jeannerod, 2006), has become more prominent within the field of motor learning and performance enhancement (Morris, Spittle, & Watt, 2005). Mental imagery refers to a simulation experience inherent in the participant's brain functioning without any overt movement execution (Mulder, De Vries, & Zijlstra, 2005). It represents a constructive mental process which is intimately related to perceptual and sensory experiences. Such a process is conscious, occurs in the absence of external stimuli, and may lead to different results from those emerging from the sensory or perceptual counterpart (Taktek, 2004). The virtue of mental imagery transpires through the equivalence between real and imagined motor actions (Nikulin, Hohlefled, Jacobs, & Curio, 2007; Radulescu, Adam, Fischer, & Pratt, 2010).

The effects of mental imagery on motor skills acquisition have been evidenced by several scientific studies (Feltz & Landers, 2007; Louis, Guillot, Maton, Doyon, & Collet, 2008). Taktek, Zinsser and St-John (2008), for instance, compared the effects of mental imagery and physical practice only on the acquisition retention and transfer of a discrete closed motor task in 8-10-year-old children. The results revealed that performance of the mental imagery (visual or kinesthetic) combined with physical practice group was, during the acquisition and retention phases, equivalent to that produced by the physical practice only group but significantly superior during the transfer of *closed motor skill*. In general, these results give clear support for the psychological skill hypothesis, notably the retention (e.g., Jarus & Ratzon, 2000) and concentration (e.g., Deschaumes-Molinaro, Dittmar, & Vernet-Maury, 1991, 2001) roles of mental imagery.

Building on the results of Taktek et al.'s (2008) research, the first purpose of the present study was to compare the effects of mental imagery combined with physical practice, and physical practice only on the acquisition, retention and transfer of an *open motor skill* in *18-22-year-old* undergraduate students. By definition, an open motor skill is performed in an environment that is variable and unpredictable (e.g., hitting ground strokes in tennis, shooting at a mobile target). Performers must be able to examine the environment in order to adjust their movements, often in a short amount of time. As for a closed motor skill, it is performed in an environment that is stable and predictable (e.g., golf, bowling, throwing a ball toward a fixed target). Performers can evaluate the environment in advance, deploy their movements without being rushed, and carry out the action without any need for sudden adjustments (Schmidt & Wrisberg, 2008).

Although the fruitful role of mental imagery in motor learning and performance enhancement was corroborated by the majority of the studies in the field of sport and exercise psychology, the manipulation of the imagery modalities was limited (e.g., Taktek, 2004; Taktek & Rigal, 2005; Taktek, Salmoni, & Rigal, 2004; White & Hardy, 1995). Several studies dealt with kinesthetic and/or visual imagery (Callow & Hardy, 2004; Féry, 2003; Roberts, Callow, Hardy, Markland, & Bringer, 2008). Whereas kinesthetic imagery allows the representation of muscular contractions as well as proprioceptive sensations inherent in the movement's execution, visual imagery permits the representation of space, size, amplitude, or movement forms. However, very few studies investigated the

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manipulation of temporal imagery, despite the fact that it plays a crucial role in the acquisition of motor skills and performance (Decety, Jeannerod, & Prablanc, 1989; Jeannerod, 1994, Taktek, 2004). Temporal imagery leads to the representation of rhythm, speed, and duration of the motor action (Louis et al., 2008).

Based on the distinction emphasized initially by Mahoney and Avener (1977) between internal and external perspectives of imagery, Hardy (1997) and also Hardy and Callow (1999) suggested that the internal visual imagery is efficient for the acquisition and performance of open skills that depend heavily on perception for their successful execution. Indeed, this internal visual imagery allows the performer to mentally rehearse the precise spatial locations, environmental conditions, and timings at which key movements must be initiated. However, external visual imagery has superior effects on the acquisition and performance of skills that depend heavily on form since it enables the performer to "see" the precise positions and movements that are required for successful performance. Moreover, Hardy (1997) emphasized that kinesthetic imagery should not be confused with internal visual imagery, and that it should enhance performance more than each visual imagery perspective alone (internal visual imagery or external visual imagery) because it helps the performer to match the timing and feel of movements to the employed visual images.

More particularly, Féry and Morizot (2000) found that kinesthetic imagery is significantly more efficient than visual imagery when the dominant parameter of the experimental task relies on the time or duration of movement. Elsewhere, Féry (2003) reported that kinesthetic imagery is significantly superior to visual imagery in the case of the reproduction of a task involving a time parameter or coordination of the two hands and that is completely the opposite with respect to form reproduction (drawing). Thus, the second purpose of this study was to determine the mental imagery modality (visual, kinesthetic, or temporal) which has the most impact on the acquisition, retention and transfer of sport rifle marksmanship. As a complex motor skill, marksmanship involves an interaction of predicted relevant modalities immediately before, during and after the round goes off: trigger and breath control, postural steadiness (kinesthetic imagery), sight picture and alignment on the target (temporal imagery), and adjusting for distance, target location and other environmental variables (visual imagery) (Chung et al., 2011).

The last purpose of this study was to determine the effects of movement imagery vividness on the performance of sport rifle shooting in cadets. Several studies showed that high-imagers outperform lower or occasional imagers (Robin et al., 2007; Taktek, 2004). Using a closed motor skill, such as propelling with the nondominant hand a miniature vehicle toward a target distance, Taktek and Rigal (2005) as well as Taktek et al. (2004) did not find any correlation between the children's motor performance and their score obtained in the adapted and validated French version of the Vividness of Movement Imagery Questionnaire. This could be related to the fact that imagery ability has been shown to be not fully developed in children. Several other studies also failed to indicate a positive correlation between mental imagery ability and motor performance in adult participants. The main reason for such results was related to the validity weakness of the questionnaire used to measure the participants' imagery ability (Morris & Spittle, 2012; Taktek, 2012).

Based on the above literature overview, this study's hypotheses were as follows: (a)

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mental imagery combined with physical practice produces equivalent acquisition and retention performance to that of the physical practice only but significantly better transfer performance; (b) kinesthetic or temporal imagery combined with physical practice provide significantly better acquisition, retention and transfer performance than visual imagery combined with physical practice; and (c) high-vivid imagers perform significantly better than low-vivid imagers during the execution of sport rifle marksmanship.

METHODS

Participants

Seventy undergraduate students from the United States Military Academy (USMA), West Point, participated in this study. They were right-handed (based on Oldfield's laterality test (1971)) and aged between 18 and 22 years (see Table 1, for the groups' average age). Participants, first year cadets enrolled in a mandatory introductory psychology course, displayed no apparent physical or sensorial disability that could have potentially affected their performance. Although the participants had previous experience with rifle marksmanship as part of their training schedule at the USMA, they had never been exposed to formal mental imagery and were unfamiliar with the experimental protocol of the present study. They participated voluntarily and received no rewards or incentives. Above all, any participant who was left-handed, knew about mental imagery or was familiar with the experimental protocol was released from the study. Participants were first divided into two groups (men and women). Each group ranged from high-imagers to low-imagers based on their mental imagery ability score (Taktek et al., 2008). Participants were then divided into seven experimental groups. Each group was composed of one woman and nine men, distributed based on their score on the *VMIQ*,

Table 1

Mean (M) Results and Variability (SD) for Each Experimental Group in the Imagery Test and in the Motor Performance (Treatment Blocks and Experimental Phases)

	Age		EIP		IIP		TIP		Pre-test		Block1-2		Block3-4		Block5-6		Clarity		Control		Posttest		Transfer	
Groups	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
PPG	18.9	0.9	53.8	15.6	49.4	21.4	103.3	36.4	4.4	1.5	4.3	1.7	4.5	1.9	5.3	1.6					6.7	1.4	4.0	2.3
VIG	19.0	0.7	36.0	9.9	36.5	14.7	72.5	23.0	3.2	1.3							1.9	.74	1.6	.52	5.1	1.7	3.7	1.5
PPVIG	18.7	0.5	38.9	15.9	34.8	12.6	73.7	28.0	4.1	1.5	5.3	2.2	7.1	0.9	6.3	1.9	1.7	.67	1.8	.63	6.3	1.5	4.9	1.4
PPKIG	19.1	0.9	45.5	13.3	43.2	9.7	88.7	17.5	3.8	1.2	5.6	2.7	5.8	1.7	7.1	2.1	1.3	.48	1.2	.42	6.6	1.1	6.8	1.6
PPTIG	19.1	0.9	59.9	14.6	49.2	12.2	109.1	25.9	4.2	1.4	5.4	1.9	6.8	1.6	6.5	1.4	1.3	.48	1.3	.48	6.2	1.3	6.2	1.4
PPRG	19.2	1.1	41.9	10.9	38.3	6.9	80.2	16.8	3.9	1.4	5.7	1.4	7.0	1.4	6.5	1.7					4.3	1.7	3.5	1.0
CG	18.9	1.2	54.0	19.9	45.7	10.3	99.7	28.3	3.5	0.8											2.8	1.0	2.5	1.1
Total	19.0	0.9	47.1	16.3	42.4	13.9	89.6	28.3	3.9	1.3	5.3	2.0	6.2	1.8	6.3	1.8	1.55	.59	1.48	.51	5.4	1.9	4.5	2.0

Note. PPG = Physical practice only group; VIG = Visual imagery group; PPVIG = Physical practice plus visual imagery group; PPKIG = Physical practice plus kinesthetic imagery group; PPTIG = Physical practice plus temporal imagery group; PPRG = Physical practice plus rest group; CG = Control group; EIP = External imagery perspective; IIP = Internal imagery perspective; and TIP = Total imagery perspective.

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in such a way to maintain a homogeneous gender and imagery ability between the groups (see Table 1).

Apparatus and Materials

The experimental task consisted of 12 rifle shooting stations located at the Marksmanship Range of the USMA. Participants used their dominant hand to shoot (live-fire shooting) rotating targets. The length of the targets' exposure was automatically controlled by an IBM PC computer. Indeed, as soon as the time of the targets' exposure had elapsed, each target rotated automatically on its side preventing the reception of any additional bullets. The weapon used was an M4 assault rifle, Caliber 5.56 mm. The magazine size was semi-automatic and held 30 rounds. No optic was employed. The M4 was the standard training weapon used by USMA cadets at the time of the present study. All magazines were loaded manually by research team members prior to shooting. Participants loaded the magazines into their weapons once they took position in their respective shooting lanes. Each target was composed of five concentric circles within diameters of 3.5, 7, 10.5, 14.3, and 18 cm. The scores were recorded as follows: 10 points if the bullet hit the smallest concentric circle, 9, 8, 7, and 6 for the other circles, respectively. The center of the target was located at a height of 150 cm above the ground. The prerecorded imagery instructions were transmitted to the participants by a Toshiba laptop, model Satellite X200-FG1.

Vividness of Movement Imagery Questionnaire

Participants were asked to respond individually (in a quiet area at the Marksmanship Range of USMA) to the Vividness of Movement Imagery Questionnaire (*VMIQ*) detailed by Isaac, Marks and Russel (1986). This Questionnaire is designed to be appropriate for all age groups. It uses a similar format to the Vividness of Visual Imagery Questionnaire (*VVIQ*). The test-retest reliability of the *VMIQ* and the validity (relationship between the *VMIQ* and *VVIQ*) were respectively r = .76 and r = .81 (Isaac et al., 1986). Each participant was required to assess the clarity of the visual image evoked by using 24 items indicated on a 5-point Likert scale. Participants were asked to, firstly, imagine someone else doing each movement (external imagery perspective) and, lastly, imagine themselves performing each of these movements (internal imagery perspective; Mahoney & Avener, 1977). The imagery score ranged between 0 and 120 for each internal or external imagery perspective, where a higher score suggested a vague and dim image.

Rating Scales

At the end of the treatment phase, participants of each imagery group completed two rating scales manipulation checks designed to assess aspects of clarity and control of the image modality (visual, kinesthetic, or temporal) used during the imagery training. More particularly, the first rating scale asked participants to rate how clear the image was. The second rating scale asked participants to rate their ability to control the image. Spittle (2001) underlines that "Rating scales represent a quick and easy method of assessment because participant response is simple and fast, and there is no need for transcription or content analysis" (p. 194). Participants made their response on 5-point Likert scales, the clarity scale ranging from 1 = perfectly clear image to 5 = no image and the control scale ranging from 1 = complete control of the image to 5 = no control of the image. The present study used Likert scales to assess the image clarity and control because

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several other research studies on imagery have employed the same format (Mahoney & Avener, 1977; Isaac et al., 1986; Roberts et al., 2008, Spittle, 2001).

Verification Question

After the completion of the two rating scales manipulation checks, participants of the various imagery groups were asked if they switched between visual, kinesthetic and temporal modalities during their imagery training and to explain their response (i.e., "While experiencing the imagery of the shooting task, did you switch between visual, kinesthetic and temporal modalities? Yes / No. Please explain your response.")

Procedures

The research project was approved by the Laurentian University Research Ethics Board as well as the USMA's Institutional Review Board. The research team contacted the participants by email. They were individually briefed about the research project and received a copy of the experimental protocol, the USMA's Institutional Review Board approval letter, and the participant's consent letter. Two field-grade military officers (Majors) at USMA took the responsibility to distribute the consent letters to the cadets and to ask that they return these letters within a week. Furthermore, these Majors organized a schedule of participation for all of the experimental groups, kept the consent letters for the experimenter, and helped with the security aspect of the shooting during the entire research project.

At the beginning of the experiment, participants were initially asked to respond to the Oldfield's Laterality test (1971). Only the right-handed participants were then selected to respond to the *VMIQ*. The experimenter explained the details regarding the Laterality Questionnaire and *VMIQ* and responded to all questions. Participants were also asked if they have ever been exposed to mental imagery and if they were familiar with the experimental protocol. Before the experimental shooting began, participants received an explanation and demonstration of the required task and questions were entertained. Furthermore, participants were informed of the number of sessions that needed to be performed and how measurements would be conducted.

Participants were asked to choose one of the 12 shooting stations and to be positioned facing the shooting area, notably in the direction of the appropriate target which was hanging at a certain distance in front of them. While executing the movement, participants were required to stand up or to kneel behind a red shooting line marked on the floor. In the kneeling position, there are three points of contact with the ground: the left foot, the right knee and the right toes. This study entailed an experimental task, conducted within an open environment (because of the rotating targets, see Schmidt & Wrisberg, 2008, for further details). Under the physical practice condition, participants were asked to hold the weapon and shoot rotating targets. The location of the targets was determined in advance. As soon as the time of the targets' exposure had elapsed, each target automatically rotated sideways, thus, preventing it from being hit by any additional bullets. Mental imagery conditions required the participants to close their eyes, hold the weapon as if they were going to shoot, listen to the imagery instructions, and imagine or feel the scene of the movement (visual, kinesthetic, or temporal). Participants were given 30 s to generate and focus on their respected imagery. During the treatment phase, participants in each of the physical practice combined with mental imagery groups (physical practice combined with visual imagery group, PPVIG; physical practice combined with kinesthetic imagery group, PPKIG; and physical practice combined with temporal imagery group, PPTIG) as well as physical practice combined with rest group (PPRG), alternated between the physical practice and mental practice or rest after each trial (e. g., Kohl, Ellis, & Roenker, 1992a, Taktek et al., 2004, 2008). Therefore, the length of the target exposure was 1 shot / 1 s.

Upon the completion of all the imagery trials at the end of the treatment phase, participants of each imagery group completed two rating scales manipulation checks in order to examine the clarity and control (Spittle, 2001) of the image (visual, kinesthetic, or temporal) used during the imagery training. Moreover, they were asked to specify and explain if there was any switching between visual, kinesthetic and temporal modalities during their imagery training. Several participants (maximum of 10 students) belonging to the same group executed their physical or imagined shooting at the same time, under the signal given by the military officer.

Before each actual shot, participants were required to insert their ear-plugs. After each block of five trials, the participants were asked by the military officer to remove the target, to record the number of points, to write down at the back of each target the corresponding experimental phase (familiarization 1, familiarization 2; pretest 1, pretest 2; treatment 1, treatment 2, treatment 3, treatment 4, treatment 5, treatment 6; posttest 1, posttest 2; transfer 1, transfer 2), and to post a new target. Two assistant researchers verified the correctness of the reported scores by adding the corresponding number of points left by the bullets on each target. Participants initially attended 30 minutes of weapon handling (security) followed by a familiarization period composed of two sessions of five shots each. After each set of five shots, a 2-min rest period was given to the participants so that they received the necessary feedback on the results of their shots, removed the target, wrote the appropriate point numbers and phase, posted a new target, and got ready for the subsequent trial. Moreover, after each session of 10 trials, a 5-min rest period was allocated to the participants in order to eliminate the effect of fatigue. Finally, a 15-, 60-, and 15-min period of time separated respectively the pretest from treatment, treatment from posttest, and posttest from transfer (Kohl et al., 1992a, Taktek et al., 2008). The participants of the physical practice only group (PPG) executed a total of 70 shooting trials, divided into 10, 10, 30, 10 and 10 respectively, during the familiarization, pretest, treatment, posttest, and transfer. The participants of each of physical practice combined with mental imagery groups (PPVIG, PPKIG, PPTIG) and physical practice combined with rest group (PPRG) performed 55 shots divided into 10, 10, 15, 10 and 10 respectively, during the familiarization, pretest, treatment, posttest, and transfer.

Experimental Phases

This study comprised four principal phases, namely the pretest, treatment, posttest (retention) and transfer (Shapiro & Schmidt, 1982; Taktek et al., 2004, 2008; see Table 2).

Pretest Phase

The participants of each experimental group initially practiced 10 shooting trials from a standing position. The shooting line was located at a distance of 14 m from the target. The length of the target exposure was 5 shots / 5 s. The M4 assault rifle weight was 3.9 kg (8.6 lbs), fully loaded.

Treatment Phase and Experimental Groups

The participants of the physical practice only group (PPG) were required to execute 30 shooting trials. The position of shooting, distance of shooting, length of the target exposure, and M4 assault rifle weight were identical to those used during the pretest phase.

The participants of the visual imagery group (VIG) practiced mentally 30 shooting trials. They received the following instructions: “Hold the weapon as if you are going to fire it. Close your eyes. Imagine, in as clear and precise a manner as possible, the distance which separates you from the target. Imagine the bullet hitting the center of the target. Open your eyes. Release the weapon and relax”.

The participants of the PPVIG were required to execute the same number of shooting sessions as each of the other groups. However, they had to alternate after each trial between physical practice and visual imagery (for a total of 15 physical practice trials and 15 visual imagery trials). The instructions were identical to those of the VIG.

The participants of the PPKIG were subjected to the same protocol as the PPVIG. However, they had to alternate after each trial between physical practice and kinesthetic imagery (for a total of 15 physical practice trials and 15 kinesthetic imagery trials). The instructions were: “Hold the weapon as if you are going to fire it. Close your eyes. Feel, in as clear and precise a manner as possible, the contractions of the muscles in your arm and forearm. Feel the movement of your index finger as you pull the weapon’s trigger and

Table 2
Characteristics of the experimental conditions (pretest, treatment, posttest, and transfer) for each group

LT 20’	*VMIQ* 45 min	Groups	Pretest (10 trials) Standing position	(15 min rest) Treatment (30 trials) Standing position	RS VQ	(60 min rest) Posttest (10 trials) Standing position	(15 min rest) Transfer (10 trials) Kneeling position
X	X	PPG	10 PP: Distance (D) = 14 m; Target exposure (TE) = 5 shots / 5 s; M4 assault rifle weight = 3.9 kg (8.6 lbs), fully loaded	30 PP: D = 14 m; TE = 5 shots / 5 s; M4 assault rifle weight = 3.9 kg (8.6 lbs), fully loaded		10 PP: D = 14 m; TE = 5 shots / 5 s; M4 assault rifle weight = 3.9 kg (8.6 lbs), fully loaded	10 PP: D = 15 m; TE = 5 shots/ 4 s; M4 assault rifle weight = 3.6 kg (7.9 lbs), half loaded
X	X	VIG	Idem	30 VMI (no PP)	X	Idem	Idem
X	X	PPVIG	Idem	15 PP: D = 14 m; TE = 1 shot / 1 s; M4 assault rifle weight = 3.9 kg (8.6 lbs), fully loaded + 15 VMI	X	Idem	Idem
X	X	PPKIG	Idem	15 PP + 15 KMI	X	Idem	Idem
X	X	PPTIG	Idem	15 PP + 15 TMI	X	Idem	Idem
X	X	PPRG	Idem	15 PP + 15 Rest		Idem	Idem
X	X	CG	Idem	Reading (no PP and no MI)		Idem	Idem

Experimental phases

Note. LT = Oldfield’s Laterality Test (1971); *VMIQ* = The Vividness of Movement Imagery Questionnaire (Isaac, Marks, & Russel, 1986); RS = Rating Scales; VQ = Verification Question; PPG = Physical practice only group; VMIG = Visual imagery group; PPVIG = Physical practice plus visual imagery group; PPKIG = Physical practice plus kinesthetic imagery group; PPTIG = Physical practice plus time imagery group; PPRG = Physical practice plus rest group; and CG = Control group; PP = Physical practice; MI = Mental imagery.

*PPVIG, PPKIG, PPTIG, and PPRG alternated between physical and mental practice or rest after each trial (see Kohl, Ellis, & Roenker, 1992; Taktek, Zinsser, & St-John, 2008).

feel the weapon firing. Open your eyes. Release the weapon and relax".

The participants of the PPTIG were required to execute the same number of shooting sessions as each of the other groups. However, they had to alternate after each trial between physical practice and temporal imagery (for a total of 15 physical practice trials and 15 temporal imagery trials). The instructions were: "Hold the weapon as if you are going to fire it. Close your Eyes. Imagine, in as clear and precise a manner as possible the length of the target exposure. Imagine the appropriate time for firing. Open your eyes. Release the weapon and relax".

The participants of the PPRG were asked to alternate between physical practice and rest (for a total of 15 physical practice trials and 15 rest trials), with a similar protocol to that of PPVIG, PPKIG, or PPTIG. However, during each rest trial, the participants were asked to read silently material that was irrelevant to the task.

Finally, the participants of the control group (CG) were involved in silent reading (irrelevant to the task) for the same period of time as each of the other groups. More particularly, the participants of the CG were requested to read sports and leisure magazines that had no relation to the experimental shooting task (e.g., Athlon Sport, ESPN, Outside). Silent reading was also intended to prevent the participants of the CG from practicing imagery.

Posttest Phase

The experimental protocol was identical to the one used during the pretest phase.

Transfer Phase

During the transfer phase, the shooting position, distance, target speed, and M4 assault rifle weight were all changed from those in the other phases in order to test participants' transfer of performance when the parameters of the task are altered (see Shapiro & Schmidt, 1982; Taktek et al. 2004, 2008, for more details on the selected type of "intratask" transfer). Indeed, the participants executed 10 shooting trials from a kneeling position. The shooting line was located at a distance of 15 m from the target. The speed of the rotating target was 5 shots / 4 s. As for the M4 assault rifle weight, it was 3.6 kg (7.9 lbs), half loaded.

Design

Independent Variables

The independent variables were: (a) for the analyses of results obtained during the treatment phase, the between-groups variable was the five experimental groups (PPG, PPVIG, PPKIG, PPTIG, and PPRG). The within-group variable was the trial block numbers (Block 1-2, Block 3-4, and Block 5-6). Indeed, in order to facilitate the result comparisons of the five experimental conditions, the number of points obtained, during the 30 trials of the treatment phase, was calculated based on the average of three blocks of 10 successive trials: (a) Block 1-2 (1-10 average trials), Block 3-4 (11-20 average trials) and Block 5-6 (21-30 average trials); (b) for the analysis of results produced during the pretest, posttest and transfer, the between-groups variable was the seven experimental groups (PPG, VIG, PPVIG, PPKIG, PPTIG, PPRG, and CG). The within-group variable was the experimental phases (pretest, posttest and transfer); and (c) for the analysis of results obtained on the *VMIQ*, the between-groups variable was the seven experimental groups (PPG, VIG, PPVIG, PPKIG, PPTIG, PPRG, and CG). The within-group variable was the imagery perspective (external imagery perspective, EIP; internal imagery perspective, IIP; and total imagery perspective, TIP).

Dependent Variables

The dependent variable was the mean number of points corresponding to the M4 assault rifle shooting and the scores obtained at the *VMIQ* or rating scales.

Measures and Statistical Analyses

The analyses of variances were conducted according to the following designs: (a) for the analyses of results obtained during the treatment phase, 5 (PPG, PPVIG, PPKIG, PPTIG, and PPRG) X 3 (Block 1-2, Block 3-4, and Block 5-6), with repeated measures on the last factor; (b) for the analysis of results produced during the pretest, posttest and transfer, 7 (PPG, VIG, PPVIG, PPKIG, PPTIG, PPRG, and CG) X 3 (pretest, posttest, and transfer), with repeated measures on the last factor; and (c) for the analysis of results obtained on the *VMIQ*, 7 (PPG, VIG, PPVIG, PPKIG, PPTIG, PPRG, and CG) X 3 (EIP, IIP, and TIP), with repeated measures on the last factor. All these analyses of variances were performed using the General Linear Model, for repeated measures (George & Mallery, 2016)**.**

The four ANOVAs assumptions (independence of observations, normality of observations, homogeneity of group variances, and sphericity) were satisfied. The technique suggested by Sidak (Hsu, 1996, p. 160) was utilised for the *post hoc* comparisons of means. Finally, the degree of relationship between the scores on the mental imagery ability and motor performance obtained during the experimental phases was calculated with Pearson's correlation coefficient.

RESULTS

Group Effect during the Four Blocks of the Treatment Phase

Table 1 shows the results in each experimental condition. The ANOVA/MANOVA revealed that the Block trials, $F(2,90) = 8.4$, $p < .001$, $\eta^2 = .16$, Observed Power (OP) = .96, and Group effect, $F(4,45) = 2.78$, $p < .05$, $\eta^2 = .20$, OP = .72, were significant. The Block trials X Groups was not significant, $F(8,90) = 1.13$, $p > .05$, $\eta^2 = .09$, OP = .50 (see Table 1, Figure 1).

Group Effect during the Three Experimental Phases

Table 1 also shows the results of each group in each experimental phase (pretest, posttest and transfer). The ANOVA/MANOVA revealed that the Experimental Phase, $F(2,126) = 31.89$, $p < .001$, $\eta^2 = .34$, OP = 1.00, and Group effect, $F(6,63) = 9.57$, $p < .001$, $\eta^2 = .48$, OP = 1.00, were significant. The Experimental Phase X Group interaction was significant, $F(12,126) = 5.54$, $p < .001$, $\eta^2 = .35$, OP = 1.00.

The simple effects analysis of the Experimental Phase X Group interaction revealed that differences between the seven groups were significant only during the experiment's posttest, $F(6,63) = 10.72$, $p < .001$, $\eta^2 = .51$, OP = 1.00; and transfer, $F(6,63) = 10.50$, $p < .001$, $\eta^2 = .50$, OP = 1.00. Additionally, differences between experimental phases were significant for PPG, $F(2,62) = 16.1$, $p < .001$, $\eta^2 = .34$, OP = .10 ; PPVIG, $F(2,62) = 10.44$, $p < .001$), $\eta^2 = .25$, OP = .99; PPKIG, $F(2,62) = 22.65$, $p < .001$, $\eta^2 = .42$, OP = 1.00; PPTIG, $F(2,62) = 10.73$, $p < .001$, $\eta^2 = .26$; OP = .99; and VIG, $F(2,62) = 8.25$, $p \leq .001$, $\eta^2 = .21$, OP = .95, except for PPRG and CG, ($p > .05$).

The *post hoc* comparisons (technique suggested by Sidak, see Hsu, 1996, p. 160) for the posttest phase of the experiment revealed that the number of points for PPG, PPVIG, PPKIG or PPTIG was significantly higher than that for CG ($p < .001$; $p < .05$; $p < .001$; $p < .001$, respectively) or PPRG ($p \leq .005$; $p < .05$; $p \leq .01$; $p < .05$, respectively). In addition, the number of points for VIG was significantly higher than that for CG ($p < .05$) but equivalent to that for PPRG ($p > .05$). For the transfer phase of the experiment, the number of points for PPKIG or PPTIG was significantly higher than that for PPG (p < .005 and p < .05, respectively); CG (both $p < .001$); VIG ($p < .001$ and $p < .01$, respectively); or PPRG ($p < .001$ and $p \leq .005$, respectively). The number of points for VIG was significantly higher than that for CG ($p \leq .01$). Furthermore, the number of points for PPG, PPVIG, PPKIG, PPTIG or VIG at posttest phase was significantly higher than at pretest phase (all $p \leq .001$). The number of points for PPKIG or PPTIG at transfer phase was significantly higher than that at pretest phase ($p < .001$ and $p < .005$, respectively). Finally, the number of points for PPG and PPVIG at posttest phase was significantly higher than that at transfer phase ($p < .001$ and $p < .05$, respectively; see Figure 2).

Group Effect on the VMIQ

Table 1 also shows the results of each experimental group on the *VMIQ*. The ANOVA/MANOVA revealed that the Imagery Perspectives, $F(1,63) = 13.92$, $p < .001$, $\eta^2 = .18$, OP = .96 and Group effect, $F(6,63) = 3.24$, $p < .01$, $\eta^2 = .24$, OP = .90, were significant. The Imagery Perspective X Group interaction was not significant ($p > .05$).

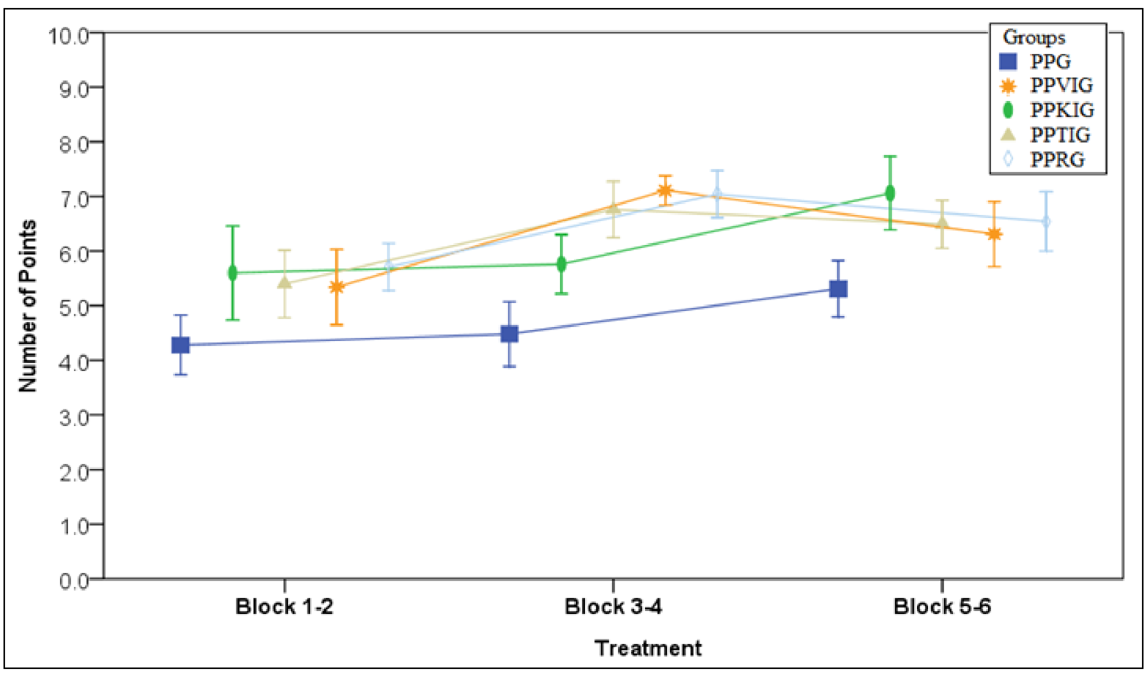

Figure 1. Mean point numbers obtained during the different blocks (Block 1-2, Block 3-4 and Block 5-6) of the treatment phase by the experimental groups PPG = Physical practice only group; PPVIG = Physical practice plus visual imagery group; PPKIG = Physical practice plus kinesthetic imagery group; PPTIG = Physical practice plus temporal imagery group; and PPRG = Physical practice plus rest group.
Vertical lines depict ± one standard errors of the mean.

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Clarity and Control of the Image

The first rating scale probed how clear the image (visual, kinesthetic, or temporal) was and the second scale examined the controllability of such image. The results for these scales are provided in Table 1. Generally, the clarity and control of the image were high. All imagery groups (VIG, PPVIG, PPKIG, and PPTIG) had ratings less than (*M* = 2.0) with the lowest ratings (which indicates highest clarity and control) produced by PPKIG and PPTIG and the highest ratings obtained by PPVIG and VIG for clarity and control. However, no significant difference was found between the four imagery groups for clarity and control.

Verification Question

In general, participants of the various imagery groups (VIG, PPVIG, PPKIG, and PPTIG) did not report any switching between the imagery modalities (visual, kinesthetic, and temporal) during their imagery experience of the shooting task. All participants asserted that they imagined the shooting task as instructed.

Relationship between Mental Imagery Ability and Motor Performance

The correlation coefficients between the scores at *VMIQ* and at motor performance were close to zero in most cases. The only significant correlations exist between the

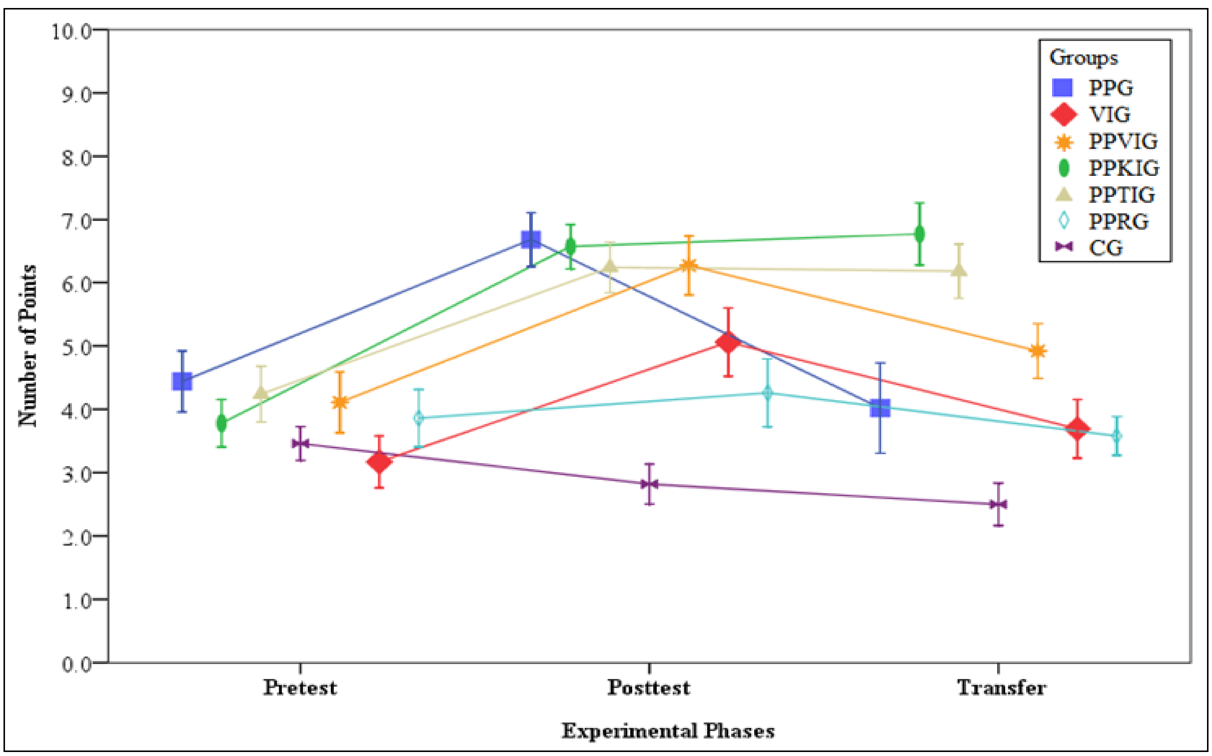

Figure 2. Mean point numbers obtained during the different phases (pretest, posttest and transfer) by the experimental groups PPG = Physical practice only group; VIG = Visual imagery group; PPVIG = Physical practice plus visual imagery group; PPKIG = Physical practice plus kinesthetic imagery group; PPTIG = Physical practice plus temporal imagery group; PPRG = Physical practice plus rest group; and CG = Control group.
Vertical lines depict ± one standard errors of the mean.

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scores for external and internal imagery perspectives, $r = .76$, $p < .001$.

DISCUSSION

The Effects of Visual, Kinesthetic, and Temporal Mental Imagery on Marksmanship's Performance during the Treatment/Acquisition Phase

In general, performance (number of points) obtained during the treatment phase by the different experimental groups was equivalent. These results could be explained by the fact that the experimental protocol required from participants of the physical practice only group (PPG) successive execution (and without rest) of 5 shots per 5 s (for a total of six sets of five shots each). On the contrary, in each of the other groups, participants were asked to execute (for the same number of trials) one shot per 1 s and to engage, for the following trial, in a mental imagery (PPVIG, PPKIG, and PPTIG) or rest period (PPRG). This experimental protocol may have caused temporal stress, or "high contextual interference" (Keller, Li, Weiss, & Relyea, 2006; Taktek et al., 2004, 2008) as well as fatigue and physical exertion for participants of the PPG, as an average of only four of five shots may have reached the target successfully. However, for the other groups, the alternation between physical and mental or rest practice may have provided sufficient time for participants to better adapt their shots to the length of target exposure and given their body essential rest to better support the M4 assault rifle.

In their comprehensive literature review dealing with the relationship between practice distribution and acquisition of motor skills, Lee and Genovese (1988) reported that when the number and/or duration of acquisition trials are held constant, intertrial rest enhances motor performance for continuous task (such as the pursuit rotor). Furthermore, Lee and Genovese (1989) found that intertrial rest facilitated retention for a continuous task, but not for a discrete task. The results of the present study showed that intertrial rest could be beneficial even for the acquisition performance of an open motor task.

Based on the fact that distributed practice may enhance motor learning and performance, Kohl et al. (1992) proposed that when physical and imagery practices were alternated, imagery practice allowed the distribution of physical practice in the same way as a rest interval. This assumption is fully endorsed by the acquisition results of the present study, notably the equivalence between the PPRG and each of the imagery groups (PPVIG, PPKIG, or PPTIG).

Deschaumes-Molinaro et al. (1991) subjected national and international level shooters to three conditions; concentration prior to shooting (CS), actual shooting (AS), and a mental representation of shooting (MS). Six autonomic nervous system (ANS) variables were assessed (skin potential; skin resistance; skin blood flow; skin temperature; instantaneous heart rate; and respiratory frequency). The participants were tested first in the field during a competition (measures were taken during the CS and physical practice phases) and then in the laboratory (for MS). The results did not reveal any significant differences between the three experimental conditions for the six autonomic nervous system variables, prompting Deschaumes-Molinaro et al. (1991) to conclude that these three conditions engaged similar viscero-motor phenomena and that mental imagery represented a form of concentration. Thus, with respect to Deschaumes-Molinaro et al.'s (1991) point of view, the acquisition results of the present study may be explained by the psychological skill (notably concentration) and peripheral (physiological) hypotheses of mental imagery (see Collet et al., 2011; Holmes & Collins, 2001, Papadelis, Kourtidou-Papadeli, Bamidis, & Albani, 2007, for further details).

The interaction between the number of Block trials and groups did not reveal any performance improvement from Block 1-2 through Block 5-6. On the one hand, these results could have emerged as a consequence of the block trial performance combination (average of Block 1-2, Block 3-4, and Block 5-6, of ten trials each), which could have hidden the eventual intertrial improvement. On the other hand, these results indicated the possibility that the potential benefit of each practice strategy (PPG, PPVIG, PPKIG, PPTIG, and PPRG) did not manifest itself in the short term, notably during the treatment phase, likely due to latent learning (Taktek et al., 2008). It is also possible that the number of practice trials (30 shots) was not sufficient for the performance enhancement (Shapiro & Schmidt, 1982; Taktek, 2004). Hence, the question arises concerning to what extent the performance obtained during the treatment could be generalized to retention (posttest) and transfer.

The Effects of Visual, Kinesthetic, and Temporal Imagery on Marksmanship's Performance during the Retention and Transfer Phases

The interactions between the experimental phases and groups revealed that the performance obtained during the pretest phase by the seven experimental groups was equivalent. This shows that the initial motor skill level was homogeneous between the groups and thus satisfied the prerequisite of the mental imagery research hypothesis (Feltz & Landers, 2007; Taktek, 2004).

Moreover, performance produced during the posttest phase (retention) by each imagery group (VIG, PPVIG, PPKIG, or PPTIG) was equivalent to that obtained by the physical practice only group (PPG). These results support the psychological skills hypothesis, which proposes that mental imagery develops diverse forms of cognitive functioning, notably concentration (Deschaumes-Molinaro et al., 1991, 2001) and retention (Jarus & Ratzon, 2000; Kohl et al., 1992). Indeed, by using a pursuit rotor task, Kohl et al. (1992, experiment 1) found that the retention performance of the physical practice combined with mental imagery group was equivalent to the physical practice only group, but each of them was significantly superior to the mental imagery group and physical practice combined with rest group. The latter groups were equivalent but were significantly superior to the reading control group. Thus, the results of the present study are consistent with those reported by Kohl et al. (1992, experiment 1) and show that visual imagery (VIG) can be as efficient as any other form of physical practice (PPG, PPVIG, PPKIG and PPTIG). However, the fact that the CG was equivalent to the PPRG but inferior to the VIG suggests that mental imagery is probably more beneficial for retention in an open motor task than simple rest.

With respect to Feltz and Landers' (2007) view point, the shooting retention performance produced by each of the imagery groups (VIG, PPVIG, PPKIG, and PPTIG) could be explained by three principal functions inherent in the potential benefits of mental rehearsal for the acquisition of motor skills and performance, namely (a) the symbolic learning role, which refers to the formation of movement image or motor program in the central nervous system. Thus, mental imagery may function as a coding system in order to help with the acquisition of the shooting movement patterns of the appropriate motor task; (b) the psycho-neuromuscular role, which consists of the evocation of muscular contractions similar to those produced during real physical practice of shooting. Although the magnitude of the muscle contractions is reduced during mental imagery, these contractions represent a mirror image of the actual shooting performance pattern; and (c) the “psyching up” role, which refers to the “psychological skills hypothesis,” notably the alert state raised by the non-localized muscular activity following the mental practice of the shooting task. Therefore, mental imagery may have developed concentration (Deschaumes-Molinaro et al., 1991, 2001), optimized preparation (Jeannerod, 1994), and/or enhanced retention (Jarus & Ratzon, 2000; Kohl et al., 1992).

With respect to Holmes and Collins’ (2001) argument, the equivalence between each of the mental imagery groups (VIG, PPVIG, PPKI, and PPTIG) and the physical practice only group (PPG) could be explained by three principal evidences, namely behavioural, central and peripheral. In fact, after comparing the results of physical practice and mental imagery during the execution of several motor actions (such as signing, writing a sentence, drawing a cube, walking towards fixed targets), Decety, Jeannerod and Prablanc (1989) did not find any significant difference. These results are consistent with those of the present study and could be explained, on the one hand, by the similarity of the mechanism responsible for the movements’ temporal organization and, on the other hand, the involvement of the same motor program during both physical and mental practices (e.g., Taktek, 2004). These conclusions account for the behavioral evidence of functional equivalence between mental imagery and physical practice (Holmes & Collins, 2001). Therefore, such conclusions endorse the symbolic learning hypothesis, according to which mental imagery plays a coding system to help athletes and/or individuals understand the characteristics of movement patterns and better shape out the motor program of the task at hand (Feltz & Landers, 2007).

The central evidence for functional equivalence between mental imagery and physical practice emerges from studies carried out on the pattern of brain activation through functional magnetic resonance imaging (fMRI; Hanakawa, Dimyan, & Hallett, 2008), modulation of neural circuits (Pascual-Leone, Dang, Cohen, Brasil-Nato, Cammarota, & Hallett, 1995), and the increase of the values of the regional cerebral blood flow (rCBF; Malouin, Richards, Jackson, Dumas, & Doyon, 2003). Decety, Sjoholm, Ryding, Stenberg, & Ingvar (1990), for instance, reported that during a tennis task, the values of the rCBF increased in both hemispheres significantly more under mental imagery condition than a rest or silent counting condition, prompting them to conclude that the cerebellum may play a dynamic role during mental rehearsal. Overall, the results reported by Decety et al. (1990), Malouin et al. (2003), and Pascual-Leone et al. (1995) show that mental imagery and physical practice only may share some neural/cognitive processes. Therefore, this give clear support to the psycho-neuromuscular hypothesis as well as the central evidence for functional equivalence between mental imagery (PPVIG, VIG, PPKIG, PPTIG) and physical practice only (PPG; Holmes & Collins, 2001; Taktek, 2004; Taktek et al., 2008). Elsewhere, several studies carried out at the level of diverse variables of the autonomous nervous system (such as skin potential and resistance, skin blood flow, pulmonary ventilation and cardiac rhythm, skin temperature, electromyographic activity) brought clear support to the peripheral evidence for functional equivalence between mental imagery and physical practice only (for further details, see Deschaumes-Molinaro et

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al., 1991, 2001; Holmes & Collins, 2001; Jeannerod, 1994, Papadelis et al., 2007).

As for results of the transfer phase, they indicated that performance of PPG, VIG, PPRG, or CG was significantly lower than PPKIG or PPTIG. These results could be explained by the fact that each of the latter group involved similar parameters of the shooting task and that they emphasized the perception of the body as a producer of force ("Feel, in as clear and precise a manner as possible, the contractions of the muscles in your arm and forearm ...") or time ("Imagine, in as clear and precise a manner as possible the length of the target exposure. Imagine the appropriate time for firing") required for the shooting task (Féry, 2003; Féry & Morizot, 2000; Taktek et al., 2008). Hence, alternating between physical practice and kinesthetic (in the case of PPKIG) or temporal (in the case of PPTIG) imagery may have led to the optimal behavioral, cortical and peripheral functioning (Holme & Collins, 2001).

In addition, the failure to find any differences between each of the kinesthetic or temporal imagery group (PPKIG or PPTIG) and visual imagery (PPVIG) may have been the result of the imagery instructions directing the participants' attention toward the object of the imagery process rather than the type of imagery (body vs. bullet; Taktek et al., 2008).

It is also possible that although the responses to the verification question indicated that there was no switching between visual, kinesthetic and temporal modalities during the imagery experience of the shooting task, participants were probably unconsciously using both visual and kinesthetic/temporal imagery instead of just the modality of imagery they were assigned.

Finally, it could be argued that the results were driven by the relevance of imagery as much as by the modality of imagery. Indeed, it is plausible that (a) the kinesthetic imagery instructions focused participants on trigger control and steady firing position (i.e., "Feel, [...] the contractions of the muscles in your arm and forearm. Feel the movement of your index finger as you pull the weapon's trigger and feel the weapon firing"); (b) the temporal imagery instructions focused participants on sight picture and alignment on the target (i.e., "Imagine [...] the length of the target exposure. Imagine the appropriate time for firing"); and (c) the visual imagery instructions ironically focused participants on irrelevant aspect of marksmanship performance (i.e., Imagine [...] the distance, which separates you from the target. Imagine the bullet hitting the center of the target). Therefore, because the kinesthetic/temporal imagery combined with physical practice (PPKIG/PPTIG) did not always reflect significantly better retention and transfer performance than the visual imagery combined with physical practice (PPVIG), the study's second hypothesis was rejected.

The Effects of Mental Imagery Ability on the Performance of an Open Motor Task

The results of the present study did not show any significant positive coefficient of correlation between the participants' score on the *VMIQ* and their motor performance at the pretest, treatment, posttest or transfer phase. Moreover, none of the variance analyses revealed any significant effect of image vividness on motor performance. These results do not support the third hypothesis of the present study, according to which high-vivid imagers perform significantly better than low-vivid imagers during the execution of an open motor skill. Nevertheless, such results are consistent with those reported in several other studies (Morris & Spittle, 2012; Pie et al., 1996; Taktek, 2012; Taktek & Rigal, 2005; Taktek et al., 2004).

The experimental task of the present study (shooting towards a mobile rotating target) corresponds to the criteria underlined by several scientific studies dealing with the mental imagery (Taktek, 2004; Taktek et al., 2004, 2008; White & Hardy, 1995). Hence, the principal reason for the absence of correlation between the imagery capacities and motor performance may relate to the validity weakness of the *VMIQ* (Callow & Hardy, 2004). More particularly, this questionnaire needs to be revised (Morris & Spittle, 2012; Roberts et al., 2008, Taktek, 2012).

An alternative explanation for the non-significant correlation between imagery vividness and motor performance could be that the *VMIQ* provides a measure of participants' "general" imagery vividness, rather that a measure of participants' imagery vividness specific to the imagery used during the experiment. Indeed, studies have shown that participants' general imagery vividness may not be related to task specific imagery vividness, which may have an impact on motor performance (Williams, Cumming, Ntoumanis, Nordin-Bates, Ramsey & Hall, 2012). These two reasons highlight that a particular consideration needs to be taken when using imagery questionnaires as research tools to assess imagery ability (Callow & Hardy, 2004).

CONCLUSIONS AND RECOMMENDATIONS

The results of the present study showed the potential benefits of mental imagery combined with physical practice as an efficient dynamic strategy intended for motor skills and performance enhancement as well as different forms of cognitive functioning development (retention, concentration, transfer, etc.). Indeed, these results could be explained by three principal evidences for functional equivalence between mental imagery and physical practice, namely behavioural, central and peripheral (Feltz & Landers, 2007; Holmes & Collins, 2001; Taktek et al., 2008).

These results offer athletes, educators, coaches, and sport psychologists relevant strategies for systematically developing intangible motor and mental skills. More precisely, the ultimate objective and challenge of the mental imagery training strategy consisted of helping participants to reach the cognitive psychological level where they achieved their full potential based on the use of mental imagery manipulated at the level of the principal parameters (visual/space, kinesthetic/force, and temporal/time).

Overall, the significance of the present study's mental imagery strategy is substantially apparent at five levels: first, reduction in costs, since mental imagery requires the simple evocation of movement and does not involve any expenditures in terms of materials (weapons, ammunitions, targets, etc.), sophisticated equipment, or practice environments; second, optimization of effort, because mental imagery is mostly inherent in the mind's ability to imagine or feel (simulation) and does not solicit any open movement; third, control of proper physiological autonomous nervous system variables (Deschaumes-Molinaro et al.,1991) as well as neurological responses (Decety et al., 1990; Hanakawa et al., 2008; Malouin et al., 2003; Pascual-Leone et al., 1995); fourth, development of different forms of cognitive functioning, which is indispensable for any strategic motor skill acquisition, retention and more particularly transfer; and fifth, enhancement of motor skills and performance (precision, mastery of movements, etc.).

As recommendation, it is proposed that further studies be carried out in order to explore extensively and in more detail the effects of mental imagery strategy manipulated at the level of the principal modalities (visual, kinesthetic, and temporal) during actual conditions of training, competition, and/or tactical intervention plans. These studies should involve more participants in order to permit generalization of the results. It is also proposed that a large number of physical practices be envisioned in order to ensure a substantial improvement in motor learning and performance (Shapiro & Schmidt, 1982). Lastly, more consideration should be attributed to transfer because the majority of studies dealing with the mental imagery hypothesis are limited to acquisition or retention (Taktek et al., 2004, 2008; Wakefield & Smith, 2009).

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