INTRODUCTION

The relationship between physical exercise and neurocognitive functions is an issue that generated interest from longstanding researches stating that psychomotor learning brings many positive effects on human intellectual functions (Piaget, 1956). Numerous studies have shown that physical exercise has positive effects on neurocognition in healthy adults (Szuhany et al., 2015; Audiffren et al., 2011; Ratey and Loehr, 2011; Sandroff et al., 2015). A recent systematic review (including experimental, longitudinal, and epidemiological studies) showed that physical activity may protect against cognitive impairment (Coelho et al., 2009; Sofi et al., 2011; Hamer and Chida, 2009; Sandroff et al., 2015).

The study findings concluded that the neurocognitive improvements affect both children, adolescents, adults, and the elderly either during acute exercises or training sessions of physical activity. In fact, several recent meta-analysis revealed multiple positive associations between physical activity and neurocognition (Etnier et al., 2006; Ratey and Loehr, 2011; Audiffren et al., 2011; Szuhany et al., 2015).

However, physical inactivity is associated not only to deleterious effects on physical health but also to a decrease in cognitive abilities (Lipnicki and Gunga, 2008). Indeed, several studies have shown the positive effects of exercise training, fitness level, lifestyle physical activity (Dunn et al., 1998), and acute exercises (Dietrich and Audiffren, 2011; Sandroff et al., 2015; Sandroff, 2015) on cognition abilities.

ABSTRACT

The aim of our study was to determine the effect of acute exercise on neurocognitive functions. 19 trained athletes, aged 20.68 ± 0.82 years, pursuing a program university sports for 3 years and been have evaluated at rest and after an intense physical exercise on cognitive tests: Working memory tests, processing speed tests, perceptual reasoning tests (Wechsler, Intelligence Scale Wechsler tests for Children, Fourth Edition [WISC-IV], 2003), and Rey complex figure test (RCFT). The results show that exercise increased slightly and significantly the performance specifically at the visuomotor coding-decoding system of 4.57%, perceptual skills of 15.45%, the spatial organization of objects 13.39%, and the visuospatial memory tasks of 15.41% (RCFT). The exercise affects positively but selectively on certain cognitive functions. The extension effects of exercise should not be generalized to all the functions. These findings suggest that physical exercise program should be a support of the cognitive enrichment of students.

Keywords: Physical exercise, cognitive function, working memory, processing speed and perceptual reasoning
A single session of physical activity increases attentional performance (span and capacity) and speed of decision making in children and adolescents (Tomporowski et al., 2011; Gallotta et al., 2012; Budde et al., 2008). Other studies have observed an improvement in cognitive function with increasing reaction time, the magnitude of memory. In experimental studies, it has been observed the positive effects on memory performance after 40 min of playing team sports (Pesce et al., 2009; Budde et al., 2010) and logical memory assessed by the Wechsler Memory Scale (Hill et al., 1993; Tomporowski et al., 2011). Furthermore, the executive functions are varied positively through physical education (Kubesch et al. 2009; Hill et al. 2010; 2011) and even in a month of fasting, the work memory and visual perception increase significantly after exercise (Lotfi et al., 2010). In other studies, it has been concluded that aerobic activity in physical training increases the ability of solving mathematical problems (Gabbard and Barton, 1979; McNaughten and Gabbard, 1993; Lojovich, 2010; Bula, 2014).

The neurophysiological mechanisms, which are often mentioned in literature as explaining the regular physical activity effect, are related on the one hand at an increasing in regional cerebral blood flow, activating of synaptic plasticity, neurogenesis, and brain catecholamines, and on the other at the effort invested in cognitive tasks. The purpose of this study is to evaluate the effects of intense exercise on neurocognitive functions related with working and visual-spatial memory, processing speed and perceptual reasoning. This work is part of a strategy to improve cognitive and academic performance.

**MATERIALS AND METHODS**

**Participants**

About 19 healthy university students were recruited for this study aged 20.68 ± 0.82 years, with a body mass index of 21.27 ± 2.05. All subjects recruited from Physical Education Program at the Hassan II University, Casablanca and pursued 2-4 regular physical training sessions per week during 3 years. All of the subjects were informed of the purpose and procedures of the tests, and informed consent was obtained before the commencement of the study.

**Research Design**

The subjects were evaluated at rest and 15 min after the exercise test on cognitive tests: Working memory tests, processing speed tests, perceptual reasoning tests (WISC-IV, 2003), and Rey complex figure test (RCFT), whose the psychometric properties are very strong. The peer items of each test are administered at rest and odd items after exercise. The test administration order is reversed in the second phase of the evaluation to preserve the same duration of both sides of physical exercise. Before each passing tests, some repetitions were performed to familiarize them and avoid the effect of learning.

**Physical Test**

The physical exercise performed is a speed running on foot 250 m realized in the form of timed competition in a circular track 250 m athletics, after warming up for 5 min. This test mobilizes the capacity of the anaerobic system, sufficient to induce a significant cardiovascular activity, and an increasing in blood lactate accumulation.

**Working Memory Tests**

The memory tests are used to assess the short-term auditory memory, sequencing capabilities, attention, and concentration (Wechsler, 2003). It contains two subtests: The digit span (forward and backward).

The digit span forward (DSF) is formed by eight-digit sequences with progressive difficulties, which are played on one after the other that must be repeated in the same order (each sequence is composed of two different series).

The digit span backward (DSB) is also formed by eight-digit sequence to which the subject restores them in reverse order. The sequences of figures presented at rest and after exercise are different.

The calculated scores are: The total score in memory numbers (MW) is the sum of the marks obtained in the two subtests (Baddeley, 1986): DSF and DSB, each is scored on 16 points. WM (32 points) = DSF (16 points) + DSB (16 points).

The calculated scores are: The span memory (SM) corresponds to the amplitude of the memory. It is cleared from the number of digits returned correctly in the block the last test in each subtest. The span in memory (SM) is the sum of the marks obtained in SM forward (SMF) noted on 9 points and in the SM backward (SMB), recorded on 8 points.

SM (17 points) = SMF (9 points) + SMB (8 points)
Letter-number sequencing (LNS) assesses mainly short-term auditory memory, the ability to make sequences, attention, and concentration. It requires examinees to recall numbers in ascending order and letters in alphabetical order from a given number and letter sequence. The subject must repeat 10 sequences of numbers in the same order and reverse order then. The evaluator reads a sequence of letters and numbers and the subject must return, starting with the numbers in ascending order, then the letters in alphabetical order.

The scores of WM and LNS subtests are transformed into standard notes, then an index of working memory (WMI) using the scoring tables proposed by Wechsler, 2003 (WISC IV). The WMI assesses the attention, concentration, and working memory. The internal consistency coefficient in these tests is very high (0.92).

**Processing Speed Tests**

*Coding subtest (CD)*

The subject copies symbols matched with numbers and utilizing 9 symbols randomly presented in a limited time. This test evaluates primarily the velocity of information processing, short-term memory, visual discrimination, visual perception, visual-motor coordination, visual scanning and attention, and cognitive flexibility (Wechsler, 2003).

*Symbol search subtest (SS) (Wechsler, 2003)*

The test takes place in 120 seconds during which the subject observes a series of 60 different items each formed of a series of five symbols and must decide each time, as soon as possible if one of two target symbols is present or not in the series. The test assesses visual perception, i.e. the capacity and processing speed of visual information (Flanagan and Kaufman, 2004; Sternberg, 1995). The internal consistency coefficient in the SS is very high (0.91).

The scores obtained in both tests (CD and SS) are transformed into a standard note and a perceptual reasoning index (PRI) according to scoring tables proposed by Wechsler, 2003 (WISC IV). The PRI assesses the perceptual reasoning and organization.

**Perceptual Reasoning Tests**

*Block design subtest (BD)*

The subject uses colored cubes to reproduce a construction, in a determined time, from a model presented in different forms. This test evaluates primarily the analytical capacity and synthesis of abstract visual stimuli.

*Picture concepts subtest (PC)*

The subject observes two or three rows of pictures and selects one picture from each row to form a group with a common characteristic. This test consisting of 28 items, measures the categorization and abstract reasoning.

*Matrix reasoning subtest (MR)*

The subject views an incomplete matrix or series and selects the response option that completes the matrix or series. This test consisting of 36 items, evaluates primarily the processing of visual information and abstract reasoning. The subject observes an incomplete matrix in series and selects the response option that completes the matrix among five possible answers.

The scores obtained in the three tests (BD, PC, and MR) are transformed into a standard note and a perceptual reasoning index (PRI) according to scoring tables proposed by Wechsler, 2003 (WISC IV). The PRI assesses the perceptual reasoning and organization.

**RCFT**

The RCFT is developed by André Rey-Osterrieth, in 1941, and standardized by Osterrieth, in 1944, and recalibrated by Mesmin and Walloon, 2011, allows the assessment of executive functions such as visual-spatial abilities and visuoconstructive, non-verbal memory and working memory, attention, and planning. It is a neuropsychological test. The figure is composed of 18 elements organized in 3 parts: Overall shapes (rectangles) and external members (squares, crosses, and triangles) and the internal components to the overall shapes (internal, lines, and circles). It is administered in two phases, reproduction by direct copying of the figure (unaccounted), followed by 2 min of memory reproduction, it indicates what spontaneously remained in memory. It is the latter which is considered in notation according to a rating scheme Boston qualitative scoring system (qualitative rating system Boston).

**Data Analysis**

The comparison of averages scores at rest and after exercise for each test is analyzed by the non-parametric Wilcoxon t-test valid for dependent samples, with significance threshold set at $P < 0.05$. The data were processed with SPSS (21).
RESULTS

Variation in the parameters of the scores of memory, processing speed, and perceptual reasoning at rest and after exercise are presented in Table 1. It is noticed that compared to the values obtained at rest, there is a significant increase (P < 0.05) after exercise at the CD test (4.57%), SS (15.45%), BD (13.39%), and figure Rey (15.41%), whereas the means of the working memory index (WMI) (DSF, DSB, and LNS), PRI (BD, PC, and MR), and PSI (CD and SS), remain stable after exercise.

Results regarding memory span scores at rest and outside of exercise are presented in Figure 1. The average of the scores obtained at the SMF (6.00 ± 1.09 vs. 6.36 ± 1.08) and SMB (5.21 ± 1.43 vs. 5.64 ± 1.55) after exercise were not significantly varied compared with at rest values. While the averages scores of the RCFT increase significantly (P < 0.008) of 15.41% after exercise.

DISCUSSION

The aim of our study is to evaluate the effect of physical exercise on cognitive function. For this, we conducted an experimentation on 19 healthy university students athletes, assessing three neurocognitive indexes: The WMI, PRI, and the PSI before and after exercise, referring to the intelligence scale Wechsler (WISC-IV, 2003), and the visual-spatial memory by the RCFT.

The results obtained from this study show that exercise increased slightly and significantly the performance specifically at the visuomotor coding-decoding system of 4.57% (CD), perceptual skills of 15.45% (SS), the spatial organization of objects 13.39% (BD), and the visuospatial memory tasks of 15.41% (RCFT), and no effect recorded in the Wechsler Index Scores of cognitive functioning (WMI, PSI, and PRI). These results partially assume the model that physical exercise has a positive impact on the functions of cognitive skills of the subjects practicing physical activity.

Indeed, several meta-analyses have shown a causal relationship between physical exercise (moderate- to high-intensity exercises) and cognitive performances and that the size of this effect is moderate to large (Audiffren et al., 2011; Colcombe and Kramer, 2003; Angevaren et al., 2008; Smith et al., 2010). Other epidemiological studies have often reported a positive correlation between physical fitness and vitality of neurocognition (Barnes et al., 2003).

Table 1: Variation of test scores of memory, processing speed, and perceptual reasoning at rest and after exercise (n=19)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tests</th>
<th>At rest</th>
<th>After exercise</th>
<th>Wilcoxon test</th>
<th>Z</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing speed</td>
<td>Coding test</td>
<td>95.45±13.00</td>
<td>99.82±19.59*</td>
<td>−1.958</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Symbol search</td>
<td>31.18±5.53</td>
<td>36.00±9.61*</td>
<td>−2.398</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Processing speed index</td>
<td>113.87±17.67</td>
<td>122.20±18.98*</td>
<td>−1.679</td>
<td>0.093</td>
<td></td>
</tr>
<tr>
<td>Work memory</td>
<td>Digit span forward</td>
<td>9.93±2.37</td>
<td>10.07±2.31</td>
<td>−0.655</td>
<td>0.512</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digit span backward</td>
<td>10.60±2.20</td>
<td>10.13±2.13</td>
<td>−1.116</td>
<td>0.264</td>
<td></td>
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<tr>
<td></td>
<td>Letter-number sequencing</td>
<td>20.73±3.27</td>
<td>20.18±3.16</td>
<td>−0.565</td>
<td>0.512</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working memory index</td>
<td>100.56±15.03</td>
<td>98.31±16.76</td>
<td>−0.948</td>
<td>0.343</td>
<td></td>
</tr>
<tr>
<td>Perceptual reasoning</td>
<td>Picture concepts</td>
<td>11.42±1.00</td>
<td>11.08±1.31</td>
<td>−0.877</td>
<td>0.380</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Matrix reasoning</td>
<td>14.92±1.44</td>
<td>14.33±1.67</td>
<td>−0.873</td>
<td>0.382</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Block design</td>
<td>23.00±3.41</td>
<td>26.08±2.43*</td>
<td>−2.953</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perceptual reasoning index</td>
<td>97.71±13.05</td>
<td>102.07±13.36*</td>
<td>−1.061</td>
<td>0.289</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented mean±SD. *Significant comparison with P<0.05. SD: Standard deviation
Considering the results of this study, the acute exercise has mobilized the spatial memory ability is the part of memory responsible for recording information about one’s environment and its spatial orientation and the processing speed capabilities of information, visual discrimination, visual perception, visual-motor coordination, visual scanning, and discrimination as well as attention and cognitive flexibility, which are evaluated in this study by the CD subtest and SS subtest by Wechsler scale (2003). During practicing physical exercise, the appearing and disappearing of all play objects (the movements of the defenders, attackers, the ball, and the body) require permanently complex perceptual-cognitive skills: Perceiving opportunities into free space, judging distances, actions anticipation, trajectory analyses, and good visual field.

Some experimental studies have concluded that an exercise program increases significantly several regional brain volumes (frontal lobes, dorsal anterior cingulate cortex, supplementary motor area, and gyrus) that are implicated in the attentional control and memory processes (West, 1995; Duncan and Owen, 2000; Gunning-Dixon and Raz 2003; Colcombe et al., 2006). Specially, the gyrus plays a critical role in several higher brain functions such as learning, memory, and spatial CD (Jonas and Lisman, 2014). Different neurophysiological mechanisms involving activation process of central nervous system (synapses, motoneuron, and neuron activation [P3 component]) and neurotrophic factors (brain-derived neurotrophic factor, insulin-like growth factor-1, and c-Fos) released during exercise could explain the brain plasticity. Cognitive control and spatial, working memory, processing speed, attention, and executive function (Smith et al., 2010; Voelcker-Rehage and Niemann, 2013; Bherer et al., 2013).

On the other hand, the catecholamines are responsible for many adaptations both at rest and during exercise. Among these, responses are the substrate mobilization and utilization capacity to control blood flow in the working muscles, to control cardiac function and metabolism (Mazzeo, 1991; Savard et al., 1989; Hooker et al., 1990), and increase with the workload (Marshall, 1989), then can be used to estimate the sympathetic nervous system activity (Savard et al., 1987).

On another side, the secretions of a certain group of neurotransmitters, i.e. endorphin and dopamine provide a source of pleasure and facilitate the learning (De Moor et al. 2006). The electric responses (EEG) recorded during the neuromotor process show a three endogenous potential: (1) the P500 (P3) wave occurred especially in the oddball tasks, i.e. detecting the target in a series of different stimuli including many distracters (Van Dinteren et al., 2014; Polich, 2004; 2007), (2) the contingent negative variation is observed in the anticipation tasks and associated with information processing and response preparation (Walter et al., 1964; Ruchkin et al., 1986), and (3) the pre-motor potential or readiness potential is occurred during the motor cortex activity (Kornhuber and Deecke, 1965; Nguyen et al., 2014). Several studies confirmed the cognitive enrichment theory (Hertzog et al., 2009; Hertzog, 2008; Goldberg, 2005) suggesting that all activities related to physical stimulation have a positive impact on the level of neurocognitive efficacy and brain plasticity (Greenwood and Parasuraman, 2010).

Further research should be undertaken to investigate the correlations between academic performance and physical performance, and the effects of sex, age, and the recovery time following the physical training session and also the duration of the positive effects on the brain, examining each time, the cognitive functions, and most sensitive to change.

CONCLUSION

This work was carried out to evaluate the effect of acute physical on the cognitive functions. The main results have shown a significant increase in the visuomotor coding-decoding system, perceptual skills, the spatial organization of objects and the visuospatial memory tasks, and no effect recorded in the Wechsler index scores of cognitive functioning. The exercise affects positively but selectively on certain cognitive functions. The extension effects of exercise should not be generalized to all the functions. These findings suggest that physical exercise program should be a support of the cognitive enrichment of students.

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