Analysis of the Relation between M-Capacity Development, Expertise and Motor Learning in Young Volleyball Players

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Abstract

The main purpose of the study was to examine whether M Capacity, as it is defined in Pascual-Leone's Theory of Constructive Operators as the maximum number of schemes which can be simultaneously activated by attentional resources, is predictive of motor learning – in this case, of the acquisition and development of the "third touch" in volleyball. This hypothesis, supported by some preliminary observations on a small sample of young volleyball players (Bisagno & Morra, 2013), was investigated through a study with the participation of 120 volleyball players, aged between 6 and 26 years, engaged both in working memory tests and practical tests of volleyball. Furthermore, each athlete reported on his expertise, in terms of years of practice and number of trainings per week. The results pointed to a very clear dissociation: while M Capacity represents the best predictor of correct motor performance, experience was the key for the precision of the athletic skills.

Keywords: motor learning; M-Capacity development; expertise; volleyball

Introduction

It is well established that sport and cognitive activity are highly interconnected. Ellemberg & Deschês (2010) compared the effect on cognitive performance of 30 minutes of aerobic exercise to the same time spent in watching television, finding that even a single session of aerobic is able to produce a significant, though not permanent, improvement in cognitive performance. Similar results were reported by Pesce et al. (2009) and Davranche, Hall & McMorris (2009). Also Diamond (2000) underlined the link between cognitive and motor development since, when the first is affected (for example, because of a neurodegenerative disorder), also the second is. All these and many other studies point to a strong connection between sport and cognitive development, but often they study how physical activity affects our cognitive processes, not the opposite. The aim of this study, instead, was to understand if and how ability in sports –volleyball in particular– is affected by cognitive abilities, such as working memory.

The framework for this study is the TCO (Theory of Constructive Operators) of Pascual-Leone (1987; Pascual-Leone & Goodman, 1979), which includes two levels of constructs: (a) subjective operators or schemes, units of analysis of cognitive processes, and (b) metasubjective operators, general resources of the mind without a specific content, but operating in processing information. The outcome of a cognitive process depends on both the activated schemes and how the metasubjective operators influence them. Historically, the TCO grows out of a comparison between Piaget's theory of development and Witkin's studies on cognitive style (e.g., Witkin et al., 1974). Pascual-Leone (1970, 1987) claims that several tasks, including the Piagetian ones (for example, the conservation tasks), require to keep in mind and work on a number of "schemes" (information units) that may exceed the capacity of a child who has not yet reached a sufficient maturation of attention and working memory. Instead of an increasing logical competence (as claimed by Piaget), according to Pascual-Leone, cognitive development depends on the child's ability to coordinate an increasing number of mental schemes; this number is called M Capacity – where "M" stands for "Mental energy". The M-Operator is a metasubjective operator that increments the activation of the schemes relevant to a task; in this sense, it is an attentional resource, whose capacity is expressed as the maximum number of schemes that can be activated at the same time. Pascual-Leone (1987) suggests a possible neuropsychological base for the M-Operator in the frontal and prefrontal lobes: the attentional resources would be used to activate the schemes, localized in different cortical areas.

Due to maturation, M Capacity develops during childhood and adolescence: according to the theory, at the age of 5-6 a typical child can coordinate 2 schemes, and this number increases by one unit every second year, until about 15 years of age. At that point, the individual is able, on average, to coordinate up to seven schemes – Miller's (1956) famous magical number. Pascual-Leone's TCO was mainly supported by studies on perceptual-attentional tasks, such as the Compound Stimuli Visual Information task (Pascual-Leone, 1970), and reasoning tasks, such as the "horizontality of water level” problem (Pascual-Leone & Morra, 1991).

Only rarely was motor learning studied in this framework; in this field, the most important experiments were carried out by Todor (1975, 1977, 1979; see also Pascual-Leone, 1987). In Todor’s Rho Task, participants were asked to perform as quickly as possible a simple action, made of two basic movements, one circular and one linear: combined, they describe a figure that is similar to the Greek letter ρ (“rho”), from which the name of the task. However, the Rho Task involves a very simple movement, hardly comparable to the complexity of real-life motor tasks. Also based on the encouraging results of a preliminary observational research (Bisagno & Morra, 2013), this study aimed to testing Pascual-Leone’s theory in the field of motor learning and in the context of a structured sport, volleyball. In particular, we investigated whether M Capacity is a prerequisite of learning specific technical gestures.

Materials, Method and Hypotheses

Participants and the general research design

The study began in December 2013, contacting volleyball teams for participation and collecting the informed consent from each athlete; it involved 120 young volleyball players, 15 males and 105 females, from five different clubs. The participants were divided into six age groups of equal size, which made it possible to observe a wide range of levels of M Capacity development as theorized by Pascual-Leone.

There were 20 participants in each age group: 5-8 years, 9-10, 11-12, 13-14, 15-17, as well as a group of adult athletes, 18-26 years old and with at least 10 years of volleyball experience. This broad age range brings about a large variability of both M Capacity and volleyball experience. Consequently, it was possible to measure both variables and test their effects; based on studies, like that of Chi et al. (1978) with young chess players, one can suggest that expertise is a key factor in determining the outcome of a specific athletic gesture. Therefore, it is important to distinguish the effects of M capacity and experience.

To avoid possible biases caused by the small size of the male sample ($n_M = 15$; $n_F = 105$) and its unequal distribution within the various groups of age, analyses were performed twice, i.e., on the full sample and only on the female subsample. For brevity, only the analyses on female participants are reported below. The pattern of results in the whole sample, however, was nearly identical. The actual size of the age groups of females, on which the analyses reported below were carried out, varies from 15 to 20.

This study involved collecting two major types of data: measures of the participants’ motor skills and of their M Capacity. In addition, we considered the players’ age, their years of volleyball experience and their number of training sessions per week during the current year.

Motor Learning Measurement

The first challenge in this study was finding a way to measure each athlete’s “level” of motor learning; this was not an easy task, because volleyball is an open sport (Nicoletti & Borghi, 2008), in which success is determined not only by the ability to reproduce a set of movements, but also by adaptability to the changing conditions of the game. However, in order to “purge” (as much as possible) the measure from the many uncontrollable variables that would have been involved if we used an actual game action, we decided to evaluate only a single technical gesture, the so-called “third touch” (or “attack”), the one with which the player pushes the ball into the opponent’s court. Probably, this gesture is also the one that undergoes the largest changes during the years, thanks to the physical growth and improved technique of an athlete.

Six attack tasks of increasing difficulty were defined. In each task, the player was required to perform a specified action, in order to get the ball in a certain part of the field – area 2 (4 meters away) for children up to 10 years old, or area 1 (7 meters) for athletes older than 11 years – and, if they could, to score a direct hit in the middle of a hula-hoop ring, located in the same area. The six task levels were:

1. “Basic” task - just throwing the ball with the two hands towards the hula-hop target placed at a distance of 4 meters, with no hedges between it and the athlete. This task was performed only by the subjects in the 5-8 years range, as a control task in comparison with the subsequent one: it was expected that all children easily succeeded (and, in fact, they did). Therefore, it has not been taken into account in the calculation of the total correct executions.
2. Tossing the ball over the net – the task is exactly the same as the previous one, but the participant had to roll over the net.
3. Set with feet on the ground – the ball was thrown, by a partner or by the coach, to the player and she had to push it with a setting, without approach, towards the area of the field indicated by the hula-hoop.
4. Set attack with approach – the gesture is the same as the previous one, but preceded by a run-up.
5. Spike, with a run-up.
6. Spike against the block – this task is exactly the same as the previous one, but with the presence of an opponent performing the block.

The trials, all video-recorded, were performed during the regular hours of training (after about 20 minutes of warm-up and some basic exercises with the ball, at the discretion of the coaches). For each task, each athlete performed five trials (items); a task level was considered passed with a minimum of 3 out of 5 correct executions. In case of 2 hits or less, the test was discontinued without the athlete passing to the next task levels. Performance on each task was scored in two ways:

(a) correct execution of the gestures, i.e., the number of items on which the athlete performed the required actions

reaching the target area of the field;

(b) precision, i.e., the number of perfect hits in the hula-hoop ring.

M Capacity Measurement

M-Capacity was measured in an individual session of about 80 minutes. Four tests were administered to each athlete, in order to average performance in different domains. Two of these tests involve visual-spatial materials, the Mr Cucumber test (De Avila, Havassy & Pascual-Leone, 1976) and the Figural Intersection Test (Pascual-Leone & Baillargeon, 1994), while the other two use verbal materials, the Backward Digit Span Test and the Direction Following Task (Pascual-Leone & Johnson, 2011). Only some of these tests had already been validated as M capacity measures also in samples older than 11 (e.g., see Morra, 1994; PascualLeone & Johnson, 2011). Preliminary analyses showed that, in the age groups from 13 years to adulthood, the Backward Digit Span (while correlating with the other measures) had a lower mean, thus underestimating the subjects' capacity. Therefore, the M Capacity measure was finally defined as the average of the other three tests.

Task Analysis of the Motor Task

To identify the tasks' difficulty according to the TCO, and in particular to model the demand they place on M Capacity, a task analysis was performed. Guided by the theory and by a theoretical interpretation of the observations gathered by Bisagno and Morra (2013), we aimed to identify the requirements for correct execution of each task – in this case, the number of schemes that need to be activated with attentional resources (M capacity).

According to our task analysis, the basic task should require an M Capacity of 2, corresponding to the schemes "target distance" and "target direction on the horizontal plane" for the throwing. To these schemes a third one is added, the "vertical push", for the task of tossing the ball over the net. Assuming that, with experience, distance and vertical push are combined and chunked into a single representation, the number of schemes necessary to succeed in the third task (set with feet on the ground), should be 4: "direction on the horizontal plane", "passing over the net", the "body and hands positioning" to embrace properly the ball without committing foul, and the "clearance timing" – which involves coordinating one's movements with the ball's parable. As regards the set attack with run-up, the schemes involved should be 5: "direction on the horizontal plane", the "passing over the net" scheme, "monitoring the airborne phase of the ball" (which is necessary to choose the time for jumping), "run-up control" (a single pattern, because this movement should already have been well practiced and automated without the ball), and the "attack timing" in harmony with the ball's downward trajectory. Set as a gesture, technically, should already be fully acquired at this point, and therefore is considered automated enough not to demand attentional resources from the individual. The M-demand of the spike gesture is 6 schemes: "direction on the horizontal plane", "throwing depth", "monitoring of the airborne phase of the ball", "run-up control", the "attack timing" (in this case as the need to hit the ball just above the net tape), and finally, control of the "closing movement of the wrist", needed to confer to the ball the spike's characteristic downward trajectory. Finally, it seems plausible to assume that the presence of the block, in the sixth and final task, adds an extra load of one unit of information to represent the obstacle that must be avoided.

Table 1: Regression analysis – Dependent variable: Total number of correct executions (Volley_tot) – $R^2 = .74$

Predictors	β	p
M Capacity	.55	<.001
Volley Years	.30	<.001
Weekly Training	.15	.012

Table 2: Regression analysis – Dependent variable: Volleyball level (Volley_lev) – $R^2 = .64$

Predictors	β	p
M Capacity	.54	<.001
Volley Years	.22	.009
Weekly Training	.17	.014

Data Analysis and Results

Four dependent variables were considered in the following analyses; two of them were related to correct execution of volleyball trials, and other two were related to the precision of actions – i.e., to the amount of perfect hits in the hula-hoop ring. In particular, we calculated:

(a) The total number of correct executions, which is simply given by the sum of all the trials properly accomplished by the athlete in all task levels except the basic task (max possible score = 25).

(b) The "volleyball level", defined as the highest level at which the participant performed correctly on at least three trials (max possible score = 6).

(c) The total precision, which consists simply of the number of perfect hits in the hula-hop in all task levels except the basic task (max possible score = 25).

(d) The "corrected precision", defined as the sum of the regression residuals, for all task levels performed by the athlete, of the number of perfect hits on the number of correct trials; this variable was constructed as a measure of motor precision that controls for simple correct execution.

The following variables were considered as predictors:

- M Capacity, defined as the average of the scores in three tests: the Mr. Cucumber Test, the Figural Intersections Test, and the Direction Following Task;

Table 3: Contingency table between Volleyball level and M Capacity

M-capacity	3	4	5	6	7	8	total
spike against the block	0 (0.86)	0 (0.52)	1 (1.14)	0 (1.00)	3	1	5
spike	0 (5.31)	0 (3.25)	2 (7.09)	11	9	9	31
set with run-up	1 (7.20)	5	17	10	8	1	42
set (feet on the ground)	11	4	2	0	0	0	17
toss	5	2	2	0	0	0	9
basic task	1	0	0	0	0	0	1
total	18	11	24	21	20	11	105

- two measures of experience, that is, the number of years playing volleyball (indicated as Volley Years in the tables), and the current number of training sessions per week (Weekly Training);

As one can note in Table 1, the best predictor of the total number of correct executions was M-Capacity (ß = .55), followed by the years of volleyball (ß = .30) and the training sessions per week (ß = .15). To assess whether any other age-related variable accounts for an additional portion of variance, we subsequently entered age in the analysis, but it did not account for significant variance in addition to that already explained by the three main predictors. This result is consistent with our hypothesis that an adequate M Capacity is required to learn motor skills in volleyball. Similar results were found analysing the volleyball level (see Table 2); also in this case, M Capacity was the first predictor (ß = .54), followed by the years of practice (ß = .22) and training per week (ß = .17). The prominent role of M Capacity as a predictor of acquisition of volleyball skills is the main finding in this study.

Furthermore, we tried to infer whether there is a minimum (threshold) prerequisite M Capacity, below which a given technical gesture cannot be accomplished. To do so, we classified participants according to the "volleyball level" they reached, and to their M-Capacity, approximated to the nearest integer (3 to 8). The contingency table (Table 3) reports the observed frequency of participants with a certain M Capacity who passed each level. A statistical test, called Prediction Analyses of Cross-Classification (Hildebrand, Laing, & Rosenthal, 1977), was performed on these data; our initial theoretical prediction stated that all frequencies should be zero for the volleyball levels that (according to our task analysis presented above) require a larger M Capacity than the participant has. The test compares the observed frequencies in these cells with those expected by chance (expected frequencies, reported in parentheses for the critical cells in Table 3). Hildebrand et al.'s (1977) index "Del" expresses the extent to which the prediction that one or more cells have null frequency explains the difference between observed and expected frequencies in the critical cells. A positive value of *Del* indicates that the observed frequencies in the critical cells are lower than expected by chance; its maximum value is 1, when all the critical cells are empty. A *z* value and a confidence interval can be calculated for *Del*. If the confidence interval only includes positive values, then the prediction is better than chance; if the interval, besides being positive, also includes *Del* = 1, then one accept the hypothesis that the frequencies in the predicted cells are not different from zero.

In our first attempt, based on the hypotheses derived from our original task analysis, the model was supported only in part; this led us to a slight revision of the initial model that, for the sake of brevity, is the only one presented in this paper (see the critical cells, for which the frequencies expected by chance indicated in parentheses in Table 3). In the final discussion, we explain in detail which aspects in the task analysis we modified after revising our predictions.

As one can observe in Table 3:

Total observed frequencies in the critical cells = 4

Total expected frequencies in the critical cells = 26.37, from which the following statistics were computed:

Del = .848 (*S.E.* = .074)

z = 11.40, *p* <.001

99% C.I. = (.656, 1.040)

Because the confidence interval includes *Del* = 1 (and does not include *Del* = 0), this revised prediction can be considered accurate.

Whereas the results for correct performance clearly pointed to a major role of M capacity in learning the actions involved in the "third touch", very different results emerged for the motor precision of these actions.

Table 4: Regression analysis – Dependent variable: Total number of perfect hits (Hits_tot) – R^2 = .20

Predictors	β	p
Volley Years	.45	<.001
Weekly Training	(excluded variable)	
M_Capacity	(excluded variable)	

Table 5: Regression analysis – Dependent variable: Corrected precision (Accuracy) – R^2 = .06

Predictors	β	p
Volley Years	.25	.010
Weekly Training	(excluded variable)	
M_Capacity	(excluded variable)	

The results of a regression analysis with the total number of perfect hits as dependent variable are reported in Table 4, and those for corrected precision are reported in Table 5. The variance accounted for in these analyses was much less than for correct performance variables (R^2= .20 for total precision and R^2= .06 for corrected precision). In both cases, the years of volleyball experience were the only significant predictor. Not surprisingly, in the precision of gesture there was a major difference between the experienced adult athletes and the others: of the overall 164 perfect hits, 56 were attained by this group.

Conclusions

General findings

In general, it is possible to say that the results of the study are consistent with our main hypotheses: M Capacity actually proved to be the best predictor of motor learning in executing correctly the third touch in volleyball, whereas experience is the key predictor of precision of the athletic gesture.

This clear dissociation between measures of correctness and precision seems to clarify the existence of different processes in motor learning. In the "cognitive phase", when a gesture is learned in the first place (Nicoletti & Borghi, 2007), M Capacity is fundamental; however, when the overall task is learned and sufficiently mastered, experience enables technical refinement, essential to perform with consistency and precision the same task over and over again, and achieve a higher degree of expertise. These two different mechanisms could also influence each other; for example, experience can lead to automation (and chunking) of certain motor patterns, thus reducing the M-demand for a given motor task. On the other hand, a larger M Capacity could facilitate faster acquisition of a technical movement.

The more specific predictions of our initial task analysis, however, were only partly confirmed – that is, with two exceptions. Specifically, we found that the set from standstill (which, according to our task analysis, should have requested a M Capacity of at least 4 units) was performed by athletes with an M Capacity of about 3. Similarly, the set with run-up would seem to require fewer attentional resources than we hypothesized (4 activated schemes instead of 5). These findings provide suggestions for refining our analyses as follows.

The schemes we assumed as necessary for execution of the set from standstill were "direction on the horizontal plane", "passing over the net", "body and hands positioning", and the "clearance timing". Those for the set with run-up were "direction on the horizontal plane", "passing over the net", "monitoring the airborne phase of the ball", "run-up control", and the "attack timing". To discover where the flaw in our model was, we returned to the video recordings. One possibility is that the "body and hands positioning", in the set gesture, does not represent a load for M Capacity. Another possibility is that the throwing direction and the passing over the net actually are a single representation. These hypotheses might explain the results, and warrant further investigation. Our task analysis of the spike, instead, seems to be already accurate. The six hypothesized schemes were "direction on the horizontal plane", "throwing depth", "monitoring of the airborne phase of the ball", "run-up control", the "attack timing", and the "closing movement of the wrist".

Further observation of the athletes engaged in the task, and of their main errors, confirmed that the "monitoring the airborne phase of the ball" and the "attack timing" are actually different schemes. The errors related to this skill, in fact, seem to be of two types: some athletes started the run up in the wrong moment, others delayed too much the "stroke" with the arm.

This study could be continued, for instance replicating it with a larger number of male athletes. More important, this model could be extended to other sports, including open-skills, like volleyball, but also closed-skills sports and motor activities, such as gymnastics or dance.

Further research may also consider a broader range of predictors of sports performance, including for instance executive functions, cognitive styles and emotional regulation.

Practical implications

Identifying in the TCO a good framework for the theoretical modelling of motor learning processes can be useful not only for the research, but also for practical applications. In fact, knowing the M-demand of each single technical gesture would allow improving the training curricula for young athletes and, through a separate automatization of some schemes involved in the movements, could facilitate a faster learning of complex tasks.

Besides the creation of customized curricula, a task analysis of the movements could be the grounds for important improvements in the training techniques for those "late" athletes who start playing sports after 7-8 years of age and, therefore, must learn complex athletic gestures quickly.

Also on the practical side, the benefits that coaching could have from this line of studies are therefore manifold, and worth of being explored.

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