

ATTENTION ALTERS APPEARANCES AND SOLVES THE 'MANY-MANY PROBLEM': IMPLICATIONS FOR RESEARCH IN SKILL ACQUISITION AND EXECUTION

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ABSTRACT

This article states that research in skill acquisition and execution has underestimated the relevance of some features of attention. We present and theoretically discuss two essential features of attention that have been systematically overlooked in the research of skill acquisition and execution. First, attention alters the appearance of the perceived stimuli in an essential way; and second, attention plays a fundamental role in action, being crucial for solving the so called 'many-many problem', that is to say, the problem of generating a coherent behavior by selecting between many inputs and many potential outputs. We discuss the importance of these features for skill acquisition in sport. We also suggest empirical ways to assess the precise impact of taking them into consideration and at the same time we propose important implications for training derived from the ideas discussed in the paper.

Key Words: attention, skill acquisition and execution, perception, action selection, sports

RESUMEN

El presente artículo afirma que la investigación en adquisición y ejecución de habilidades ha subestimado la relevancia de algunos rasgos de la atención. Presentamos y discutimos de forma teórica dos rasgos de la atención que han sido sistemáticamente obviados en la investigación sobre adquisición y ejecución de habilidades. En primer lugar, la atención altera la apariencia de los estímulos percibidos de modo esencial; en segundo lugar, la atención juega un papel fundamental en la acción, siendo fundamental para resolver el llamado "many-many-problem", es decir, el problema de generar un comportamiento coherente al seleccionar entre muchos inputs y muchos potenciales outputs. Discutimos la importancia de tales rasgos para la adquisición y ejecución de habilidades en deporte. Además sugerimos formas empíricas para evaluar el impacto específico que supondría tomar esos rasgos en consideración y proponemos importantes implicaciones para el entrenamiento derivadas de las ideas discutidas en el artículo.

Palabras clave: atención, adquisición y ejecución de habilidades, percepción, selección de acción, deportes

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INTRODUCTION

An interesting way of approaching the problem of attention is by an intuitive and pre-theoretical conception. William James ([1890] 2007) presents it as follows:

"Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatter-brained state which in French is called distraction, and Zerstretheit in German. (pp. 403-404)".

Attention is a constitutive part of human's pre-theoretical understanding of other's cognition and behaviour; in other words, it is a constitutive part of our folk-psychology. Humans make use of the notion of attention (in the same way that we use the notions of belief, desire, or intention) to make sense of other's actions and predict their behaviour on that basis. One speaks of focusing attention on—directing attention to—the coming ball to return a serve in tennis or in the opponent's balance when applying a winning technique in judo. If someone focuses attention on a certain part—e.g. the tennis ball—someone might not hear the sound of the crowd, not even notice the presence of the judges (Chabris & Simons, 1999). It is clear that one plays better tennis when one does it attentively to the game than when distracted by trivial thoughts or by the sound in the stands. Some skills—like driving—are likely to be deployed in the absence of attention, while engaging with other activities: listening to music, talking on the phone or even thinking our own private thoughts. Nonetheless, that can be performed if the skill is easy enough: it is doubtful that you could do those kinds of tasks while driving a F-1 at 300 km/h!

Watzl (2011) characterizes attention as "the selective or contrastive aspect of the mind: when you are attending to something you are contrasting what you pick out with what remains in the background." (p.845). Nonetheless, it is very difficult to go beyond these intuitive definitions and provide a more detailed characterization of what attention is and this is partially because it is a complex neuropsychological function. Already in 1959, Moray (1959) found more than 12 different definitions for the term attention and nowadays there is no full agreement about what attention is and what is not. A complete definition should incorporate aspects not only related to the selection of stimuli in the environment, but also to the selection of plans directed to goals (Tirapu-Ustároz, Ríos-Lago & Maestú, 2011, Chapter 6). From a neuropsychological perspective, Luria (1975) made use of this idea and defined attention as selection process for the necessary information, the consolidation of the eligible action programs and the maintenance of a permanent control over them.

This paper highlights two essential features of attention that have been systematically overlooked in the research of skill acquisition. First, attention modifies the appearance of the perceived stimuli, a phenomenon independent of the subjects' intentions. We review the empirical evidence showing the crucial implications of attention in the way things appear to us. This evidence strongly suggests that attention modulates the perception of all prothetic properties—those with a gradable scale—,such as speed or strength. These properties are paramount features of almost any sport. Second, following Wu's (2011a, 2011b) theoretical considerations, we show the relevance of attention in solving what he dubbed 'the many-many problems', whose solution depends on the subject's intentions: in order to be able to act, to do something, we have to solve the problem posed by being potentially influenced by several inputs that should match several outputs. Attention allows us precisely to solve this kind of situation. The rest of the paper is organized as follows: section 1 presents two features of attention overlooked in the sport literature on skill acquisition: the modification of appearances and its role in solving the many-many problem. Section 2 reviews the skill acquisition literature on attention within the field of sport (where the information processing is still the predominant paradigm). The aim of this section is to support the claim that the features of attention described in the previous section have been ignored in this field. Section 3 first discusses the *prima facie* relevance of these features for skill acquisition in sports and then suggests empirical ways to assess their real scope. Finally, we propose new lines of training derived from the ideas discussed beforehand.

1. Novel findings in the study of attention

This section introduces two relevant aspects of attention which have not been covered in the existing studies. Attention is not a mere filter of stimulus since it actively modifies the appearance of the perceived objects. We present the empirical evidence collected by Carrasco and colleagues that support this claim. Besides, Wu's argument on the 'many many problem' shows the paramount importance of attention as selection for action.

1.1. Attention modifies appearances

Attention improves performance by increasing accuracy and reducing the reaction time in tasks such as detection, discrimination, visual search, etc. Attentional mechanisms allow sensory systems to prioritize relevant information. For example, one can dynamically concentrate processing resources at a certain spatial location. This spatial attention usually coincides with foveation, but one can also covertly attend to locations in the periphery without any eye movements (Posner, 1980). The study of covert attention

allows us, for example, to determine whether the source of the difference in the processing of perceptual information is due to attention or just to overt eye movement. Covert attention has both an endogenous (top-down) and an exogenous (bottom-up) component (Lyon, 1991; Jonides & Yantis, 1988; Nakayama & Mackeben, 1989; Posner, 1980)¹.

A particular feature of attention seems to be especially relevant for skill acquisition: attention alters the way in which one perceives the surrounding environment. Carrasco and colleagues have shown that attention alters how things appear to us. It alters perceived speed, saturation, contrast, spatial frequency, flickering rate, etc. (Anton-Erxleben, Henrich, & Treue, 2007; Carrasco et al., 2004; Fuller & Carrasco, 2006; Turatto, Vescovi, & Valsecchi, 2007). These findings are especially important in sports contexts where distracting stimuli (from other players or from spectators) abound among the game in many circumstances of the game and could affect the perception of the players.

In a brilliant paradigm, Carrasco et al. (2004) tested the subjective contrast perceived by the subjects without asking them to rate their subjective experience, avoiding bias in the response while measuring the effect of attention in appearances and performance. In the experiment we are going to present, Carrasco and colleagues used a common stimulus in psychophysics: a Gabor patch—an oriented grating whose luminance profile is a sinus. These Gabor patches can be seen in fig.1, which illustrates the setup of the experiment. Subjects in the experiment were asked to fixate their gaze and attend to a central point. Then, two Gabor patches appeared. One of them had a fixed contrast and the other's contrast was modified randomly. The orientation varied randomly for both Gabor patches.

¹ A common way to taxonomize attention is by distinguishing controlled and automatic attention (Schneider and Schiffman, 1977), their difference based on whether attention depends on the goals and intentions of the subject or not. A bit more formally, and following Wu (2014, p.33), we can say that a subject's attention to X is controlled relative to its feature F if and only if her attention having F results from her intending it to have F. Automatic attention can then be negatively defined by the absence of control.

Another distinction just mentioned is the one between top-down (endogenous) and bottom-up (exogenous) attention, depending on whether attention involves a non-perceptual psychological state/capacity for its occurrence or not (ibid. p.30), a distinction which cuts across the previous one. We will be concerned with top-down/controlled attention and bottom-up/automatic attention. For further discussion on this issue and other forms of attention, like top-down/automatic, see Wu, 2014, especially chapter 1.

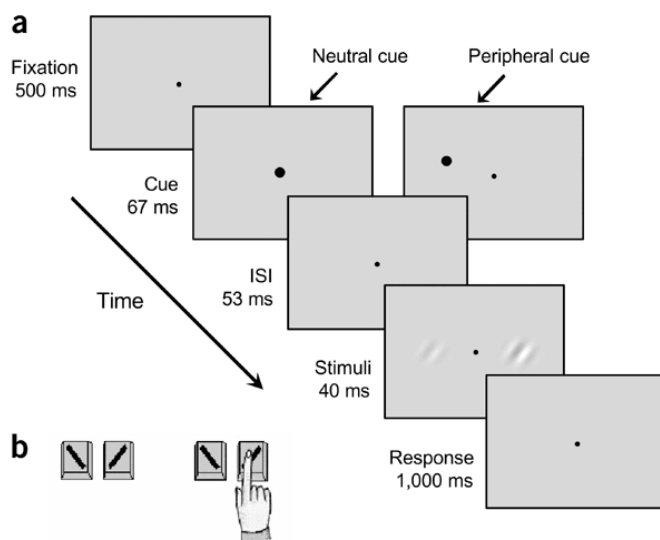


FIGURE 1: Carrasco et al. (2004)'s paradigm.

(a) Each trial started with a fixation point followed by an uninformative brief peripheral or neutral cue.

(b) Participants' task was to indicate the orientation for the stimulus that appeared higher in contrast.

In a first condition, researchers asked subjects to press a key with the orientation of the most salient Gabor patch. If the more salient Gabor was the one on the right, they would have to use the key on the right to indicate its orientation as shown in fig.1. The response of the subject in this condition was compared to the response of the subject in a second condition (see fig.1) where a cue appeared and automatically captured attention—bottom-up attention. The timing of the stimuli's presentation was selected in such a way that it prevented eyes movements. The cue could be neutral (it coincides with the fixation point), or peripheral (it automatically captured the attention to the side where it appeared) and it was uninformative: the relation between the position of the cue and the most salient Gabor patch was random.

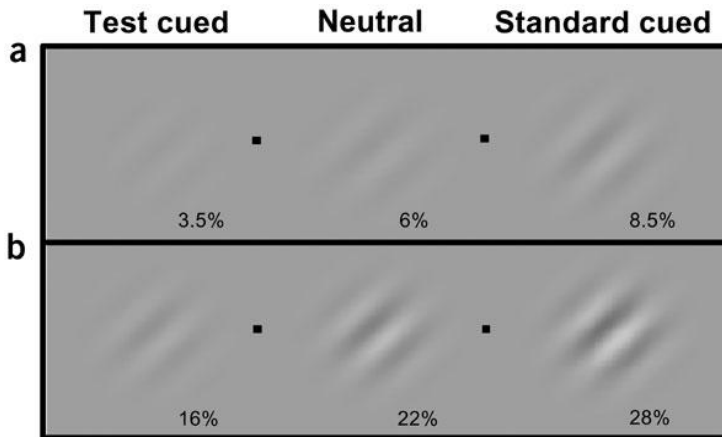


FIGURE 2: Result of the Experiments by Carrasco et al. (2004).

If a subject is looking at a fixation point (black dot) and the Gabor at the left of that fixation point is cued, the stimuli at both sides of the fixation point appear to be the same in contrast.

Carrasco and colleagues found that when subjects are looking at the fixation point and (covertly) attend—due to the effect of the cue—the location of a Gabor patch, this Gabor appears to be more salient than when not attended. Figure 2 presents some of the results for high and low contrast. For example, in the high contrast condition (b in fig.2), if the Gabor with a contrast of 22% is cued, so that attention is covertly directed to its location, then it looks like a Gabor with a contrast of 28% (if the figure is located at an adequate distance from the eyes, the reader would be able to experience the effect of attention on appearances: just gaze the black dot and switch attention from one Gabor to the other). As a result of this experiment, Carrasco et al. showed that subjects tend to perceive the cued Gabor as more salient. Therefore, attention modifies how objects appear to subjects; i.e., the phenomenal character of experience.

Attention modifies perceived properties, thereby, facilitating discrimination tasks. Nonetheless, attention seems to modify only what Stevens and Gallanter (1957) dubbed *prothetic properties*, which are properties with a meaningful zero value and inherent directionality such as saturation, contrast, spatial frequency, speed, etc. There is a gradable scale for prothetic properties: no (zero) contrast, more or less contrast, more or less saturation, etc. On the contrary, there is no such a gradable scale for metathetic properties, like hue. Attention does not modify non-prothetic (metathetic) properties such as hue (Fuller & Carrasco, 2006).

1.2. *Attention as selection for action*

The previous case showed that attention modifies the way things appear to us; attention changes the experience one has when one perceives objects. The modification of appearances has been reported both when bottom-up and when top-down attention is involved (although the effect differs slightly—see Bardot et al. 2012). This will affect every decision process that one makes at a conscious level (in contrast with automatic decisions), which, at least partially, depends on how things appear to someone.

In this part we would like to discuss controlled, top-down attention, where the intentions of the agent enter into play. We want to underline the relation between attention and action and not merely between perception and action, remarking the role of controlled attention in skill acquisition.

Controlled attention serves a purpose. It depends on the subjects' intentions and motivational states—what she wants to do. In performing an action the subject is *attuned* to relevant information, which guides the subject's response. E.g., if you want to open the door, you will (at least typically) focus on—attend to—the door's handle shape while ignoring other information such as the bumpy texture of the door or the color of the handle. The motivational state—to open the door—plays a causal role in the generation of the action; first by selecting a collection of stimuli and movements directed to the satisfaction of the motivational state and second by keeping these movements *attuned* by means of the relevant information.

Attention, as a controlled process, is not a mere passive filter which let some information and avoids other to go through. On the contrary, at the very least, it is a flexible filter that pipes some information to serve certain purposes, to do something, to act in the environment. Although the theoretical and folk psychological notion of attention is tied up to that of selectivity, not every selection process is an attentional one. This leads us to the question of what attention is for. Attention serves action, understood both as bodily and mental behaviors (i.e. thinking, reasoning, imagining, etc.). This has led some author to maintain that attention is *selection for a specific task, selection for action* (Wu, 2011a, for discussion of the empirical literature supporting the selection for action view see Wu, 2014)².

Very recently and following ideas previously voiced by Alan Allport and Othmar Neumann (see for example Allport, 1987; Neumann, 1987), Wu (2011a)

² We will talk of selection for action as a feature of attention, something attention does, as 'the many-many problem' exemplifies. We do not want to commit ourselves to the claim that attention is selection for action, as Wu does. For there seems to be cases in which attention is deployed and the information is not filtered to respond to any particular task (just consider a sudden noise that suddenly calls your attention while you are watching TV—for discussion of cases like this see Wu, 2014)

has convincingly argued that typically the selection in attention is for action and that attention helps solving what he calls 'the Many-Many Problem' (Wu, 2011b): the problem of generating a coherent behavior by examining many inputs and many potential outputs. As the author claims: "The agent must be selective in the face of this Problem on pain of failing to act: she must select a specific input to inform a specific output" (Wu, 2011b, pp. 50-51). Wu uses the following toy example to illustrate the problem (the demand for selection is much greater in real life situations):

"Consider the following scenario. Two objects are in your field of view: a football and a basketball. Focus also on the possible use of your two legs to kick either ball, the left or right leg. We can then consider what I shall call a (restricted) behavioral space for the agent at that time that is constituted by a mapping that links "many" possible inputs to which the subject can respond and "many" possible outputs that count as the relevant responses. In the current case, the behavioral space is constituted in this way: for each of the two objects, two responses at a given time are available, namely kicking with the left leg or kicking with the right[...] In this scenario, you can only do one such action at a time. The Many-Many Problem is illustrated by noting that to do anything at all at a time, selection of one among the four behavioral possibilities must take place within the behavioral space at that time. If selection does not happen, then nothing does. Thus, if there is to be action at this time, the Many-Many Problem must be solved: appropriate selections must be made where an input informs a specific output. (Wu, 2011a, pp.100-101)".

Selection for action depends on the subject's intentions and goals and, in that sense, it is not merely an automatic process.

Before moving into the implications of these features of attention for skill acquisition, it would be useful to review the literature about the role of attention in skill acquisition to justify our vindications.

2. *The study of attention in skill performance*

The existing literature in the study of attention within skill acquisition in sport comes mostly from an information processing paradigm (Janelle, Duley, & Coombes, 2004)³. Traditionally, these studies have been focused on topics such as *selective attention, divided attention and alertness as attention* (Posner &

³ It is also worth to mention that ecological psychology has extensively treated the issue of attention within the field of skill acquisition as well. Gibson (1966) considered attention as a process for selecting information. He explained the "education of attention" as a gradual "attunement of perception" to the invariants offered by the environment and a progressive detection of specifying sources of information (Jacobs & Michaels, 2002; Müller & Abernethy, 2006; Cañal-Bruland et al., 2010; Shafizadeh, McMorris, & Sproule, 2011).

Boies, 1971). Due to the fact that the two first topics are the most interesting ones for the aims and discussion of the present paper, the following two subsections present a review of studies on selective attention and divided attention. The aim of this review is to show that the features mentioned in the previous section have not been taken into consideration enough within the research on skill acquisition.

2.1. *Selective Attention*

The origin of the idea that attention selects for action is to be found in the proposals of Broadbent (1958). It understands attention as “the preferential detection, identification, and recognition of selected stimulation” (Woods, 1990, p.178). As several inputs from different sensorial modalities (visual, haptic, auditory...) are constantly reaching the subject, attention allows certain information to be processed while other is just ignored.

Selective attention has been often measured through indirect indexes as reaction time (RT) differences as a function of cue availability. Experiments presenting cue availability have used spatial and/or temporal occlusion as research strategies (Starkes, Helsen, & Jack, 2001). Also, search patterns have been registered and verbal reports analyzed in order to infer areas or aspects that are attended. The main accepted hypothesis places a strong relation between level of expertise and ability to allocate attentional focus. The more expert the subject becomes, the better her ability to attend to significant cues for the skill at hand correctly (for a metanalysis of different studies supporting this thesis see Mann, Ward, Williams & Janelle, 2007).

A vast range of research has been devoted to study performance depends on where attention, visual or otherwise, is directed, what is called *the focus of attention*, dealing with the area, sensation, effect, etc. where the subject should be oriented during performance. Basically, the debate surrounding such issue deals with the comparison of the effect in performance between directing the attention, visual or otherwise, to our own movements and directing attention to the effects or implements of those effects. In the first case, we can talk of an *internal focus of attention* and of an *external focus of attention* in the latter case.

According to recent studies, instructions and feedback that direct the learner to an external focus of attention while performing a task are more beneficial than those directing him to have an internal focus. Such hypothesis has been successfully tested in a balance task (Wulf, Hoess, & Prinz, 1998); golf putting (Wulf & Su, 2007); tennis backhand and striking accuracy (Maddox, Wulf, & Wright, 2000); volleyball serves (Wulf, McConnel, Gärtner, & Schwarz, 2003), soccer kicks (Wulf, Wächter, & Wortmann, 2003) basketball free throws (Zachry, Wulf, Mercer, & Bezodis, 2005), discus throwing (Zarghami, Saemi, & Fathi, 2012) or swimming crawl stroke (Stoate & Wulf, 2011). A

punctualization to these studies is offered by the results of Castaneda and Gray (2007); Uehara, Button, and Davids (2008); and Lawrence, Gottwald, Hardy, and Khan (2011). They show how the differences of using external or internal focus of attention depend highly on the level of subjects' expertise.

Apart from the *focus of attention* topic, there is other vast group of researches centered on the study of differences between *novice/expert search patterns*. Whereas focus of attention refers to *where* to pay attention, search patterns refer to *how* to pay attention (e.g. using a visual pivot to control the whole scene through peripheral vision). The predominant measures used in the studies were the frequency of gaze fixations and associated gaze behavior characteristics such as relative location, duration and frequency of occurrence (see Button, Dicks, Haines, Barker, & Davids, 2011 for a review of the literature on visual search in sport). Such patterns are useful to infer the attentional strategies used by the subjects in order to select crucial cues for the skill to be performed.

2.2. *Divided Attention*

Performers can regulate their mental resources across different actions taking place in the performance of a certain skill. As expertise develops, there is a shift from declarative to procedural control of the movements (Anderson, 1982, 1983, 1993; Fitts & Posner, 1967; Proctor & Dutta, 1995). Declarative, step-by-step control of the action through working memory is slow and very attention demanding. By contrast, procedural, automatic and unconscious control of the actions is fast and does not produce so much burden in the attentional resources that can be used in other requirements of the situation (e.g. decision making in a complex situation). It seems that due to prolonged practice some processing activities do not need the same amount of attentional demand and become acted and controlled unconsciously.

One classical strategy to assess automaticity in sport has been the use of a dual-task paradigm where the performer has to divide his attentional demands between different tasks performed simultaneously. Comparing the performances of single-task condition (e.g. soccer dribbling) with dual-task condition (e.g. soccer dribbling while doing some basic arithmetical problems) the results show indirect indications about attentional demands of the primary task (the soccer dribbling). Specific researches has been conducted by Parker (1981) examining ball catching/throwing as a primary task and peripheral vision detection as secondary task; and Tenenbaum, Levy-Kolker, Bar-Eli, and Weinberg (1994) examining the recall of structured game situations as primary task and handball bouncing as secondary task.

The dual task paradigm has been used also to assess the attentional demand during different stages of performance (Rose & Christina, 1990; Davids,

1988), suggesting that attentional demands are greater at the beginning and at the end of the movement, being the middle portion more prone to be controlled automatically. Also, the dual task paradigm has been applied to equally important tasks, the core issue being the flexibility of performers to switch attention from one to the other and the influence of different levels of expertise upon such ability (Allport, Antonis, & Reynolds 1972; Smith & Chamberlin, 1992; Beilock, Carr, MacMahon, & Starkes, 2002). Leavitt (1979) compared experienced and novice ice hockey players' ability to complete a hockey task while performing a secondary visual shape-identification task. Leavitt found that the performance of the experienced hockey players was not affected by the secondary task as they were able to switch attention from one task to the other. That was not possible for novice players, whose performances were negatively affected to a greater extent.

In this section we have shown the most relevant research on attention within skill acquisition in sport. Nonetheless, it is our claim that such research has generally neglected two important features of attention, those highlighted by Carrasco and Wu.⁴ Research on selective attention tends to assume that attention is a kind of filter for inputs, placing special importance on the focus of attention and the search pattern of agents. Depending on where and how you place your attention the filter would act upon certain inputs of information. Nevertheless, Wu's discussion offers a view of attention as a kind of filter not only for inputs but also for outputs (goals, intentions) so the agent can match both elements in order to decide and act. Divided attention research places special importance on the progressive acquisition of automatic, non-voluntary control of movements as expertise is developed, relieving some attentional burden that can be used for other purposes such as decision making. Nonetheless, it neglects what Carrasco and colleagues' studies show about the influence of automatic, bottom-up attention on the appearance of the perceived stimuli, affecting the decision making process.

3. *The relevance of (other features of) attention for skill acquisition*

In this section we specifically show the relevance of the features of attention highlighted by Carrasco's and Wu's in relation to the field of skill acquisition in sport. First, we remark their *prima facie* importance for research on skill acquisition in sport. Our main claim is that empirical research should be conducted in order to test their explanatory power. We then propose and discuss possible ways to empirically assess the scope of such *prima facie*

⁴ An honorable exception might be related to the studies conducted by Witt and colleagues (Witt et al. 2008; Witt & Proffitt, 2005; Witt & Sugovic, 2012), which explores "altered appearances" from a different angle. We will discuss these studies in section 3.1.

relevance and finally speculate about the implications for training derived from such possible findings of the empirical research.

So far we have stated there are some features of attention which have been neglected, both in the general study of attention and in the skill acquisition literature: Carrasco and colleagues' findings on the importance of attention modifying appearance and Wu's analysis of (controlled) attention as selection for action. This section presents the specific implications that both features of attention have for sports.

The relevance of Carrasco and colleagues' findings for skill acquisition in sport dwells in the fact that modification of appearance due to attention applies to prothetic properties such as force or speed. In fact, the paradigm presented in these findings has been used specifically to test the influence of attention in the perception of speed (Fuller, Park, & Carrasco, 2009; Turatto et al., 2007). For these purpose, Gabor patches were used but this time the changing parameter was the moving speed of the Gabor instead of its salience. The study revealed that participants overestimated the motion speed of the attended Gabor by approximately 10% (Turatto et al., 2007), regardless of adaptation effect (Anton-Erxleben, Herrmann, & Carrasco, 2013).

Generally speaking, such results have important implications for any kind of interceptive action in sport, on the uncontroversial assumption that many actions depend on the appearance of the relevant input: imagine the importance of correct speed estimation for a tennis players or a baseball batter and the possible disruptive effect that covert attention may cast into the situation. Speed is a property which is present in almost any sport, where moving targets—objects or humans—are ubiquitous. It may be the case that expert players use different attentional strategies and/or compensating actions in order to avoid the overestimation of speed effect. Such relevant topics have been neglected so far in sport. The present paper points precisely at such blind spot whose research may lead to a better understanding and improvement of expertise, enhancing instruction and training programs as well. In the section *New lines of research* we will further develop this issue.

The relevance of Wu's argument on "attention as selection for action" referred us to the so-called Many-Many Problem: the problem of generating a coherent behavior by examining many "inputs" and many potential "outputs". Players in the sport ground have to face and deal with this kind of problem constantly. Consider this situation during a soccer match: a forward player is close to the goal. The goal keeper is in front of him, a bit far from the goal line; a defender is next to the forward player and he is trying to take the ball away; there is a team partner on the forward player's right side. In this particular situation, these three elements, with all their properties, can be considered the relevant inputs within the behavioral space of the player. Following Wu's

argumentation, there are many possible outputs counting as relevant responses. The player can try to score, flickering the ball or making a direct shoot; he can face the defender trying to dribble him or protecting the ball; and alternatively he can pass the ball to his partner's foot or to an advanced position in the field. Thus, six possible actions at a time, defined by specific input-output linkages, constitute the behavioral space available to the agent at that time. Attention offers the selection mechanisms to link specific inputs with possible outputs required for the player to act. Such selection produces a specific path in the behavioral space: the player does something. That action would not happen (the player would not do anything) if the many-many problem was not solved. In this simple example we are only considering vision in order to act, selecting object, speed, position, color etc. In a real situation, there is a bunch of other possible inputs coming through multiple exteroceptive and interoceptive channels. Having said that, it is easy to understand why within real conditions of the game, the many-many problem is more significant than ever. Furthermore, managing such many-many problems represents a crucial role in the learning process. Skill acquisition in sport implies a lengthy learning process in order to reach a certain degree of expertise and the many-many problem could be a decisive factor to discriminate expert players from intermediates or beginners.

After showing the relevance of other features of attention through the proposals of Carrasco and Wu respectively, we aim at (a) proposing possible research specifically applied to the field of sport and (b) discuss some implications for training derived from the new proposals presented along the paper.

3.1. *New lines of research*

Carrasco and colleagues stated that attention modifies appearances but only in the case of prothetic properties (those with a gradable scale) such as speed and force. If one takes a closer look to sport activities, one may find a number of cases where such prothetic properties are paramount. Imagine the importance of correct speed estimation for a tennis player or a baseball batter; for intercepting a ball pass in basketball; for a goalkeeper's save in football; for the reception of the far coming ball in order to score a touchdown; or for a definitive spike in volleyball. Also, think about the importance of correctly estimating the force applied in the grip of the jacket of a judo player or in the front line of a rugby scrum. Both speed and force are prothetic properties. Our perception of them, at least at the conscious level, is affected in an essential way due to attention. Thus, how attention is affecting these properties in different sports is a must for skill acquisition research. In order to advance in this direction, instead of Gabor patches—as in Carrasco's original proposal—

experimental protocols could use sports related stimuli, closer to domain specific situations. So to say, tennis balls could be used in computer simulation programs; within virtual environments (Miles, Pop, Watt, Lawrence, & John, 2012), using spherical panoramic projection screens; or real balls in a conditioned experimental room adapted to generate measurable distracting cues. Our expectation in such studies predicts that distracting cues would induce worse estimations of the ball's speed.

These types of experiments could shed interesting results, as distracting stimuli (from other players or from spectators) abound among the game in many sports and the potential disruption of attention would affect perception of the ball's speed that would help to produce a worse performance. Moreover, in the case of stressing or threatening situations, this effect is expected to be even more perturbing. According to attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), under high threat conditions, participants display an attentional bias toward threat-related distracting stimuli. The predictions of ACT were corroborated by Wood and Wilson (2010): by manipulating the salience of the goalkeeper in a penalty shoot (by waving his arms in order to distract the penalty taker) they introduced a disruption of attention and consequently achieved a significantly greater number of saved penalties when compared to a non-distracting condition.

Wu's proposal shows how volition modulates attention, understood as an active filter (non- passive, as in classical filter models) that allows pertinent selection for action. Taking this fact into account, it would be interesting to introduce some variations in Carrasco and colleagues' experiment, both in the original setting (using Gabor patches) or in sport settings (e.g., using balls coming in a panoramic projection screen) in order to assess the influence of controlled top-down attentional strategies upon automatic bottom-up processes of attention. Carrasco's condition in the experiment took into account how appearances were altered due to changes in attention in normal subjects. One could introduce other conditions in which subjects were previously trained through specific attentional strategies. For example, in the case of penalty kick, Lopes, Araújo and Davids (2014) suggest that goalkeepers should focus on the penalty taker's non-dominant foot, as its position influences the trajectory of the ball to a great extent. Significant differences between non trained and different attentionally trained conditions would have profound implications: we would be able to discriminate more effective attentional strategies from others. Consider a hypothetical study where goalkeepers face an image of a player in a panoramic projection screen in front of them. One group is not trained, other group is trained to pay attention to the ball and other third group is trained to pay attention to the penalty taker's non-dominant foot. In the experiment, a distracting stimulus is included (a cue appearing in the screen)

when the penalty is shot. We expect the group trained to pay attention to the penalty taker's non-dominant foot to make the least errors when estimating ball's speed or force, two outstanding factors to determine the ball's trajectory and thus the goalkeeper action.

It might be the case that attentional strategies are task specific (better attentional strategies in soccer goalkeeper might not be the most suitable in tennis players). Thus the experiment should be replicated in different sports implementing different attentional training regimes.

If Wu is right, attentional effects, and the modification of appearances that Carrasco and colleagues found with them, are expected to depend on the task. So, before finishing this section it will be worth discussing the possible relationship between our perspective and the work of Witt and colleagues that approached the issue of modification of appearances from a different angle. They suggest that perception is action-specific and more precisely that the perceiver's abilities modifies perception (Witt, 2011). For example, softball players who are hitting better than others see the ball bigger (Witt & Proffitt, 2005) and golfers who are playing better than others see the hole bigger (Witt et al. 2008). A few things should be noted in regard to the relation of these results and the ones we are presenting here. Some critics of Witt and colleagues (Loomis & Philbeck, 2008) have noted that it is unclear whether those effects are due to differences in post-perceptual processes such as a response bias (see Durgin et al. 2009) rather than perceptual ones. Carrasco's paradigm explicitly avoids a response bias as an alternative explanation of the experimental result (subjects are asked about the Gabor patch and only indirectly about what patch is more salient—see Carrasco 2011 for further discussion) showing that the attentional effect is a truly perceptual one.

In response to their critics, Witt notes that the effects of ability are also modulated by intention. For example, although wielding a tool increases the subject's ability to reach, the act of holding this tool only influences the judged distance when the perceiver intends to reach with it. Otherwise, the targets look to the subject the same distance away as when the she does not hold the tool (Witt et al., 2005). Furthermore, a target that is beyond reach is judged to be closer by a perceiver who intends to pick up the tool than by a perceiver who intends to reach it without the tool (Witt & Proffitt, 2008). Witt (2012) remarks that it is difficult to account for these results with a non-perceptual explanation. We agree, but she goes further and claim that “no alternative explanation has been presented that can explain the effect of intention in modulating these effects.” (p.204). We would like to suggest that these results might be due to the effect of attention in perception. Experts are better at deploying attention and the use of tools modifies where one attends, which in turn, following Carrasco's results, modifies appearances and the judgment of

the perceivers. If attention depends on the task, as Wu argues, we have a straightforward explanation of the effect of intention in modulating this effect. If selection is for a task, then we should only expect the effect of attention in perception to be different depending on whether the task is to reach the object or not (on whether the subject intends to pick up the object or not) and this is precisely what the experiments of Witt and colleagues show.

Witt (2011) also observes that better sport performance (which specifies current ability) does not always lead to judge everything bigger. Witt notes that whereas better batting performance leads players to judge that the ball looks bigger (Witt & Proffitt 2005), better return tennis leads players to judge that the net is lower (Witt & Sugovic, 2010). Assuming that the effect is perceptual, this is precisely what one would expect due to the influence of attention in perception: the selection for different tasks implies differences in attention and consequently a different effect on perception.

If our interpretation is right, attention influences perception that in turn influences performance. Witt argues that the causal link is in the opposite direction and that performance influences perception (Witt & Dorsch, 2009). Nonetheless, we see no tension between both hypotheses. Surely perception influences performance and if attention alters perception then attention influences one's performance as we have argued. This is not incompatible with the claim that there is also a causal influence of performance on perception. Further experiments are required in order to assess the relevance of each component.

3.2. *Possible implications for training*

Although the design of training programs to enhance attentional abilities of players has been a paramount issue in the field of skill acquisition in sport, we suggest that some blind spots in the area still remain. We have already presented the different implications of directing the subject towards an internal or external focus of attention. Besides, observational learning approaches in sport stress the importance of directing attentional cueing.

Most studies have focused on enhancing the anticipation skills. Janelle, Champenoy, Coombes, and Mousseau (2003) tested the effectiveness of different cueing conditions during observational learning of a soccer accuracy pass. They concluded that the use of video modeling with visual and verbal cues collectively improved performance as verbal information combined with visual cues enhanced perceptual representation and retention of modeled activities. Williams, Ward, and Chapman (2003) used video simulation training in field-hockey goalkeepers in penalty-flick situation and concluded that the group who received the perceptual training improved their response times significantly (when compared to control and placebo groups). They also concluded that such

training effect on anticipation skills had transference from the laboratory to the field, highlighting the practical application of the program.

Not denying the important findings achieved so far, at least one step further is needed. What is missing is not what or where to look at but with which intentions one pays attention to the situations within the game. We claim that paying attention with specific intentions is crucial to foster better results. Therefore, in our view, the new implications for training should be focused in the development of voluntary strategies for attentional control. In this vein, Wood and Wilson (2011) presented a quiet-eye training program for penalty kicks. Their aim was “to align gaze with aiming intention to optimal scoring zones”, avoiding the bias effect produced by anxiety on visual attention. Their results showed a partial support for quiet-eye training: despite the fact that the quiet-eye trained group presented greater visual attentional control, were significantly more accurate, and had 50% fewer shots saved by the goalkeeper than the placebo group, they failed to maintain their accuracy advantage under a stressing situation. Vickers (2007) had already shown how gaze was influential on visual attention and Land (2009) how gaze was driven by controlled (top-down) attentional control. According to Wilson, Wood, and Vine (2009) anxiety—pressure under threatening situations—was responsible for disrupting the goal-driven attentional control in penalty kick. However, a quiet-eye program was a suitable (controlled and top-down) strategy to try to overcome such non desired bias.

Despite the degree of success of such training program—also positively tested in other activities such as golf-putting (Moore, Vine, Cooke, Ring, & Wilson, 2012)—, what is important is the direction it points towards. This direction is perfectly aligned with the contributions we have brought forth in this paper. Wu’s theorizing points towards the possibility for attention to be voluntarily trained and modulated in order to affect action, avoiding the hindering effect of distracting stimuli that, as Carrasco and colleagues’ experiments showed, could alter perception in an essential way. Thus, the control of attention is an utmost demand for every player in order to do a good performance and to avoid being disturbed (by anxiety)—or distracted (by tricks or feints).

Based on these novel approaches to attention, our proposal aims not only to specify points or areas where to look at or to attend to. This does not suffice. What is important is to be able to develop what we call an “attentional state”: to attend to with the intention of. Thus, we refer to attention affected by volition (volition used as a synonym of intention to act); attention voluntarily modulated by the subject. Intentions can be generic (e.g. go for the attack or defending mode) or more specific (e.g. overtake the car in the next turn). Thus, we would bring together attention and intention, two determining factors

influencing perception that we presented as compatible in our debate with Witt and colleagues in section 3.1.

Imagine an already planned play in a corner kick. As players have been trained previously on this specific play, everyone knows the pre-arranged pattern of actions in order to score; thus they have been trained not only on the moves but on the specific intentions about their specific future actions. So to say, every player is attending to the game with different specific intentions: the player kicking the ball from the corner wants to pass the ball over the penalty area for player number 9 to head the ball; player number 9 attends the play with the intention to set himself free from the defenders in order to head the ball; his team mates attend the play with the intention of dragging the defenders out of the selected zone for player number 9 to be able to head the ball and score. For the moment, this kind of controlled attentional training has been applied only to simple, closed, controlled skills, such as penalty kicks, as in the research of Wood and Wilson (2011), or anecdotally to more complex situations such as pre-arranged plays. Nonetheless, we claim that this is just the first step for a practical and systematic application to game situations through well planned training programs.

The possibility for controlled attentional training in real, dynamic sport settings is still to be researched. This paper has tried to call attention to this underdeveloped field of study in skill acquisition from a theoretical perspective and to highlight the need of empirical studies in this area that would end up in the implementation of suitable controlled attentional training programs. Although we acknowledge that this later conclusion is still speculative, we hope to have presented clear evidence that motivates research on this topic.

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