Are motor and verbalization decision-making choice reaction tasks affected differently by subconscious visual cues?

Master's Thesis to obtain the Master of Science,
Department of Motor and Sport Sciences,
University of Fribourg

Mattia Werner

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Supervised by Prof. Wolfgang Taube

Supported by Martin Keller

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1. Abstract

Leukel et al. (2012) recently demonstrated that humans are able to perform corrections during movement execution in response to subliminal cues presented alone as the sole target with no previous priming and with a successive neutral mask. This was demonstrated using a task that either required hand reaching to a target button, upward arrow, or stopping the movement in response to a downward arrow. The authors used two different protocols. First, a verbalization protocol tested for conscious perception (i.e. to identify the percentage of correct responses for different display durations based on verbalized answers). In the second protocol (motor reaction protocol), the same visual stimuli was provided on a computer screen, but now subjects were asked not to verbalize their response but to perform a motor response that was dependent on the direction of the displayed arrow (an arrow showing upwards indicated that subjects should press a second button whereas a downward arrow indicated not to press the second button).

The results provided further support for the existence of direct visuomotor circuits which enable correct motor behaviour without necessarily involving conscious perception. The observations of this study are well in line with previous studies using similar visual priming experiments (Eimer & Schlaghecken, 1998, 2003), blindsight behaviour (Cowey, 2010) and artificially suppressed visual awareness (Christensen, Kristiansen, Rowe, & Nielsen, 2008). After having drawn some links between overt sport performances and subliminal visual cueing, we reviewed the most important contributions to this field of research.

We conducted a similar experiment where we tested whether subliminal visual cues alone can influence decision making between leftwards or rightwards movements. Leftwards or rightwards pointing arrows were presented to participants at twelve different display durations, ranging from 8.33 ms to 100 ms. In a *verbal protocol*, subjects were asked to state verbally (and also consciously) the orientation of the displayed arrows after pressing a start button. This protocol was used in order to determine the duration of the conscious detection threshold. In the *motor response protocols*, subjects were asked to trigger the start of the computer program (pressing a start button or triggering a light barrier) and to perform a movement in the direction of the displayed arrow that appeared 20 ms after triggering the program. Two different motor protocols were used in order to identify possible differences between a simple motor task (pressing buttons) and a sports-related task (moving a racket/hockey stick in the correct direction).

Our results reveal (fig. 19. pg. 53) no significant difference between the three protocols. This means that the present study was not able to identify any differences between a verbalization task where conscious perception is necessary and a motor task where conscious perception is not a prerequisite for correct decision making. Therefore, the results of the present study do not support the findings of previous studies that used a similar experimental design. Reasons and possible explanations for the observed findings are discussed.

Preface

I am Swiss man, born in the 20th century. I have enjoyed doing sport since I was a young boy. Over the last five years, I have tried to be a scientist during my university studies in sport sciences. This is the work that will certify me and give some academic value to what I've done in my life till now. By introducing this study, I would like to try to explain the connections I see between two of the greatest authorities ever in the sport and scientific world respectively. Two men, who seem to have more than one link with my country, with the historical period I was born in, and of course with the two fields in which I have spent the most time doing in recent years. One is Roger Federer, worldwide, a well appreciated athlete, Swiss born like me, just five years before me, and also a key figure during my formative years. For me, he is much more than a compatriot to support in front of the TV while he's fighting for victory in the most prestigious international tennis tournaments. Billions of people all over the world have been fascinated by this tremendous player, million's of women would like to marry this valorous and sensitive man, thousand's of young men try to imitate him on court, but I suppose that fewer people spend so much time studying Federer as I do. I am used to analyzing in detail everything he does, during rallies but also between them, as well as observing him when he's sitting on the bench or when he's talking at the press conference. How does he move, how is he working with his feet, how wide does he keep them while hitting, how does he bend his knees while serving, these are just some biomechanical examples of my observations while he's playing points. When he's walking on the baseline or to the bench, I used to try to watch how he is breathing, and what he is doing to recover faster, to keep calm and to relax his body. For sure, another thing which excites me is trying to guess what he's thinking about, entering his psychological sphere is something that I would like to be able to do. Somehow he is the most open player while talking about his performance, but there is no chance to get in his interview some direct information about his fears or real troubles. Nevertheless, on each kind of video I could find about him, showing him off season, during charities or in his private life, I always try to capture his nature and his attitude. I cannot really explain this obsession for this person, but I can just say that he represents for me the best way to be an athlete. Not because of his results, nor because of his playing style. What always strikes me again when I see him, is how he seems to love what he's doing. For a long time, only one possibility for me to study him was on TV, till the day he came playing in Fribourg. Here I can point to the only real link between Roger Federer and my experience as a sport student, and not only because he came to the city where I was studying. I found no ticket for his matches that were all sold-out and I felt quite desperate, but at my university mail address I received the proposition to work voluntarily for the tournament organisation. This allowed me to see him playing live, a possibility that definitively changed my way of conceiving movement and the science of movement.

The other man, the renowned person I'd like to mention in this preface is Albert Einstein, who was the most important scientist of the century I was born in, and who also did his studies in Switzerland as I am doing. There was no chance for us to initiate a discussion about Einstein's physics principles; nevertheless, we know that his most famous findings turn around the concepts of time and space at the same time. General relativity is the "description of gravity as a geometric property of space and time, or spacetime"[1]. This cheap sentence is quite enough for people who know practically nothing about of quantum physics like me, but it is enough to know that the connection between space and time is the key point focused on by Einstein. However, the attempt to understand and find a model to explain the nature of space and time, is probably connected with the keys of our existence, where human experience is possible only through this. It is also not surprising if all of the greatest fields of human thought, theology, philosophy and of course science, crush against the description of spacetime, our reality.

I used this last sentence in an article I wrote when I came home from Fribourg Forum, after having seen Roger live for the first time, precisely during the practice session. Briefly, I said in a few columns, that while he moves, this wonderful athlete seems to give a response to the enigmatic connection between space and time.

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[1] http://en.wikipedia.org/wiki/General_relativity

Of course, this excited, mystical perception of what Roger does is only acceptable for a passionate newspaper article dedicated to his fans. A master's thesis in sport sciences demands a quick switch to a more concrete dimension, necessarily testable through experimental evidence. Fortunately, as students with scientific faculties, we have no doubts in taking the following consideration as a start point, namely, that everything that an athlete does is scientifically explainable. And if no explanation can be found, this is just because of a lack in the method or in the instruments used to observe the event. This, because everything an athlete does exists in a concrete world which is framed by time and space as the expression of precise effects that are spatially organised and timed by his or her body. This is obviously true also for the "divine" Federer. Perhaps it is also true that everything a human does at the highest level creates a connection with the absolute. Such links seem to happen when performance implies a great connection with the task, making the performer unaware of anything else around him. But this kind of sensation is not an exclusive possibility given to the greatest athletes or artists or thinkers or mystics. Everybody should experience, at last once, this sensation of absolute connection with the action they are performing. It is impossible to know whether such feelings really connect us to the unknown, absolute, side of our nature. On the other hand, humans usually tend to explain everything they are not able to control with the power of reason with mystical arguments. On the other hand, no reason will allow us to further discuss a sport performance with such naivety. So let us start by using reason and try to explain why bodies that are moving appropriately, congruent to the situation, despite highly uncertain situations and spatiotemporal constraints, leave us with a feeling of the mysterious.

2. Introduction

2.1. Why unconscious motor control

As a first consideration, we should remember that all human actions directly depends on neuronal activations, which are obviously concrete, and that no muscle fiber can be activated without an electrical signal stimulating it. Nevertheless, we cannot be aware of those activations and this is true for all movement because we cannot perceive that deeply what is happening in our nervous system to generate the action. Moreover the famous Libet experiment (Libet, Gleason, Wright, &

Pearl, 1983: 73-79) shows us that "the onset of cerebral activity clearly preceded by at least several hundred milliseconds the reported time of conscious intention to act." The absence of awareness at the early stages of the beginning of movement suggests that movement can escape our voluntary control. Movement can be decided and started in a time delay prior to the moment when we report being aware that we have decided and initiated it. Volition and awareness do not have the same meaning and such aspects are not necessarily linked. Nevertheless their findings let us investigate whether conscious intention to act has just been reported later or whether conscious intention is not even involved in decision taking. In fact Libet et al. challenged the concept of free will for motor decision and could deny this principle.

2.1.1. Anticipation

Superficially, it is possible to think that in overt sport performances quick appropriate reactions are just possible thanks to anticipation. This last concept expects that before the relevant information which should trigger the response has been presented or before it is completely detectable a specific movement congruent to the situation already begins. For instance, response triggering information could be either ball or opponent displacement. Anticipated decision taking for movement selection, could also use other features from the presented condition, such as triggering factors, namely tactical or technical features which force or induce an opponent to do what is expected rather than any different action. Taking advantage of such details is a possibility that has been studied by Shim, Carlton, Chow, & Chae, (2005) where players had to respond either to a ball machine or to a real shooter. Compared to the machine, real opponents allowed faster reaction times indicating that expert hitters are able to use movement-pattern information to determine shot selection and to use such information to significantly reduce their response delay times. Many studies have proved that elite athletes have higher anticipation capacities than novices in different games as the following articles reveal regarding basketball, ice hockey, soccer and tennis. Professionals show faster and higher rates of correct anticipation than less trained players. Differences between them may come from different visual perceptions (Wu et al., 2013). For instance, elite players have longer fixation periods on fewer relevant points in the visual field while saccade switches between them are faster (Martell & Vickers, 2004) Recently, this fact has also been explained by neuroimaging, whereas "perceptual-cognitive superiority was associated with greater activation of cortical and subcortical structures involved in executive function and oculomotor control" (Bishop, Wright, Jackson, & Abernethy, 2013). In the above mentioned experiments, participants were always asked to anticipate what was going on. While it was discovered that, in this condition, elite players performed better, the authors do not indicate how often anticipations occur during a real performance. Interesting research (Triolet, Benguigui, Le Runigo, & Williams, 2013) based on several recordings of professional tennis matches, reveals that "observable anticipation behaviours in professional tennis occur on between 6.14% and 13.42% of the shots played". Nevertheless, compared to Triolet's experiment mentioned above, that compared reaction time against machine or a real opponent respectively, the concept of anticipation is quite different here. Triolet's anticipation concept is more linked to player movement choice based on tactical situations while Shim's is based on triggering features based on an opponents' movement. This first kind of anticipation occurred almost nine out of ten movements to the ball. Other anticipations are also reactions based rather on an opponents' gestures and we suspect this always happens with professionals where their responses take under 200 ms (but not shorter than 127 ms according to Shim et al., 2005).

2.1.2. Automaticity

To be precise, professionals' reactions are that quick not only because of using triggering information before ball hits occur in an anticipatory way. Expert performer's skills are also automatized; this implies that because of the amount of practice time over their lives, neural region activation for specific motor responses are significantly different compared to when they began their practice regime or to beginners. Fitt and Posner's (1967) famous model presents three learning stages from "cognitive" to "autonomous" through "associative". As can be seen in figure 1, this could be integrated with a modern neuroimaging study (Puttemans, Wenderoth, & Swinnen, 2005) which shows the neuronal activation for motor control switching from motor cortex rather than to subcortical structures during a period where participants learned a new bimanual coordination task.

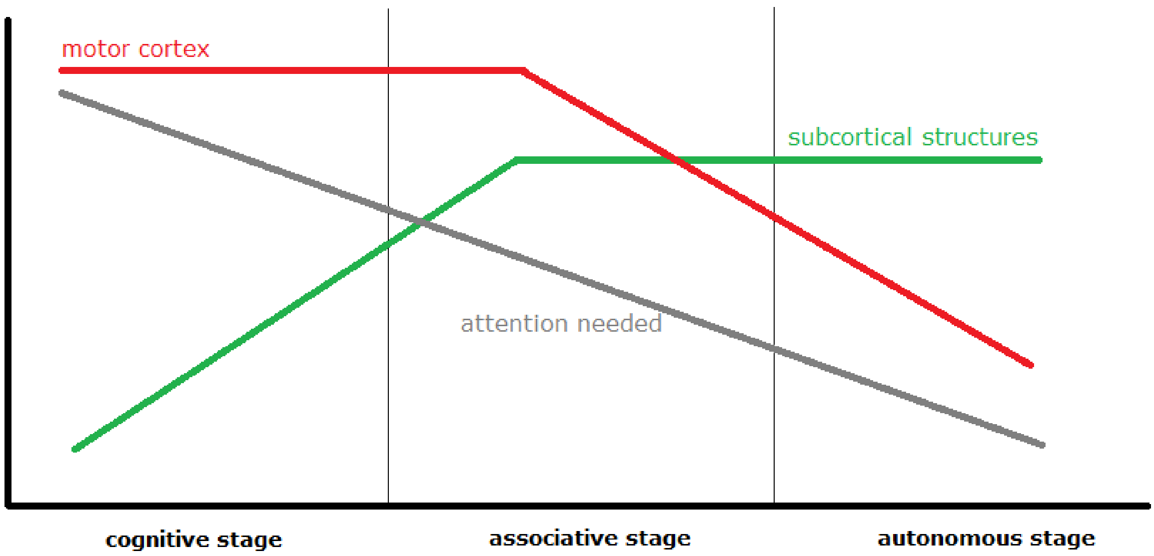

Fig. 1: the link between a theoretical model (M Fitts & I Posner, 1967) *and a neuroimaging study* (Puttemans et al., 2005) *of the movement learning stages (Taube W., 2009, handout from the "Theory of learning and motor control" course).*

Another experiment (Poldrack et al., 2005) using a serial reaction time task, after "extensive behavioral training" also showed decreased activity in bilateral ventral premotor regions, the right middle frontal gyrus, and the right caudate body activity in other prefrontal and striatal regions. This also implied a decrement in reaction time in all four tasks (four different protocols were presented to participants, namely single or dual task both in randomized or sequence trial succession).

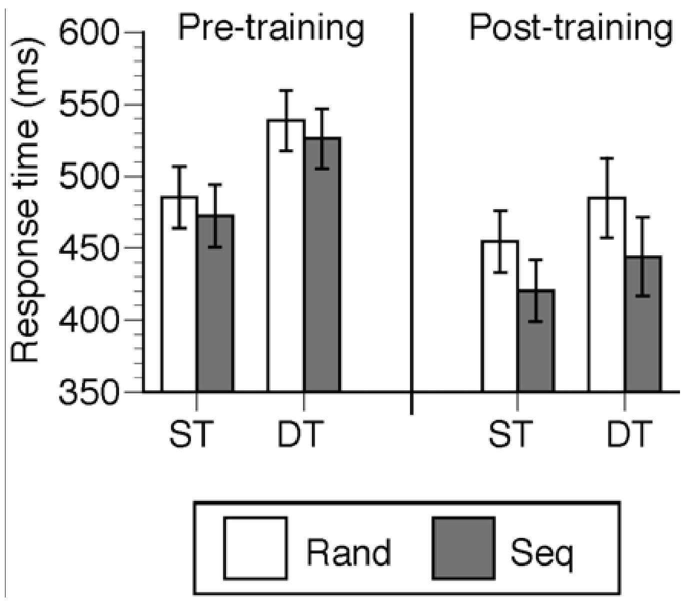

Fig. 2: post training decrement of the reaction times in all four task types [ST = single task, DT = dual task, Rand = randomized, Seq= sequence] (Poldrack et al., 2005).

Of course, despite the modern machinery, neuroimaging still cannot be displayed while an athlete is playing on court. Nevertheless, by reason of faster reaction times, we can deduce that expertise involves less cortical contribution than what is needed in novices players, as happens in experimental motor actions.

Anticipation and automaticity are two principles that also make skilled players react with very short delays. In addition, when they are not relying on anticipation due to particular tactical situations, reactions between 130 and 200 ms for tennis have been noted (Shim et al., 2005). -This means that professionals start moving to the ball with a very short delay, because of this spectators may have the impression of watching a movement performed at almost miraculous speed.

To better understand how those two principles allow time saving, we can remember Schmidt's famous model (Schmidt & Lee, 2005, p.52) that simplifies the different stages of motor responses. According to their model for open loop movements, such as, for example, a split or a hand movement to the left or to the right, such motor behaviour implies action programming preceded by action selection induced by perception, which is, of course, the first fact. In such a simplification, the principle of anticipation permits time saving at the stage of response selection. Based either on tactical and/or technical clues observed in the situation, a player can select the appropriate motor response before the triggering action of the opponent has been executed or completed. Once the action has been selected, the principle of automaticity allows time saving by the programming stage, namely, when subcortical rather than cortical structures can program the motor act. As discussed above, this is a possibility that is proportionally linked to the degree of expertise of the performer. Naturally, Schmidt's model is rather simple, and different theories from dynamic systems (Glazier, Davids, & Bartlett, 2003) or computational (Karniel, 2011) approaches would present those stages as consequences emerging from occasional self-organised neuronal systems rather than fixed sequential moments. Nevertheless, ongoing investigations regarding the neuronal organisation of motor actions during the moments preceding the visible output, generate strong discussions in the scientific world about a subject that may represent one of the most complex neurological domains. At present, there is no chance for us to enter this field with academic coherence, by reason of the fact that assumptions about motor control and learning models, even those advanced by renowned researchers, are just something more than speculative proposals (Glazier et al., 2003; M Fitts & I Posner, 1967; Schmidt & Lee, 2005).

However, we have mentioned Schmidt's model to identify an important consideration, namely, that anticipation and automaticity happens at the moment when motor output is being developed. Furthermore, such elaboration represents a very complex neurological interaction that seems to prevent us from pursuing the nature of motor actions performed under time and space constraints.

2.1.3. Visual perception in overt sports

Fortunately, there is an aspect that is more accessible to research than action programming which precedes all decision making in overt sports. In fact, it is unlikely that anyone would ever deny that perceptions represent the first unavoidable moment for any motor action. Even reflex movements come in response to perception, somatosensory or proprioceptive in this case, but we are looking at action that requires decision making, those that are voluntary movements because they involve higher brain structures. Naturally, for this kind of action proprioception provides relevant information about body position that is taken into account for decision making. However, we are not at the moment referring to player's internal conditions, but to external situations that the player is required to solve. The most important information needed to give an appropriate answer in an overt sport situation is visual. Perceiving visual information is the first unavoidable step, and such perception must be exploitable as useful input to trigger a congruent motor output.

In tennis, for example, relevant information is about the ball, precisely where the ball will arrive when hit should take place. Its localization depends on direct ball watching and tracking, but the decision to move towards the ball is strongly influenced by an estimation of where it will approximately arrive. Studies show that for expert players in sport with moving objects the accuracy of this kind of estimation is higher than that of novices (Moreno, Luis, Salgado, García, & Reina, 2005). When experts tennis players look at the court surface where the ball is expected to bounce, they even focus on a smaller area whereas novices cannot be as precise and wait for the ball, focusing on a bigger portion of the surface (Singer et al., 1998). Furthermore, it has also been demonstrated (Overney, Blanke, & Herzog, 2008) that expert tennis players have better temporal processing, such as speed discrimination, than non-athletes or athletes of sports without moving objects aspects (triathletes in this study). Improvements in visual capacities for tennis players happen intrinsically thanks to performance. In fact, no voluntary strategy is adopted in order to better anticipate or perceive the ball's destination. Another study shows this type of spontaneous correct behaviour, where skilled tennis players were able to anticipate ball destination with more accuracy than novices (Shim et al., 2005). In this experiment, participants had to simulate a stroke in response to opponents hitting movements that were displayed either in 2D and 3D real sized videos (point-light displayed opponents were also used as test protocols but in this case did not find significant differences between participant groups). Nevertheless, a study investigating basketball professionals (S. M. Aglioti, Cesari, Romani, & Urgesi, 2008) showed that elite players were able to discriminate whether a shot would score before the ball was seen to leave the model's hands, suggesting that athletes predicted the basket shot's fate by reading the body kinematics.

2.1.4. Mirror neurons

To verbally indicate the destination of a flying ball implies that the observer is aware of his prediction. In an experiment by Aglioti et al (2008), professional basketball players had to verbally guess the success of a free shot, by just observing in the video the shooter and the first portion of the ball's flight. Professionals showed better prediction abilities than novices and than people used to watching basketball, such as, for instance, journalists and coaches. The former are even able to predict the result already when the ball was leaving the shooter's hand, while less trained people needed to observe at least the early trajectory of the flying ball. Because of this, the authors argued that professionals are able to "read" the body kinematics of the opponent, a consideration that represents a clue to an emphatic relationship between the player and the observed opponent, which is possible thanks to mirror neuronal networks. In addition to this, the authors also recorded the participants' MEPs (motor evoked potentials) in a second experiment while participants observed both free shots in basketball and free kicks in soccer. "Both visuo-motor and visual experts showed a selective increase of MEPs during observation of basket shots. However, only athletes showed a time-specific motor activation during observation of erroneous basket throws." By reason of the first and second experiments, they conclude that "Results suggest that achieving excellence in sports may be related to the fine-tuning of specific anticipatory 'resonance' mechanisms that endow elite athletes' brains with the ability to predict others' actions ahead of their realization." As mentioned above, other authors believe that "This paper links the mirror system, presumed to have a key role in action understanding, with the anticipatory decision making abilities shown by athletes in response to the movements of their opponents" (Yarrow, Brown, & Krakauer, 2009).

Being able to determine relevant cues for decision making based on the opponent implies being well-skilled in the performed actions. Research has "revealed the influence of motor expertise on action observation" by showing that mirror neuron activation of observers were directly correlated to their familiarity with the observed task (B Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). In Calvo-Merino's investigation of this, the authors first looked at the mirror network activations in dancers while observing unfamiliar and familiar dancing styles. The authors found out that observing the own (familiar) dancing style causes stronger activation of the brain (B Calvo-Merino 2005). He was then even able to demonstrate (B Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006) a stronger activation of mirror networks while observing dancers of the same gender performing alone rather than observing dancers of the other gender alone in their own dance style (which is usually coupled). However, this was only possible for those who where experts in the observed dance style.

The final considerations suggest that such neuronal activations allow generating empathy with the observed performer. In overt sports, such empathy may suggest an opponent's intention allowing us to anticipate. One study (Buccino et al., 2004) has demonstrated that only movements that are part of the observer's movement repertoire cause neuronal activation in motor areas during observation. Besides this, not only gestures but also speed may leave spectators stunned while observing professionals. It seems to us impossible to reproduce such performance because they move in a much higher spatiotemporal dimension. This may be not due not only by an increased automaticity but also by visual inputs perceived much earlier than those perceivable for much less-skilled individuals. Spectators mirror neurons cannot reproduce when witnessing what seems to be impossible action. This may cause such of a spectators wonder by reason of the impossibility to generate empathy with the observed performer, however this is mere speculation. We are falling dramatically again into a superstitious approach. There is no reason for this approach, because the speeded up capacities of Federer and of his worthy rivals are not due to clairvoyance. They are capacities triggered by concrete visual stimuli which are (as seen through several articles) scientifically increasingly explicable. Despite the fact that triggering information for decision making and movement are detected before the relevant object (in many cases, the ball) leaves the opponent, precedents cues are concrete visual stimuli based, for instance, on opponents' movement.

2.1.5. Towards our experiment

Summarizing the most interesting considerations for our purposes in the articles mentioned in the previous section, expert players benefit from two different kinds of facilitation for giving correct motor responses in overt sport. On one hand, they can better understand the displacement of the played object (the ball) for both its speed (Overney et al., 2008) and its arriving point (Singer et al., 1998). On the other hand, they are also able to read what opponents are doing, increasing the possibility to predict and anticipate their actions (Shim et al., 2005) and the results of their actions (S. M. Aglioti et al., 2008). Investigations into this latter capacity imply the involvement of mirror neural networks, but we have no access to directly monitor mirror neuron activity during sports. Inevitably we must avoid an experimental design that presents to participants a whole body representation of other people's motion, in order to prevent the activation of their mirror system. In order to keep the subject more accessible, our research will only present simple visual stimuli to participants. Renouncing visual stimuli including opponents, which links experiments directly to overt sport, it is not necessarily limiting. Mirror system help performance in overt sport by facilitating the possibility of correct anticipation. Nevertheless anticipation is probably not the only quality which makes players better; it is certainly not the only increased capacity noticed in expert players. For instance, Overney's study based on tennis players, shows that sport expertise is linked to increased capacity independent of the opponent's motion. To be more precise, players are better able to discriminate the speed of moving objects while another study revealed better and earlier understanding of the ball trajectory (Moreno et al., 2005).

In addition to this, it is important to emphasize that processes occur subconsciously, that is performers are not aware of which signals really make them select the appropriate response, despite the fact that they may consciously report estimations (as seen for verbally reported shots result predictions in M. Aglioti et al., 2008) which are based on the same kind of unconscious perceptions. Therefore, they are not even aware that such cues may have determined their decisions for congruent motor action.

Consequently, visual perception of simple stimuli representing the first stage of decision making and the utilization of this information for consequent motor behaviour, both processes, without necessarily involving consciousness, are now fixed as the focus of our interest. We have therefore chosen to prepare an experiment which could prove that humans can act in the above mentioned way.

Previously it was concluded "that humans may reach decisions based on subconscious visual information in a choice reaction task" (Leukel et al., 2012). Our intention is to add other considerations and evidence to their conclusions, a purpose that also demands an experiment presenting similarities but also important differences with the protocols.

We consider that in overt sport, almost all motor actions occur in response to the visual cues. Only in consequence to a first visual input, anticipation and/or automaticity capacities and the involvement of mirror neuron networks can facilitate a congruent motor response. Specifically, anticipation simply means that the visual information taken into account for decision making happened before the situation was totally unequivocal, as, for instance, before the relevant object (the ball) had already been played by the opponent. Besides this, automaticity and mirror network activations concern the elaboration phase of the perceived visual input which remains the first step. Nevertheless, in our work we will prevent anticipation and emphatic elaboration of the situation, because we want to investigate the possibility of using unconsciously[2] perceived visual stimuli for direct decision making. In other words, the subject of our work is visual perception and its utilisation for decision making in the absence of awareness.

2.2. State of the art

In the research of Leukel and colleagues (2012), authors first affirm that "a question that fascinates both psychologists and scientists interested in motor control is whether our behaviour can be influenced by sensory information that is not consciously perceived". As we will see in the following sections, many studies have investigated the effects of subliminal primes on different kinds of subsequent behavioural responses. Leukel et al. (2012) lament that no previous study had been able to clarify whether "a subconscious cue alone is sufficient as a basis for choosing

[2] In this text we use the terms unconscious, unaware and subconscious interchangeably.

between two possible motor responses", and their experiment was the first designed exactly to fill this gap at least for vision. Before discussing their study, which is the basis of our attempt to further investigate in their direction; we now want to look in detail at earlier research that is relevant to our study.

In this section, we will look at the state of the art as applicable to our experiment. We first look through behavioural effects of unconscious perceived stimuli for senses other than vision. After this, we will determine how we want to use the word "unconscious" without opening new controversies about its definition. Last introductory considerations are about Blindsight, which is the first significant evidence of subconscious visual processing sustaining motor behaviour. The following chapters will enter and focus on the research field, as it pertains to our study..

2.2.1. Subconscious audition, touch and olfaction

"Not only visual information can be processed at intensities below conscious perception" Leukel et al. (2012), but also other senses can be cued unconsciously. As an example of auditory subliminal priming, a recent paper (Sadaghiani, Hesselmann, & Kleinschmidt, 2009) that tested participants at their individual perception threshold and recorded fMRI. Subjects reported by button pressure when they believed the target stimulus had been presented (before subliminal tones were presented to participants as cues). In these cases, the trial was considered correct. Results confirmed that correct trials were preceded by "greater pre-stimulus activity in related early sensory cortex". Unfortunately, we did not find any evidence there that non-conscious perceived tones permitted correct responses, but just that correct answers are preceded by higher cerebral activity in specific areas. On the other hand, the possibility for hearing, that unconscious priming influences target identification, has been researched by others without real success. Till now, nearest finding to this is from a team (Kouider & Dupoux, 2005) that used a new masking technique for speech priming which both time compressed and hid subliminal speech in a speech-like background noise that resulted in "unintelligible babble" (Quinlan, Quinlan, & Dyson, 2008). In the latter, they admit that Kouider's article had provided little evidence of semantic priming for hearing, and that this kind of protocol will be "an outline for future, albeit limited, adventures in subliminal audio presentation". Five years later the same researchers (Kouider, De Gardelle, Dehaene, Dupoux, & Pallier, 2010) were still only able to prove, through neuroimaging subliminal priming for spoken words, essentially what they did before. In any case, evident behavioural effects of speech perceived at unconscious stages have not been found.

For somatosensory unconscious processing, an article (Eimer, Maravita, Van Velzen, Husain, & Driver, 2002) investigated "the electrophysiological correlates of left-sided tactile extinction in a patient with right-hemisphere damage". While the subject could not report a conscious tactile perception on the contralateral side (left, also in the limb for which the damaged right-hemisphere should permit perception), ERP (evoked related potential) showed a residual activation in the somatosensory cortex related to this induced left finger stimulation. This finding suggests that extinguished perception does not come from response absence, but from its diminution. In a similar experiment (Preissl et al., 2001), despite participants' inability to consciously feel tactile stimulations, magneto encephalographic (MEG) recordings showed an "early (40 ms) neural activation in primary somatosensory cortex and absence of later (>60 ms) neural activation in the primary and associative areas". This demonstrated again that the activation of those areas does not accordingly imply that stimulus enters awareness, but that it needs to reach an intensity threshold. While this latter study tested two patients waiting for brain surgery because of tumors, this fact should not affect the normal processing which discriminates between conscious/unconscious perceptions. We argue this based on a more recent and considerably larger (14 participants) study (Palva, Linkenkaer-Hansen, Näätänen, & Palva, 2005), which also gives importance to the early activity in somatosensory and associate areas, which has to reach a degree of relevance to enter awareness. Here the first stage after stimulus onset was not related to ERP nor to MEG, but to neural oscillation which seemed to link conscious somatosensory awareness with alpha waves and conversely, very weak presence of those waves by unperceived trials. Nevertheless, none of the reported articles try to investigate the effects of somatosensory subliminal perception on behavioural actions in response to this. Instead, they just focus on the implicit effects measurable through brain activity machinery. While we were looking for the typical "masked stimulus perception and relative response" experiment paradigm, as used in several studies on subliminal vision, one author provided us with such a protocol to investigate touch. Nevertheless, Schubert and colleagues (2006; 2009) again confirm what respectively Eimer (et al., 2002) and Palva (et al., 2005) found out through ERP and EEG, adding just some evidence that the early phase activity plays a crucial role for conscious perception also in a masked priming protocol. In both of Schubert's experiments, participants were asked to press either a left or right pedal in response to stimuli presented either on the left or right index finger, while target touch stimuli were preceded by weaker and masked priming. However, neither behavioural nor imagery effects and till now neither touch nor auditory systems, have been able to show that subliminal perceived somatosensory stimuli alone are able to trigger a decision between two alternative motor responses.

The sense of smell has also been investigated in the field of unconscious stimuli about its effects on humans. For instance, it is known that smell plays a role in partner selection (Herz & Inzlicht, 2002), a mating process which we are mainly unaware of. Olfaction also seems to determine less “crucial” social predilection according to a study (Li, Moallem, Paller, & Gottfried, 2007) where “participants rated the likeability of neutral faces after smelling pleasant, neutral, or unpleasant odors delivered below detection thresholds”. The influence effect of smells, on the preference of extraneous images of faces, decreased when the odors became more intense and also consciously perceivable. Likewise, other article (Walla et al., 2003) argues that while it remained unperceived, the smell stimulus had more power to perturb other processes, such as face recognition in this experiment, caused by such “multimodal sensoric interactions” between visual and olfactory senses. Nevertheless, we found no study that discusses the interactions between odors and motor control processes or decision making through different motor actions. Obviously, we suspect that a bad smell even if subliminally perceived could trigger an escape decision or at least a position change of the participants walking away from the source. However, experiments linking motor behaviour and olfaction, in addition to being humorous, would also likely be very interesting as there are many studies about smell sense and behavioural decision in general (Hall, Johansson, Tärning, Sikström, & Deutgen, 2010; Mitchell, Kahn, & Knasko, 2007). It is likely that many links could be drawn between unconscious smell perception and motor behaviour, and perhaps some have already been investigated. In any case, we are unaware of any published work in this area explicitly investigating this. We can nevertheless summarize, by stating that odors can have some effects on discriminative processes even when they are not consciously perceived.

2.2.2. What "unconscious" means for us

We have already made a short review regarding some recent findings about subliminal perception for other senses than vision and their related effects on behaviour. In some manner, many stimuli of different kinds have some effect on neural processes even when they were not consciously perceived by the participants of those experiments. However, as we have seen in the previous section, it is possible to conclude that also for other senses it has not been possible to demonstrate that unconscious perceived information alone triggers a related motor response. This lack generates a debate about how decision making can be influenced from subliminal stimuli and even if this is possible (Leukel et al., 2012). In addition, the unconscious mind is a controversial field of research, where many discussions turn around main and basic points such as its definition, and the power and consequences of processes in response to stimuli which do not enter our awareness. John A. Bargh is a famous social psychologist who has made a significant contribution to the nature and implication of the these debates (J.A Bargh & Chartrand, 2000; John A. Bargh, 1992). Our present necessity is to collocate our work in his research, while also considering the ongoing controversy and Bargh's four year old review of "the unconscious mind" (John A Bargh & Morsella, 2008) provides us with a good starting reference and a broad perspective. He identifies a first problem in the definition of unconscious, a word which has not been interpreted with the same meaning since the beginning. Originally, evolutionary biologists such as Darwin, but also a neurologist such as Freud, used the word *unconscious* "much more in terms of unintentional actions rather than unawareness of stimuli". This meaning survived till the end of the last century where "this equation of *unconscious* with *unintentional* is how unconscious phenomena have been conceptualized and studied within social psychology". Nevertheless, at the same time the doubt that behaviour was not only and always consciously guided, pushed researchers to challenge this overall assumption. Social psychology also started to investigate the effects of priming on behaviour and Bargh determined here that the main point in research into the unconscious became "unconscious influences in terms of a lack of awareness of the influences or effects of a triggering stimulus". This is true obviously just for one of the two traditions in unconscious research that are largely independent from each other, namely: "the New Look research in perception involving the preconscious analysis of stimuli prior to the products of the analysis being furnished to conscious awareness, and skill-acquisition research involving the gain in efficiency of processes with practice over time until they become subconscious (see the review in Bargh and

Chatrand, 2000)" (John A Bargh & Morsella, 2008). This latter field of research is rather more linked to motor control science than the former, to which this work however belongs. To avoid misunderstanding, we also specify here that in our work we will be using Bargh's "operational definition" of *unconscious*, namely: "as a system that handles subliminal-strength stimulation from the environment".

2.2.3. Blindsight

We have already clarified our meaning of *unconscious* after reviewing the state of the art of this particular perception condition for other senses than vision. Now, we are interested in the effects of unconscious vision on motor behaviour. Existence of this kind of interaction was evident to us long before any investigation through research working with typical subliminal priming and related response protocol. In the so called "Blindsight behaviour" patients show reactions in response to unconscious visual information"

Specifically, the general definition of Blindsight "is the ability of patients with absolute, clinically established, visual field defects caused by occipital cortical damage to detect, localize, and discriminate visual stimuli despite being phenomenally visually unaware of them" (Cowey, 2010). In contrast, in this recent and quite broad look,the "Blindsight saga" author discusses his own definition based on some effects which should challenge the principle of unaware perception for this kind of visually impaired patients. Many doubts are considered that even constrain him to ask whether the "unconscious nature of Blindsight is trivial". This is based on at least two main facts already observed in patients with field or complete blindness. First, he set as "clear" evidence that "subjects who report no visual percepts commonly retain reflexive responses to light, which might, in theory, underlie their correct forced-choice performance". Second, he looked at the residual visual discrimination capacities observed instead by Weiskrantz (Weiskrantz, Warrington, Sanders, & Marshall, 1974) who found, among other things, "target localization and shape discrimination in the famous patient DB, whose surgical removal of right V1[4]". We may conclude that light reflexes and residual discrimination constitute two important points for the ongoing debate about the effective unconscious perception condition for Blindsight patients. Further, while the above

[4] The subject still had healthy eyes but neural signals from the eyes could no longer be processed in V1. Therefore, the processing of this information must have taken place elsewhere in the brain.

definition does not directly imply that such features can be used for motor actions, several experiments have proved this possibility as it will be mention below. Furthermore, obstacle avoidance, as we have already seen above, is already an evidence of movement performed in response to visual information about which the person was not aware. There obstacles were not identifiable as stimuli that changed the light contrast and that developed reflex effects, and still, participants did not verbally report any kind of awareness of them (Gelder, de, Haan, & De Heywood, 2001). Further still, this adaptation to obstacles had been observed for quite different tasks as, for example, when McIntosh required participants to perform a hand reaching movement (McIntosh, McClements, Dijkerman, Birchall, & Milner, 2004). Here “patients with left visual neglect had to bisect the gap between two cylinders or to reach rapidly between them to a more distal target zone” and reported that “in the bisection task, all neglect patients showed qualitatively the same asymmetry, with the left cylinder exerting less influence than the right. In the reaching task, the neglect group behaved like normal subjects, being influenced approximately equally by the two cylinders.”

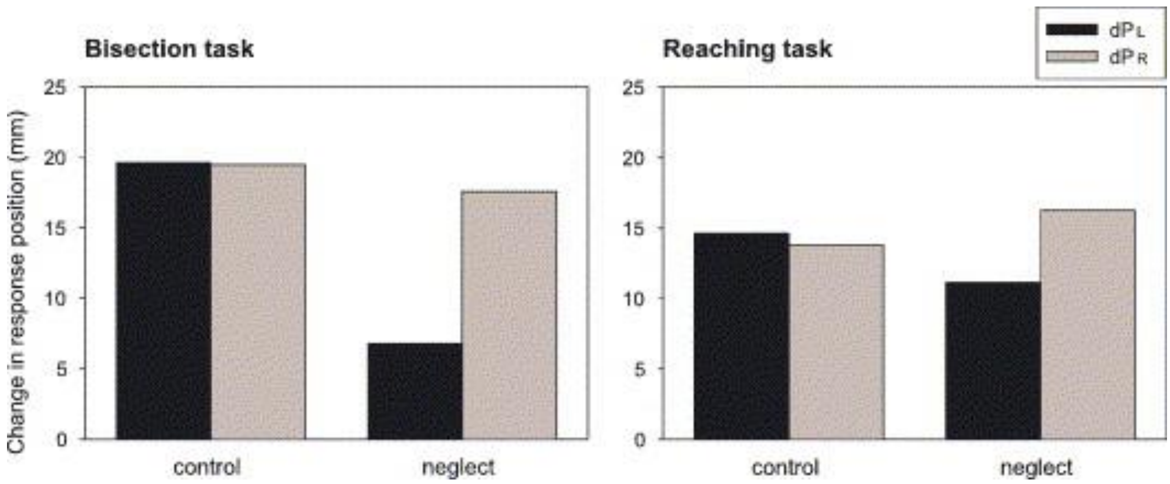

Fig. 3: a lower score in mm indicates less influence from the related cylinder ($_{d}P_{l}$ -> left cylinder $_{d}P_{r}$ -> right cylinder); normal subjects are influenced equally by the left and right cylinders. Therefore left visual neglect affected a patient’s performance stronger for perceptual bisection tasks than for the motor reaching task (R D McIntosh et al., 2004).

Of course we cannot speak, in this case, about totally unconscious controlled movement because participants were nevertheless aware of the presence of the left cylinder perceived on the peripheral left side of the intact right visual field. In any case, this experiment represents for us a case where motor tasks indicate a different behaviour process than the perceptual one which should imply a different neural process as well. An experiment (Goodale, Milner, Jakobson, & Carey, 1991) based on just one patient, represents another case in this sense. A woman who had a “profound disorder” in the recognition of “shape, orientation and size” of a three dimensional object, could nevertheless “demonstrate “strikingly accurate guidance of hand and finger movements directed at the very objects whose qualities she fails to perceive.” To explain such facts, the authors of the above bisection task experiment, mention the famous contribution of Milnar and Goodale (A. David Milner & Goodale, 1995) as well, arguing that there “may be separate neural modulation processes for “visuomotor attention” and “perceptual attention” operating in the dorsal and ventral streams respectively, with the dorsal attentional system in control overall”. A broader discussion about this operational separation will follow in section 2.2.6. Blindsight, patients’ perceptual processing does not work while processing for correct motor behaviour does. This is therefore, in some ways, another reason to suspect that subliminal priming may also be processed by other brain regions other than occipital areas. However, for such purposes, instead of walking through obstacles we should test the Blindsight effect while performing the same tasks as in our experiment. In spite of the fact that the above considerations about Blindsight were all based on patients, the blindness condition does not always come from pathologies or lesions (Christensen et al., 2008). Christensen et al (2008) induced blindness in healthy subjects “by using transcranial magnetic stimulation over the visual cortex”. Because of this artificial suppression, participants were also “truly blind” and neither partial sight nor light changes or movements or flickering could be reported, as instead do patients with visual impairment, where, because of such perceptions, their true “blindness” is a controversial point of discussion. The method used for this experiment is interesting for us because of the same purpose: it was designed to gather, in a number of trials, a left/right reaching response to unconsciously perceived visual stimuli. However, this unawareness condition was here (Christensen et al., 2008) obtained by timed suppression of V1 and not by displaying very fast stimuli as in our experimental design. In their study, “the subjects were required to reach toward one of three buttons indicated by a light. In 40% of the trials, a second light was turned on either to the left or the right, and the subjects then tried to correct the movement in response to this light. To induce virtual blindness, a single pulse of TMS was applied in half of the trials over the visual cortex 80–90 ms after the second light was turned on”. In each trial, subjects had both to correct the movement to the second light and to report verbally if they perceived the stimulus.

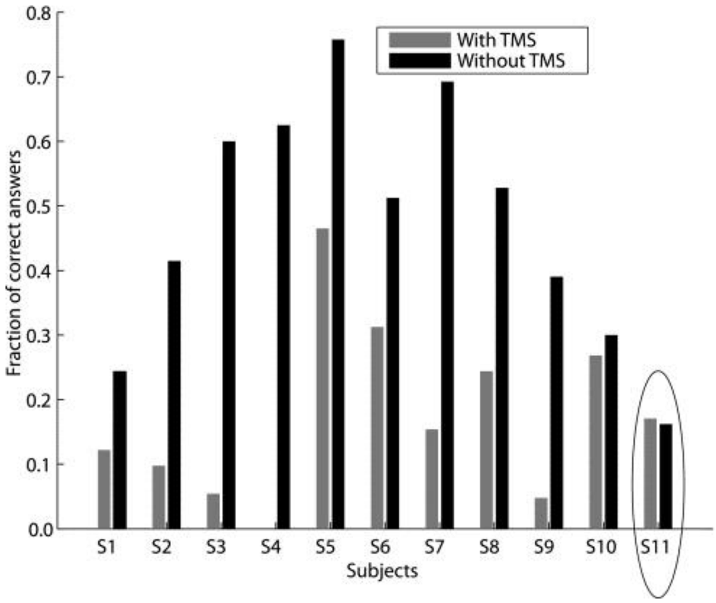

Fig. 4: TMS strongly reduced awareness perception of the visual stimuli in all participants except subject 11 (Christensen et al., 2008)*.*

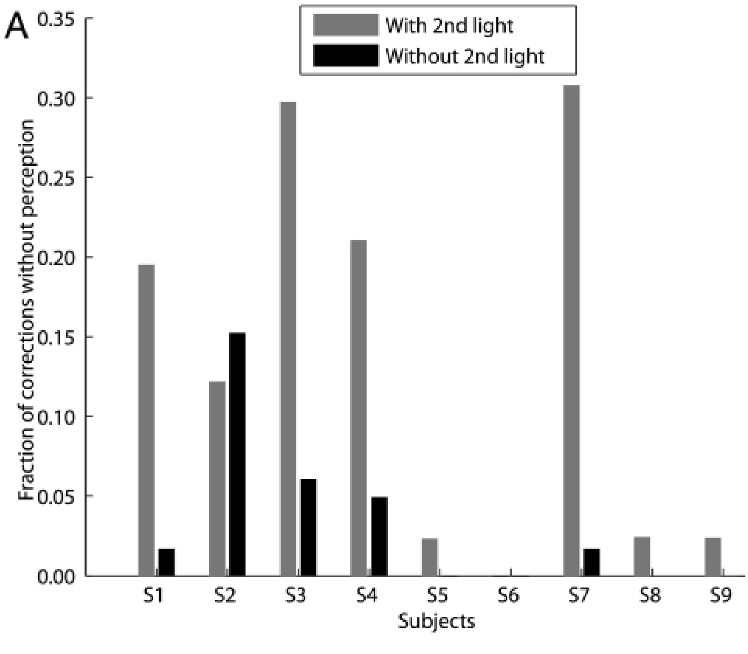

Fig. 5: successful corrections of the reaching action were performed in response to an unperceived second light stimulus (with a 2nd light), otherwise corrections without a 2nd light represent erroneous responses (Christensen et al., 2008)*.*

On one hand, results demonstrate that TMS can strongly reduce correct stimuli identification (fig. 4). On the other hand, because fig. 5 only shows trials with TMS, corrections were nevertheless possible despite a loss of awareness reporting of the stimulus. Briefly, the authors have arguments to support that they have provoked Blindsight-like behaviour in healthy subjects, based on the fact that participants “could perform corrective reaching movements without being aware of the presence of the visual signal that guides behavior.” Christensen et al. (2008), however, did not try to advance many explanations regarding neural systems which allow such behaviour. They merely suppose that “the mechanism responsible for fast visually guided corrective movements lies outside visual cortex” and that “the visual signals used for correction of movements bypass visual cortex. There may be subcortical routes for visually guided reaching that bypass the cortical regions affected by TMS”. Some help seems to come from at least two experiments which deal with the “crucial role of the collicular-extrastriate pathway in non conscious visuomotor integration by showing that, in the absence of V1, the superior colliculus is essential to translate visual signals that cannot be consciously perceived into motor outputs” (Tamietto et al., 2010). In addition, Schmid’s et al., (2010) results “demonstrate that direct LGN (lateral geniculate nucleus) projections to the extrastriate cortex have a critical functional contribution to Blindsight. They suggest a viable pathway to mediate fast detection during normal vision.” This last consideration interests us particularly because of the very short duration of the stimuli in our experiment. However, Blindsight and our experiment conditions are not the same. Blindsight is a visual lack because of a complete or partial lesion or inhibition of the striate cortex, while in our experiment, this brain region in participants presents no kind of perturbation and can operate normally.

Two further suggestions come now from Blindsight, in addition to the intrinsic inspiration to our experiment: the existence of extra striate visual pathways working in some manner together with motor cortex and the existence of an ongoing debate about the role played by V1 for visual awareness. This latter interaction has been, in fact, often discussed together with Blindsight behaviour (Lamme, Supèr, Landman, Roelfsema, & Spekreijse, 2000; Stoerig, 2006; Leopold, 2012).

In the previous four paragraphs, we have briefly overviewed studies in the field that is similar to our own, namely, the field we would like to call “responses related to visual subliminal priming” , a name that emphasizes the typically used experimental protocol. Before having clarified what “unconscious” means in our case, we quickly found that unconscious perceptions by other senses than vision have already been investigated. Till now, vision however seems to be the sense that is most influenced by information perceived without consciousness. This is demonstrated by Blindsight (see “introduction” above), while being one of the most unusual effects in motor behaviour, is nevertheless that has been explained scientifically. These examples may have influenced us towards accepting our research assumptions even before any precise investigation oriented to our goal, namely that motor responses could bypass conscious perception of the triggering stimuli. In the next section, we will enter our research field and review some significant contributions which will bring us to the point of Leukel's most recent considerations.

2.2.4. Motor response setting before the end of perceptual processes

Before investigating how subliminal perceived stimuli could trigger a motor response, we need to be sure that the perceptual processing and the response process are not necessarily sequential. This would be the case if we accept that becoming aware of a stimulus is part of the perceptual process, when the stimulus has the power to trigger an evident motor action in response to it. We also have to exclude the possibility that motor action in response to a stimulus starts only once there is awareness of the relevant stimulus. Otherwise, it would be, in any case, impossible that a subconscious visual stimulus could influence a motor response to this.

In a ten-year old paper (Eimer & Schlaghecken, 2003), the author distinguished between two kinds of models that could represent perceptual-motor interactions. The older one is the traditional representation, where "discrete stages" of these interactions should follow one another in a "strictly successive order". This has been replaced by models which respect the principle of "flow of information" between sensory and motor systems. For this more recent representation, Eimer e Schlaghecken cited some articles where the response process is influenced by sensory information before the analysis of their stimuli has been completed (responses occurred after stimuli apparition). Two of those studies (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Smid, Mulder, & Mulder, 1990) used "the muscle activity through electromyogram as indicator of peripheral activity onset" and "the latency of the P3 component of the event related brain potential (ERP) as an index of stimulus evaluation duration". Smid et al. (1990) added "the onset of lateralized motor activity derived from the ERP as an index of selective central motor activation". However, this last method merely confirms what the two studies were able to demonstrate, namely that before stimulus analysis is completed the perceived information already has some effects on the response process.

It is not important for our purposes whether or not Eimer distinguishes between "continuous" for the first mentioned study and "asynchronous" for the second model of perceptual-motor interaction (Eimer & Schlaghecken, 2003). The important point for us is that stimulus perception processes and the set of response processes are not necessarily subsequent stages of processing and that the first can also be completed when the latter already has started.

2.2.5. Unconscious stimuli can initiate response processes

What we have affirmed in the previous section about the interposition of perceptual and response phases does not consequently mean that a stimulus can trigger a correct motor response before awareness. Other studies cited in Eimer's & Schlaghecken's (2003) paper, however, claim to have demonstrated this, where Elmer states that "even stimuli presented near or below the threshold of conscious awareness can trigger response activation processes" (as we have seen in the previous section). We would like now to briefly investigate other articles which appear to confirm the possibility for a subconscious stimulus to start a motor response.

Neumann & Klotz's experiment (1994) presented to the participants a "two-choice situation" (a condition that has a strong similarity to our experiment), where, depending on the position of the stimulus (this is an important difference compared to our experiment as we will explain in section 2.2.7.), information follows a prime which has been made subliminal by a metacontrast [5] effect. This implies that prime and target are not projected to a fixation point, but are displaced either to adjacent positions for congruent and, at quite separated locations, for incongruent trials. This experimental condition, as we will discuss, constitutes an improvement possibility for our experiment and the experiments that inspired us. When stimuli are presented at fixation, the participants can solely perceive the meaning of the cues (in our case, their direction demanding either left or right choice) without being helped by their localization on the spot. Furthermore, also compared to our experiment the method used for masking the prime is here in many ways different, because we exploit the absolute display duration and a low color contrast between the prime and its background, but not the metacontrast as in this case. In any case, they also obtained

[5] The relevant information that appears in a zone of the visual field adjacent to the prime's position. Because of the short delay, the subjective brightness of the prime dramatically decreases till it becomes consciously unperceived, as happened in the cited article.

an unconscious perception of the masked prime which has an influence on the motor response to the stimulus. Another interesting point in their results is the amount of errors for the incongruent primes which are 5 times higher than for the other two conditions.

Table 5.1 Percentage Errors in Experiments 1–3

			Experiment 3	
	Experiment 1	Experiment 2	Compatible	Incompatible
Congruent	1.4	0.1	1.6	2.0
Incongruent	7.0	6.7	9.6	10.1
Neutral	1.1	1.5	2.3	3.2

Fig. 6: Compared to neutral trials, reaction times are shorter when target and prime are compatible and longer when they are incompatible (Neumann & Klotz, 1994).

The authors take the frequent errors induced by incongruent primes as "strong evidence that the masked prime triggered the response in a considerable number of trials" which also implies "that a stimulus can have access to the motor system and activate or even start an intended, planned response without being represented in consciousness".

In the successive experiment, Eimer & Schlaghecken (1998) challenge the benefit (discussed above, see fig. 6) of congruent primes on reaction time and error rates. They suspected that "cost-benefit" pattern reported by them (Neumann & Klotz, 1994) may at least partially be attributable to sensory priming because primes and targets were presented at identical locations in compatible trials but at contralateral sides in incompatible trials". To investigate only motor behavioural response effects, they also decided to present primes and targets (either left or right response demanding) at fixation. Furthermore, they recorded lateralized readiness potential (LRP) which indicates the left-right activation degree of motor cortex areas responsible for hand movements. A 16 ms prime (left-right pointing arrow or LL RR letters in one control trial block) appears on display and is followed by 100 ms neutral masking. Neutral masking is made by a double arrow pointing inside or outside before the target follows the prime with the same or opposite pointing direction. Targets appear for 100 ms. Contrary to what the authors expected based on the inspiring article by (Neumann & Klotz, 1994) and the logical hypothesis, results showed an inverse influence between primes and targets.

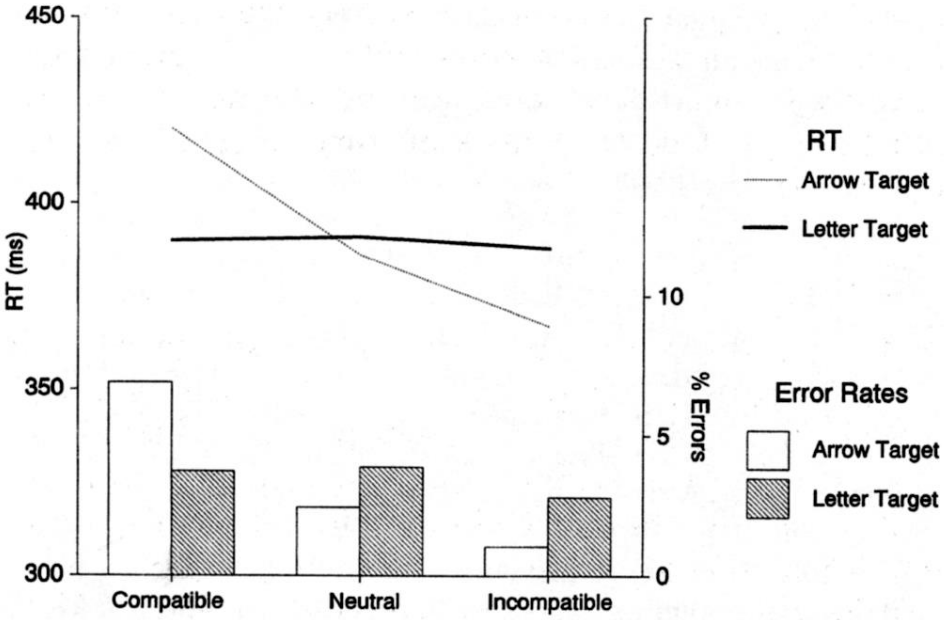

Fig. 7: compatibility between cues and target caused higher error rate than incompatible trials (Eimer & Schlaghecken, 1998)

We do not consider the protocols where letters were used as targets because they were just used as control trials. They were presented in order to be sure that responses are not triggered automatically from any kind of stimulus, for instance from stimuli that are not assigned to a precise response. Incompatible trials need shorter reaction times and trigger fewer errors while compatible primes cause the highest error rate and need the longest reaction times on average. LRP confirms the tendencies about delay time at motor cortex level, and provide further interesting information about the response process.

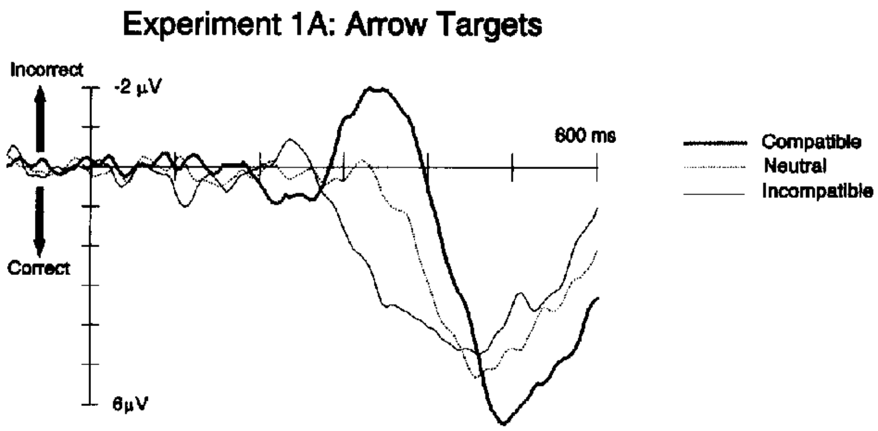

Fig. 8: Lateralized Readiness Potential recording. Compatible trials initially show a correct motor response activation followed by an inversion which delays the response and also causes errors in many cases. The same principle, only reversed, is evident for the incompatible trials while no such pre-response activation pattern is present for neutral trials (Eimer & Schlaghecken, 1998).

The authors challenge their own results with two other similar experiments. The second protocol is presumed to prevent the aforementioned response inversion's dependence on the "sequential presentation of prime and mask". In the original protocol, the double-arrow masks could be perceived as a single arrow added to the opposite side of the prime's, causing a moving effect which is suspected to inverse the first response activation which is coherent with the prime direction. In the second experiment, double arrows pointing either outside or inside (< > , > <) are used as symmetrical primes and targets, requiring respectively a left or a right hand movement. Neutral trials were also excluded. Nevertheless, compared with first protocol used, results do not change, but rather reflect the same tendencies.

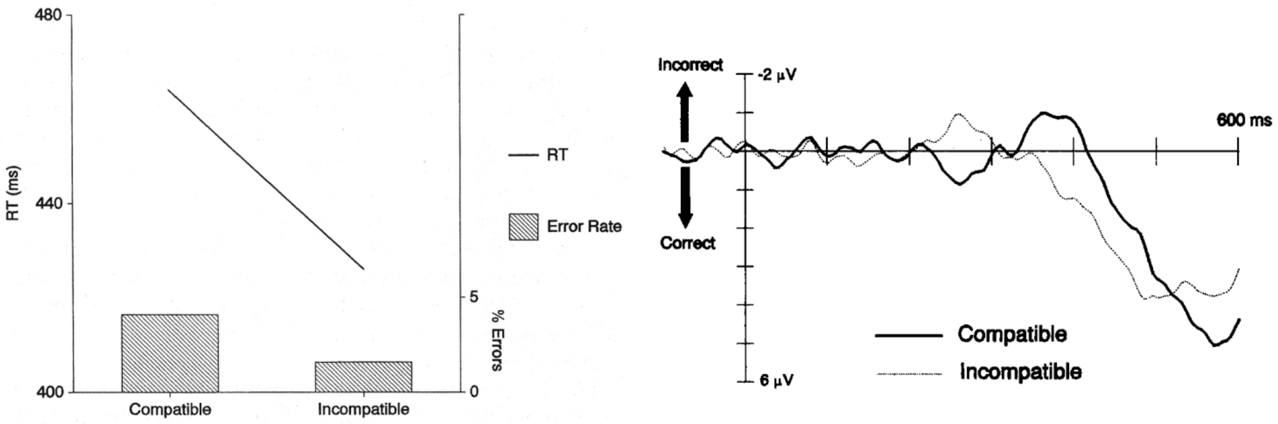

Fig. 9: analogue results as in the first protocol (fig. 8 and 9), where asymmetrical targets were presented, also with symmetrical targets (Eimer & Schlaghecken, 1998).

Behavioural responses are already facilitated by incompatible trials and affected by a compatible relationship between prime and target. Furthermore, the LRP wave demonstrates that the activation, in response to the prime, reverses about 100 ms later in an opposite response, before finally corresponding to the target. The authors also investigate the second and last possible reason suspected to be responsible for this effect, namely that in the presence of a two-hand choice task both are activated successively , causing the RT costs while stopping the reaching action of the other hand. To exclude this factor, a third experiment uses both a single-hand and a single-finger movement task.

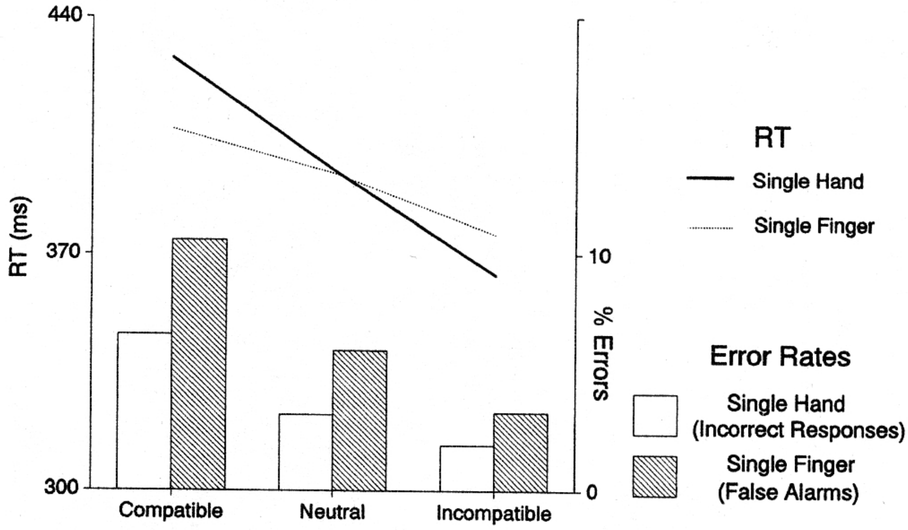

Fig. 10: a third protocol involving a single-hand and a single-finger movement task, confirming what was observed in the two previous protocols, namely, shorter reaction delay and lower error rates for incompatible trials. LRP was not recorded, (Eimer & Schlaghecken, 1998).

The authors finally considered the presence of an inhibitory process to explain these results. Correct response activation after prime is suspected to be inhibited by the masking which causes such a suppression of the perceived original information. This could explain both RT costs and performance deterioration for compatible trials and benefits for incompatible trials.

This study shows that subliminal primes can influence the reaction times when reacting on subsequent target stimuli. It depends, however, on different factors whether a congruent trial facilitates or inhibits the reaction time. What is important for our purposes, as the authors in fact stressed, is the fact that "the results of our experiments have again demonstrated that stimuli that are not consciously perceived nevertheless can have a strong influence on motor activation and behavioral performance." (Eimer & Schlaghecken, 1998).

In addition, the authors argue that this inhibition effect would provide further evidence of the "direct visuomotor control system of the dorsal processing stream" as theorized by the famous book by Milner and Goodale (A. David Milner & Goodale, 1995). A detailed discussion of their work will follow in the next section.

2.2.6. Visual system

The last section ended mentioning the fundamental contribution of David Milner and Melvyn Goodale (A. David Milner & Goodale, 1995), which is a great point of reference for all successive studies into the structures and functioning of visual systems. Their book “The Visual Brain in Action”, published for the first time in 1995, contains their most important considerations and those of others regarding the separation between dorsal and ventral visual systems. The latest edition of their book, published seven years ago (A. David Milner & Goodale, 2006), still promotes this distinction. Their main and central topic is the existence of two separate systems for vision: “In summary we are suggesting that two separate networks of areas have evolved in the primate visual cortex: a perceptual system which is indirectly linked to action via cognitive processes, and a visuomotor system which is intimately linked with motor control.” Such a dichotomy, “Perhaps the best functional distinction in visual neuroscience” (p. 21), had first been advanced in 1968 by Trevarthen. His work is quite commendable, considering that brain functioning was investigated without the use of today’s modern machinery. Just by reason of “The survey of anatomical and physiological features of the primate brain, and the result of behavioural experiments following surgery to parts of the visuo-motor mechanism” he concluded “that two kinds of visual function may be distinguished in the regulation of primate behaviour. One is *ambient* or extensive, the other is *focal* or intensive”. This implies different structures, respectively the dorsal and the ventral pathways, where the former is responsible for whole body actions such as locomotion and posture and the latter for guiding fine motor acts such as manipulation (A. David Milner & Goodale, 2006, p. 21).

A very common simplified definition calls the occipito-temporal (ventral) stream the "what" pathway, whereas the occipito-parietal (dorsal) stream implied in the mediation of spatial perception and visually guided actions is named “where” and/or “how” pathway (Creem & Proffitt, 2001). In a review, which provides many considerations about dorsal and ventral processes, Norman (Norman, 2002) summarizes well the main features of the two systems.

Factor	Ventral system	Dorsal system
Function	Recognition/identification	Visually guided behaviour
Sensitivity	High spatial frequencies - details	High temporal frequencies - motion
Memory	Long term stored representations	Only very short-term storage
Speed	Relatively slow	Relatively fast
Consciousness	Typically high	Typically low
Frame of reference	Allocentric or object-centered	Egocentric or viewer-centered
Visual input	Mainly foveal or parafoveal	Across retina
Monocular vision	Generally reasonably small effects	Often large effects e.g motion parallax

Fig. 11: the main differences differentiating the two distinct visual processing streams in the original model (Norman, 2002)[6]

After checking this table, it seems easy to attribute to the dorsal system the effects described by Eimer (in Eimer & Schlaghecken, 1998), reported in the previous section, where a "visually guided behaviour" task, requiring high speed processing with no consciousness of the primes, was being described. Nevertheless, this is merely a theoretical model, whereas neuronal reality is of course much more complicated and still under investigation. For instance, already ten years ago, Rizzolati (Rizzolatti & Matelli, 2003) presented "a detailed description of the multiple neural circuits connecting the frontal, temporal, and parietal cortices" (Binkofski & Buxbaum, 2012). While this consideration was originally based on a study of macaque, the previously mentioned review of Binkofski (2012) confirms that this is also true for humans. His recent contribution argues that the "dorsal system is further divided respectively in the dorsal-dorsal and in the ventro-dorsal processing streams." Whereas "the former also called "Grasp" system, processes structural characteristics of particular exemplars of currently-viewed objects (e.g., shape, size, and orientation) for the purposes of prehensile actions" the latter or "ventro-dorsal stream, named "Use" system, is concerned with long-term storage of the particular skilled actions associated with familiar objects." However, this further distinction summarized by Binkofsky still remains near to the Milner and Goodale (1996) perspective, while adding some improvements. Nevertheless, other contributions challenge or even deny their renowned model. A quite recent review entitled "Two visual systems for perception and action: current trends" (McIntosh & Schenk, 2009) present a useful instrument for looking through all main discussions about this model. For example, the

[6] (5 mars 2013) http://en.wikipedia.org/wiki/Two-streams_hypothesis

authors first mentioned a consideration based on a single patient with agnosia who showed “impaired planning contrasting with preserved action programming” (R D McIntosh et al., 2004). Because of this observed fact, Milner and Goodale (2008) see "planning-programming distinction as a critical boundary between ventral and dorsal stream influences on behaviour" and further contributions about it are waited for the future. Another disease which calls into question the separation between two visual systems is optic ataxia that follows a dorsal stream lesion presenting misreaching problems like attentional simultanagnosia, “which often accompanies optic ataxia following bilateral parietal lesions”. The similarity of the two mentioned diseases “raises the important question of the functional relationship between attentional and visuomotor impairments following dorsal stream lesions”. Another distinction under investigation is the delayed actions that should always be supported by the ventral stream because, according to the binary model, the dorsal stream “shouldn’t be able to store visual representations across temporal gaps” (Robert D McIntosh & Schenk, 2009). They also mention experiments that used prism adaptation to check whether difficult transfer between immediate and delayed actions could demonstrate different processing streams. Controversially, while the older research (Baraduc & Wolpert, 2002; Scheidt & Ghez, 2007) argued, in fact, for an overlapping between visuomotor systems, more recent studies have reported perfect transfer for immediate and delayed pointing (Rogers, Smith, & Schenk, 2009). The most controversial ongoing debate about the validity of the dorsal and ventral model turns around visual illusions. Following the concept of dissociation between an allocentric (ventral) and egocentric (dorsal) system, manipulations of a visual context which are able to produce fake perceptions of objects’ size, location or orientation, should not affect the latter mentioned system nor motor behaviour with respect to an object. An article with an appropriate title, “Size-contrast illusion deceives the eye but not the hand” (S. Aglioti, DeSouza, & Goodale, 1995) provides evidence in this sense. Subsequent criticism about dissociate affection of visual illusions came primarily from a German research team (V H Franz, Gegenfurtner, Bülthoff, & Fahle, 2000) that showed “no difference in the sizes of the perceptual and grasp illusions if the perceptual and grasping tasks are appropriately matched”. Eight years later, Franz and Gegenfurtner (Volker & Gegenfurtner, 2008) published an article entitled “Grasping visual illusions: consistent data and no dissociation”. Unfortunately, not all studies used the same type of illusion, and this fact alone causes controversy where same illusion also produces different results (Bruno, Bernardis, & Gentilucci, 2008). For instance, Müller-Lyer’s illusion affects both perception as well as grasping, but when hand reaching enters the visual field, online correction occurs and allows for normal reaching despite disturbed perception (Bruno et al., 2008).

However, after mentioning the key points that have generated debate about the two visual system model, our reference review (Robert D McIntosh & Schenk, 2009), speaks in favour of this model, but denies a clear independence between the two systems. In fact, they prefer to identify a dynamic collaboration of "the many visual brain areas that arrange themselves from task to task into novel functional networks".

Recently, it was argued that "it has to be mentioned that it is still under debate whether or not there exist two different streams for processing different aspects of visual perception (Leukel et al., 2012). Therefore, conclusions about the neural processing of unconscious information in the present study cannot be drawn". This is a consideration that can also be used for our experiment. Naturally, we are not able to add personal considerations about this renowned visual model. Nevertheless, Eimers' considerations from the previous section, forced us to further investigate his attempt to rather quickly attribute his results to the existence of a dorsal processing stream. Moreover, for work centred on visual processing, it is unavoidable to focus, at least briefly, on Milner and Goodale's fundamental assumption.

We have in section 2.1.5. considered the admission of the impossibility of defining a precise model of the visual system which permits correct motor behaviour. Of course, the main functioning of single organs and the main pathways of the visual system are today generally well known. Photoreceptors in the retina transform light changes into action potentials which are transmitted and mediated through other important structures (such as the lateral geniculate nucleus, the pulvinar nuclei and the superior colliculus) before reaching V1 (primary visual cortex) and associated visual cortex areas. Nevertheless, as seen in the light of the debate mentioned in last paragraph, it is still unclear how visual inputs are projected from occipital areas to others. Moreover, there are "a multiplicity of parallel pathways that bypass V1 and project to other targets in the brain whose contribution to vision is multifold and not yet ultimately established" (Tamietto et al., 2010). For example, these authors demonstrate the "crucial role of the collicular-extrastriate pathway in nonconscious visuomotor integration by showing that, in the absence of V1, the superior colliculus (SC) is essential to translate visual signals that cannot be consciously perceived into motor outputs". Such an observation was made with functional magnetic resonance imaging while a "gray stimulus presented in the blind field of a patient with unilateral

V1 loss, although not consciously seen, could influence his behavioral and pupillary responses to consciously perceived stimuli in the intact field”.

Recently, new brain imagery techniques, such as diffusion tensor imaging, were used to investigate alternative visual pathways leading from pre-striate structures. For instance a study (Leh, Chakravarty, & Ptito, 2008) showed how “pulvinar nuclei are interconnected with subcortical structures (superior colliculus, thalamus, and caudate nucleus) as well as with cortical regions (primary and secondary visual areas, visual inferotemporal areas, posterior parietal association areas, frontal eye fields and prefrontal areas”. Another investigation with MRI (diffusion magnetic resonance imagery) technique showed on a single patient “two major features absent in controls: a contralateral pathway from right LGN to left MT+/V5; a substantial cortico-cortical connection between MT+/V5 bilaterally”. A case that suggests how “employing alternative brain regions for processing of information following cortical damage in childhood may strengthen or establish specific connections” (Bridge, Thomas, Jbabdi, & Cowey, 2008).

The three articles above represent just a small example among several studies that have attempted to understand alternative neural pathways involved in the visual system. Despite the fact that two of them were based on medical patients and do not represent normal functioning, it is necessary to consider some important points. First, we have seen an example of a structure that provided motor output bypassing V1, which also happened through a stream that leaves the relevant stimulus consciously unperceived. This is significant for our purposes, because it permits the study of other similar possibilities in normal subjects, namely that extra striate pathways that process visual information can enable correct motor behaviour in response to subliminal stimuli. Secondly, the last article (Bridge et al., 2008) suggests that because of neural plasticity, new connections for visual perception could be established to repair lesions. This latter, represent a first example to our knowledge of neural plasticity related to visual processing. We suggest that, the strengthening or even the establishment of alternative connections could perhaps occur to facilitate specific tasks even when lesions are absent. More precisely, it follows that similar adaptation in visual neural circuits may also occur after regular practice doing tasks that demand specific processing, as may occur in overt sports. In Leukel’s experiment, a skilled table tennis player was able to consciously give correct responses even at the shortest stimuli duration (20 ms) while all other participants had a higher conscious detection threshold. This case shows that better capacities for visual processing could be either congenital or reinforced through sport practice. On the one hand, no study has tested individual improvement in such experimental quick visual detection due to ball sport practice. On the other hand, more than one article mentioned in sections 2.1.2., 2.1.3 demonstrated that in experimental conditions as well, better visual capacities were found for tennis players compared to the control group. It would be interesting to research, through neuroimaging, at which stage and how the visual perception of players differs from normal people. We would like to verify whether players use other visual pathways specifically developed for similar tasks or whether the same circuits that normal people have, are used only faster. In any case, it is important to point out that in order to deal with the presence of lesions or to solve specific demands, alternative pathways for visual processing may be used, old ones may be strengthened and even new ones established, thanks to brain plasticity. Further, as mentioned above, we have already seen one of those streams transforming unconsciously reported stimulus into motor output.

2.2.7. Subliminal cues alone permit correct motor reaction.

In the previous section, we looked at the state of the art regarding neuronal organisation of the visual system. Before this, we saw how subliminal cues could influence a successive target which triggered a related response. There we saw a case where unconscious congruent stimuli reduced reaction time and another case where reaction times were instead affected differently by compatible or incompatible cues. Other recent studies and reviews (Boy, Clarke, & Sumner, 2008; Van den Bussche, Van den Noortgate, & Reynvoet, 2009) reported similar experiments using a masked-cue paradigm to investigate the effects on successive targets. Further studies have added to the knowledge of unconscious motor behaviour, for example regarding the role played by attention (Kouider & Dehaene, 2007) or about unconscious conflict adaptation (Desender, Van Lierde, & Van den Bussche, 2013). However, according to Leukel (et al., 2012), an open crucial question seems to be unanswered since the beginning of such studies. Specifically, he argues that no one has been able to clarify whether an “unconscious stimulus alone is sufficient as a basis for choosing between two possible motor responses.” To emphasize this point, Leukel refers to a relatively old article (Taylor & McCloskey, 1996) that attempted to solve this question. Despite the fact that the authors concluded “that subconscious information may not only be used for initiating motor responses in simple tasks”, Leukel clearly disputes this by stating that “the experiment could not clarify whether the subconscious cue indeed initiated the response or whether it only facilitated the reaction (in terms of a faster reaction time) that is actually initiated in response to the strong stimulus (mask). This is because the mask was always exclusively presented on the same side as the subconscious cue, not on both sides (i.e. it was not a ‘‘neutral’’ mask). Both stimuli, the subconscious (first) and conscious (second) one, therefore had the same meaning.” Nevertheless, Leukel seems here to overlook that in Taylor’s protocols, the mask did not always follow the “test” light. In the picture below, it is reported how the test light was displayed alone in some trials.

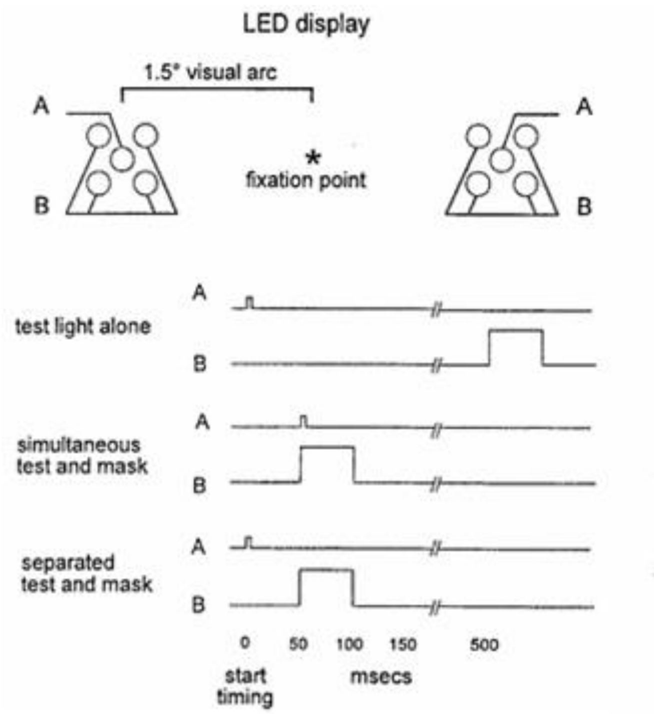

Fig. 12: a mask also followed in protocol “test light alone” trials, but this occurred with a delay time (500 ms) that was longer than the reaction time to the test light that was being tested by those trials (Taylor & McCloskey, 1996).

In those trials without masking stimuli, participants reacted as quick and correctly as in the trials followed by masking. Because of this fact, the authors expect to have demonstrated correct motor response while choosing between two different possibilities. More precisely, they summarized their finding as follows: “appropriate programs for two separate movements can be simultaneously held ready for use, and that either one can be executed when triggered by specific stimuli without subjective awareness of such stimuli and so without further voluntary elaboration in response to such awareness.” After having carefully investigated Taylor and McCloskey’s contribution we still cannot decide if their experimental condition was really able to demonstrate their conclusion. This conclusion would be of course strongly relevant for us, but one important detail, however, leads us rather to Leukel's experimental design. In Taylor's experimental protocol, participants' choices depend on the location of the target cue and not on its features, because they have to respond to flashing circles either on the left or right side of the visual field. This causes us to think that while doing sport, humans can make decisions dependent on the location of perceived stimuli without awareness. In any case, we are more interested in the idea that humans are able to use relevant information for motor behaviour that also depend on the nature of the fixed location and not just from its location. Vicker's great contribution (Vickers, 2007) to the understanding of human gazing behaviour while performing sport, revealed that, compared to novices, expert players have a different gazing behaviour with regards to the action. They fixate on fewer locations, but gazes stay longer on each fixation point while saccade switches are faster. Because of quicker and more appropriate tactical responses (Martell & Vickers, 2004), experts unconsciously guide and focus their gaze to the locations where relevant information will appear (due to the sudden changes in conditions in overt sports, such information usually appears just for short times). Of course in overt tasks, relevant information could also appear at unattended locations, and the capacity to find this information in a given situation is the first step for appropriate tactical behaviour. The ability to switch gaze trough saccades among targets that are only briefly perceivable seems to be linked with what was demonstrated by Taylor & McCloseky (1996). There, participants were able to use a 5 ms unconscious stimulus, appearing at different locations, for correct motor responses. Here, the location of the stimuli alone was the determining factor for correct choice, but in other cases, once the gaze is on the right fixation point, further features of the fixed point could be determinant to make the right decision. Going back to the example of tennis from our introduction, relevant details could be, for instance, the angle of the opponent's racquet or foot position or many other types of information. Hypothetically, all kinds of tecnical or tactical information, based either on opponents or on the situation, entering a player's visual field, could be suspected as being relevant for correct visuomotor behaviour. As said in the introduction, information based on the opponent may involve a mirror system which allows player's to anticipate the opponent's action and consequently the motor response. Nevertheless, enternig the sphere of the human mirror system is beyond the scope of this present study, as well as any discussion of motorbehaviour in response to an opponent's whole body motion. In fact, we are now only considering that after the player focalizes on a relevant location in his visual field, once his gaze fixes on it, another ability is needed, namely that his brain's visuomotor system, can detect and use the fixed information for correct motor responses. Besides this, we are intrested in the degree of awareness while performing such motor responses. High time constraints in overt sports, imply that response capacity does not necessarly require conscious processing in players that unconsciously use the cues to choose and trigger the appropiate movement. Studies (Panchuk & Vickers, 2006; Savelsbergh, Williams, Van der Kamp, & Ward, 2002) demonstrate that for expert goaltenders, different gaze searches than novices are among the shooter-based cues. Of course, the former have more succesful motor responses than the latter, showing that focalizing on appropiate cues could be determinant. Naturally, such appropiate gazes in search of relevant cues, happen without volountary gaze control on the part of the player (goaltenders in the previously mentioned examples, develop such capacities with expertise, and thanks to practicing). Despite the fact that gaze orientation happens without awareness, it does not consequently prove that fixation information unconsciously triggers appropiate motor responses. In some way, the ability to use unconsciuosly perceived stimuli for correct motor behaviour, was still based on "unproved evidence" till the study by Leukel just one year ago. We wish to call this "unproved evidence" because if gaze searches enable the finding of relevant cues, logically, cues also need to be unconsciously identified depending on their nature (orientation, movement, direction and so on). Despite legitimate suspicions, no scientific research had been able to demonstrate this capacity. Leukel finally prepared a protocol which investigated whether participants are able to use unconscious targets that are always displayed at the same fixation point, where relevant information for motor behaviour is the orientation of targets which are followed by a neutral mask that makes targets the only cue provided to participants.

Summarizing, the following are the three main areas that bring us towards Leukel's study rather than any other previous priming:

-Targets represent the only triggering information, because masks have neutral meaning and because no previous or following cues are presented.

-Response depends on stimuli orientation, specifically on the arrow's direction.

-Stimuli always occur at fixation, which make processing independent from gaze. Correct perception also depends only on stimuli orientation and it is not helped by different locations (see 2.2.7. Taylor's protocol).

In the presence of correct response rates that are higher than guessing probability, also at durations under the conscious threshold, and by taking into consideration the three points above, findings from Leukel's experiment would constitute the "unproved evidence", namely that fixed cues unconsciously perceived, are sufficient to trigger a correct motor response. This possibility may have some similarity with the capacity of unconsciously using relevant cues while playing an overt sport.

Our experiment should therefore be considered an extension of Leukel's research. In light of this, we will now report on this study in much more detail. This will help us to emphasize the similarities and differences between our experiment and theirs as well as provide us with a reference method.

Leukel's Methods.

Participants (8 women, 3 men, aged 29 ± 5 years) were seated at a distance of 60 cm in front of a computer screen. The right hand of the subjects, resting on a start button, had to be lifted and moved forward to a target button placed 50 cm in front of the start button. 30 ms after pressing the start button, pointing arrows were shown to participants requiring the pressing of a target button or to stop the reaching movement. Less than 1 ms after the target cue, double pointing arrow of same color was displayed as a mask for 60 ms, after which a second double pointing arrow with different colors followed until next trial. The target and the first mask were dark blue on a light blue background, while the second mask was orange on a dark green background. Participants had to fixate on the spot where the cue was displayed while pressing the start button. If the arrow cue pointed upward, they had to reach and press the target button, otherwise for a downward pointing cue they had to stop the reaching movement resulting in no recorded response.

Leukel's experimental protocol.

300 accustomization trials were performed, with 300 ms long cues requiring a reaching movement, in order to accustomize all participants with such easy consciously reportable trials. After the accustomization protocol 1, they "tested the ability of the subjects to make correct motor responses to visual cues with different display durations (Motor reaction)". Following this, in protocol 2, they "tested the ability of the subjects to correctly verbalize the meaning of the visual cues with different display durations (Verbalization)". This second protocol revealed what the individual threshold for conscious perception was for each participant . Correct verbal

responses at guessing rates indicates no conscious perception at that specific cue duration. Consequently, Leukel et al. “argued “that if subjects were able to perform the Motor reaction protocol correctly in the absence of conscious perception (tested in the Verbalization protocol), this would indicate the capability of the subjects to have correct action selection based on subconscious visual information.”

Leukel’s results and discussion

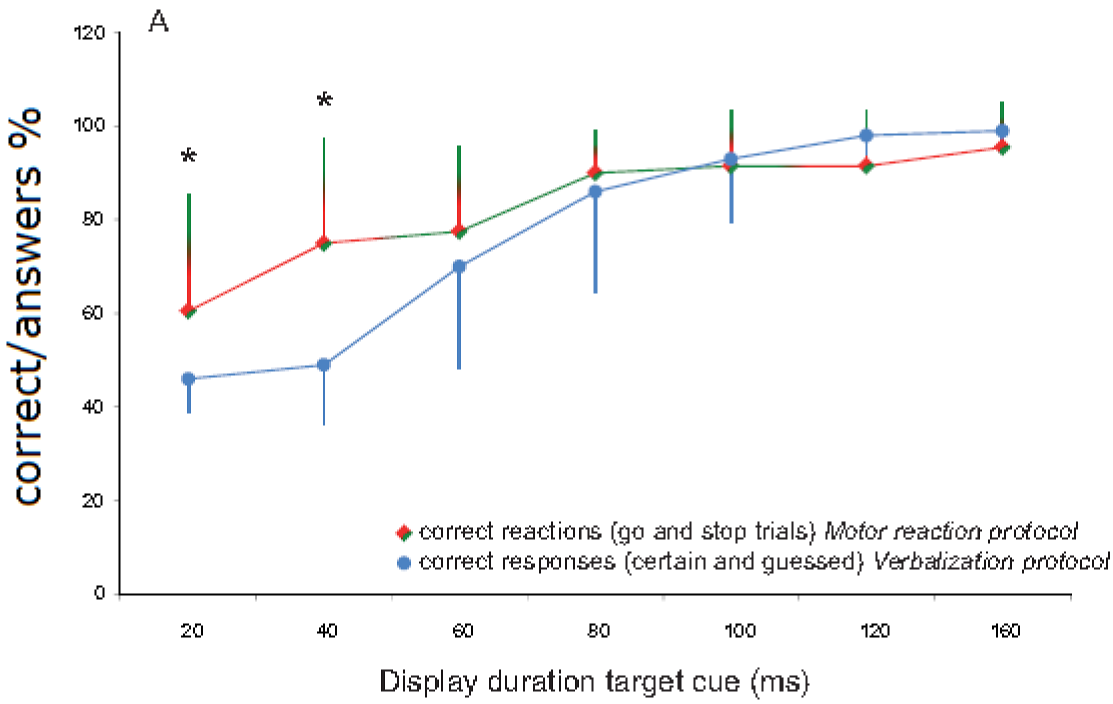

Fig. 13: results demonstrated that at the two shortest display durations (20 ms and 40 ms) participants had significantly better percentages of correct answers in the motor protocol than in the verbalization task (Leukel et al., 2012).

Based on these findings, they argued that “at these two short display durations, subjects were significantly more likely to make a correct motor response than to consciously perceive and verbalize the meaning of the visual cue”. Moreover, individual results indicated that at the display duration where conscious verbalization resulted in being purely guessed (50% right and wrong answers) subjects had significantly higher correct response rates in the motor trials. Overall and individual comparisons, between the verbal protocol entailing conscious perception and the motor task, led the authors to argue that subjects were able to choose the correct motor action in response to subconscious visual cues.

The researchers remarked that there was some similarity with Christensen's results (see also pg. 29-33), where corrections were also unconsciously performed but to the left or to the right. Leukel sees here the difference between his and their task, namely the fact that his task demanded either to stop or to complete the reaching action, while in Christensen's study, participants were always asked to complete the reaching action. However in this latter task, unconscious cueing worked in the trials that required a correction either to the left or to the right. We emphasize the presence of a correction as evidence of a strong similarity between the two tasks, despite the fact that in the former the correction means stopping the reaching action, while in the latter the correction required a leftward or rightward reaching action. Christensen (Christensen et al., 2008) explained this unconscious corrective capacity as follows: "our results suggest that the mechanism responsible for fast visually guided corrective movements lies outside visual cortex and that the visual signals used for correction of movements bypass visual cortex. There may be subcortical routes for visually guided reaching that bypass the cortical regions affected by TMS". Leukel suggested that TMS could "manipulate consciousness per se" and conscious perception of the stimuli would be missed because of a lack of attention rather than because of V1 bypassing of visual input. In any case, correct motor behaviour in response to unperceived stimuli was observed in both Leukel's and Christensen's studies, for corrections during the reaching movement. The former study is more significant for us because no alteration to the normal functioning of the visual system was adopted and because cues were presented at fixation points followed by the neutral mask. No other information influenced upward or downward pointing arrows that were the sole cues which could determine movement correction. We still emphasize that the decision whether to complete the reaching movement or not was not made with limbs starting from a rest position, but while already in the process of movement as a correction.

2.3. Hypothesis

Leukel demonstrated that "solely in response of unconscious cues" humans can select correct decisions for a motor reaction. This was proved through an experiment where cue direction required either the completion or the stopping of the reaching movement. The decision should discriminate between whether the movement should be performed or not. We suspect that subliminal cues can lead to decision making not only between completing or stopping the movement, but also between rightward or leftward movements. We expect this because of the study of Eimer & Schlaghecken (1998) (presented in detail in section 2.2.4.). Here, LRP showed that unconsciously perceived priming arrows activated congruently either left or right index finger pressure on buttons placed just under participant's fingertips. All motor responses were executed in response to consciously perceivable targets. This succession of primes and targets, that caused correct activation initiated by compatible primes, was then inhibited and caused reaction time costs while responding to the target. Further investigations of their researchers confirmed this kind of inhibition (Eimer & Schlaghecken, 2003) and regarding this they argued that "early response facilitation mediated by direct perceptuo-motor links is subsequently inhibited by a central mechanism operating to prevent behaviour from being controlled by irrelevant information" (M Eimer, 1999). Such mechanisms may also take subconscious cues such as "irrelevant information" into consideration, because participants were instructed to respond to the following target. In contrast to Leukel's protocol, subliminal cues are the only relevant information presented to the participants. No inhibition would affect direct perceptuo-motor links if no irrelevant information is presented before the target which could lead to left or right response distinction, even at subconscious levels. In addition to successive studies, shorter reaction times instead of inhibition had been reported for primes preceding targets at closer intervals; this revealed a relationship between priming and target intervals and either response facilitation or affection (Schlaghecken, Bowman, & Eimer, 2006).

Briefly, we hypothesize that unconsciously perceived visual cues can trigger correct action selection (as it occurred in Leukel's experiment) but for movements to the left or to the right (as priming prompted them to the correct side in Eimer's LRP observation).

Our assumption mainly comes from Leukel's and Eimer's studies, that, as discussed above, suggest that unconscious stimuli can initiate response process (pg. 17-21) and that subliminal cues alone allows for correct motor reaction (pg. 24-28). Furthermore, our overview of both Blindsight and the organization of the visual system (pg.21-24) adds some general consistency to our hypothesis. Correct behaviours in response to visual stimuli about which we are not necessarily aware in order to solve different tasks are in fact widely reported and partially explained scientifically. The existence of direct visuomotor circuits that process visual stimuli without necessarily involving awareness is taken into account for several examples that reveal such evidence.

In addition to our hypothesis, we are also interested in investigating whether different motor tasks produce different results in response to subliminal cues. Since Leukel only tested one motor task and was the first to present subliminal cues alone as targets, we have no precise expectations for different results with different motor tasks. Nevertheless, we do know that a task involving either left or right limb movement is intrinsically different from a task always requiring a movement from the same limb. It is intrinsically understood that the former kind of task requires neuronal activation respectively on the left or right hemisphere of the motor cortex, whereas single hand action always requires motor cortex activation on the same side. Moreover, differences between bimanual or unimanual tasks have already been reported in subliminal priming experiments (Serrien, Sovijärvi-Spapé, & Rana, 2012). For instance, differences were noted mainly because of handedness dominance in relation to priming susceptibility.

Finally, despite the fact that no precise supposition can be drawn about differences between tasks demanding unilateral or bilateral actions, these last points suggest that it is important to also use a protocol involving both hands. Two separated motor protocols were therefore presented to participants in order to reveal the possible differences in subliminal motor behaviours related to differences in the types of action.

3. Methods

3.1. Participants

No neurological disorders were known for the eleven participants (2 women, 9 men, aged 27.4 ± 6.4, mean ± STD). All participants were also considered healthy, and all of them had normal or corrected to normal vision. They were all right handed, a fact that avoids possible differences owing to left-handedness, as discussed in the Oldfield handedness inventory (Oldfield, 1971). Participants became verbally informed about procedural aspects of the experiment and then filled out an information sheet. The study was performed according to the Declaration of Helsinki (1964) and approved by the local ethics committee of the canton of Freiburg (014-CER-FR).

3.2. Experimental procedure

The experiment was composed of four protocols: one accustomization protocol, ”accust.” protocol “0”; the “motor” protocol, “1”; the ”verbal” protocol, “2” and the “sport” protocol, “3”.
A computer screen (17 inch, Dell E170S) was placed about 50 cm in front of the participants that were seated in protocols 0, 1, 2 and standing up in protocol 3.
In protocol 0 and 1, the participant’s right hand was placed on a three-button board. The three buttons on the board (3 mm long x 3 mm wide) were placed on a horizontal line 3 cm apart, the button in the middle was light blue while the left and right buttons were red. The central blue button was used as the start button in protocols 0 and 1. The pressing with the index finger of this central button produced a TTL-pulse and triggered a custom-built software programme (LabView based, National Instruments, Austin, Texas), which was used to present the visual cues. In protocol 2, participants held in the right hand another single start button (5 mm long x 5 mm wide) while in protocol 3, light barriers were used to trigger the visual signal. 20 ms after the trigger, a 3 cm long by 6.1 cm wide target cue (leftward or rightward arrow) was displayed in the middle of the computer screen. The colour of the target cue was dark blue, and the background colour was light blue. This method of colour selection was suggested by Leukel “In a preliminary study, we tested the combination of different cue, mask, and background colours on conscious perception. We found that, at a fixed display duration, this combination of colours served best to degrade conscious perception of the target cue”. Contrast between background and target is of course not enough to make them unaware, but them duration have to be shortened at few milliseconds. After the target cue (whose duration is one of the twelve target durations) four dark blue triangles on a light blue background were displayed around the cue’s spot as a neutral mask for a duration of 100 ms. This first mask was followed by an orange double pointing (leftwards and rightwards at the same time) arrow on a dark background. Subjects were instructed to fixate on this starting neutral double arrow (specifically at the point where the target cue would have been displayed) while triggering the target cue. Twelve different target cue durations ranged from 8.33 ms to 100 ms, target cue duration being the relevant variable across trials. Subjects were asked to respond as quickly as possible after the cue’s appearance, and responses were recorded by pressing one of the two red buttons on the board. Pressing one of the buttons resulted in an electric square pulse that was recorded for offline-analysis (LabView based, National InstrumentsH, Austin, Texas). During accustomization and in protocol 1, participants had to press either the left or the right red

button with the index finger, in response respectively to a left or a right pointing arrow cue. In protocols 2 and 3, the researcher pressed the red buttons to record the participant's verbal response in protocol 2 (by saying left or right respectively) and. The upper limb motion response (to the left or to the right) in protocol 3 was recorded equally.

3.3. Experimental protocols.

60 accustomization trials were first performed. Here the cues were long enough (300 ms) to allow for easy conscious perception so that participants could get used to giving correct responses by pressing the red target button. The "motor" protocol ("1") tested the ability to select between left or right movements of the index finger of the same hand, triggered by the visual target but using stimulus durations between 8 ms and 100 ms. Similarly, the "sport" protocol ("3") tested the motor action selection ability, but differently from protocol "1" in that it involves either the left or right hand. "Verbal" protocol "2" tested at which stimuli duration participants were able to verbally report the arrow's direction correctly; this will provide us with the individual conscious detection threshold.

Comparing the verbal protocol to the other two protocols will indicate whether the subliminal action selection between go or stop demonstrated by Leukel, also occurs for choosing between left or right movement. In other words, it will indicate whether correct action selection based on subconscious visual information is possible when choosing between leftwards or rightwards movements. This would be demonstrated if correct motor response rates are above chance rates at stimuli durations where correct verbal responses are at chance rates.

In addition to this, different results among "motor" and "sport" protocols may reveal a relationship between decision making that is dependent on subliminal cues and the specificity of the task. Moreover, differences between leftwards and rightwards correct response rates of the single "sport" protocol, may indicate a relationship between decision making that is dependent on subliminal cues and the handedness dominance or perhaps other aspects related to limb's side.

Motor protocol

For this protocol, participants were seated about 50 cm in front of the computer screen, with their right arm stretched to the table, and with the right arm leaning on the board while the index finger moved from the central button either to the one on the left or right. The motor protocol required participants to apply pressure to the left button in response to a left pointing arrow or right button pressure to a right pointing arrow. Participants decided autonomously when to trigger the cues by applying pressure to the central button that allowed self-paced trial succession, nevertheless, software (STIMULI) prevented intervals between triggers of less than 1.5 seconds. Before beginning this protocol, we gave participants the following instructions: “In some trials you will probably feel as if no arrow was shown, but an arrow will always come after your trigger. In any case, try to give the correct response that you feel is right. Do not skip giving a response. Also do not give a random response and do not try to guess. Just make an immediate spontaneous decision whether to press the right or the left button”.

Fig. 14: in the motor task, a participant is triggering the target by pressing the central blue button on the board before pressing either the left or right button in response to the arrow’s direction.

Verbal protocol

Participants were seated about 50 cm in front of the computer screen, with their right arm placed wherever they liked because hand-held button had a wire that enabled free positioning of the arms. The verbal protocol required participants to state the orientation of the arrows just by saying “left” for left pointing arrows or “right” for those pointing to the right. Participants held a triggering button in their right hand and decided autonomously when to trigger the cues by pressing it; this also allowed for self-paced trial succession, software (STIMULI) prevented intervals between triggers of less than 1.5 seconds. Before beginning this protocol, we gave participants the following instructions: “In some trials you will probably feel as if no arrow was shown, but an arrow will always come after your trigger. In any case, try to give the correct response that you feel is right. Do not skip giving a response. Also do not give a random response and do not try to guess. Just make an immediate spontaneous decision whether to press the right or the left button”.

Fig. 15: in the verbal protocol, a participant is triggering the target by pressing the button in his hand before saying either “left” or “right” to report the arrow’s orientation. The researcher is ready to record participant’s verbal response with the button board.

Sport protocol

Participants stood about 50 cm in front of the computer screen and about 20 cm behind two light barriers placed at 50 cm above the ground. Participants had to move both arms together from the bottom up through the light barriers which triggered the cue. After triggering, the sport protocol required participants to move either the left or the right arm upwards in response respectively to a left or right pointing. Participants decided autonomously when to move across barriers, this also allowed for self-paced trial succession, but software (STIMULI) prevented intervals between triggers of less than 2 seconds in order to prevent unwanted triggers. Before beginning this protocol, we gave participants following instructions: “In some trials you will probably feel as if no arrow was shown, but an arrow will always come after your trigger. In any case, try to give the correct response that you feel is right. Do not skip giving a response. Also do not give a random response and do not try to guess. Just make an immediate spontaneous decision whether to press the right or the left button.”

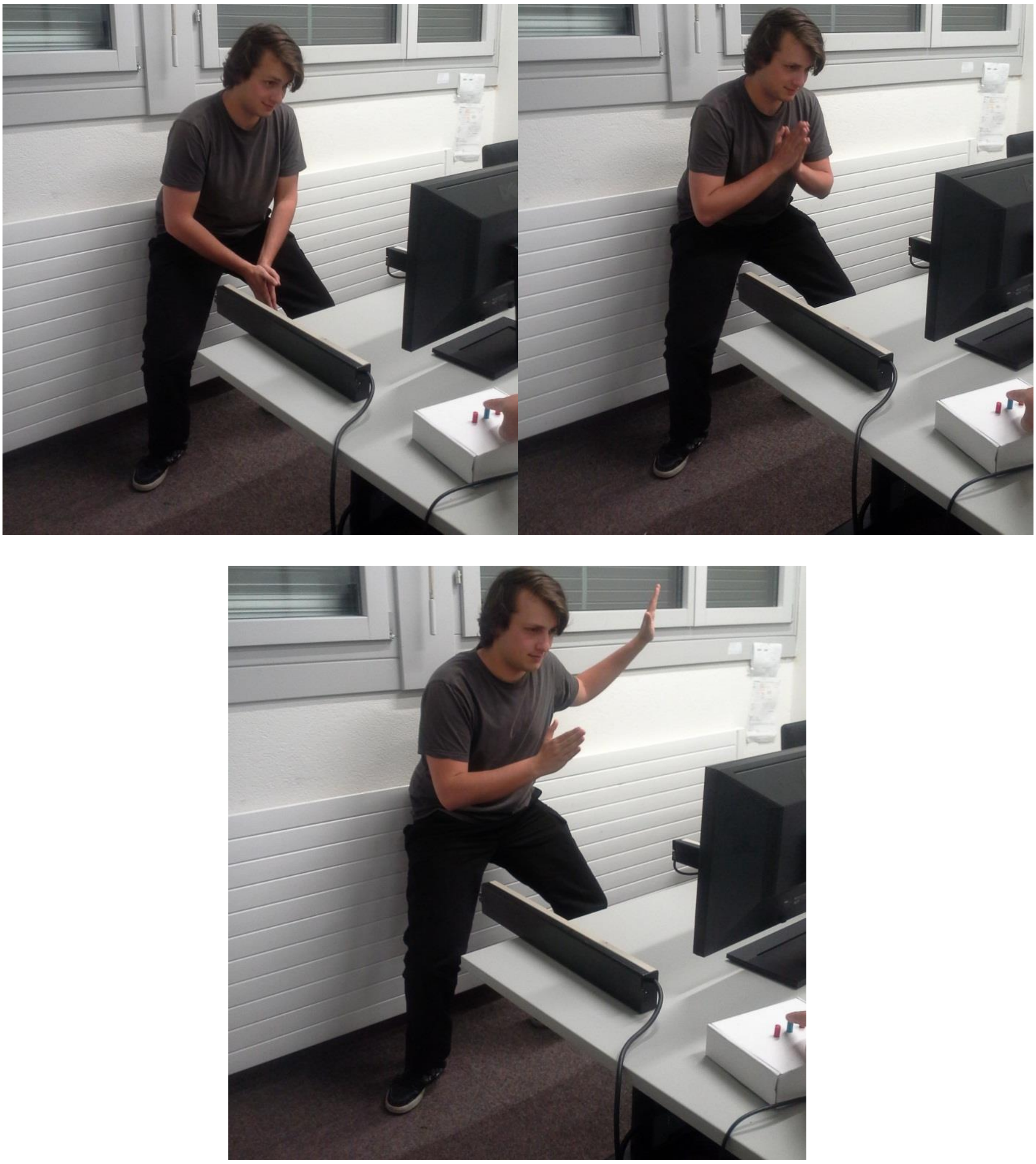

Fig. 16: in the sport task, a participant triggers the target by hand lifting between the photocells (image 1 and 2) and responds either with a right or left hand movement (image 3).

For each protocol, four blocks of 72 trials were presented with 2 minutes pause between each of them. The duration of the displayed arrows ranged between 1 and 12 frames, the screen refresh rate, as indicated by the manufacturer, is 120 frames per second, cue durations also varied as follows: 8.33 ms, 16.66 ms, 25 ms, 33.33 ms, 41.66, ms, 50 ms, 58.33 ms, 66.66 ms, 75 ms, 83.33 ms, 91.66 ms, 100 ms. These twelve different stimuli durations for the left and right pointing arrows, represent twenty-four different conditions that were equally distributed across each single block (consisting of 72 trials), but in random succession. In order to test the effective duration of each cue, we placed a 3 x 3 cm solar cell on the screen spot just under where the arrows appeared, recording screen light changes. More precisely, the light changes detector was placed where one of the four triangles of the neutral mask would have appeared after the target. This triangle was dark blue and was preceded by a light blue background surrounding the arrows.

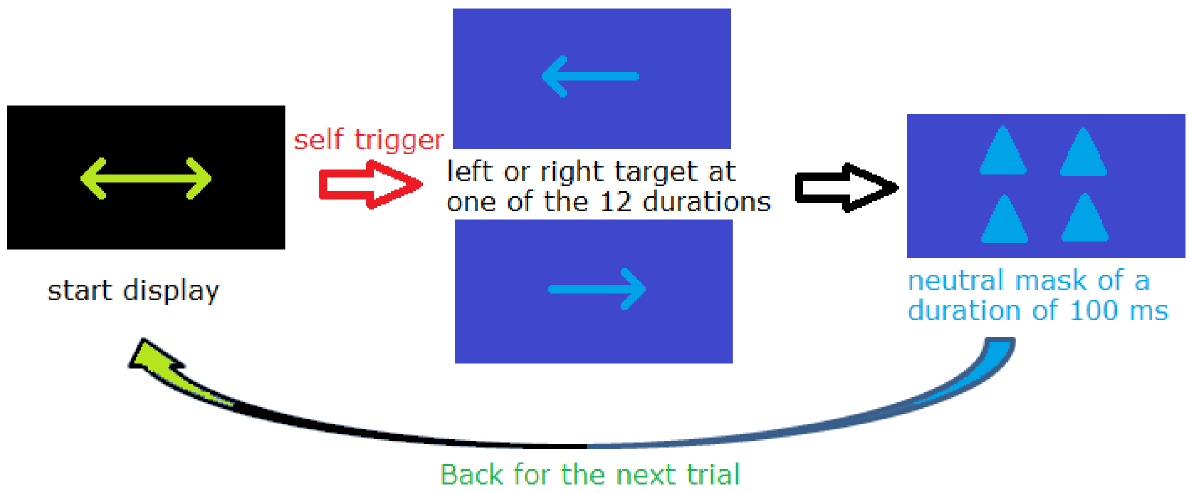

Fig. 17: display succession.

3.4. Data analysis and statistics

To test whether the number of correct responses was significantly different between the three different conditions, a two-way repeated-measures ANOVA was used with the within-subject factors condition (Motor reaction versus the Verbalization and versus the Sport protocol) and display duration (20 ms, 40 ms, 60 ms, 80 ms, 100 ms, 120 ms, and 160 ms) [condition (3) * display duration (12)]. In case of significant results from the ANOVA, post-hoc (Bonferroni) corrected paired student T-tests were used to indicate differences between the three conditions for each of the display durations. For instance, a condition * duration interaction effect.

4. Results

The ANOVA indicated that the number of correct responses differed between the twelve display durations (duration effect: $F_{11;110}$=28.42; p<0.001). However, we did not find any significant differences between the three conditions (Condition effect: $F_{2;20}$=2.31; p=0.13). In addition, we did not find an interaction effect between conditions and display duration (Condition*duration effect: $F_{22;220}$=1.22; p=0.23).

Trials without responses were not taken into account.

Each trial had been recorded respectively as correct “OK” (the participant’s response matched the direction of the arrow), erroneous “ER” (wrong response) or “No Answer”[7] for targets that did not receive a response. In any case, regardless of whether we speak about the number of errors or correct responses, a “blank” response would influence the results either as correct or incorrect depending on the responses we are considering. For instance, if we have 6 correct answers out of 10 trials, the percentage says that we have a 60 % of correct response rate; however, the remaining 40 % is not made up of just errors but sometimes also of non-responses trials. Automatically counting blank trials as errors or as correct responses could be misleading, because we cannot know whether the participant would have responded correctly or not. Furthermore, we do not know whether a blank response is caused by the participant’s uncertainty, which caused a voluntary incorrect answer (despite the fact they were asked to always attempt to give a response even if they had no idea about arrow’s orientation), or if it is caused by technical problem which prevented the recording of the response.

[7] In excel and final tables we called the “blank” trials “No anwers”, whereas they were called “blank” or “no response” in the whole document.

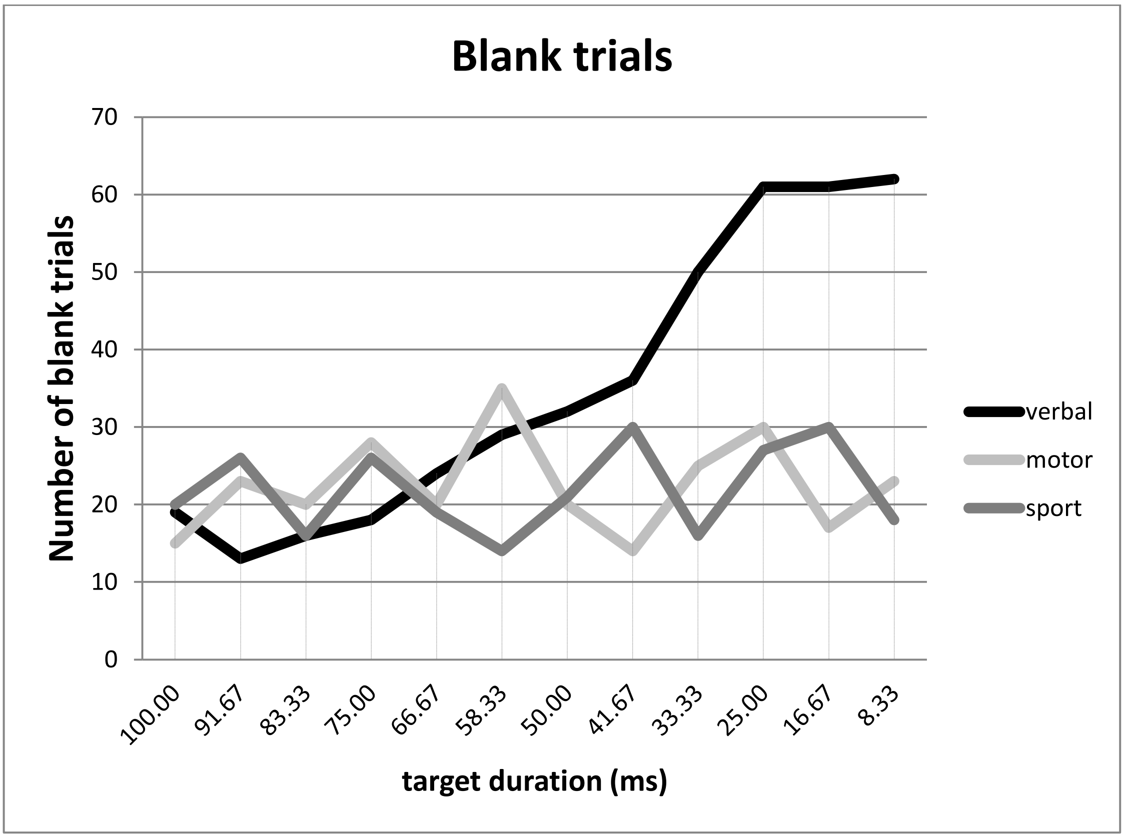

Fig. 18: only for the verbal task, the number of blank responses in trials increases with the shortening of the stimuli duration. A significant increase blank responses in trials for the verbal protocol is noticed between the durations of 41.67 ms and 25 ms.

Because of the relationship between stimulus length and the amount of blank responsesin the verbal protocol, we suggest that they are more due to uncertainty than technical problems[8]. We maintain this because the blank trials tend to increase with the difficulty of perceiving the stimuli. Participants appear to give no response when they are less able to report the stimuli consciously, specifically, at a display duration where correct response rates approaches guess rates (around 50 %). In any case, this fact does not necessarily mean that they would have responded correctly, rather we are investigating the possibility that participants can still respond correctly despite the fact that the stimuli had been successfully processed without consciousness. However, we cannot consider trials without responses as either correct or incorrect because we are only interested in the participant's direct and spontaneous responses without any conscious decision. Not responding because of uncertainty is of course a conscious decision. It is also important to

[8] We did not find any direct evidence of technical problems while testing for the recorded participants. Nevertheless, it may have occurred that some responses were not recorded even though participants or the researcher (for verbal and sport protocol), pressed the button. Such missing response attempts could be due to insufficient pressure on the button, electrical connections (cables) or software standby.

emphasize here that the relationship between stimuli perception difficulty and trials without responses exists and that this is evident just for the verbal protocol, that is, the protocol where all participants' answers are presumed to be always consciously given.

In conclusion regarding how to consider the blank trials, they will be considered as No trials. This is right also for those blank trials caused by technical problems, obviously because no one knows whether the response missed by the machinery was correct or not. We therefore decided to omit all No response trials, and simply calculate the percentage of correct answers on the total trials (for the same stimuli length) excluding those missing.

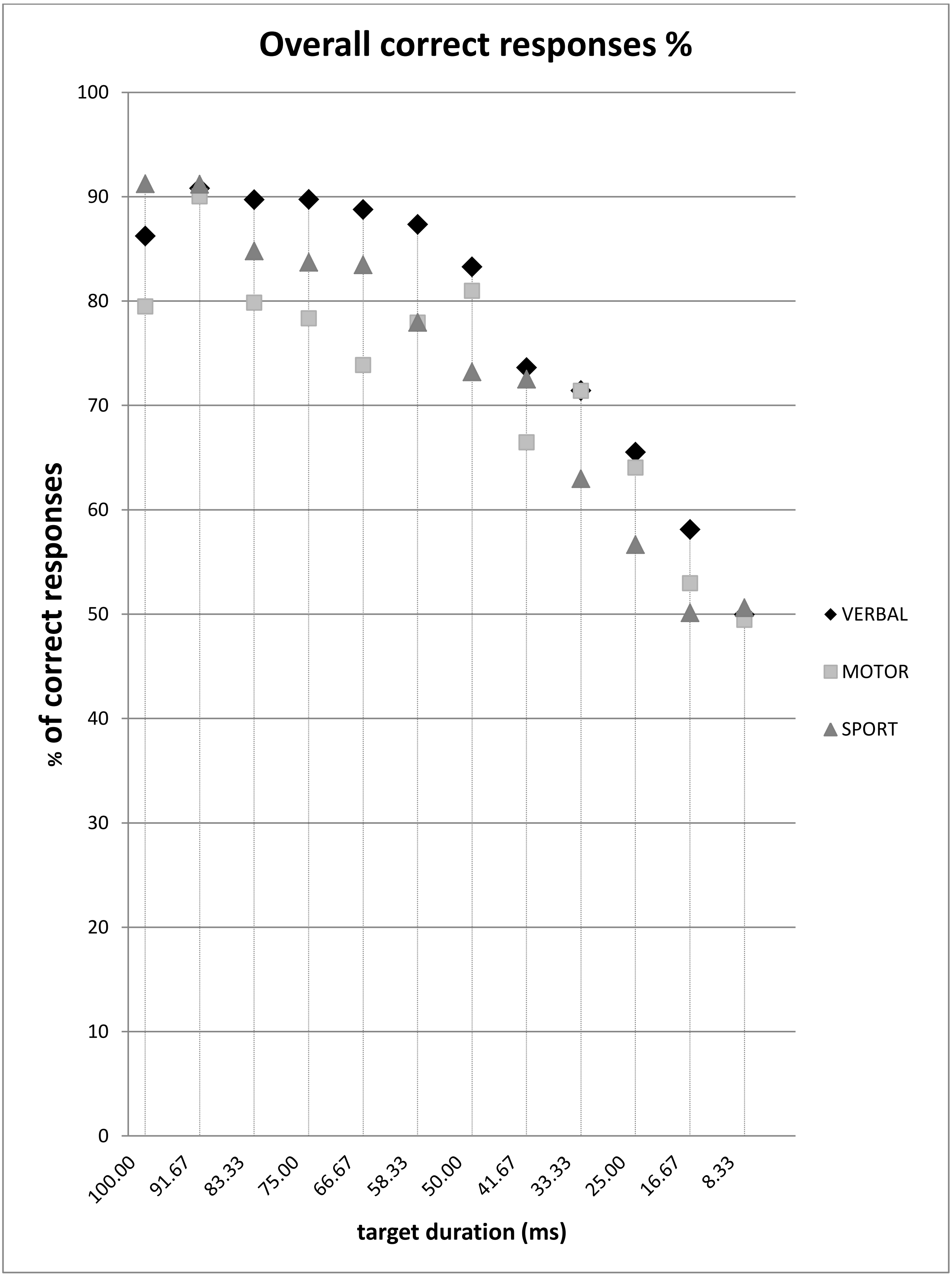

Fig. 19: Graphic representation of our overall results shows the same tendency for the three protocols, namely, performance drops progressively with the shortening of the stimuli's duration. In addition, verbal tasks had, at almost all durations, a higher correct response rate, (the overall percentage of correct responses is 78% for the verbal, 72% for the motor and 73% for the sport protocol).

5. Discussion

Regarding our hypothesis

We confirmed that the length of the stimulus can affect correct responses, as occurred in Leukel's experiment. A decrease in cue display duration was directly correlated with a decrease in the amount of correct responses. The method used to reduce the cue's duration in order to prevent conscious perception worked. However, in the verbal protocol (where all responses are supposed to have been consciously given) just 8.3 ms stimuli resulted in purely guessed responses (50 % correct) while in Leukel's experiment this already occurred at the duration of 40 ms and 20 ms. Different hypotheses can be drawn to explain what made our participants more able to correctly verbalize stimuli orientation at very short durations. First, stimuli durations were not exactly the same. Second, there was some difference in display settings between our experiment and Leukel's, namely the starting background colour and the neutral mask. Furthermore, such differences between our results and theirs could be accounted for because of a discrepancy between the real duration and the duration reported by the software, as we will discuss below. It may also be the case that up or down arrow orientation is easier to distinguish than left or right pointing, revealing a different perception of the same form depending on spatial orientation. It is of course possible that our participants had better capacities. In any case, contrary to Leukel, we do not know whether incorrect verbal responses were totally unperceived or just consciously non-reportable. He claimed to have demonstrated the latter possibility by reason of the motor task that allowed for correct responses at higher rates than guessing at stimuli durations where consciously (verbally) this was not possible. Nevertheless, our results show no difference between the implicit (motor and sport) and the explicit (verbal) protocol. While our results were unable to confirm Leukel's main assumption, we are ready to point out many doubts about our experiment rather than discredit his findings. Despite the fact that our data disconfirms his results, we are still inclined to support his findings because of at least two prior considerations. First, the effective number of certain consciously (verbal) perceived responses is still at the chance rate at the display duration of 60 ms. -Leukel gave participants the possibility to distinguish between certain or uncertain verbal answers ("I guess left/right" if they were not sure about the arrow orientation).- From this point of view, between his correct motor responses and the verbal responses at the three lowest durations, the gap is still larger, which makes Leukel's discovery even more evident. Second, his findings are already supported by several assumptions mentioned in our introduction, suggesting that visual stimuli that are not consciously reported are somehow nevertheless perceived and in many cases operating on cognitive and motor processes. In addition to this, in our experiment, for the verbal protocol, cues were definitely consciously unperceived only at the duration of 8.3 ms. In fact, even at the duration of 16.6 ms in the verbal task, participants had a correct response rate of 58 %, and while small, this nevertheless represents a significant difference when compared to the rate for no perception (50%). In Leukel, 40 ms long cues were still not verbally reportable, while the overall conscious perception threshold is significantly much lower (16.6 ms) in our experiment. As said above, the main discrepancies between our results and theirs could be explained, in part, by different experimental details.

Memory extinction or conscious control over spontaneous decisions

In order to prevent memory extinction of the perceived targets, whereas a very short delay could cause at least partial suppression of information storage, Leukel's participants had to verbalize a cue's orientation within 1 second (a tone came 1 s after cue was displayed). Despite the fact that we did not force our subject to a quick verbalisation, memory extinction should not have influenced the verbal task which had higher correct response rates almost at all display durations compared with motor tasks. Consequently, because of the better results in the verbal protocol, we suspect that memory extinction may have influenced the motor and the sport trials. In fact, our participants were instructed to give an immediate spontaneous response but no other constraint other than the instructions prevented them from consciously manipulating their motor responses. In Leukel's motor tasks, targets where presented while the subject had already started moving. This type of protocol implies that participant's motor response was a corrective reaction and not a decision made from rest as with our subjects.

Christensen's (et al., 2008) experiment suggests the idea that subconscious selection is possible even for left or right movement choice. The use of TMS in his protocols, in order to suppress conscious visual perception, makes comparison between our experiment and theirs unlikely. However, as already highlighted in the previous paragraph, his task also demanded a correction rather than a pure decision. Finally, the fact that our participants started the movement from rest is suspected to have prevented participants from being influenced by the targets perceived below the conscious threshold. In the presence of unperceived targets, at rest, without any other constraint forcing participants to respond immediately after cues appear, they may have felt uncertain and tried to guess the arrow's direction, and thereby avoided the spontaneous response. Even if the memory of the unconsciously perceived information is not already extinct, this would be ignored in favor of an independent decision. According to the results, the cueing, about which subjects seem to be unaware (8.33 ms), does not seem to become relevant for decisions whether to move to the left or to the right.

By reason of what has already been considered, the aspect that separates our experiment and Leukel's, is the kind of motor response taken at rest and while moving in a corrective manner respectively. We suggest that unconscious visual discrimination, whether moving to the left or to the right, may be demonstrated if tested in a corrective way.

Non demonstrable unconscious influence

Regarding movement initiated from the rest position, after examining the graphs of our individual performances at critical durations, only one subject appears to partially show the hypothesized results.

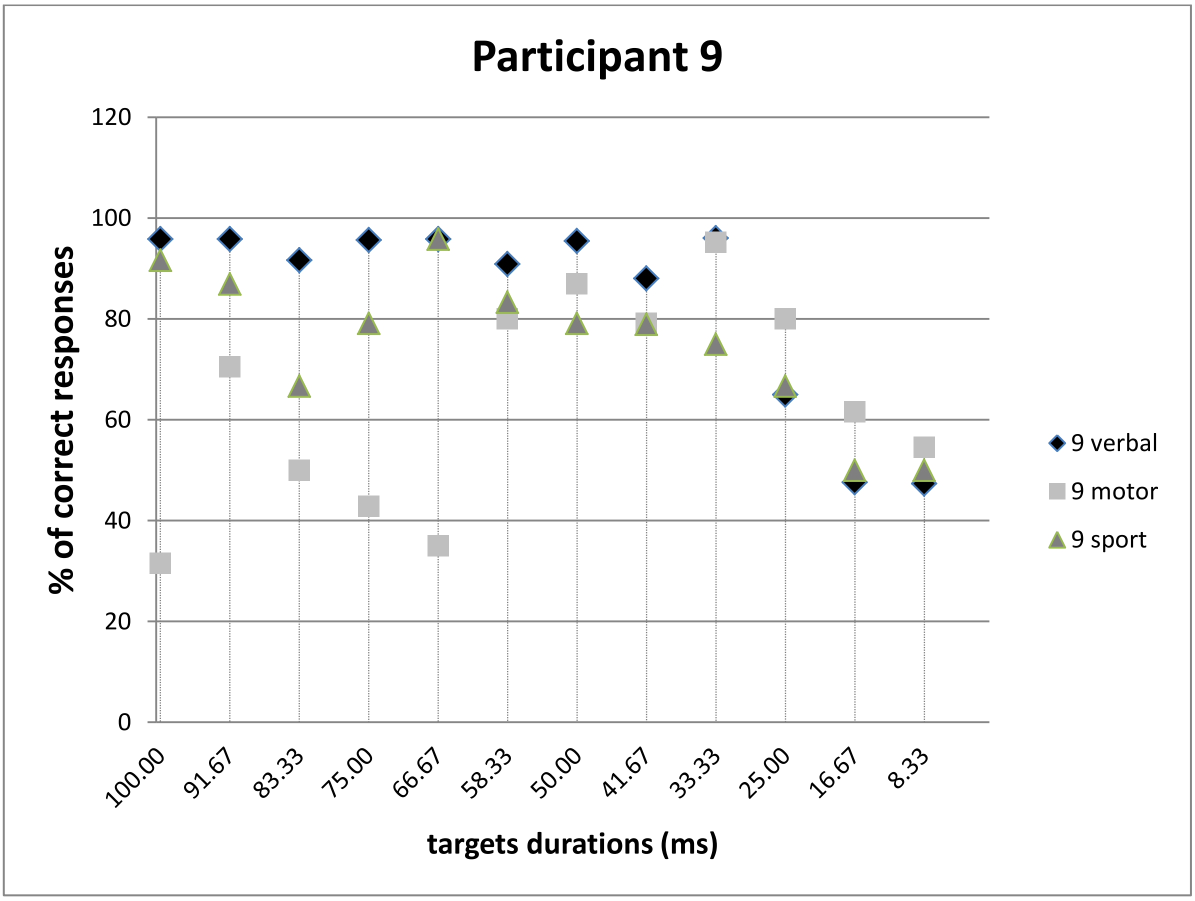

Fig. 20: subject 18 had two target durations around the chance rate (50 %) in the verbal task: 16.67 ms (47.6 %) and 8.33 (47.3 %) ms. In the motor protocol, at the former stimuli duration, he responded correctly at a quite higher rate (61.5 %), while for the latter he was just slightly better (54.5 %).

However, this was an isolated case and likely occurred by pure chance. In fact, no other participant showed similar behaviour.

On the other hand, regarding all participants, we do not know whether some motor or sport correct responses were in fact given unconsciously, that is, even if the verbal task revealed conscious perception of the targets at the same duration. Furthermore, in the verbal task, subjects were aware of the direction they were saying but does this necessarily mean that they have consciously perceived the arrow? The systematic link between verbalization and conscious perception had been taken from Leukel's assumptions, but this represents a significant doubt for our experimental procedure. He has already remarked that verbalization also requires muscular activation, but dependent on speech areas rather than motor areas as for a limb response. Therefore, if direct visuomotor links between the visual system and motor areas bypassing consciousness exist (as largely discussed in the introduction) similar connections between vision and speech areas may have determined unconscious verbalization. The argument against this possibility is that verbalization is under conscious control and that no arrow direction would be pronounced without being filtered. Still, despite conscious control, the verbalised arrow direction could be cued unconsciously; participants feel they have consciously seen the target while there is really only awareness of what is being reported. We suspect this because of two considerations. On the one hand, our results show rates above guessing at shorter durations compared to Leukel for the verbal task. Nevertheless, if we look at the blank trials (fig. 15) as an index of uncertainty - because blank verbal trials increase together with perception difficulty of the shorter durations (we note a significant drop below the duration of 41.67 ms. Similarly, Leukel observed performance drops to guess rates at the duration of 40 ms for verbalization.). - On the other hand, the trend in our results is that correct verbal response rates are higher than guessing even at the duration of 33.33 ms, 25 ms and 16.66 ms. Both considerations together could speak in favor of conscious verbalization unconsciously cued by the targets. Why this effect did not occur with Leukel's participants may depend on the possibility they had to report "I guess up/down" which makes them aware of the uncertainty and blocked the unconscious cueing that could correctly influence verbalization. Suspected overlapping between unconscious cueing and conscious reporting is certainly fascinating and suggests the need for further research based on experiments with targets presented too quickly for conscious perception. However, in order to understand whether unconscious perception does or does not influence verbalization in such tasks, we suggest that only neuroimaging techniques, or at least LRP, may reveal answers unequivocally.

Methodological limitations

In any case, even if we agree with the assumptions which influenced the design of the experimental procedure, this presents other reasons for doubts regarding procedures. For instance, we must admit that the accustomization blocks may have been too short to prepare participants for the motor task. This was sufficient to make them understand what they had to do, but even though the task was simple, they may not have developed enough automaticity to prevent conscious control of the action. (It would be interesting to give participants a practice period before the tests in order to check whether automaticity could facilitate unconscious answering.) Furthermore, no accustomization block prepared participants for the sport task. However, since no significant differences between the results of the three conditions were found, this implies that there is no particular dependence on the type of the motor task (72 % of overall correct answers in motor protocols and 73.2 % in sport protocols). This reveals that performance, for one index finger and for either the left or right hand respectively, drops at the same duration of the presented target and no kind of action causes motor response facilitation or affection.

In our experiment, still at a duration of 33.33 ms, correct responses were above 60 % while in Leukel's experiment, at 40 ms responses were already at chance rates, despite the fact that the target's design and distance from the screen were almost the same. We therefore suspect that the real duration of the targets displayed on our screen did not correspond to the duration indicated by the software. In order to record the real duration of the target for each trial, we tried to use a solar cell placed on the screen which unfortunately did not function properly. On the other hand, results do show a precise trend related to display duration which could not represent any random manipulation of the supposed length by the screen. If real stimuli durations were perturbed by the screen, this occurred either for very short time durations or in the same manner for all durations.

6. Conclusion

In our lengthy introduction, we hypothesized that unconscious perceived cues alone could determinate decision making whether to move the index finger to the left or to the right or whether to raise the left or right arm. Such expected results have not been confirmed independently of action type. We therefore conclude that visual targets which remain consciously unperceived do not permit decision making whether to move left or rightwards from a resting position.

However, Leukel was able to demonstrate the possibility to correct a movement during its execution in response to an unconscious perceived cue. In particular, the purpose of our research was to investigate whether humans can decide to move from a state of rest[9] sideways to the left or right, in response to either left or right pointing arrows made consciously unperceivable by the rapidity of their appearance. –Such a method was confirmed to be working; decreasing the durations of the displayed stimuli made some trials subliminal-. In any case, unconscious correct motor behaviour remains demonstrated only for movement inhibition in response to downward pointing unconsciously perceived arrows, according to Leukel's research. Furthermore, we admit to having doubts regarding our specific experimental procedure, mainly because anything other than instructions forced participants to respond without conscious control of their motor decisions. Additionally, we also opened the discussion regarding the real degree of consciousness in all protocols of both experiments. Finally, we have argued that the influences of the cues displayed at critical durations could be better investigated through neuroimaging, or at least LRP.

6.1. Looking Ahead

At least four main unanswered questions remain:

Would left-right choices have been demonstrated if they had been tested in a corrective way?
-For example, exploring a movement that does not start from rest but left-right targets appear while moving, requiring a related correction of the movement, as examined in a previously mentioned study (Eimer & Schlaghecken, 1998).

[9] Before moving in response to the target, participants pressed the start button or passed their hands through photocells. This could be interpreted as the participants not being at rest. Nevertheless, we suggest that such limb-motion after having triggered the target, simply occurs because they were not instructed to stop all movement between triggering and responding. Therefore, the latent movement derived from the triggering should have neutral influence. In fact, we observed that the finger (in protocol 1) and hands (in protocol 3) continued to lift up, perpendicular to the triggering button/spot without pointing rightwards or leftwards before responding to the target.

Were correct unconscious motor responses inhibited because nothing forced subjects to make a spontaneous decision which would have been blocked by uncertainty?

Were some unconscious motor responses correct thanks to direct visuomotor interaction?
-This may have been the case in some individual trials, even though this does not emerge from our experimental procedure that was based on overall data comparison between protocols, and could not reveal what really happened on each trial.

For short durations in the verbal task, did subjects consciously report the orientation of the arrows correctly thanks to the influence of unconscious perception?
-In other words, they were aware of what they reported but not of what they perceived and this influenced the report.-

Naturally, we hope that we or other researchers will have the possibility to investigate these areas in future studies. As said above, the main doubt that we wished to resolve remains despite our research, namely, whether a movement starting from rest can be triggered by cues that are unconsciously perceived, and whether this can determine decision making between left or rightwards action. Nevertheless, before further exploration of these areas, another attempt should be made to clarify the real degrees of conscious perception and its implications for verbal or motor responses to subliminal visual stimuli presented alone. As already stated above, advanced technology can enable the investigation of our cerebral activities, and may be able to provide concrete evidence in these areas. We also hope that researchers with access to such technology will be interested in unconscious triggering of movements. Further contributions in this area could orient our approach to overt sports in different ways. The capacity to notice the orientation of a single cue fixed in the environment in order to select an action in response to this, could suggest that a single piece of information could be relevant for decision making while playing. Otherwise, other individual aspects in the observed ongoing conditions would be necessary for correct motor behaviour in response to the situation. Of course, it seems evident that decision making for motor responses in overt sport conditions involves more neuronal resources processing several of the observed aspects at the same time, while in the laboratory we can only isolate and prove a few of them together. Nevertheless, the sum total of small scientific contributions will add to our knowledge of such complex interaction, which may help us to understand how things occur in the real world.

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Tables

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate	F	Sig.
condition	Sphärizität angenommen	2614.982	2	1307.491	2.314	.125
	Greenhouse-Geisser	2614.982	1.940	1348.181	2.314	.127
	Huynh-Feldt	2614.982	2.000	1307.491	2.314	.125
	Untergrenze	2614.982	1.000	2614.982	2.314	.159
Fehler(condition)	Sphärizität angenommen	11299.112	20	564.956		
	Greenhouse-Geisser	11299.112	19.396	582.537		
	Huynh-Feldt	11299.112	20.000	564.956		
	Untergrenze	11299.112	10.000	1129.911		
duration	Sphärizität angenommen	63370.381	11	5760.944	28.421	.000
	Greenhouse-Geisser	63370.381	4.240	14947.299	28.421	.000
	Huynh-Feldt	63370.381	7.749	8178.241	28.421	.000
	Untergrenze	63370.381	1.000	63370.381	28.421	.000
Fehler(duration)	Sphärizität angenommen	22297.233	110	202.702		
	Greenhouse-Geisser	22297.233	42.396	525.929		
	Huynh-Feldt	22297.233	77.487	287.756		
	Untergrenze	22297.233	10.000	2229.723		
condition * duration	Sphärizität angenommen	3960.260	22	180.012	1.227	.227
	Greenhouse-Geisser	3960.260	4.231	936.096	1.227	.314
	Huynh-Feldt	3960.260	7.719	513.021	1.227	.296
	Untergrenze	3960.260	1.000	3960.260	1.227	.294
Fehler (condition*duration)	Sphärizität angenommen	32274.033	220	146.700		
	Greenhouse-Geisser	32274.033	42.306	762.869		
	Huynh-Feldt	32274.033	77.195	418.085		
	Untergrenze	32274.033	10.000	3227.403		

Results in % of the **MOTOR** task

Duration	100.00	91.67	83.33	75.00
Right-Left	24-23	22-21	20-19	18-17
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	100	91.66666667	91.66666667	87.5
2	100	100	100	100
3	95.83333333	100	100	100
4	95.65217391	80.95238095	73.91304348	52.63157895
5	31.57894737	100	68.42105263	73.68421053
6	70.83333333	78.94736842	76.19047619	87.5
7	100	86.95652174	70.83333333	77.27272727
8	83.33333333	94.44444444	86.36363636	77.77777778
9	31.57894737	70.58823529	50	42.85714286
10	73.91304348	86.95652174	65.2173913	75
11	91.66666667	100	95.83333333	87.5
TOT	79.48997989	90.04655811	79.85808485	78.33849431

Duration	66.67	58.33	50.00	41.67
Right-Left	16-15	14-13	12-11	10-9
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	73.91304348	54.16666667	50	45.83333333
2	100	100	95.83333333	79.16666667
3	100	100	91.66666667	81.81818182
4	61.9047619	79.16666667	86.95652174	60.86956522
5	54.54545455	80	90.47619048	62.5
6	70.83333333	66.66666667	82.60869565	70.83333333
7	76.47058824	73.33333333	71.42857143	66.66666667
8	90.90909091	78.26086957	62.5	69.56521739
9	35	80	86.95652174	79.16666667
10	73.91304348	66.66666667	85	52.17391304
11	75	79.16666667	87.5	62.5
TOT	73.86266508	77.94795784	80.99331828	66.46304947

Duration	33.33	25.00	16.67	8.33
Right-Left	8-7	6-5	4-3	2-1
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	65.2173913	60.86956522	33.33333333	45.83333333
2	70.83333333	79.16666667	54.16666667	45.83333333
3	86.36363636	42.85714286	38.0952381	63.15789474
4	75	69.56521739	52.38095238	42.85714286
5	95.23809524	58.82352941	61.53846154	54.54545455
6	60.86956522	73.91304348	54.16666667	34.7826087
7	41.17647059	35.29411765	68.42105263	57.89473684
8	60.86956522	78.26086957	52.38095238	69.56521739
9	95.23809524	80	61.53846154	54.54545455
10	65	63.15789474	52.38095238	25
11	69.56521739	62.5	54.16666667	50
TOT	**71.39739726**	**64.03709518**	**52.96085493**	**49.45592512**

TOT correct **MOTOR** answers%	77.88279489

Results in % of the **VERBAL** task

Duration	100.00	91.67	83.33	75.00
Right-Left	24-23	22-21	20-19	18-17
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	93.75	94.44444444	94.44444444	100
2	95.83333333	100	100	95.83333333
3	85	90	100	100
4	100	100	91.30434783	91.30434783
5	100	95.83333333	91.66666667	95.83333333
6	100	100	100	100
7	52.38095238	95.65217391	91.66666667	90.47619048
8	75	79.16666667	73.91304348	62.5
9	95.83333333	95.83333333	91.66666667	95.65217391
10	59.09090909	52.17391304	56.52173913	64
11	91.66666667	95.83333333	95.83333333	91.66666667
TOT	**86.23229044**	**90.81247255**	**89.72880984**	**89.75145869**

Duration	66.67	58.33	50.00	41.67
Right-Left	16-15	14-13	12-11	10-9
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	77.77777778	73.33333333	83.33333333	60
2	100	100	91.66666667	78.26086957
3	100	100	100	80
4	85.71428571	84.21052632	81.81818182	72.22222222
5	100	95.83333333	73.91304348	70.83333333
6	100	100	92.30769231	100
7	95.23809524	90	100	76.47058824
8	66.66666667	69.56521739	54.16666667	59.09090909
9	95.83333333	90.90909091	95.45454545	88
10	63.63636364	69.56521739	60	58.33333333
11	91.66666667	87.5	83.33333333	66.66666667
TOT	**88.77574446**	**87.35606533**	**83.27213301**	**73.62526568**

Duration	33.33	25.00	16.67	8.33
Right-Left	8-7	6-5	4-3	2-1
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	56.25	66.66666667	68.75	56.25
2	75	79.16666667	75	66.66666667
3	66.66666667	100	75	50
4	86.66666667	60	64.28571429	50
5	35	45.83333333	62.5	58.33333333
6	84.61538462	75	25	33.33333333
7	68.42105263	52.94117647	62.5	36.36363636
8	54.54545455	63.63636364	54.54545455	45
9	96	65	47.61904762	47.36842105
10	95.83333333	50	50	52.17391304
11	66.66666667	62.5	54.16666667	54.16666667
TOT	**71.42411138**	**65.52220062**	**58.1242621**	**49.96872459**

TOT correct **VERBA**L answers%	72.07094836

Results in % of the **SPORT** task

Duration	100.00	91.67	83.33	75.00
Right-Left	24-23	22-21	20-19	18-17
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	91.66666667	100	83.33333333	75
2	100	100	100	100
3	100	100	100	100
4	100	100	100	100
5	100	100	79.16666667	100
6	100	94.44444444	95.23809524	88.88888889
7	87.5	95.83333333	82.60869565	95.83333333
8	83.33333333	77.27272727	78.26086957	64
9	91.66666667	86.95652174	66.66666667	79.16666667
10	86.95652174	77.77777778	72.72727273	68
11	62.5	70.83333333	75	50
TOT	**91.23847167**	**91.19255799**	**84.81832726**	**83.71717172**

Duration	66.67	58.33	50.00	41.67
Right-Left	16-15	14-13	12-11	10-9
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	66.66666667	66.66666667	41.66666667	33.33333333
2	100	100	100	83.33333333
3	100	91.30434783	87.5	95.45454545
4	89.47368421	100	88.23529412	78.26086957
5	88.88888889	75	66.66666667	94.73684211
6	80.95238095	80	65	63.15789474
7	91.30434783	91.66666667	87.5	84.21052632
8	76	75	77.27272727	73.68421053
9	95.83333333	83.33333333	79.16666667	78.94736842
10	75	69.56521739	66.66666667	54.16666667
11	54.16666667	25	45.83333333	58.33333333
TOT	**83.48054259**	**77.95783926**	**73.22800194**	**72.51081125**

Duration	33.33	25.00	16.67	8.33
Right-Left	8-7	6-5	4-3	2-1
Subject	% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	58.33333333	66.66666667	33.33333333	41.66666667
2	70.83333333	79.16666667	58.33333333	50
3	69.56521739	39.13043478	52.17391304	56.52173913
4	71.42857143	61.9047619	52.38095238	50
5	71.42857143	61.9047619	57.89473684	52.63157895
6	47.82608696	52.63157895	40	38.0952381
7	62.5	29.16666667	54.16666667	66.66666667
8	42.10526316	76.92307692	47.05882353	42.10526316
9	75	66.66666667	50	50
10	69.56521739	47.61904762	56.25	55
11	54.16666667	41.66666667	50	54.16666667
TOT	**62.97747828**	**56.67699958**	**50.14470538**	**50.62307448**

TOT correct **SPORT** answers % :	73.21383178

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