UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXIX CICLO DEL DOTTORATO DI RICERCA IN NEUROSCIENZE E SCIENZE COGNITIVE

PERCEIVING OPPONENT'S ACTION IN BALL SPORTS: THE CONTRIBUTION OF EARLY AUDITORY AND VISUAL INFORMATION

Settore scientifico-disciplinare: M-PSI/01

DOTTORANDO
FABRIZIO SORS

COORDINATORE
PROF. TIZIANO AGOSTINI

SUPERVISORE DI TESI
PROF. TIZIANO AGOSTINI

CO-SUPERVISORE DI TESI
PROF. WALTER GERBINO

CO-SUPERVISORE DI TESI
DOTT. MAURO MURGIA

ANNO ACCADEMICO 2015/2016

Contents

Chapter 3. The contribution of early auditory and visual information to the discrimination of shot power in ball sports

Chapter 4. The contribution of early auditory and visual information to the anticipation of volleyball serves

Introduction

In recent years, there is a growing interest towards the role of auditory information in sport. Research revealed that, on the one side, the sounds deriving from sport movements provide important information concerning the movements themselves; on the other side, it has been highlighted that when these sounds are used appropriately, they can promote significant improvements in different performances. Various studies also revealed that, in some cases, auditory information is even more relevant than the respective visual information, thus challenging the traditional superiority of the visual domain in sport.

The present thesis aims to contribute to this rapidly expanding body of research, by investigating some aspects that have not been studied yet. In particular, the focus is on the sounds produced by the others. Indeed, in order to perform effectively, it is not sufficient for an athlete to focus only her/his own movements, but also on those of the other people competing together and against her/him, to react appropriately to them. Specifically, the aim of this thesis is to investigate the contribution of early auditory information in perceiving opponent's actions in two ball sports – soccer and volleyball – and to compare this contribution with that of the respective early visual information.

The thesis is structured in five chapters. In Chapter 1, an overview of the literature dealing with sound and movement is provided, ranging from laboratory experiments concerning simple, rhythmic gestures/movements to field experiments aiming at the improvement of athletes' performances. Within this chapter, some theoretical considerations are also made, and potential frameworks are mentioned.

In Chapter 2, a series of four simple reaction time experiments is described. The aim of this preliminary set of experiments was to investigate whether the well-established phenomena observed in response to pure tones could be replicated with ecological sounds; in particular, football impacts of soccer penalty kicks were used as stimuli.

In Chapter 3, two experiments whose aim was to investigate the contribution of early auditory and visual information to the discrimination of shot power are described; in particular, the first of these two experiments is focused on soccer penalty kicks, while the second one is focused on volleyball smashes. Both experiments were based on a two-alternative forced choice paradigm: pairs of stimuli were presented in a rapid sequence, and participants' task was to discriminate whether the shot in the second stimulus was more or less powerful than the one in the first stimulus.

In Chapter 4, three experiments whose aim was to investigate the contribution of early auditory and visual information in anticipating volleyball serves are described. In all the three experiments, participants were asked to predict the landing zone of the serves on the basis of their length. What differentiated the experiments among them were the stimuli and the number of possible answers: in the first experiment, auditory and visual information were either congruent or incongruent between them, and there were two possible answers; in the second experiment there were always two possible answers, but participants could rely only on one of the two sources of information at a time; in the last experiment, participants could rely only on one of the two sources of information at a time, and there were three possible answers.

Finally, in Chapter 5, a general discussion touching all the various issues mentioned in the thesis is provided. Moreover, potential directions for future experiments within this field of research are suggested, and some implications considering the applied point of view are also discussed.

Chapter 1

The relevance of auditory information in sport: An overview[1]

1.1 Sound and movement: A natural connection

It is undeniable that humans, during their everyday activities, are mainly guided by visual information. However, it is not possible to ignore the relevance of other sources of information related with movement, like auditory, tactile and proprioceptive information. In particular, there is a strong natural connection between sound and movement, which can be deducted not only through scientific research, but also – more easily – by observing some common phenomena. In this regard, a clear example is provided by the ability to “keep the rhythm”, which has been defined as sensorimotor synchronization (Repp, 2005; Repp & Su, 2013) or as rhythmic entrainment (Hickok, Farahbod & Saberi, 2015; Merker, Madison & Eckerdal, 2009; Schachner, 2013; Thaut, McIntosh & Hoemberg, 2015).

The main foundation of this connection between sound and movement is ecological: while moving, human body produces acoustic events that contribute to the closure of a specific sensorimotor loop, i.e. the one in which walking, breathing and other actions produce rhythmic sounds, whose perception supports and regulates their programming and execution (Hunt, McGrath & Stergiou, 2014; Larsson, 2014; Murgia et al., 2016; Santoro et al., 2015). Several hypotheses and evidences make explicit reference to the ecological foundation of this connection. One example is the idea, already suggested by Morgan (1983), that the development of music would be related to the human specialization of the auditory-motor circuit connected with locomotion (Trainor, 2015); always related to music is the hypothesis that its perception would be mediated by the simulation of motor actions (Patel & Iversen, 2014). Examples form other fields are the observations that auditory perception promotes the activation of motor areas of the brain (Chen, Penhune & Zatorre, 2008), and that deafness hinders the development of babbling (Oller & Eilers, 1988). Another example is provided by the effectiveness of the so called rhythmic auditory stimulation for the gait rehabilitation of patients with Parkinson’s Disease (for a review, see Murgia et al., 2015).

---

[1] Some parts of the present chapter are published in the following review: Sors, F., Murgia, M., Santoro, I., & Agostini, T. (2015). Audio-Based Interventions in Sport. *The Open Psychology Journal, 8*, 212-219.

Within this framework, there is a specific field in which research is revealing that auditory information has a relevant role, i.e. sport. The aim of the present thesis is to contribute to this rapidly expanding line of research, by investigating some aspects that have not been studied yet. In this chapter, after presenting some theoretical perspectives, an overview of the literature dealing with sound and movement is provided, ranging from laboratory experiments concerning simple gestures/movements to field experiments aiming at improving athletes' performances.

1.2 Empirical foundations and theoretical perspectives

A general empirical foundation of the connection between sound and movement is provided by the studies that highlighted a tight relationship between the mechanisms underlying auditory perception and motor production (Bengtsson et al., 2009; Fujioka, Trainor, Large & Ross, 2012; Grahn & Brett, 2007; Schubotz, Friederici & von Cramon, 2000, Van Vugt, 2103). Among these studies, the one by Chen and colleagues (2008) is particularly relevant. In the first experiment, participants were asked to listen to some rhythmical sequences, being aware that they had to reproduce them later by tapping; in the second experiment, other participants listened to the same rhythmic sequences, without being aware that they had to reproduce them. The authors used the functional Magnetic Resonance Imaging (fMRI) to compare the cerebral activity at rest with that deriving from the listening task. The results revealed that, in both experiments, during the listening phase there was a significant activation not only in perceptual areas, but also in the supplementary motor area, in the mid-premotor cortex and in the cerebellum. These outcomes highlighted that listening to rhythmic sequences promotes the activation of motor areas of the brain, even when there is no foreknowledge that a motor task related to those stimuli would have to be performed in a second moment.

Other studies revealed that motor areas are activated not only by rhythmic sequences, but also by more complex auditory stimuli, like those deriving from the movement sonification. This technique consists in applying the general principles of sonification (Hermann, Hunt & Neuhoff, 2011) to human movement. In particular, it is based on the conversion of some physical and/or kinematic parameters that are considered as relevant (e.g., force, velocity, acceleration) into the parameters of a synthetic sound, with the aim to convey significant information concerning the movement under investigation (Dubus & Bresin, 2013; Effenberg, 1996, 2005). Schmitz and colleagues (2013) applied this technique to swimming, sonifying some kinematic parameters of a solid, computer-generated swimmer model performing breaststroke movements (see figure 1). Participants were exposed to videos in which the sound was either synchronized (congruent condition) or asynchronyzed (incongruent condition) with the observed movement. The results from fMRI highlighted a greater activation of premotor and motor areas in the congruent condition compared to the incongruent condition. Such effect can be obtained not only by means of synthetic sounds, but also with natural sounds. In this regard, Pizzamiglio and colleagues (2005) observed that the sounds produced while performing gestures/movements promote the activation of premotor and motor areas, while this does not happen for sound of a different nature, like noise and various environmental sounds.

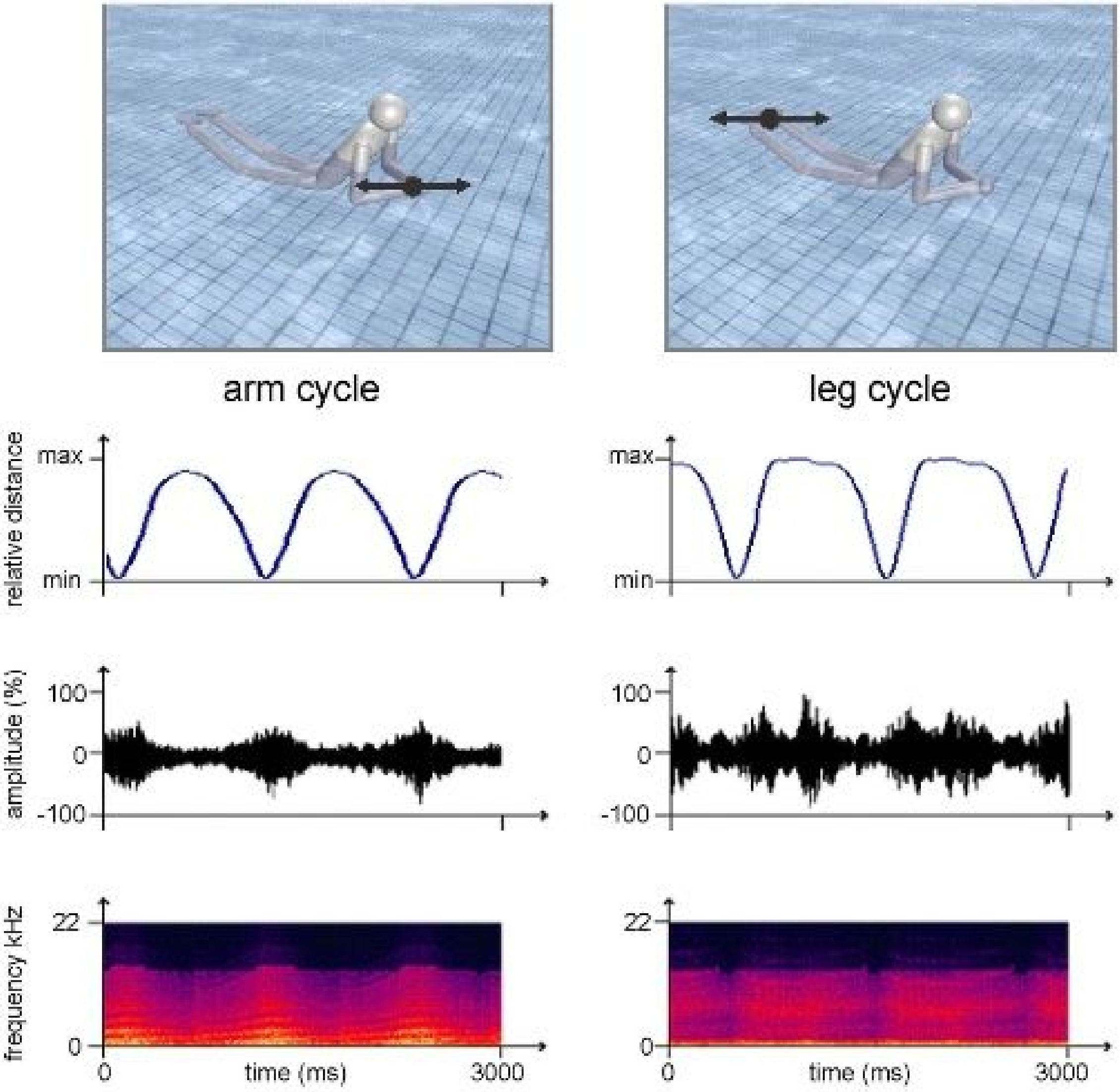


Figure 1. The movement sonification used by Schmitz and colleagues (2013, p. 4). The kinematic parameters taken into consideration were the variations in the relative distance of the wrist joints ("arm cycle") and of the ankle joints ("leg cycle") to the centre of the pelvis; these parameters were used to modulate the amplitude and the frequency of electronic sounds.

The above described observations have been supported by various studies (e.g., Aziz-Zadeh, Iacoboni, Zaidel, Wilson & Mazziotta, 2004; Gazzola, Aziz-Zadeh & Keysers, 2006).

Among these, one deserves particular attention within the present thesis, as the sounds used as stimuli derived from sport. The research we refer to is that by Woods, Hernandez, Wagner and Beilock (2014), in which fMRI was used to monitor the brain activity of expert and non-expert athletes in response to familiar and unfamiliar, sports and non-sports sounds. Participants played basketball or tennis, either at college varsity or at recreational level, and were considered experts or non-experts accordingly. The sports sounds consisted of five variations of a basketball bouncing on a court, and five variations of a tennis ball being hit by a racquet; for these sounds, familiarity depended on the sport that participants played. The non-sports sounds consisted of common environmental sounds such as toilet flushing or paper crumpling; for these sounds, the familiarity distinction was based on their identifiability, rather than on their commonality. The results not only confirmed that movement-related sounds promote the activation of premotor and motor brain areas, but also highlighted an expertise effect: experts showed greater activation than non-experts while listening to familiar sports sounds.

The connection between auditory perception and motor production received further support from Pazzaglia, Pizzamiglio, Pes and Aglioti (2008). These authors observed that patients with apraxia have difficulties in recognizing sounds deriving from specific gestures. In particular, patients with limb apraxia showed difficulties in recognizing sounds deriving from gestures performed with arms/hands and legs/feet; instead, patients with buccofacial apraxia showed difficulties in recognizing sounds deriving from gestures performed with the mouth. Such difficulties had their neurophysiological counterpart in the different profiles of cerebral activation observed in the two types of patients in response to the auditory stimuli. Novembre and Keller (2014) hypothesized that the connection between perception and action could also play an inter-individual role, promoting the coordinated execution of complex motor sequences by multiple individuals.

A first interpretation of the above described empirical evidences makes reference to the mirror neurons system. Initially, the activation of such neurons was observed in response both to the execution of actions, and to the visual exposure to the same actions (e.g., Buccino et al., 2004; Rizzolatti, Fadiga, Gallese & Fogatti, 1996). Later, researchers discovered that these neurons are also sensitive to auditory stimuli; indeed, the mirror neurons system would be activated not only when an action is performed or seen, but also when the sounds deriving from it are heard (Keysers et al., 2003; Kohler et al., 2002; Lahav, Saltzman & Schlaug, 2007).

Another interpretation makes reference to the theory of event coding (TEC) (Haazebroek, Raffone & Hommel, 2016; Hommel, Müsseler, Aschersleben & Prinz, 2001; Prinz, 1990; Zmigrod & Hommel, 2009). This theory postulates that perception and action share a common representational system. According to the TEC, the correspondence between perceptual experience and motor experience is the key element that determines the effects of perceptual processes on motor processes and vice versa. Indeed, the perception of the effects of a particular action would promote its representation, which should be strengthened by the previous motor experience concerning the action itself. The synergic activation of the representations deriving from the sensorial systems and from motor experience would determine a higher probability that people will perform an action with the features similar to those perceived in the stimulus deriving from the action itself. Instead, stimuli not deriving from a specific action would not find any correspondence with motor experience, thus having less influence on the action execution.

The two theoretical perspectives mentioned in here are examined more in depth in the debate concerning the mirror neurons system (Caramazza, Anzellotti, Strnad & Lingnau, 2014; Hickok, 2009; Lingnau, Gesierich & Caramazza, 2009) and the TEC (Hommel, 2015a, 2015b).

1.3 Sound and rhythmic movements

It is well-established in literature that sound, and in particular rhythmic sequences, promotes the acquisition and the correct reproduction of simple movements. This is particularly the case for the above mentioned sensorimotor synchronization or rhythmic entrainment, through which participants are able to reproduce an auditory rhythm by tapping (e.g., Hickok et al., 2015; Repp & Su, 2013).

Both in perception and action, a fundamental aspect is timing, i.e. the temporal structure of an event. Keele, Pokorny, Corcos and Ivry (1985) studied whether motor production timing and perceptual timing share common mechanisms. To measure motor production timing, participants were required to tap in time with a regular click; after a certain amount of time the click stopped, and participants had to keep on tapping following the same rhythm. The measure of interest was the standard deviation of the intertap intervals after the click stopped. To measure perceptual timing, participants were required to judge whether an interval between two clicks was longer or shorter than a reference interval heard one second earlier. The measure of interest was the difference between the upper and lower thresholds obtained through a series of such judgments. The results highlighted that the two measures were significantly correlated; this outcome led the authors to claim that the mechanisms underlying motor production timing and perceptual timing are closely connected.

An important distinction, described by Lai, Shea and Little (2000), is that between absolute timing and relative timing. The former concerns the overall duration of a movement (be it performed or perceived), while the latter concerns the proportion of time between the segments of a movement. Shea, Wulf, Park and Gaunt (2001) isolated the effects of auditory models on absolute and relative timing. To do so, in the acquisition phase of a rhythmic task they randomly assigned participants either to an auditory model condition, or to a control condition (no model). Moreover, the authors also manipulated the physical practice with the task; indeed, within the auditory/control conditions, participants were coupled, so that in each couple one participant physically practiced the task, while the other one only observed her/him. In the retention phase, twenty-four hours after the acquisition, all participants were required to perform the task. The results revealed that the participants who were in the auditory condition had a more accurate relative timing compared to those who were in the control group, independently from the physical practice. However, absolute timing was more accurate for the participants who physically practiced the task, and this accuracy was even greater for those who experienced the auditory model. These outcomes highlight that for improving both absolute and relative timing of a rhythmic task it is not sufficient to listen to its auditory model, but it is necessary to physically practice the specific task.

Recently, van Vugt and Tillman (2015) highlighted that, in order to learn to tap a sequence in time, a simultaneous auditory feedback is more effective than both a delayed feedback (10-190 ms) and no feedback. This superiority was transferred also to a different sequence, and was still present when the feedback was removed.

The studies mentioned in this section highlight two important aspects: the first one is that auditory perceptual timing and motor production timing share common mechanisms; the second aspect is that, thanks to this connection, it is possible to use auditory stimuli to promote the correct acquisition and reproduction of rhythmic movements.

1.3.1 Auditory models vs visual models

The acquisition and the reproduction of motor actions are promoted not only by auditory models. Indeed, research highlighted that also visual models are effective to this purpose (Murgia, Forzini & Agostini, 2014; Ste-Marie et al., 2012). Other studies compared the effectiveness of the two types of models. In this regard, Doody, Bird and Ross (1985) asked participants to displace some padded wooden barriers in a predetermined sequence and time, a task that produced a distinct, auditory rhythmic pattern. In the acquisition phase, participants performed the task being exposed either to an auditory model, to a visual model, to an audiovisual model, or to no model; later, in the transfer phase, all participants performed the same task without any model. The results revealed that, both in the acquisition phase and in the transfer phase, the critical factor for the accurate reproduction of the motor sequence was the auditory model, regardless of the visual model. Subsequently, results by McCullagh and Little (1989) supported the superiority of auditory and audiovisual models over visual ones, also highlighting the importance of the knowledge of results in promoting improvements in the reproduction of the motor sequence.

A study of particular interest is that of Glenberg and Jona (1991). In their first experiment, participants were required to reproduce sequences composed of short (200 ms) and long (600 ms) stimuli; these sequences were presented either in the auditory modality or in the visual modality. When the interstimulus interval (ISI) constantly lasted 200 ms, the stimuli could have been chunked in beats of 800 ms (containing either two short stimuli and their ISIs, or a long stimulus and its ISI); this was not possible when the ISI was variable. Results revealed the superiority of the auditory model over the visual model in the constant condition compared to the variable condition. The second experiment, for which both longer stimuli and longer ISIs were also used, highlighted that this superiority was still present only if the beats were shorter than 2000 ms. According to the authors, these outcomes would be due to the fact that, considering the duration of echoic memory (Darwin, Turvey & Crowder, 1972), only short beats can be chunked in rhythmic units, while it is harder to do the same with longer beats.

Beyond the studies described above, other research demonstrated that auditory models are more effective than visual models in promoting the identification, the discrimination, the memorization and the reproduction of precisely timed, rhythmic movements (Collier & Logan, 2000; Glenberg, Mann, Altman, Forman & Procise, 1989; Glenberg & Swanson, 1986; Grondin & McAuley, 2009; Han & Shea, 2008; Kohl & Shea, 1995; Lai, Shea, Bruechert & Little, 2002; Repp & Penel, 2002, 2004). Altogether, the studies mentioned here suggest that the auditory system is apter than the visual system in identifying the rhythmic features of simple movements; this, in turn, promotes the accurate reproduction of the movements themselves by means of auditory models.

1.4 Sound and sport

Like in their everyday activities, also in sport people are primarily guided by visual information. This is the main reason why, within this field, research has traditionally focused on the visual domain. On the one hand, it is well-established that the ability to anticipate the opponents' actions on the basis of their kinematic information heavily depends on expertise (Abernethy, Gill, Parks & Packer, 2001; Abernethy & Russell, 1987; Mann, Williams, Ward & Janelle, 2007; Shim, Carlton, Chow & Chae, 2005; Weissensteiner, Abernethy, Farrow & Müller, 2008); on the other hand, some studies revealed that athletes can improve their perceptual abilities and, in turn, their performances thanks to interventions focused on visual information (Abernethy, Wood & Parks, 1999; Farrow & Abernethy, 2002; Hopwood, Mann, Farrow & Nielsen, 2011; Murgia et al., 2014; Ryu, Kim, Abernethy & Mann, 2013; Ste-Marie et al., 2012).

Notwithstanding the major role of (and interest toward) the visual domain in sport, also in this context people can obtain important information concerning movement through other perceptual modalities, like audition, touch and proprioception. In particular, there is a growing interest toward the role of auditory information, as research highlighted – and it's still revealing – that it can have a relevant role in determining certain performances, as well as in improving them if such information is appropriately used in training. One of the first demonstrations of the importance of auditory information in sport was provided by Takeuchi (1993). This researcher asked a group of experienced tennis players to play several tie-break matches against each other, first in normal conditions and then depriving one of the two players of auditory information by means of synthetic rubber earplugs. Results highlighted that playing in the auditory deprivation condition significantly hindered performances compared to the normal condition, as players obtained less points, thus losing more games. Further analyses revealed a decrease in the number of correctly received and returned serves in the auditory deprivation condition compared to the normal one, while no differences were found concerning the execution of the serves.

In the two following sections, an overview of the studies dealing with sound and sport is provided; the studies are divided on the basis of how auditory information is used, i.e. either as a feedback or as a model. Excluded from this categorization is music. Indeed, most of the research dealing with music and sport is focused on variables like psychophysiological arousal, mood and motivation (e.g., Karageorghis & Jones, 2014; Sanchez, Moss, Twist and Karageorghis, 2014), which are beyond the scope of the present thesis. There are some rare exceptions, with studies focusing on sensorimotor synchronization (e.g., Bood, Nijssen, van der Kamp and Roerdink, 2013). This ability is fundamental in aesthetic sports (rhythmic gymnastics, figure skating, and so on), as athletes have to be "on time" while performing their movements; however, music does not directly convey any information about movements' execution itself. For these reasons, the studies concerning music and sport are not addressed in this thesis (for a review on this topic, see Karageorghis & Priest, 2012a, 2012b).

1.4.1 Auditory information as a feedback

When performing an action, people naturally receive some sensory-perceptual information, which is called task-intrinsic feedback. It is possible to enhance this intrinsic feedback by adding additional action-related information, which is called augmented feedback (Magill, 2010). Specifically, augmented feedback can be defined as information provided by a trainer or a display (Schmidt & Wrisberg, 2008; Utley & Astill, 2008); the latter term is referred not only to the visual modality (e.g., screens, projectors), but it includes also the auditory modality (e.g., speakers, headphones). Thanks to these displays, augmented feedback can provide knowledge of performance, i.e. information concerning the current status of the action that is being performed (Magill, 2010; Sigrist, Rauter, Riener & Wolf, 2013).

As previously described, auditory information deriving more or less directly from an action promotes the activation of premotor and motor areas of the brain (Aziz-Zadeh et al., 2004; Gazzola et al., 2006; Pizzamiglio et al., 2005; Schmitz et al., 2013; Woods et al., 2014). Other studies investigated whether these sounds, used as augmented feedback, can positively influence sport performances. In this regard, the first sport taken into account was swimming: it was observed that online sonification of the crawl promoted significant improvements in the performance of expert swimmers (Chollet, Madani & Micallef, 1992; Chollet, Micallef & Rabischong, 1988). More recently, Hummel, Hermann, Frauenberger & Stockman (2010) sonified the rolling motion of the German wheel, in order to compare the effects of this augmented feedback between novices and experts. The results revealed that only expert athletes significantly improved the execution of the moves under investigation, thus highlighting that expertise is necessary to interpret such a feedback and benefit from it.

Also other sports were considered, i.e. karate (Yamamoto, Shiraki, Takahata, Sakane & Takebayashi, 2004) and skiing (Kirby, 2009). However, in these studies researchers did not measure performance variables; instead, they assessed athletes' opinions about the usefulness of sonification and about its potential effectiveness in improving their performances, obtaining positive responses for both sports.

A sport that received particular attention was rowing. Perceptual studies revealed that rowers are able both to recognize the rowing cycle through various types of sonification (Dubus, 2012), and to identify their own one among those of other athletes (Schmitz & Effenberg, 2012). An on-water study by Schaffert, Mattes and Effenberg (2011) highlighted that sonification can significantly improve the performance of expert rowers. These researchers developed a device that sonified online the acceleration of the boat (see figure 2), with tone pitch increasing as the boat acceleration increased, and tone pitch decreasing as boat acceleration decreased; this augmented feedback gave athletes the possibility to monitor the effectiveness of their rowing cycle. The results revealed that, at the same stroke rate, boats were significantly faster when athletes could rely on the feedback than when they could not. Moreover, the distance travelled – a factor dependent on the boat velocity – was also greater when the feedback was present than when it was absent.

Figure 2. The sonification device used by Schaffert and colleagues (2011; image from Schaffert, Mattes and Effenberg, 2010, p. 32). The auditory feedback could have been delivered either via loudspeaker or via headphones (like in this example); moreover, the device could have been switched on and off by remote-control from the accompanying coaching boat.

Later, encouraging results were obtained also with adaptive athletes – both with physical and visual disabilities (Schaffert & Mattes, 2012) – as well as from testing various kinds of sonification, obtained by using different criteria for the conversion of boat acceleration into sound (Schaffert & Gehret, 2013). A study by Effenberg, Fehse, Schmitz, Krueger and Mechling (2016) revealed that sonification is useful not only for experts but also for novices, as it boosted the learning of the indoor rowing technique to a greater extent than a traditional approach based only on visual information.

A last study to be mentioned in this section is the one by Kennel and colleagues (2015) on hurdling. These researchers compared the effects of online auditory feedback, delayed (180ms) auditory feedback and white noise on hurdlers performance. The results revealed that the delayed feedback significantly hindered the performances, lengthening the time to complete the track; instead, no difference was observed between the online feedback condition and the white noise condition.

1.4.2 Auditory information as a model

The concept of modeling has already been introduced in the previous sections. However, before describing the studies that applied it to sport, it is useful to define this concept in detail, like it has been done for augmented feedback. According to the definition provided by APA, modeling is a process through which a person serves as a model for others, exhibiting the behaviour to be imitated (VandenBos, 2007). This concept can be extended, including the possibility that the person serving as a model can observe herself/himself in a different moment. In this regard, Dowrick (1999) defined self modeling as “an intervention procedure using the observation of images of oneself engaged in adaptive behavior. Most commonly, these images are captured on video […] and repeatedly reviewed to learn skills […] as part of a training […] protocol” (p. 23). Like augmented feedback, neither modeling is limited to the visual modality: indeed, auditory models can be defined as sequences of sounds reproducing various aspects of a given movement (e.g., timing, force, duration), thus representing an auditory form of demonstration (Sors, Gerbino & Agostini, 2014). To sum up, Magill (2010) defined modeling as the use of (self) demonstration to convey information about how to perform a skill.

An important precondition for the use of auditory modeling is the fact that people are able to identify the sound deriving from a gesture/movement that they performed among the sounds deriving from other people performing the same gesture/movement. This is true both for simple gestures like hands clapping (Flach, Knoblich & Prinz, 2004), and for the complex movements that characterize sport: it has already been mentioned concerning sonification (Schmitz & Effenberg, 2012), and other studies revealed that the same happens also for the sounds directly recorded during the execution of specific technical and/or athletic movements, like in golf (Murgia, Hohmann, Galmonte, Raab & Agostini, 2012) and hurdling (Kennel, Hohmann & Raab, 2014; Kennel et al., 2014). These observations received further support from a neurophysiological study by Justen, Herbert, Werner and Raab (2014), which highlighted that, when athletes listen to the sound deriving from their own long jumps, different brain areas are activated compared to when they listen the sound deriving from the long jumps performed by other athletes.

The first known study that investigated the effects of auditory modeling on sport performances was conducted by Agostini, Righi, Galmonte and Bruno (2004); in particular, the sport taken into account was hammer throw. On the first day, expert throwers performed two series of ten throws each, in order to control for the fatigue effect. On the second day, the athletes performed again two series of ten throws each. During the first series, the researchers recorded the sound produced by the hammer’s friction with the air while rotating, by placing a microphone near the hammer head; this series also served as a baseline. The second series was the experimental session: the sound deriving from the longest baseline throw of each athlete was used as a model, being administered five times before each new throw. Two kinds of performance improvement were observed: compared to the baseline, the experimental throws were significantly longer and there was less variability among them; thus, auditory modeling promoted an upward standardization of the performances.

Subsequently, the described *modus operandi* was adapted to the peculiar features of swimming and soccer free kicks. In particular, as concerns swimming, ideal models were created by looping the sound associated to the most effective stroke cycle, chosen by the swimmers together with their coaches (Galmonte, Righi & Agostini, 2004). Concerning soccer, as a model it was used the sound of the run up preceding the best free kick, chosen using both subjective (i.e., self-rating) and objective parameters (i.e., closeness of the ball to the top corner behind the wall) (Prpic et al., 2010). For both sports, auditory models promoted an upward standardization similar to the one observed in the hammer throw study, with better and less variable performances compared to the baseline.

Studies on weightlifting and skateboarding provided further evidence on the effectiveness of auditory modeling. In particular, as concerns weightlifting, Murgia and colleagues (2012) created auditory models to guide expert lifters during the one-repetition bench press exercise. These models consisted of an initial countdown, followed by a low-intensity sound, which corresponded to the down phase of the exercise, and then by a high-intensity sound, which corresponded to the pressing phase. The results revealed that the average power exerted by participants in the auditory stimulation condition was significantly greater than the one exerted in the control condition.

As concerns skateboarding, Cesari, Camponogara, Papetti, Rocchesso and Fontana (2014) were interested in investigating on how expert and novice skaters respond to synthetic sounds reproducing the run of a skateboard, thus they made use of electrodes and force plates to this purpose (see figure 3). The results highlighted that leg muscles were activated by such stimuli in both groups of participants; however, the activation patterns recorded for the experts, compared to those of the novices, more closely resembled the activation patterns needed to actually perform the various events that occur during skateboarding (i.e. acceleration, steady run, deceleration and jump). These results further support the already mentioned observation that familiarity is needed to correctly interpret specific sounds (Hummel et al., 2010, Woods et al. 2014).

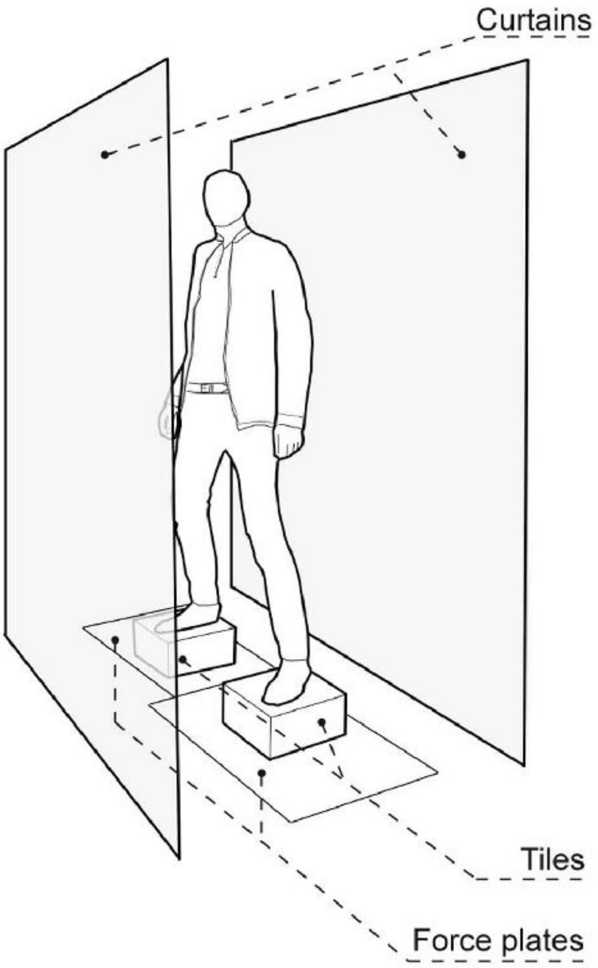


Figure 3. Reproduction of the experimental setting used by Cesari and colleagues (2014, p. 3). On each tile, the researchers applied a vibro-acoustic transducer, which reproduced the stimuli. Moreover, they also applied six electrodes on six muscles, three for each leg: the Gastrocnemius, the Tibialis Anterior, and the Rectus Femoris. Finally, the experimental setting was surrounded by curtains.

Other studies compared the effectiveness of different kinds of models. To this purpose, Effenberg (2005) sonified countermovement jumps by converting the ground reaction force into a synthetic sound (see figure 4). Sports students were then asked to reproduce as accurately as possible the height of jumps in two conditions, i.e. either after watching a mute video (visual model), or after watching a sonified video (audiovisual model). Results revealed that participants were significantly more accurate in the latter condition.

In another study, Ramezanzade, Abdoli, Farsi and Sanjari (2014) sonified the angular speed of the elbow joint of a professional basketball player performing jump shots. Like in the previous study, participants – who were novices to basketball – were exposed either to a visual model or to an audiovisual model. Also in this case, the latter model promoted significantly better performances than the former one, providing further support to the observation made by

Effenberg and colleagues (2016) that adding auditory information to visual information can be beneficial for novices. The authors of the last two studies explained the results in terms of multisensory integration; however, the absence of an audio-only condition did not allow disentangling the relative “weight” of auditory information in comparison with that of visual information.

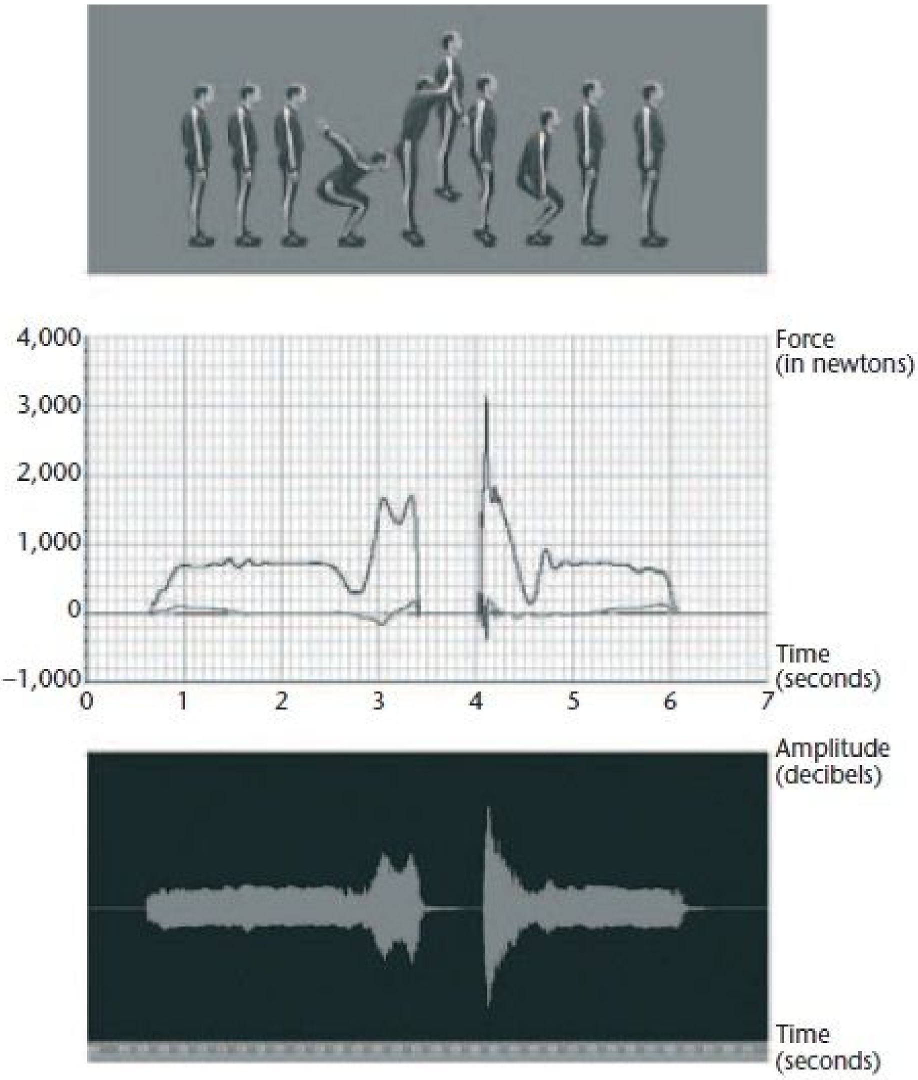


Figure 4. The movement sonification used by Effenberg (2005, p. 54). By means of a force plate, the researcher measured the ground reaction force of countermovement jumps; then, he mapped the vertical component of this parameter to the amplitude and frequency of an electronically sampled vocal *a*.

A possible insight on the contribution of auditory and visual information is provided by studies on golf and tennis. In particular, as concerns golf, Murgia, Bresolin, Righi, Galmonte and Agostini (2011) observed that auditory models were more effective than visual ones in improving the performance of expert golfers, both in terms of movement execution (standardization of both relative and overall timing of the swing) and of outcome (balls closer to the target). Similar results had been previously obtained by Righi, Ferletic, Furlan, Pin and Gherzil (2007) concerning the tennis serve, with the important addition that the improvements promoted by the auditory models were greater not only than those promoted by visual models, but also than those promoted by the audiovisual ones. The results of these studies highlighted that, at least for the movements taken into account, auditory information provides more relevant cues than visual information to standardize and improve the movements themselves and their outcomes.

1.4.3 A different approach

The studies described in the last two sections demonstrate that an appropriate use of auditory information promotes significant improvements in various sport performances. These improvements can derive either by adjusting the movement on the basis of an augmented feedback, or by shaping the execution of the movement on the basis of a model; in both cases, athletes have to interpret auditory information as related to the self. However, to effectively perform in sport it is not sufficient to focus exclusively on your own movements, but also on those of the other people around you – teammates, opponents, referees – in order to react appropriately.

Notwithstanding the obvious fact that also the movements of the others produce sound, only a couple of studies investigated its influence on sport performances. One of these studies has already been mentioned and is that of Takeuchi (1993), through which the relevance of auditory information in receiving and returning the tennis serve was highlighted. Another study that investigated the response to sounds not related to the self is that of Brown, Kenwell, Maraj and Collins (2008). These authors started from the observation of Julin and Dapena (2003) that at the 1996 Olympic Games, the reaction time of sprinters appeared to progressively increase from lane 1 to lane 8. To experimentally test the hypothesis that this effect was due to the phenomena of sound propagation and decay of the gunshot that served as “go” signal[2], Brown and colleagues (2008) manipulated its loudness. The results revealed that an increase of the gunshot loudness promoted a significant decrease of the reaction time of sprinters. Finally, a recent study by Camponogara, Rodger, Craig and Cesari (2017) highlighted that basketball players are able to anticipate the action intentions of an attacker through the sound he produces while moving towards them.

---

[2] Nowadays, to avoid such a lane bias, in all major competitions starters use an electronic gunshot delivering a beep via loudspeakers placed behind each starting block.

The present thesis is focused on this latter approach, with the double aim of investigating the contribution of early auditory information to the perception of opponent's action in ball sports, and of comparing this contribution with that of the respective visual information. To this purpose, first of all, a preliminary set of four simple reaction time experiments was conducted (Chapter 2). Then, two other experiments were conducted, in which participants were asked to discriminate the power of kicked and smashed balls (Chapter 3). In the last three experiments, participants were asked to anticipate the landing zone of volleyball serves (Chapter 4). The results of these experiments may have important implications both from a research perspective and from an applied point of view; such implications, together with other relevant issues mentioned in the thesis, are discussed in the conclusions (Chapter 5).

Chapter 2

Simple reaction time in response to ecological sounds

2.1 Introduction

The research on simple reaction time in response to auditory stimuli has a long tradition. Over the years, a general phenomenon has been repeatedly observed, i.e. that an increase of the stimulus' loudness promotes a decrease of the reaction time to that stimulus (Chocholle, 1940; Florentine, Buus & Rosenberg, 2004; Humes & Ahlstrom, 1984; Kohfeld, Santee & Wallace, 1981a; Kohfeld, Santee & Wallace, 1981b; Marshall & Brandt, 1980; Pfingst, Hienz, Kimm & Miller, 1975; Piéron, 1920; Scharf, 1978; Wagner, Florentine, Buus & McCormack, 2004; Wundt, 1874). The stimuli used in the cited studies were pure tones (alone or in combination between some of them), which are easily manipulable, but they do not occur in nature; indeed, natural sounds are not constituted of a single frequency: they comprise various frequencies, some of which are more pronounced than others. As a consequence, the results observed in previous research might not extend to ecological sounds.

To the best of our knowledge, ecological sounds were used as stimuli for simple reaction time tasks just in a few studies (Grassi & Casco, 2010; Grassi & Darwin, 2006). However, in both cases such tasks constituted only control experiments for the main experiments presented in the studies themselves, which aimed at investigating different phenomena from the relation between loudness and simple reaction time. There is only one study that can be somehow connected to these issues, as it investigated the influence of the "go" signal loudness of sprint starts on the reaction time of sprinters (Brown et al., 2008). The "go" signal in sprint events used to be a gunshot, which is an ecological sound; the sprint start cannot be considered as a typical simple reaction time task, however it requires to react as fast as possible to an auditory stimulus with an highly automated motor response, i.e. running. As described in the first chapter, the results of the study revealed a significant decrease of the reaction time of the sprinters as a consequence of the increase of the "go" signal loudness, an outcome that is in line with the above cited laboratory experiments.

In this chapter, four experiments are described, whose aim was to start filling the gap between the studies mentioned in the first paragraph and Brown and colleagues' (2008) one; to this purpose, all the experiments consisted of a simple reaction time task in response to ecological sounds. In particular, as described in detail in the methodological part, the sounds used as stimuli were foot-ball impacts of soccer penalty kicks; these stimuli were chosen in light of the growing evidence concerning the relevance of the auditory information in sport (Pizzera & Hohmann, 2015; Sors, Murgia, Santoro & Agostini, 2015), so that the results of the present series of experiments could potentially contribute also to that line of research.

2.2 Experiment 1

In Experiment 1, the loudness of a single foot-ball impact was manipulated, which can be considered a “classical” manipulation. On the basis of previous research, we hypothesized that an increase of the stimulus’ loudness would promote a decrease of the reaction time in response to it.

2.2.1 Materials and methods

Participants

Thirty university students (23 females, 7 males) took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 22 years (SD = 2.5); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Apparatus

To record the stimuli, a stereo microphone (Soundman Binaural, OKM II Professional) connected to an external sound card (M-AUDIO MobilePre) was used. To edit the recordings, the software Adobe Audition 3.0 was used.

The experimental sessions were programmed with the E-prime Professional 2.0 software, and were administered to the subjects through a laptop computer ASUS X52J; the stimuli were conveyed through Philips SHP1900 circumaural headphones.

Stimuli recording

The stimuli were recorded on a regular soccer pitch. The stereo microphone was placed on a tripod in the middle of the goal line, 1.35 cm high; this position reproduced an average goalkeeper perspective before a penalty kick, as they are slightly bent on their knees to be as explosive as possible in diving towards the corners of the goal. A wooden panel of 90x90 cm was attached to the bottom of a target wall, and placed below the microphone on the goal line; moreover, to avoid the tripod and the microphone from being hit by mistargeted shots, a plastic panel and another wooden panel were attached to the target wall, below and above the microphone itself respectively (see figure 5).

To record the stimuli, a right-footed soccer player aged 24 and with a playing experience of 17 years in amateur leagues was recruited. He was asked to kick several penalties with different powers aiming at the 90x90 cm wooden panel. Overall, 100 penalty kicks were recorded.

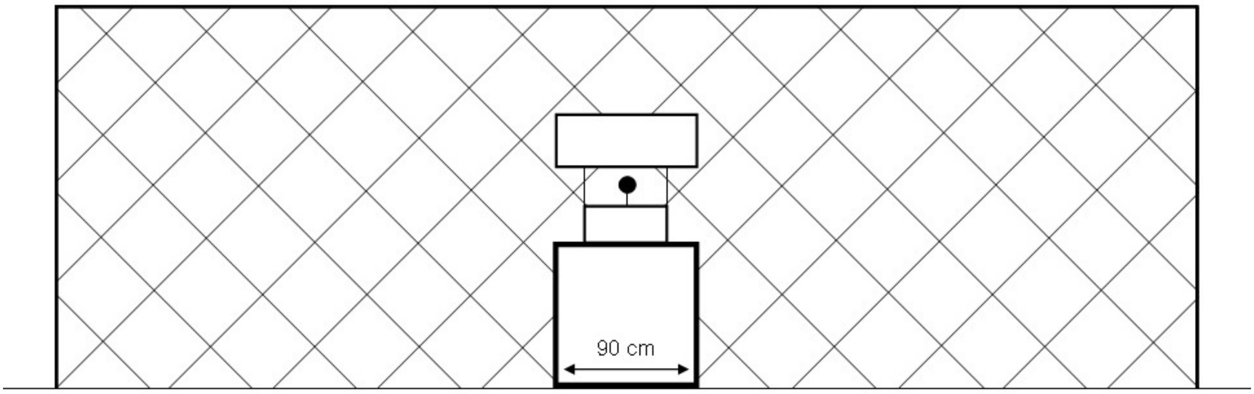


Figure 5. Reproduction of the recording setting from the perspective of the penalty taker. The square in the middle of the goal represents the 90 x 90 cm wooden panel where penalties were directed. The dot indicates where the microphone was placed; the rectangles below and above it represent the protective plastic and wooden panels respectively.

Stimuli editing

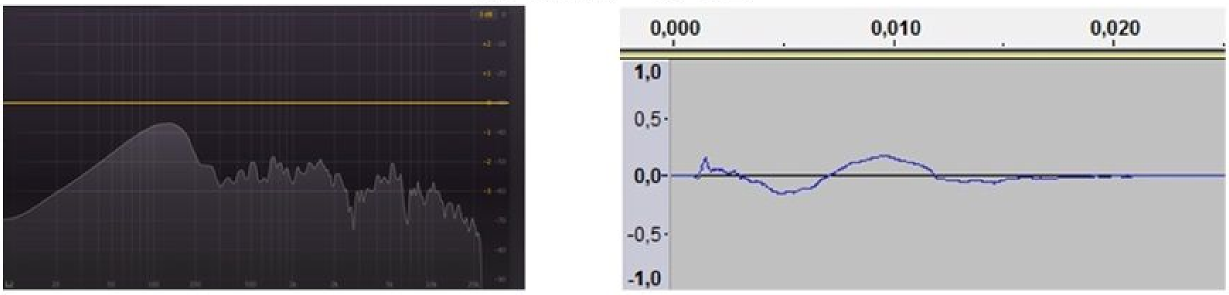
The first operation made on the penalty kicks database was to discard those that did not hit the target panel, as well as those with background noise (e.g., wind). After this operation, the database consisted of 34 penalty kicks, whose speeds were calculated dividing the distance travelled by the ball by the travel time. The distance travelled by the ball could range between 11 m and 11.046 m: given that the range was so slight, we used the distance from the penalty spot to the centre of the panel, i.e. 11.009 m, as standard distance for all the penalties[3]. The travel time was the interval between the foot-ball contact and the ball-panel one, both clearly audible in the audio files. The obtained speed values were further transformed to km/h units by multiplication by 3.6.

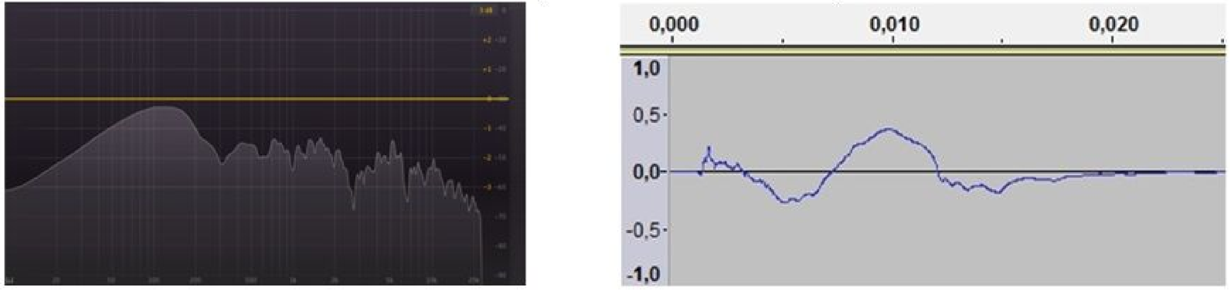
Out of the 34 penalty kicks, one with the speed of 83 km/h was selected, whose loudness was of slightly greater than 50 dB (the measurement was performed by means of a Nimex NI8030 sound level meter pointed toward one earpad, few centimetres away from it to reproduce the position of the ear). The file of this penalty was edited through the above mentioned software: the impact between the foot and the ball was isolated; this stimulus was used in the

---

[3] It is noteworthy that differences in the range of 1-2 centimeters could also occur depending on the position of the ball on the penalty spot. In any case, we calculated that a difference of few centimeters would determine an insignificant variation (about 0.07 km/h per centimeter) in an average penalty.

familiarization session. Two more stimuli were generated manipulating the loudness of the original one: in one case, the volume was decreased by 10 dB, in the other case it was increased by 10 dB (see figure 6); these two stimuli were used in the experimental sessions.


83 km/h -10 dB


83 km/h (Familiarization)

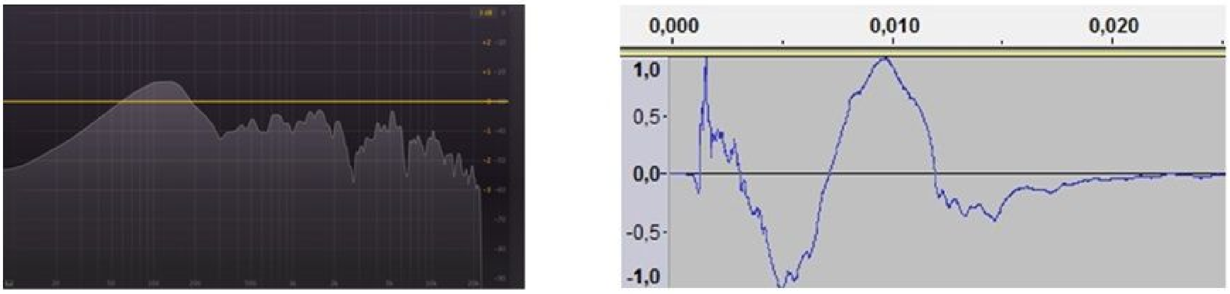

83 km/h +10 dB

Figure 6. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli. As it can be seen, the spectra profiles are superimposable, since they derive from the same original stimulus, whose loudness was decreased and increased by 10 dB respectively.

Task and procedure

The participants were involved in a simple reaction time task; in particular, they were asked to press the space bar as soon as they heard each auditory stimulus, while staring at a fixation point in the centre of the laptop display. The dependent variable was the reaction time (recorded by the software).

Every session consisted of six blocks, each one containing 24 stimuli and 8 mute tracks; the randomized reproduction of the audio files generated variable intervals between the stimuli, in order to prevent participants from "synchronizing" on a specific rhythm. Overall, for each session 144 stimuli were administered.

A within subjects experimental design was used, with the three sessions administered on three different days. The familiarization session – characterized by the original stimulus – was carried out always on the first day; then, the two experimental sessions – corresponding to the manipulated stimuli – were administered in a counterbalanced order among participants, to keep under control the potential effects of order, sequence and learning.

As concerns the procedure, participants were tested individually in a silent room. Upon their arrival, they were asked to seat in front of the laptop and to wear the headphones. Then, the experimenter launched the scheduled session. In order to standardize the instructions, they were reported in textual form at the beginning of each session; no reference was made to the nature of the stimuli: participants were simply asked to react as fast as possible to each of them by pressing the space bar with their dominant hand.

2.2.2 Results

Reaction times were collected and averaged separately for each participant in each condition. Outliers – defined as responses faster than 120 ms (i.e. anticipations) or slower than 500 ms (i.e. delayed responses) – were excluded from the averages; they accounted for about the 5% of the data collected. A paired sample t-test revealed a significant difference in the reaction time in response to the two experimental stimuli [t(29) = 4.961; $p < 0.001$; *d* = 0.58] in the hypothesized direction (see figure 7).

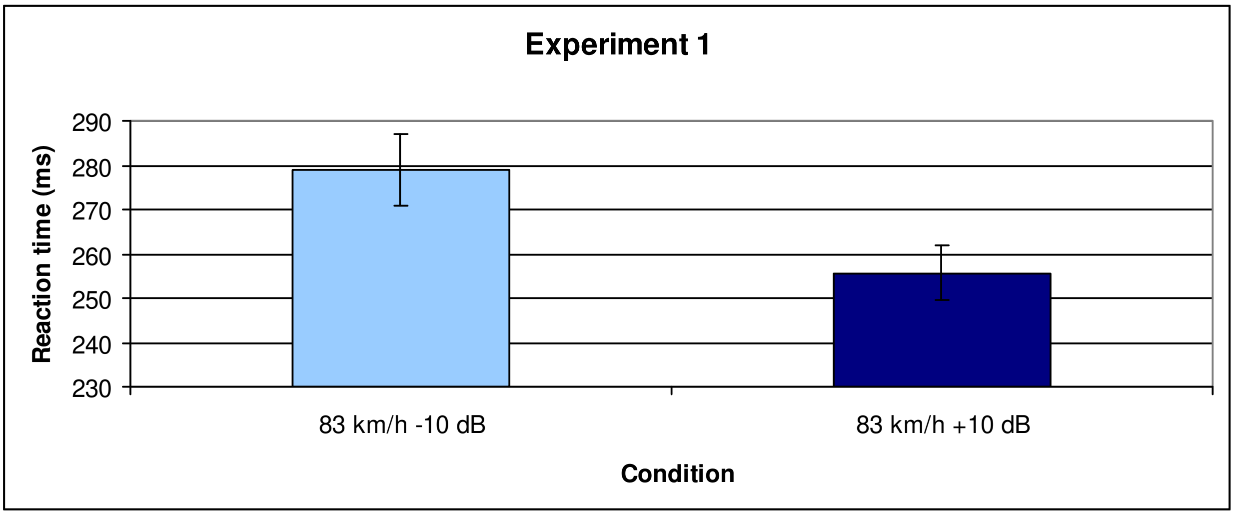


Figure 7. Reaction time in response to the two experimental stimuli. Error bars show the standard error of the mean.

2.2.3 Discussion

The aim of Experiment 1 was to investigate the effects of loudness' variation of ecological auditory stimuli on the reaction time to those stimuli. To this purpose, a "classical" manipulation was performed, decreasing and increasing by 10 dB the loudness of a single foot-ball impact. The hypothesis was that the increase of the stimulus loudness would have promoted a decrease of the reaction time.

The results supported this hypothesis, as the reaction time in response to the stimulus with higher loudness was significantly faster than that in response to the stimulus with lower loudness. This outcome is in line with previous research, thus the inverse relation between stimulus loudness and reaction time seems to hold also for ecological stimuli. However, it is worth noting that the loudness difference between the two experimental stimuli was of 20 dB, which for foot-ball impacts is too big to occur naturally, thus it cannot be considered as representative of real shots. As a consequence, on the basis of this experiment alone, it is not possible to claim whether different foot-ball impacts can themselves promote the above mentioned inverse relation, or the observed effect was due to the artificial manipulation of loudness.

2.3 Experiment 2

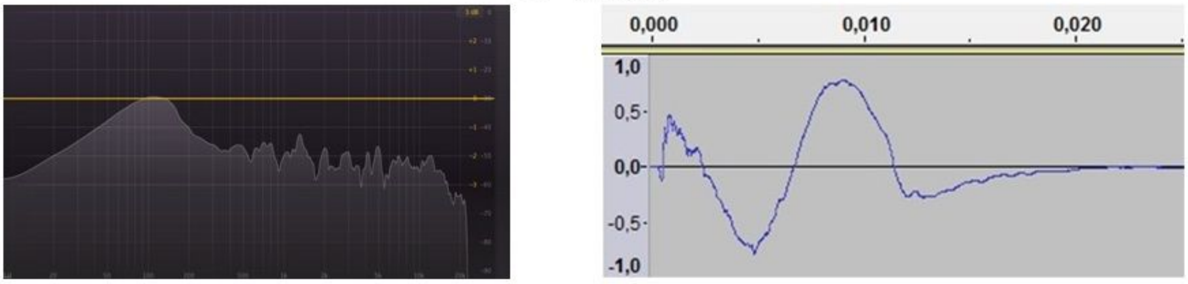
Experiment 2 was designed to try to disentangle the issue mentioned in the previous discussion, i.e. whether foot-ball impacts of shots with different speeds can naturally promote variations in the reaction time in response to them. To this purpose, instead of manipulating the loudness of a single foot-ball impact, different impacts were selected as stimuli; as described below, the loudness difference between these stimuli was smaller than that between the stimuli of Experiment 1. On the basis of previous research, and also of Experiment 1, it would be reasonable to hypothesize a decrease of the reaction time as a consequence of the increase of stimulus' loudness; however, it was not possible to predict whether the differences in loudness among the stimuli were sufficient to promote such an effect.

2.3.1 Materials and methods

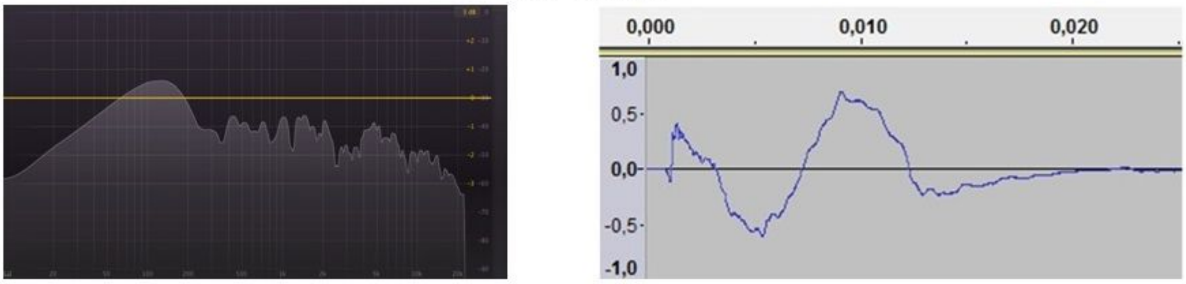
Participants

Thirty male university students took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 24.1 years (SD = 3.6); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

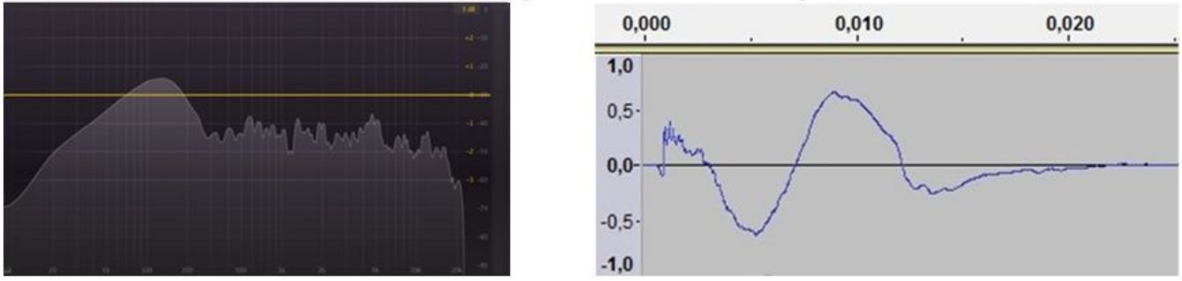
62 km/h



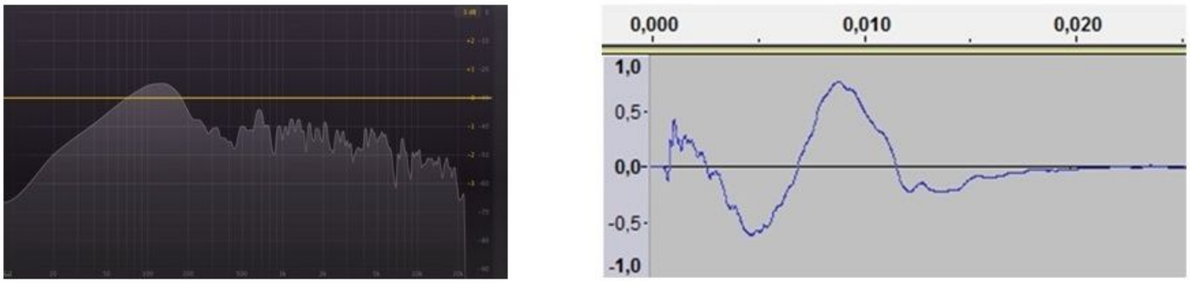
69 km/h



73 km/h (Familiarization)



76 km/h



83 km/h

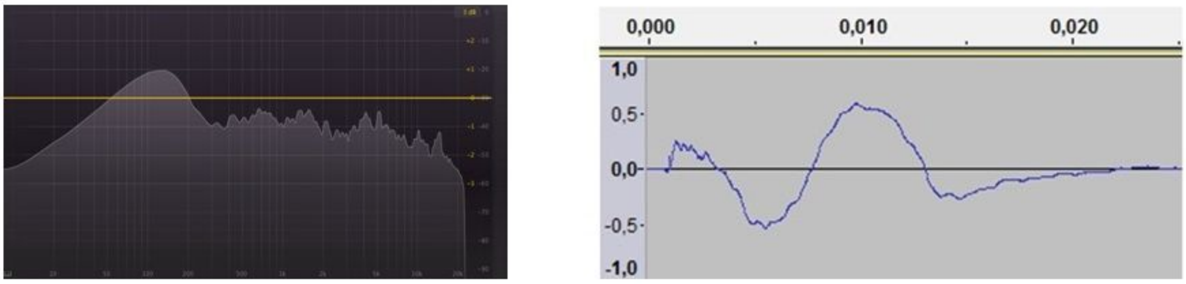


Figure 8. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli. As it can be seen, they differed not only in terms of loudness, but also in terms of pitch, with slower shots having lower pitch and faster shots having higher pitch.

Stimuli

From the same database of Experiment 1, five penalties with the following speeds were selected: 62 km/h, 69 km/h, 73 km/h, 76 km/h, and 83 km/h. The files of these penalties were edited through the above mentioned software: for each penalty, the impact between the foot and the ball was isolated. The middle stimulus, i.e. the one corresponding to the shot with the speed of 73 km/h – whose loudness was of about 50 dB – was used in the familiarization session; the other four stimuli were used in the experimental sessions. The loudness difference between the extreme stimuli, i.e. 62 km/h and 83 km/h, was of 6.12 dBFs, which is smaller than the loudness difference between the stimuli of Experiment 1. Moreover, as it can be seen in figure 8, the frequency spectra of the four stimuli were different: as the speed of the shot increased, higher frequencies became more pronounced; this means that the stimuli associated to slower shots had a lower pitch, while stimuli associated to faster shots had a higher pitch.

Task and procedure

Participants' task was the same as for Experiment 1, i.e. reacting as fast as possible to each stimulus by pressing the space bar. Also the dependent variable, the structure of the sessions, the experimental design and the procedure were the same as for Experiment 1. Moreover, always like in Experiment 1, the intermediate stimulus (73 km/h) was used in the familiarization session that was administered on the first day, and the order of the four experimental sessions (corresponding to the stimuli of 62 km/h, 69 km/h, 76 km/h and 83 km/h) was counterbalanced among participants.

2.3.2 Results

Like in Experiment 1, the mean reaction time of each participant in each condition was calculated, excluding responses that were faster than 120 ms or slower than 500 ms; the excluded data were less than 5% of the total. A repeated measures ANOVA revealed a significant main effect of the condition [$F(3, 87) = 5.552$; $p < 0.05$; $\eta^2 = 0.16$] and also a significant linear trend [$F(1,29) = 22.686$; $p < 0.001$; $\eta^2 = 0.44$]; however, the direction of this trend was opposite with respect to what was hypothesized (see figure 9).

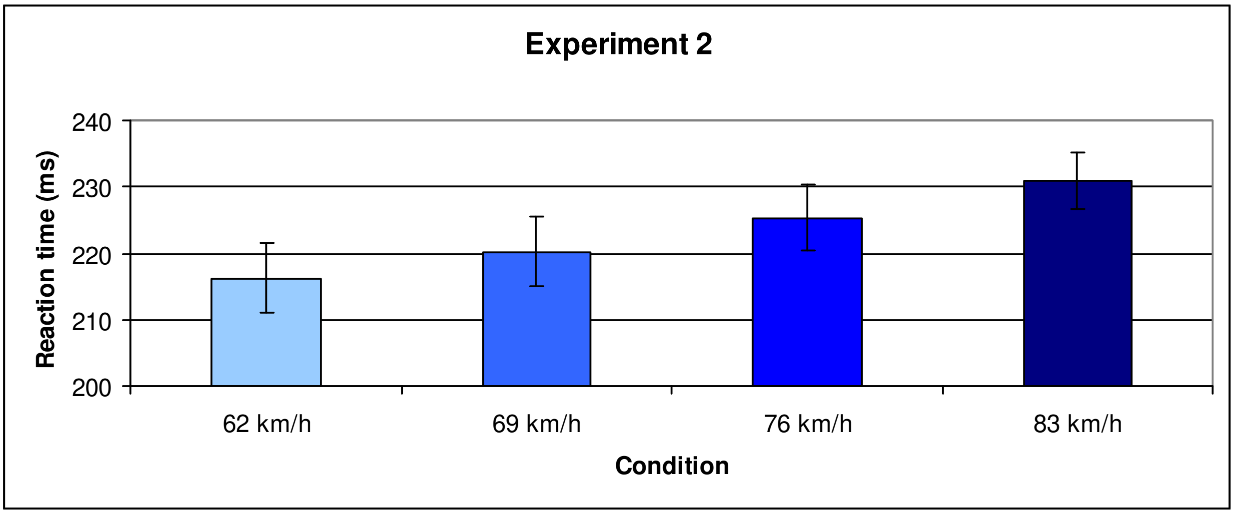


Figure 9. Reaction time in response to the four experimental stimuli. Error bars show the standard error of the mean.

2.3.3 Discussion

The aim of Experiment 2 was to investigate whether the natural loudness difference occurring between foot-ball impacts of shots with different speeds is sufficient to promote the above mentioned inverse relation with the reaction time. The results did highlight a significant linear trend, but in the opposite direction with respect to what was expected: indeed, as the speed of the shot/loudness of the impact increased, the reaction time – instead of decreasing – increased as well.

There are two possible explanations for this outcome. One is related to the pitch of the stimuli, the other is related the power of the experiment. Concerning the former, foot-ball impacts of shots with different speeds – and, in general, ecological sounds produced by the same source at different intensities – do not differ among each other only in loudness, but also in pitch. There are no known studies highlighting an effect of the pitch on the reaction time, but research in this field has always been conducted with pure tones only, thus considering isolated frequencies. As a consequence, it is not possible to exclude that pitch variation might somehow interact with loudness variation, promoting the effect observed here.

As concerns the second potential explanation, notwithstanding the statistical significance, the differences observed in this experiment were smaller than that observed in Experiment 1; this is true both in absolute terms and considering the effect size. Concerning the former, in Experiment 1 there was a difference of 23 ms in the reaction time to the two stimuli, while here the differences among the pairs of stimuli were of 4 ms, 5 ms, and 6 ms, respectively; as concerns effect sizes, for Experiment 1 the Cohen's *d* was equal to 0.58, while here the eta-squared was equal to 0.16. Thus, the power of the present experiment may have been excessively high, highlighting as significant an effect that was actually small or even accidental. This was reasonably due to the fact that the number of participants was kept the same as for Experiment 1, notwithstanding the experimental design consisted of four repeated measures instead of only two; this, in turn, may have influenced the power of statistical analyses.

To sum up, considering the issues mentioned in this discussion, it would be risky to claim that different foot-ball impacts can promote variations in the reaction time in response to them on the basis of this experiment.

2.4 Experiment 3

To better understand the results observed in Experiment 2, for Experiment 3 we selected as stimuli foot-ball impacts of shots with a greater speed difference between them. On the basis of previous research, it would be reasonable to hypothesize a decrease of the reaction time with the increase of the stimulus' loudness; however, in light of the results of Experiment 2, also the opposite hypothesis could be formulated. The amount of evidence in favour of the former hypothesis is wider than that supporting the latter, but it concerns artificial stimuli; as a consequence, Experiment 3 can be considered as an exploratory study.

2.4.1 Materials and methods

Participants

Thirty university students (17 females, 13 males) took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 23.3 years (SD = 3.7); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimuli

From the same database of Experiment 1, three penalties with the following speeds were selected: 62 km/h, 83 km/h, and 101 km/h. The files of these penalties were edited through the above mentioned software: for each of them, the impact between the foot and the ball was isolated. The middle stimulus, i.e. the one corresponding to the shot with the speed of 83 km/h – whose loudness was slightly greater than 50 dB – was used in the familiarization session; the other two stimuli were used in the experimental sessions. The loudness difference between these stimuli was of 5.27 dBFs, thus similar to that between the extreme stimuli of Experiment 2. However, as it can be seen in figure 10, the difference between the frequency spectra of the two stimuli was greater than the differences between the spectra of the stimuli used in Experiment 2.

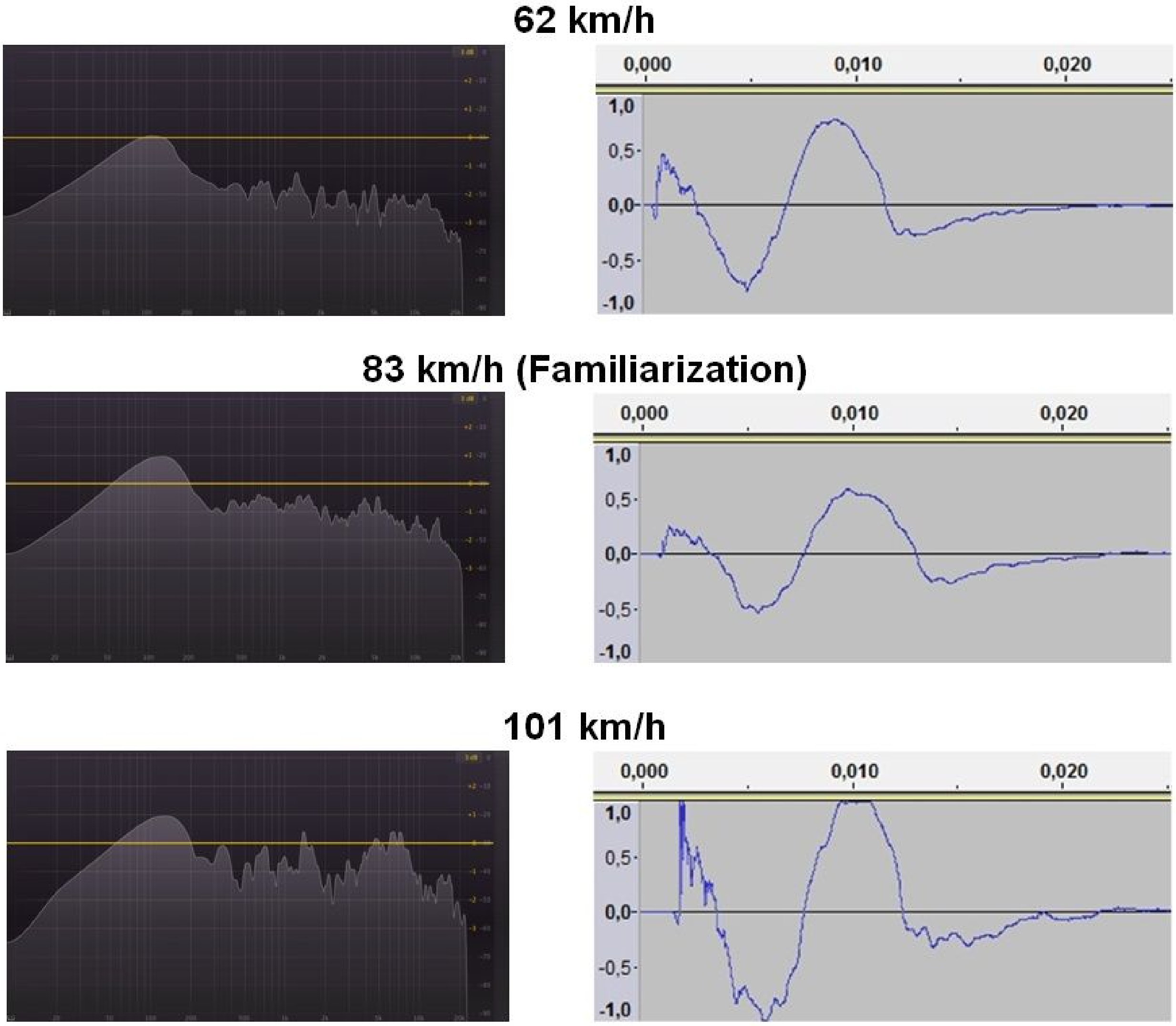


Figure 10. The frequency spectra (on the left) and the waveforms (on the right) of the stimuli. As it can be seen, they differed both in terms of loudness and pitch; the latter difference was greater than the respective differences between the stimuli of Experiment 2.

Task and procedure

Participants' task was the same as for previous experiments, i.e. reacting as fast as possible to each stimulus by pressing the space bar. Also the dependent variable, the structure of the sessions, the experimental design and the procedure were the same as for previous experiments. Moreover, always like in previous experiments, the intermediate stimulus (83 km/h) was used in the familiarization session that was administered on the first day, and the order of the two experimental sessions (corresponding to the stimuli of 62 and 101 km/h) was counterbalanced among participants.

2.4.2 Results

Like in the previous experiments, the mean reaction time of each participant in each condition was calculated, excluding responses that were faster than 120 ms or slower than 500 ms; the excluded data were about the 5% of the total. A paired sample t-test revealed no significant difference in the reaction time in response to the two experimental stimuli (see figure 11).

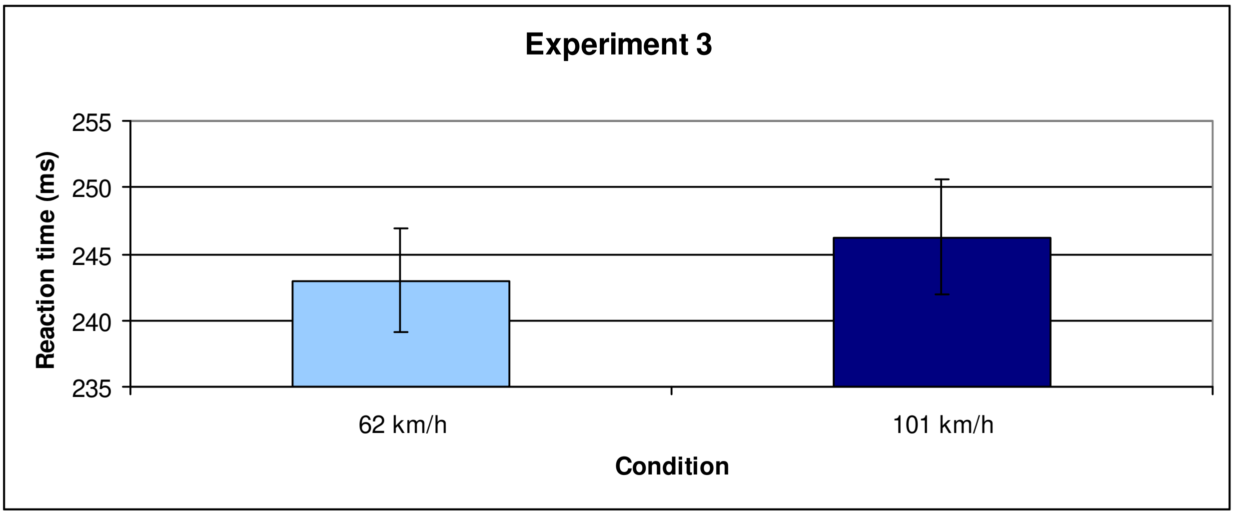


Figure 11. Reaction time in response to the two experimental stimuli. Error bars show the standard error of the mean.

2.4.3 Discussion

The aim of Experiment 3 was to better understand the results observed in Experiment 2. To this purpose, two impacts of shots that differed by 39 km/h between each other were chosen as stimuli; this difference was way greater than those of 7 km/h among the pairs of stimuli of Experiment 2, and almost the double considering only the extreme ones. This greater difference reflected itself more in terms of pitch than in terms of loudness.

Notwithstanding this greater difference between the stimuli, no difference in the reaction time in response to them was observed. As a consequence, it is reasonable to claim that the results observed in Experiment 2 could have been due to a statistical artifact, caused by the excessive number of participants in relation to the number of the repeated measures. Moreover, on the basis of the present experiment it is possible to claim that foot-ball impacts of shots with different speeds would not promote variations in the reaction time in response to them, at least for the speed range taken into consideration here.

2.5 Experiment 4

Differently from the previous experiments, in which we focused on the stimuli, in Experiment 4 we manipulated the instructions provided to participants according to the concept of framing. The traditional framing effect consists in the fact that people change choice/preference on the basis of how a problem is described, i.e. whether it is presented in terms of gains or losses (Tversky & Kahneman, 1981). There is a vast literature on framing, highlighting its effects in numerous situations (e.g., Ferguson & Gallagher, 2007; Frame, 2012; Kühberger, 1998).

To the best of our knowledge, no study has investigated the effects of framing on reaction time. In the present experiment, the concept of framing was borrowed and adapted to a simple reaction time task: two scenarios differing between each other for the magnitude of the potential loss were described, in order to investigate whether this difference could influence the reaction time in response to the same auditory stimulus. On the basis of previous research, it would be reasonable to hypothesize that the scenario with the bigger potential loss would promote a faster reaction time than the scenario with the smaller potential loss. However, due to the absence of studies on this specific issue, it was not possible to predict whether framing could actually influence such an automatic process.

2.5.1 Materials and methods

Participants

Thirty university students (18 females, 12 males) took part in the experiment. All of them had sport experience, either at recreational level or at amateur level. They had an average age of 23.9 years (SD = 4.6); none of them reported hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimulus

From the same database of Experiment 1, a penalty with the speed of 83 km/h was selected, whose loudness was slightly greater than 50 dB. The file of this penalty was edited through the above mentioned software: the impact between the foot and the ball was isolated.

Task and procedure

Participants' task was the same as for the previous experiments, i.e. reacting as fast as possible to each stimulus by pressing the space bar. However, in this experiment the conditions were not differentiated by the stimulus – which was always the same – but by the framing provided to participants trough the instructions. Indeed, beside a Neutral condition, whose instructions were the same as for the previous experiments, there was a Small loss condition and a Big loss condition. In both of them the participants had to imagine to be a soccer goalkeeper, but the described scenarios were different. In particular, the Small loss condition was characterized by the following description:

> Imagine to be a goalkeeper. You are playing a friendly match against a team of a much lower league than your one, indeed your team is leading 8-0. There are few minutes left, and the opponents are attacking en masse to try to score the consolation goal. In front of you there is a fray that does not allow you to see the ball, but you can hear the hits of the shots.
>
> Every sound you will hear corresponds to a shot toward your goal: to block it, you have to press the space bar as fast as possible.
>
> 6 minutes of injury time have just been signaled, due to the numerous substitutions. Press the space bar to enter the first minute of injury time.

Instead, the Big loss condition was characterized by the following description:

> Imagine to be a goalkeeper. It's the last match of the championship and your team is leading 1-0, the only results that would allow you to save from relegation. There are few minutes left, and the opponents are attacking en masse to try to tie the match. In front of you there is a fray that does not allow you to see the ball, but you can hear the hits of the shots.
>
> Every sound you will hear corresponds to a shot toward your goal: to block it, you have to press the space bar as fast as possible.
>
> 6 minutes of injury time have just been signaled, due to the numerous interruptions. Press the space bar to enter the first minute of injury time.

The dependent variable, the structure of the sessions, the experimental design and the procedure were the same as for the previous experiments. The Neutral condition was administered as a familiarization on the first day, while the order of the Small and Big loss conditions was counterbalanced among participants.

2.5.2 Results

Like in the previous experiments, the mean reaction time of each participant in each condition was calculated, excluding responses that were faster than 120 ms or slower than 500 ms; the excluded data were less than the 5% of the total. A paired sample t-test revealed no significant difference between the two experimental conditions in the reaction time (see figure 12).

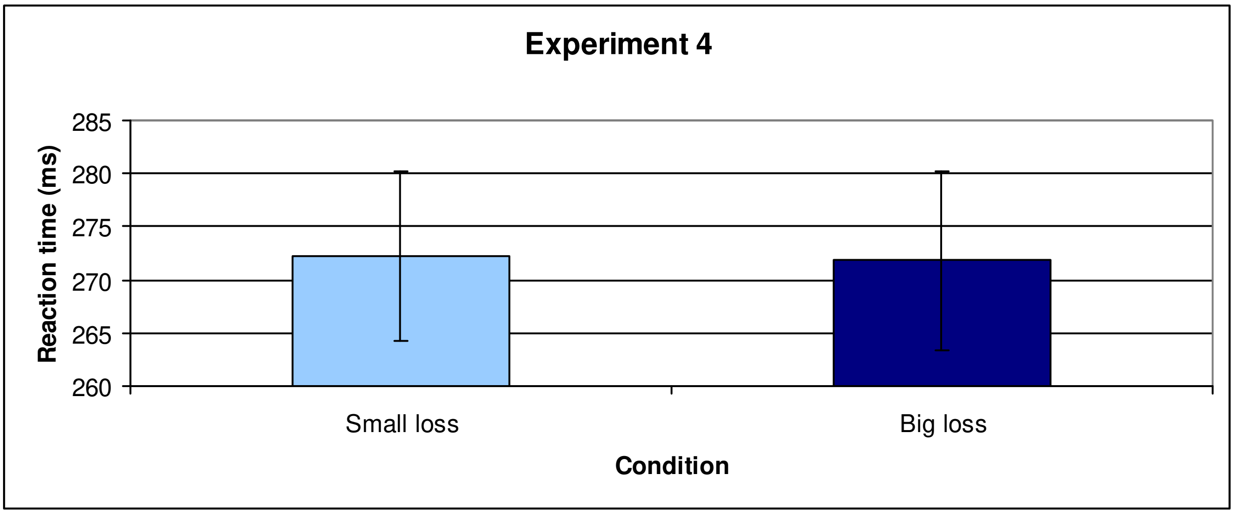


Figure 12. Reaction time in the two experimental conditions. Error bars show the standard error of the mean.

2.5.3 Discussion

The aim of Experiment 4 was to investigate whether framing can influence simple reaction time. To this purpose, the instructions provided to the participants were manipulated, describing two scenarios that differed between them for the magnitude of the potential loss.

Results highlighted no effect of this manipulation. However, on the basis of this experiment alone, it is not possible to claim that framing cannot influence reaction time. Indeed, the absence of an effect may have been due to various factors, e.g. a hypothetical weakness of the described scenarios, the absence of a reward, participants sampling, and so on. As a consequence, there is much room for future studies upon this issue, as there are several variables that can be taken into consideration.

2.6 General discussion

The aim of the present series of experiments was to investigate whether the results observed in previous research concerning simple reaction time in response to pure tones might extend to ecological sounds. In particular, the sounds used as stimuli were foot-ball impacts of soccer penalty kicks.

In Experiment 1, a “classical” manipulation was performed, decreasing and increasing by 10 dB the loudness of a single foot-ball impact. This manipulation yielded a results coherent with previous research, i.e. that the reaction time in response to the louder stimulus was faster than that in response to the quieter stimulus. However, the loudness difference between the stimuli was too big to occur naturally for foot-ball impacts, thus the effect may have been due to the artificial manipulation.

Experiment 2 was conducted to investigate whether different foot-ball impacts can naturally influence reaction time. The results did reveal an influence, but in the opposite direction with respect to the hypothesized one: indeed, as the speed of the shot/loudness of the impact increased, the reaction time in response to it increased as well. This unexpected outcome may have been due either to the variation of the pitch of the stimuli, or to the excessive power of the experiment, which may have highlighted as significant an effect that was potentially accidental.

To further investigate in this direction, for Experiment 3 were chosen as stimuli impacts of shots with a greater speed difference between them compared to those of Experiment 2; moreover, the experimental conditions were two and not four, so the power was comparable to that of Experiment 1. The results revealed no difference in the reaction time in response to the two stimuli, thus allowing to claim that different foot-ball impacts would not influence reaction time, at least for the speed range of the considered shots.

Taken together, the results of the first three experiments suggest that the natural loudness differences among foot-ball impacts of shots with different speeds would not be sufficient to promote a variation in the reaction time in response to them. However, by artificially manipulating the loudness of the stimuli it is possible to obtain the general phenomenon observed with pure tones, i.e. an inverse relation between loudness and reaction time; this is in line also with the results of Brown and colleagues (2008) on sprint starts. Obviously, these considerations are referred to the specific stimuli used in the present experiments; future studies could further investigate on these issues, to test whether other ecological sounds may have the properties to naturally influence simple reaction time.

As concerns Experiment 4, it slightly differed from the previous ones as its focus was not on the stimuli, but on the frame provided to the participants through the scenarios described in the instructions. The results revealed no difference in the reaction time between two scenarios that differed between each other for the magnitude of the potential loss. However, as mentioned above, it would be risky to claim that framing cannot influence reaction time on the basis of this experiment alone, as it has been the first known one to investigate this relation. Future studies on this issue could draw on the vast literature concerning framing to test whether some factors that modulate it can promote its effects also on simple reaction time.

Beyond the data and the results of statistical analyses, it is worth noting that almost all participants were able to perceive that, within the experiment they attended, the stimuli were different among each other (and that they were not different as concerns Experiment 4). This fact emerged during the debriefing at the end of the experiment, when the participant was informed about the details of the experiment itself; indeed, in this occasion the vast majority of participants spontaneously reported that they heard that stimuli were “somehow different between them” (or, as concerns Experiment 4, that they “sounded the same”). This was the case not only for Experiment 1, in which the difference between the stimuli was big enough to influence the reaction time, but also in experiments 2 and 3, in which the differences concerning the reaction time were small or absent at all, respectively. In the next two chapters, five experiments are described in which this ability to distinguish qualitatively similar auditory stimuli is implied.

Chapter 3

The contribution of early auditory and visual information to the discrimination of shot power in ball sports[4]

3.1 Introduction

In sport, rapidly and accurately reacting to external stimuli is important to perform effectively. In particular, in ball sports it is fundamental to be able to perceive all the information related with the ball, in order to prepare an appropriate motor response. Research has shown that, in sport-specific situations, athletes can accurately perceive the ball motion itself (Davids, Savelsbergh, Bennett & van der Kamp, 2002), but they can also infer it from the movement of the opponent who is "interacting" with the ball (e.g., Diaz, Fajen & Phillips, 2012). The latter skill, which implies the elaboration of early information, determines obvious advantages for the athletes, as they have more time to execute the appropriate motor response.

There is a vast literature dealing with the above-mentioned issues, which are typically studied in the framework of interceptive actions (Davids et al., 2002) and anticipation skills (Mann et al., 2007). For instance, it is well-established that the correct interpretation of early information is promoted by expertise, which fosters fast and accurate predictions concerning the outcome of an action in ball sports (e.g., Abernethy et al., 2001; Loffing & Hagemann, 2014; Loffing, Hagemann, Schorer, & Baker, 2015; Savelsbergh, Williams, van der Kamp & Ward, 2002). Moreover, some studies revealed that it is possible to develop perceptual training based on early information, in order to improve athletes' anticipation skills (e.g., Farrow & Abernethy, 2002; Murgia et al., 2014).

All the studies mentioned in the previous paragraph concern the visual domain, and most of them are based on the temporal occlusion technique. To the best of our knowledge, no study has applied this technique to the auditory information in sport and, in general, the auditory domain has been only rarely studied in the field of anticipation (Camponogara et al., 2017). This is quite surprising, as there is a growing body of research that highlights the relevance of the auditory information in sport (for a review, see Sors et al., 2015).

---

[4] This is the accepted manuscript of an article (The contribution of early auditory and visual information to the discrimination of shot power in ball sports) published by Elsevier in Psychology of Sport and Exercise, available online since 05.04.2017 at http://www.sciencedirect.com/science/article/pii/S1469029216303284.

As already mentioned in Chapter 1, one of the first researchers who highlighted the relevance of auditory information in sport was Takeuchi (1993). He made some tennis players play against each other, depriving one of the two opponents of auditory information. Results revealed that, compared to the normal condition, auditory deprivation significantly impaired athletes' performances, in particular concerning the response to the serve.

In more recent years, other field experiments further revealed that auditory information can affect sport performance. For instance, Brown and colleagues (2008) observed that in sprint events, an increase of the intensity of the "go" signal (i.e., a gunshot) decreases the reaction time of the sprinters. Moreover, some researchers highlighted that the sounds related to a performance, used either as a model or as a feedback, can improve the performance itself. For example, Agostini and colleagues (2004) observed that providing hammer throwers with the recorded sound of the rotation of a well-executed throw promotes an upward standardization of their performance. Along similar lines, Schaffert and colleagues (2011) observed that providing rowers with an online sonification of the acceleration and deceleration of the boat promotes an increase in the boat velocity (at the same stroke rate).

Recently, researchers have tried to better understand the mechanisms underlying the elaboration of the auditory information related to sport movements. In this regard, Woods and colleagues (2014) observed that sports-related sounds promote the activation of premotor and motor areas of the brain on the basis of expertise. The fact that action-related sounds also activate the motor brain areas is well-established (e.g., Pizzamiglio et al., 2005); the novelty is represented by the fact that this activation is greater on the basis of both the familiarity with the specific sport and the level at which the athletes compete (in that specific sport). Moreover, other researchers highlighted that athletes are able to recognize the sound produced by their own performance among the sounds of other athletes performing the same movement (Kennel, Hohmann & Raab, 2014; Kennel et al., 2014; Murgia et al., 2012).

As can be noted, the perceptual research on sound and sport covers quite a wide range of topics (for a review, see Pizzera & Hohmann, 2015), however the role of auditory information in ball sports has been rarely studied. In particular, early auditory information in ball sports includes the impact between the athletes (or their equipment) and the ball, which could provide some information concerning the power and the type of shot/hit, which determine the ball speed. To the best of our knowledge, the contribution of early auditory information to the perception of spatio-temporal aspects of ball motion has not yet been investigated by researchers.

Conversely, the role of early information in the ball motion perception has been widely studied in the visual domain (Davids et al., 2002; Mann et al., 2007). In this regard, recent studies highlighted that successful interceptions require the integration of early visual information from the kinematics of the opponent and from the ball flight (Panchuk, Davids, Sakadjian, MacMahon, & Parrington, 2013; Stone, Panchuk, Davids, North, & Maynard, 2014; Stone, Maynard, North, Panchuk, & Davids, 2015). However, as we claimed in the previous paragraph, also early auditory information about the ball motion could be useful, especially that concerning the shot power.

Summarizing, one line of research highlights that early visual information has an important role in ball sports; in particular, its correct interpretation promotes accurate predictions concerning the ball motion. Another line of research highlights that auditory information may represent a relevant source of information in various sport situations. In the present study we combine these two lines of research with the aim to better understand the contribution of early auditory and visual information to the discrimination of shot power in two specific sport situations. To this purpose, two experiments were run: Experiment 5 concerns soccer penalty kicks, while Experiment 6 concerns volleyball smashes.

3.2 Experiment 5

In Experiment 5, we decided to focus on a widely studied sport situation, such as the soccer penalty kick. Soccer is an open skill sport, within which the penalty kick, from the research perspective, is more easily controllable, and therefore manipulable, than the general gameplay. This fact, together with the importance that a single penalty or a shootout can have during a match, explains the large number of studies and the various approaches used to deal with this situation (e.g., Bar-Eli, Azar, Ritov, Keidar-Levin, & Schein, 2007; Piras & Vickers, 2011; van der Kamp, 2006; Wilson, Wood, & Vine, 2009).

By using this situation, the present experiment aimed at investigating the contribution of early auditory and visual information to the discrimination of shot power. In particular, we intended to better understand whether one of the two sources of information is more relevant than the other or, alternatively, whether they co-contribute to a similar extent. Thus, we could hypothesize three potential scenarios concerning the results: 1) if auditory information is more relevant than visual information, then when the former is present participants would be faster and more accurate in making the discriminations, compared to when it is absent; 2) if visual information is more relevant than auditory information, then when the former is present participants would be faster and more accurate in making the discriminations, compared to when it is absent; 3) if auditory and visual information co-contribute to a similar extent, then when both are present participants would be faster and more accurate in making the discriminations compared to when just one of the two sources of information is present.

3.2.1 Materials and methods

Participants

Eighteen soccer players took part in the experiment. They were all males, with an average age of 23.1 years (SD = 2.1) and an average playing experience in amateur leagues of 15.4 years (SD = 4.1); thirteen of them were right-footed, and five were left-footed. All participants had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Apparatus

To record the visual stimuli, an action camera with a temporal resolution of 60fps and a spatial resolution of 1080p was used (GoPro HD Hero 3 Black Edition; the GoPro App was used to adjust the camera framing). To record the auditory stimuli, a stereo microphone (Soundman Binaural, OKM II Professional) connected to an external sound card (M-AUDIO MobilePre) was used. To manipulate the video and audio recordings, two dedicated editing software were used, iMovie and Adobe Audition 3.0 respectively.

The experimental sessions were programmed with the E-prime Professional 2.0 software, and were administered to the participants through a laptop computer ASUS X52J with a 15.6” LCD display; auditory stimuli were conveyed through Philips SHP1900 circumaural headphones.

Stimuli recording

The stimuli were recorded in the same occasion as those for the previous group of experiments. Indeed, other than the stereo microphone, on the tripod there was also the action camera (cfr. figure 5, pp. 25).

Stimuli editing

Like for the previous group of experiments, mistargeted penalty kicks, as well as those with some interference in the recordings, were discarded from the database. Then, the speeds of the remaining penalties were calculated as previously described (cfr. pp. 25).

11 penalty kicks were selected on the basis of their speed. As a reference, a penalty with the speed equal to the average of the database was selected, i.e. 77 km/h. Moreover, we selected

5 penalties slower than the average (62 km/h, 71 km/h, 74 km/h, 75 km/h, 76 km/h), and 5 faster than the average (78 km/h, 79 km/h, 80 km/h, 83 km/h, 101 km/h). Thus, we had penalties that differed 1, 2, 3, or 6 km/h from the average; moreover, we included the slowest one and the fastest one of the entire database[5].

The audio and video files of these penalties were edited through the above mentioned software, and we created three kinds of stimuli – auditory, visual, and audiovisual – for each penalty. For every stimulus, the available information concerned the run-up of the kicker and the impact between his foot and the ball (see figure 13): at this point, the video files were occluded with a black screen, and the audio files were interrupted.

Figure 13. The last frame before the temporal occlusion.

Task and procedure

Participants' task was to discriminate the power of two penalty kicks presented in sequence, based on a two-alternative forced choice paradigm; specifically, participants were required to discriminate as accurately and as fast as possible whether the second penalty (target) was more or less powerful than the first one (reference). Thus, a prototypical trial (see figure 14) included a reference stimulus, an interstimulus interval (ISI) of 400 ms, and a target stimulus, after which participants could provide their response pressing one of two keys, i.e. "A" or "L" in a QWERTY keyboard; the subsequent trial started 1 s after the previous response. The

---

[5] The difference between the speed of the reference penalty and the fastest penalty was higher than the difference between the reference penalty and the slowest one. However, this difference is irrelevant for our scopes, because we were not interested in comparing penalties faster than the reference with those slower than the reference.

correspondence between the keys and the answers associated to them was inverted after participants had completed half of each session, in order to keep under control the effect of the dominant hand on response times. The dependent variables measured to evaluate participants' performance were response accuracy and response time.

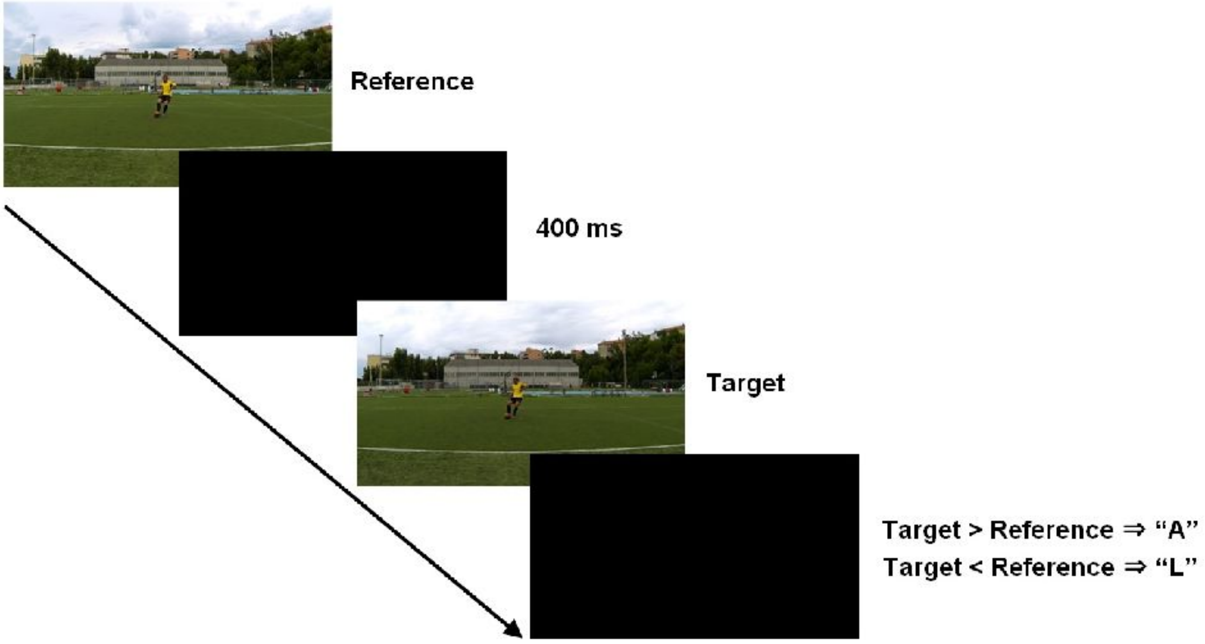


Figure 14. A prototypical trial of the experimental task in the Video condition. Both reference and target were videos showing the run-up of the kicker until the foot-ball impact (the last frame of each video is here shown). A black screen between the reference and the target was shown for 400 ms; after the target another black screen appeared, during which participants could provide their response. The structure of the trials in the Audio and Audiovideo conditions was exactly the same.

Every experimental session consisted of two blocks, each composed of 10 practice trials and 30 test trials. The reference penalty kick was always the same, i.e. the one with the speed of 77 km/h, while the target penalties were the remaining 10. In the test trials, for each block, each of the 10 target stimuli was presented 3 times in a randomized order.

The experimental conditions were three: Audio (only audio files), Audiovideo (synchronized combination of audio and video files), and Video (only video files). A within subjects experimental design was used, with the three conditions carried out in three different days and in a counterbalanced order among participants.

As concerns the procedure, participants were tested individually in a silent room. Upon their arrival, they were asked to sit in front of the laptop and to wear the headphones (also in the Video condition, so that participants were in the same situation in all three conditions). Then, the experimenter launched the session of the scheduled condition. In order to standardize the instructions, they were reported in textual form at the beginning of each session.

3.2.2 Results

For the response accuracy (figure 15) a set of one sample t-tests revealed that participants performed significantly above the chance level in all three conditions: Audio [$t(17) = 9.858$; $p < 0.001$; $d = 2.32$]; Audiovideo [$t(17) = 8.583$; $p < 0.001$; $d = 2.02$]; Video [$t(17) = 13.480$; $p < 0.001$; $d = 3.18$]. A repeated measures ANOVA revealed no difference among conditions.

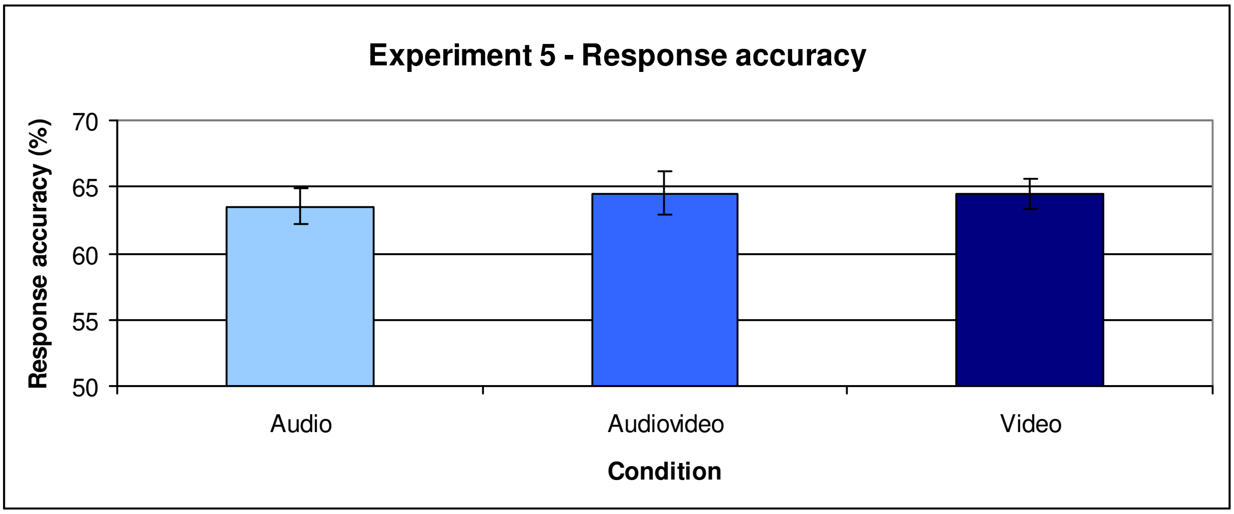


Figure 15. Response accuracy in the three conditions. Error bars show the standard error of the mean.

As concerns response times (figure 16), only those of correct responses were considered. A repeated measures ANOVA highlighted a significant main effect of the Condition [$F(2, 34) = 4.843$; $p < 0.05$; $\eta^2 = 0.22$]. A set of paired samples t-tests revealed that, compared to the Video condition, participants were significantly faster both in the Audio [$t(17) = 2.364$; $p < 0.05$; $d = 0.46$] and Audiovideo [$t(17) = 2.310$; $p < 0.05$; $d = 0.53$] conditions; no significant difference was observed between the Audio condition and the Audiovideo condition.

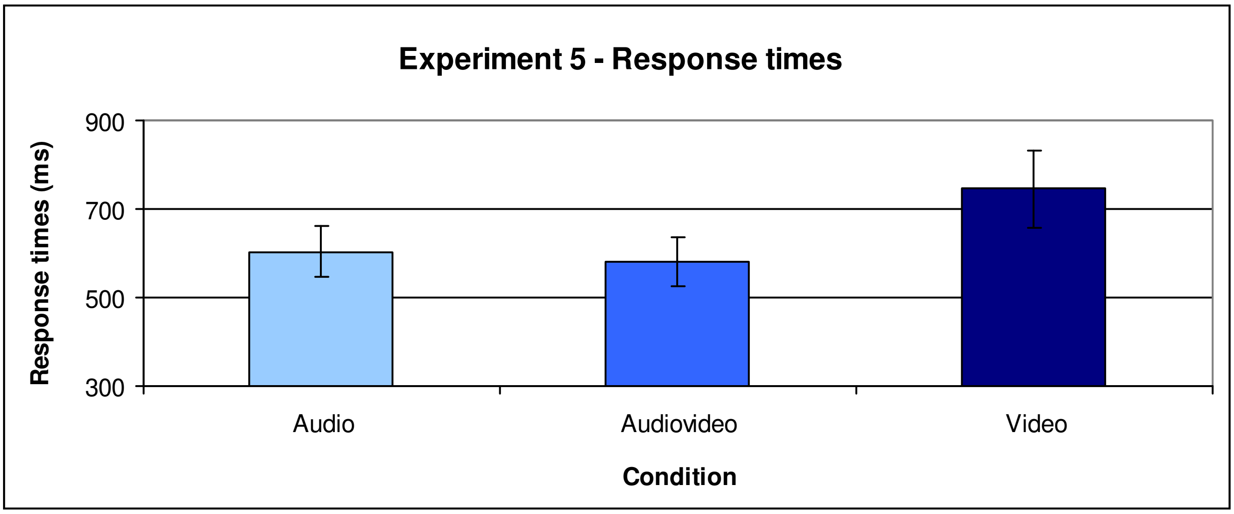


Figure 16. Response times in the three conditions. Error bars show the standard error of the mean.

3.2.3 Discussion

The aim of Experiment 5 was to investigate the contribution of early auditory and visual information to the discrimination of penalty kicks power. To this purpose, a two-alternative forced choice task was created, through which participants were required to discriminate the power of penalties presented in pairs, relying either on auditory and visual information alone or in combination between them.

As concerns the response accuracy, the results revealed that in all the three conditions participants performed above chance level, without any difference among conditions; this means that they were equally able to accurately discriminate shot power both on the basis of auditory and visual information together, and relying either only on the former or the latter alone. Conversely, as concerns the response times, the results revealed that when the auditory information was present, participants were faster in making the discriminations; our interpretation of this outcome is that the early auditory information concerning a penalty kick would be more easily processed than the respective visual information. It is noteworthy that this faster elaboration of the auditory information does not affect the response accuracy.

Although we failed to find an effect on response accuracy, taken together, the results seem to better fit the hypothesized scenario 1, thus suggesting a prevalence of auditory information over visual information. To better investigate this hypothesis, we decided to run a second experiment in another sport situation.

3.3 Experiment 6

In Experiment 6 we decided to focus on the volleyball smash. Like soccer, volleyball is also an open skill sport, in which the smash represents the most recurring type of attack. Due to the fact that a smash implies the interaction of (at least) two players, from the research perspective it is less controllable, and therefore less manipulable, than a soccer penalty kick, yet there are some studies dealing with this situation (e.g., Loffing et al., 2015; Vansteenkiste, Vaeyens, Zeuwts, Philippaerts & Lenoir, 2014).

This situation was chosen to evaluate whether the results obtained in Experiment 5 can be observed also in another sport. In light of the results of the former experiment, we hypothesized a response accuracy above chance level in all the three conditions, without differences among them; instead, as concerns response times, we hypothesized faster responses when the auditory information was present.

3.3.1 Materials and methods

Participants

Seventeen volleyball players (11 females, 6 males) took part in the experiment. They had an average age of 26.7 years (SD = 3.6) and an average playing experience in amateur leagues of 13.6 years (SD = 6.5). All of them were right-handed, had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Apparatus

The instruments and software used were the same as for Experiment 5.

Stimuli recording

The stimuli were recorded on a regular volleyball court. Observing figure 17, the smashes started from the left corner near the net and were directed toward the opposite corner of the other half of the court. In this corner, nine sectors of 1 x 1 m were delimited with some scotch-tape, in order to identify the ball landing point. On the end-line, 1 m away from the side-line, a tripod with the action camera and the stereo microphone was placed; the instruments were 1.75 m high, and they were oriented toward the smashes starting point, reproducing the possible perspective of a player ready to defend a diagonal smash.

To record the stimuli, four male volleyball players were recruited, with an average age of 30 years and an average playing experience of 12 years in amateur leagues; three of them were hitters (all right-handed), while one was a setter. According to the recoding procedure, the hitter passed the ball to the setter, the setter set the ball for the hitter, and then the hitter performed a diagonal smash. Overall, 100 smashes were recorded.

Stimuli editing

The editing phase was very similar to the one described for the previous experiment. Also in this case the mistargeted smashes, as well as those whose files had a disturbance, were discarded from the database. Moreover, an expert coach conducted a technical analysis in order to discard poorly executed smashes; this analysis was mainly based on the video recordings, but also on their comparison with the respective audio files to find potential anomalous impacts with the ball.

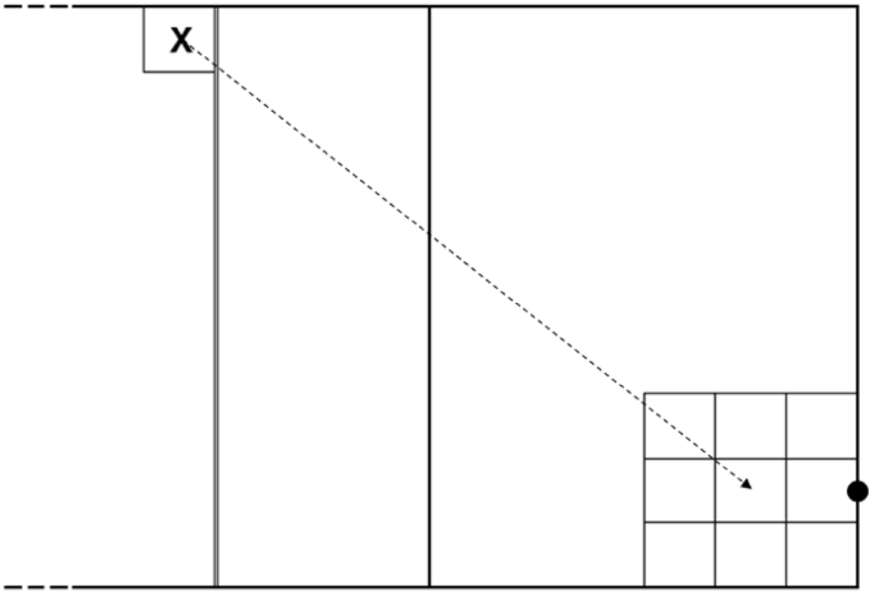


Figure 17. Reproduction of the recording setting. The "X" represents the smashing point, and the arrow indicates the direction of the smashes. The nine squares represent the sectors used to determine the landing point of the ball; the dot indicates where the camera and the microphone were placed.

After this operation, the database consisted of 39 smashes, whose speeds were calculated as described in Experiment 1, i.e. dividing the distance travelled by the ball by the travel time. In this regard, the starting point for all the smashes was arbitrarily established as distant 0.5 m from both the side-line and the net, and 2.70 m high; the distance travelled by the ball was calculated according to its landing point.

Out of the 39 smashes, 11 were selected on the basis of their speed. As a reference, a smash with the speed equal to the average of the database was selected, i.e. 59 km/h. Moreover, we selected 5 smashes slower than the average (45 km/h, 50 km/h, 53 km/h, 55 km/h, 57 km/h), and 5 faster than the average (61 km/h, 63 km/h, 65 km/h, 68 km/h, 74 km/h). Thus, we had smashes that differed 2, 4, 6, or 9 km/h from the average; moreover, we included the slowest one and the fastest one of the entire database.

The audio and video files of these smashes were edited through the above mentioned software, and we created three kinds of stimuli – auditory, visual, and audiovisual – for each smash. For every stimulus, the available information started with the pass of the hitter to the setter and ended with the impact between the hitter hand and the ball (see figure 18): at this point, the video files were occluded with a black screen, and the audio files were interrupted.

Figure 18. The last frame before the temporal occlusion.

Task and procedure

Participants' task was the same as for Experiment 1, i.e. discriminating the power of two smashes presented in sequence through a two-alternative forced choice paradigm. Also the structure of the experimental sessions, the experimental conditions and design, the dependent variables, and the procedure were the same as for Experiment 1.

3.3.2 Results

For the response accuracy (figure 19) a set of one sample t-tests revealed that participants performed significantly above the chance level in all three conditions: Audio [$t(16) = 8.785$; $p < 0.001$; $d = 2.13$]; Audiovideo [$t(16) = 6.846$; $p < 0.001$; $d = 1.66$]; Video [$t(16) = 4.504$; $p < 0.001$; $d = 1.09$]. A repeated measures ANOVA highlighted a significant main effect of the Condition [$F(2, 32) = 10.382$; $p < 0.001$; $\eta^2 = 0.39$]. A set of paired samples t-tests revealed that, compared to the Video condition, response accuracy was significantly higher both in the Audio [$t(16) = 3.925$; $p < 0.01$; $d = 0.92$] and Audiovideo [$t(16) = 3.526$; $p < 0.01$; $d = 0.81$] conditions; no significant difference was observed between the Audio condition and the Audiovideo condition.

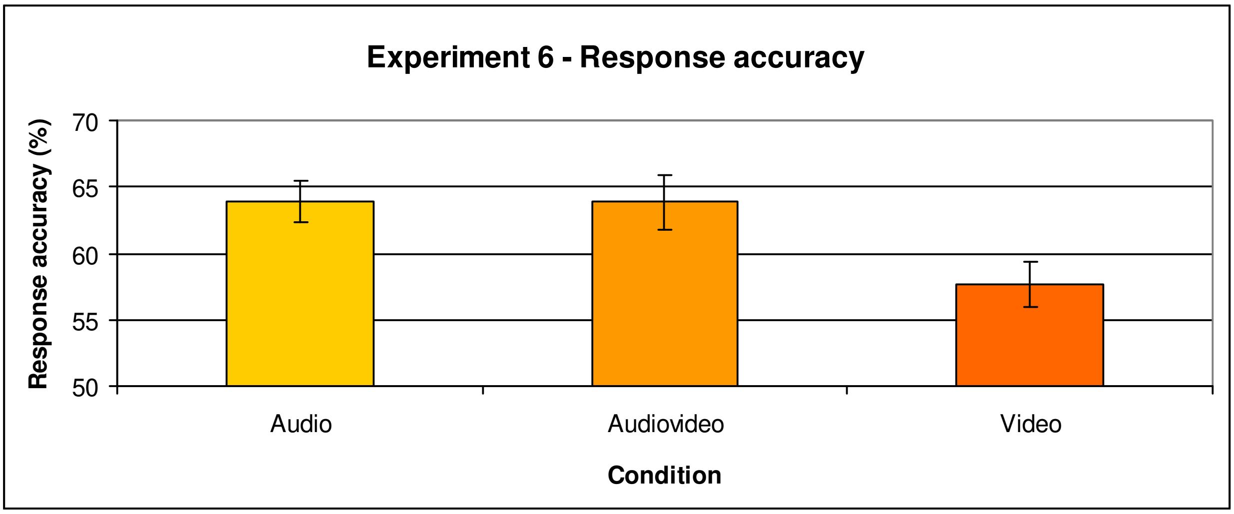


Figure 19. Response accuracy in the three conditions. Error bars show the standard error of the mean.

As concerns response times (figure 20), only those of correct responses were considered. A repeated measures ANOVA highlighted a significant main effect of the Condition [$F(2, 32) = 13.725$; $p < 0.001$; $\eta^2 = 0.46$]. A set of paired samples t-tests revealed that, compared to the Video condition, participants were significantly faster both in the Audio [$t(16) = 3.631$; $p < 0.01$; $d = 0.64$] and Audiovideo [$t(16) = 4.814$; $p < 0.001$; $d = 0.85$] conditions; no significant difference was observed between the Audio condition and the Audiovideo condition.

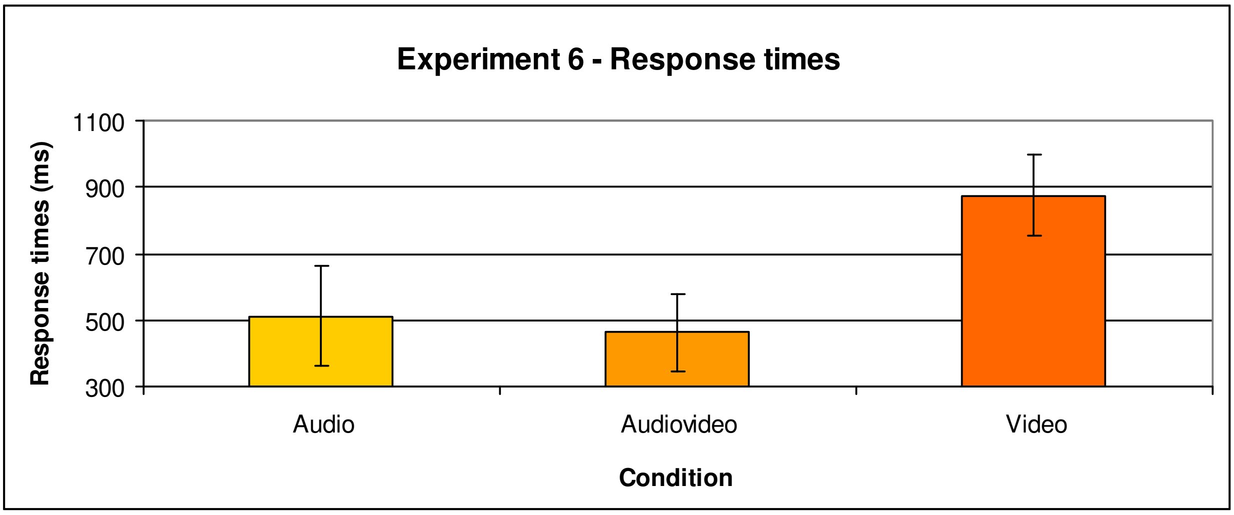


Figure 20. Response times in the three conditions. Error bars show the standard error of the mean.

3.3.3 Discussion

The aim of Experiment 6 was to investigate the contribution of early auditory and visual information to the discrimination of volleyball smashes power, and to evaluate whether the results observed in Experiment 5 could be replicated also in a situation different from the penalty kick. To this purpose, the same experimental design previously used for soccer was applied to volleyball: a two-alternative forced choice task was created, through which participants were required to discriminate the power of smashes presented in pairs, relying either on auditory and visual information alone or in combination between them.

As concerns the response accuracy, the results revealed that in all the three conditions participants performed above chance level; however, differently from Experiment 1, they were more accurate when the auditory information was present. This suggests that, even though visual information alone is sufficient to discriminate smashes power above chance level, auditory information promotes an even higher accuracy, independently of the presence of visual information. As concerns the response times, like in Experiment 5, the results revealed that when the auditory information was present, participants were faster in making the discriminations; again, we interpret this outcome in terms of ease of processing, which would be greater for early auditory information than for the respective visual information.

Taken together, the results of Experiment 6 suggest that the early auditory information associated with volleyball smashes would be more relevant than the respective visual information for the discrimination of the shot power, promoting both faster and more accurate responses.

3.4 General discussion

Previous research has extensively studied the perception of ball motion in sport focusing on the visual domain (Davids et al., 2002; Mann et al., 2007). Notwithstanding the growing evidence concerning the relevance of the auditory information in sport (Pizzera & Hohmann, 2015; Sors et al., 2015), to the best of our knowledge no study has ever investigated the contribution of sound to the perception of ball motion. To start filling this gap, two experiments were run, whose aim was to investigate the contribution of early auditory and visual information to the discrimination of shot power in two different sport situations, i.e. soccer penalty kicks and volleyball smashes.

As concerns response times, the results of the two experiments are consistent. Indeed, in both of them, participants were faster in making the discriminations when the auditory information was present, i.e. in the Audio and Audiovideo conditions compared to the Video condition. Our interpretation of this outcome is that the early auditory information concerning penalties and smashes would be more easily processed than the respective visual information.

As concerns the response accuracy, the results of the two experiments only partially overlap. In both of them, participants performed above chance level in all the three conditions; however, while for the penalties there was no difference among conditions, for the smashes participants were more accurate when the auditory information was present, independently of visual information. These outcomes suggest that in both sport situations, even auditory or visual information alone would be sufficient to accurately discriminate shot power; moreover, in the case of volleyball smashes, the auditory information seems to be more relevant than the respective visual information. One possible reason for this difference is that smashes were recorded indoor, while penalties were recorded outdoor; in this regard, future studies should explore the potential influence of the recording setting.

Taken together, the results of the two experiments suggest that, compared to early visual information, early auditory information associated with soccer penalty kicks and volleyball smashes would provide more relevant perceptual cues, which would be faster to process and, in the case of volleyball, also more informative. Thus, it seems that the power of shots can be more easily inferred from auditory cues than from visual cues. In other words, the available auditory cues (e.g., loudness and pitch of sound produced by the foot/hand-ball impact) would be more informative than the available visual cues (e.g., kinematics and velocity of the opponent's movement). Some of our methodological choices (e.g., relatively small number of repetitions per stimulus) did not allow us to make trustable comparisons among stimuli with different speeds; this aspect should be further investigated.

In perceptual-motor literature, there are several cases in which the auditory modality outperforms the visual modality. For instance, simple reaction times to auditory stimuli are faster than those to visual stimuli (e.g., Elliott, 1968; Jain et al., 2015), and discrimination between temporal intervals is more accurate in the auditory modality compared to the visual modality (e.g., Grondin & McAuley, 2009). However, these phenomena are based on mechanisms different from those determining the effect reported here. Indeed, in classic reaction times experiments participants are not required to access the semantic meaning of the stimuli; conversely, in our task participants needed to process the stimuli, to compare their properties and to make a decision. Our task also differs from those used in interval discrimination experiments, since in our study the decisions were made on the basis of temporally occluded stimuli which showed only the beginning of the action but not its end. Thus, our participants discriminated the shot power not by calculating the temporal difference between the start and the arrival of the ball, but by processing only the available cues, i.e. early information. We can speculate that, compared to the visual modality, in the auditory modality there would be a lower cognitive load in the sequence of processes needed to perform our task and, consequently, faster response times. Future studies should further clarify our interpretation.

From an applied point of view, a well-known issue for researchers working in this area is the transfer of the results observed in laboratory to real-world situations (Dicks, Button, & Davids, 2010; Farrow & Abernethy, 2002; Hopwood, Mann, Farrow, & Nielson, 2011; Put, Wagemans, Jaspers, & Helsen, 2013). In the present study we used a discrimination task, which allowed us to reach a good control of potential confounding variables but was quite unnatural for athletes. Indeed, during competitions, athletes are used to react as fast as possible to environmental stimuli rather than to compare two similar situations. However, the ability to interpret early information on shot power reasonably represents the first step for the prediction of the spatio-temporal dynamics of the ball motion. The present study helps to better understand the former mechanism; instead, to investigate the latter, future studies should use more realistic tasks, such as, for instance, the prediction of the landing zone of volleyball serves on the basis of their length as an indirect measure of ball speed.

Once the mechanisms underpinning the ball motion perception will be better clarified, it could be possible to develop new perceptual-motor training protocols. In particular, it would be useful to understand whether focusing also on auditory information could contribute to promote faster reactions to opponents' actions. Indeed, to perform effectively in ball sports it is not sufficient to accurately anticipate/perceive the direction and the speed of the ball, but it is also fundamental to be fast in doing so, in order to have enough time to execute an appropriate motor response. Thus, discovering how to help athletes to improve in this regard would represent a precious progress for enhancing their performances. Concluding, the results of the present study encourage further investigation on the role of auditory information on anticipation in sport.

Chapter 4

The contribution of early auditory and visual information to the anticipation of volleyball serves

4.1 Introduction

In sports like volleyball and tennis, the serve has a key role. Indeed, if you perform it well, you can either directly score a point (i.e., an ace), or hinder the response of your opponent(s), thus having an advantage in the gameplay. On the other hand, the receiver has to do her/his best to prevent these two possibilities from happening, trying at the same time to prepare the ground for a good gameplay. To do so, beside the importance of technical and tactical skills, it is fundamental to accurately perceive the ball motion, in order to move toward the appropriate position enough in advance. In this regard, as already said above, previous research concerning various sports highlighted that athletes can infer the direction and the speed of the ball not only by its motion, but also from the early information provided by the interaction between the opponent and the ball (Davids et al., 2002; Mann et al., 2007).

The vast majority of the studies dealing with these issues focused on the visual domain (e.g., Vickers & Adolphe, 1997). However, thanks to experiments 5 and 6 we saw that early auditory information would provide more relevant cues than the respective visual information to discriminate the power of soccer penalty kicks and volleyball smashes. In the general discussion of the previous chapter we underlined that this outcome was obtained through a task that was quite unnatural for athletes, suggesting that future studies should use tasks that more closely resemble field performance situations, to have a more direct application also from an applied perspective: experiments 7, 8 and 9 were conducted with this purpose.

For these last three experiments we decided to focus on the volleyball serve; in particular, as described in detail below, participants were asked to predict the landing zone of some serves on the basis of their length. This task was chosen as it suited our research needs pretty well: indeed, it requires an indirect estimate of shot power while engaged in a typical field performance situation. Moreover, we focused on the volleyball serve rather than on the tennis one for two more reasons: 1) in volleyball you (always) have to prevent the ball from touching the floor, while in the tennis serve the ball has to bounce once before returning it; thus, in the latter case you can still be successful even if you slightly misinterpret the landing point, while in the former case you cannot; 2) for the different gameplay of the two sports, in tennis it is not so common for the receiver to score a point directly in response to the serve (i.e., a return point), while in volleyball it is much more likely for the receiving team to score a point in the first action after the serve: being able to accurately receive it represents an important precondition to prepare an effective attack.

4.2 Experiment 7

The aim of Experiment 7 was to investigate the relevance of early auditory and visual information in anticipating volleyball serves. To this purpose, as described in detail below, audio and video recordings of overhand serves were assembled either congruently or incongruently and then administered to participants, whose aim was to predict the landing zone of the serves.

In light of the results observed in Experiment 6, we hypothesized that in the incongruent trials, participants would have relied more on auditory information than on visual information to make their predictions. Moreover, independently from the results of the previous experiment, it was reasonable to hypothesize slower response times in the incongruent trials than in the congruent ones, because of the conflict between auditory and visual information. Finally, it was not possible to predict whether the response accuracy for congruent trials would have been higher than chance, as no known study previously investigated on this issue.

4.2.1 Materials and methods

Participants

Twenty-one volleyball players (15 females, 6 males) took part in the experiment. They had an average age of 23.7 years (SD = 4.6) and an average playing experience in amateur leagues of 9 years (SD = 4.1); nineteen of them were right-handed, and two were left-handed. All participants had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Apparatus

The instruments and software used were the same as for experiments 5 and 6 (cfr. pp. 43).

Stimuli recording

The stimuli were recorded on a regular volleyball court. Observing figure 21, the serves were performed right behind the end-line, 1.5 m away from the side-line, and were directed toward the opposite side-line of the other half of the court; in this area, three sectors of 3 x 3 m were delimited with some scotch-tape, in order to identify the ball landing zone. Centred with respect to the width of the court and 1.5 m away from the end-line (inside the court), a tripod with the action camera and the stereo microphone was placed; the instruments were 1.75 m high, and they were oriented straight on, reproducing the possible perspective of a player waiting to receive a serve.

To record the stimuli, a right-handed volleyball player aged 23 and with a playing experience of 12 years in amateur leagues was recruited. He was asked to perform several overhand serves aiming at the three delimited sectors. Overall, 90 serves were recorded.

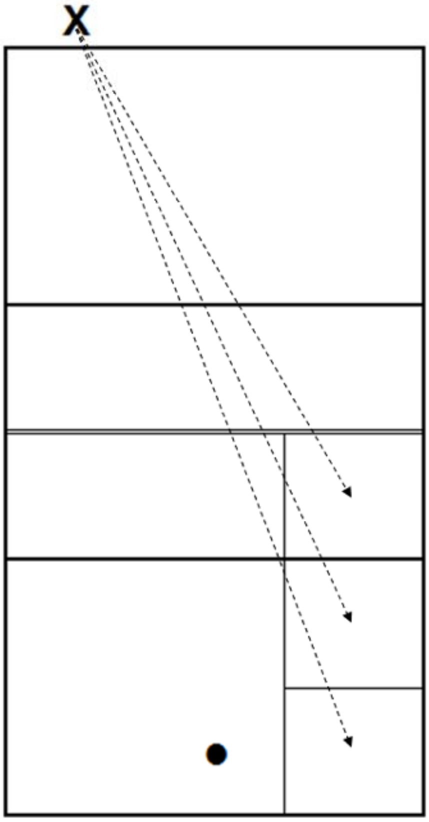


Figure 21. Reproduction of the recording setting. The "X" represents the serving point; the arrows indicate the direction of the serves, and the squares represent the three landing sectors. The dot indicates where the camera and the microphone were placed.

Stimuli editing

The first operation made on the serves database was to discard those that did not land in one of the three delimited sectors, as well as those that had a disturbance either in the audio file (e.g., voice/noise echoes) or in the video one (e.g., the net moving because a previous serve touched it). After this operation, the database consisted of 48 serves. Out of these 48 serves, 20 were selected, half of which landing in the sector near the net (short serves), and the other half landing in the sector near the bottom of the court (long serves). An expert coach assisted the selection, evaluating the technical similarity among the serves.

The audio and video files of these serves were edited and assembled through the above mentioned software. Two kinds of stimuli were created: 1) congruent stimuli, in which the video and the audio files of the same serve were assembled; 2) incongruent stimuli, in which the video of a short serve was assembled with the audio of a long serve, and vice versa. Altogether, 40 stimuli were created: 20 were congruent (10 shorts and 10 longs) and 20 were incongruent (10 with the combination video short-audio long and 10 with the combination video long-audio short). Moreover, 4 other stimuli were created for the practice trials, assembling as just described the audio and video files of 2 of the serves that was not selected.

For every stimulus, the available information started 1 second before the impact between the hand of the server and the ball, and ended 250 ms after it: at this point, the video was occluded with a black screen, and the audio was interrupted (see figure 22). These 1250 ms included the whole serve movement (including the toss) and the first portion of the ball flight.

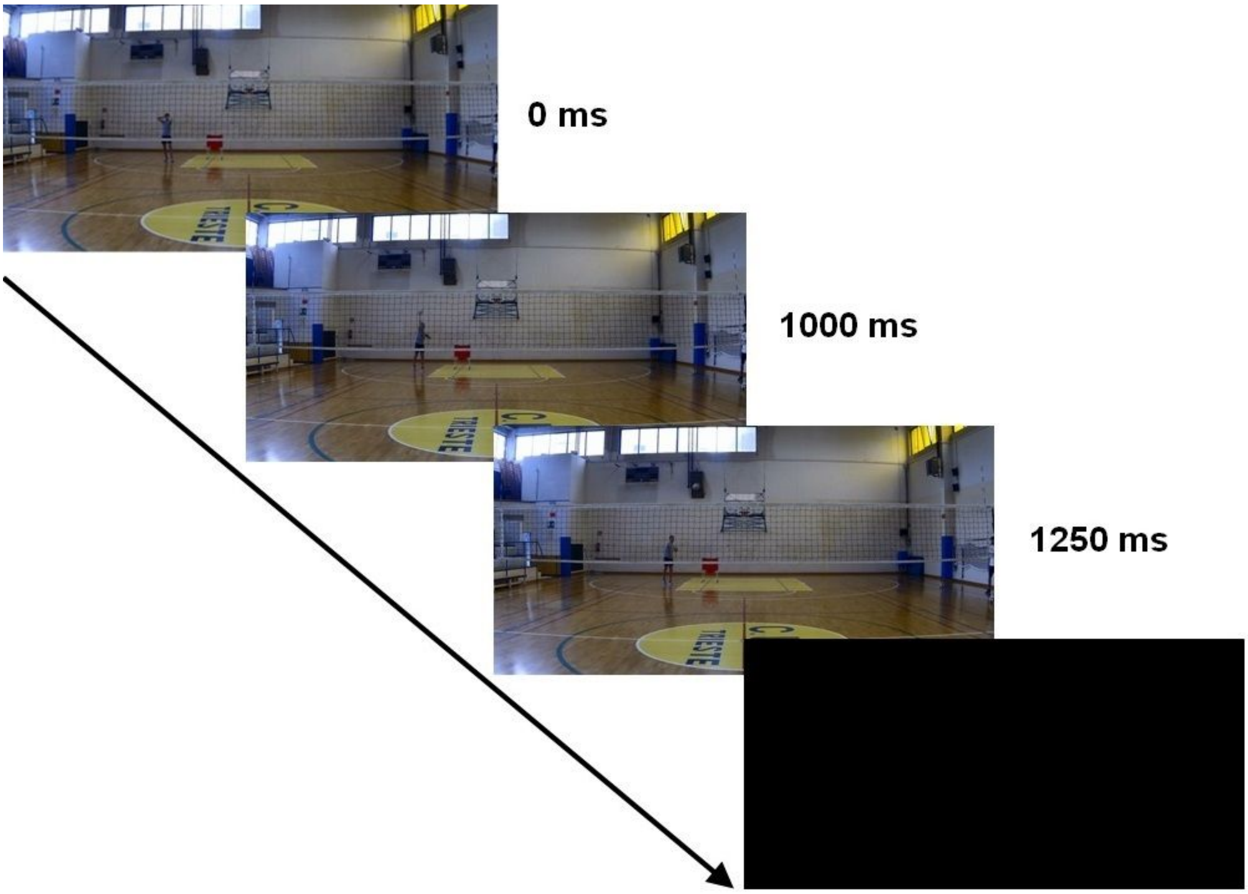


Figure 22. The visual part of a prototypical stimulus. The audio was synchronized with the video, and they were either congruent or incongruent between them as concerns the length of the serve.

According to the data of Vickers and Adolphe (1997) concerning elite players, the onset of the first step to the ball to receive a serve is around 200 ms after the impact between the server hand and the ball, while the onset of the last step is around 700 ms after the impact; finally, the reception is around 1400 ms after the impact. Obviously, the last value varies on the basis of the ball speed and of the receiving point: in their experiment, the estimated ball speed was 45-60 km/h, and athletes received the ball 4-5 m away from the court end-line. In our experiment the participants were amateur players, the estimated ball speed range was comparable to the one above, and the recording instruments were 1.5 m away from the end-line. As a consequence, with the temporal occlusion occurring 250 ms after the impact between the server hand and the ball, we feel entitled to claim that the auditory and visual information provided to our participants can be considered as early information, since after it there would be more than 1 s before the hypothetical receipt.

Task and procedure

Participants' task was to predict in which of the two considered sectors each serve would have landed. Specifically, they were required to do so after every stimulus by pressing one of two keys, i.e. "8" or "2" on the keypad of a QWERTY keyboard (see figure 23 for the correspondence between the sectors and the keys). These keys were chosen to reproduce the proximity/distance of the sectors from the self. The subsequent stimulus started 1.5 s after the previous response.

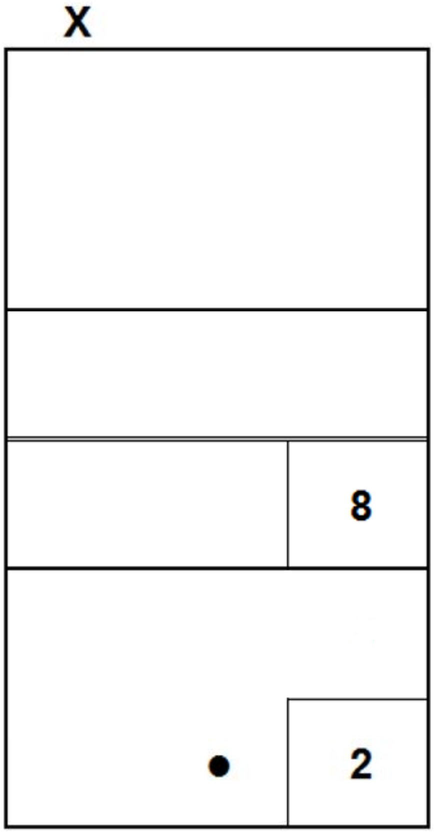


Figure 23. Correspondence between the sectors and the response keys on the keypad. This image was included in the instructions.

The experimental session started with 4 practice trials, and then consisted of two blocks, each composed of 20 test trials; out of these 20 trials, 10 were congruent (5 shorts and 5 longs) and 10 were incongruent (5 with the combination video short-audio long and 5 with the combination video long-audio short). For the congruent trials, the dependent variables used to evaluate participants' performance were response accuracy and response time; for the incongruent trials, the variables considered were the proportion of predictions on the basis of the two sources of information and response time.

As concerns the procedure, participants were tested individually in a silent room. Upon their arrival, they were asked to seat in front of the laptop and to wear the headphones. Then, the experimenter launched the experimental session. In order to standardize the instructions, they were reported in textual form (together with the image reproduced in figure 23) at the beginning of the session.

4.2.2 Results

As concerns the response accuracy of congruent trials, a one sample t-test revealed that participants did not perform above the chance level. As concerns response times (figure 24), a paired sample t-test highlighted significantly slower predictions in the incongruent trials than in the congruent ones [$t(20) = 2.296$; $p < 0.05$; $d = 0.17$].

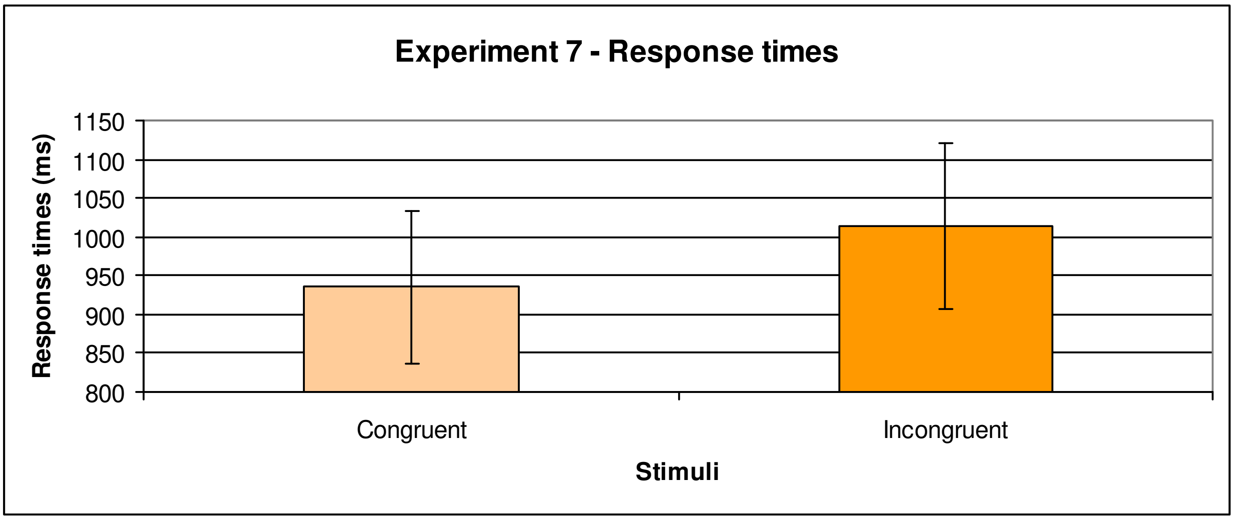


Figure 24. Response times for the two kinds of stimuli. Error bars show the standard error of the mean.

As concerns incongruent trials (figure 25), a paired sample t-test revealed that the proportion of predictions made on the basis of auditory information was significantly greater than the respective proportion of predictions made on the basis of visual information [$t(20) = 1.901$; $p < 0.05$; $d = 0.83$].

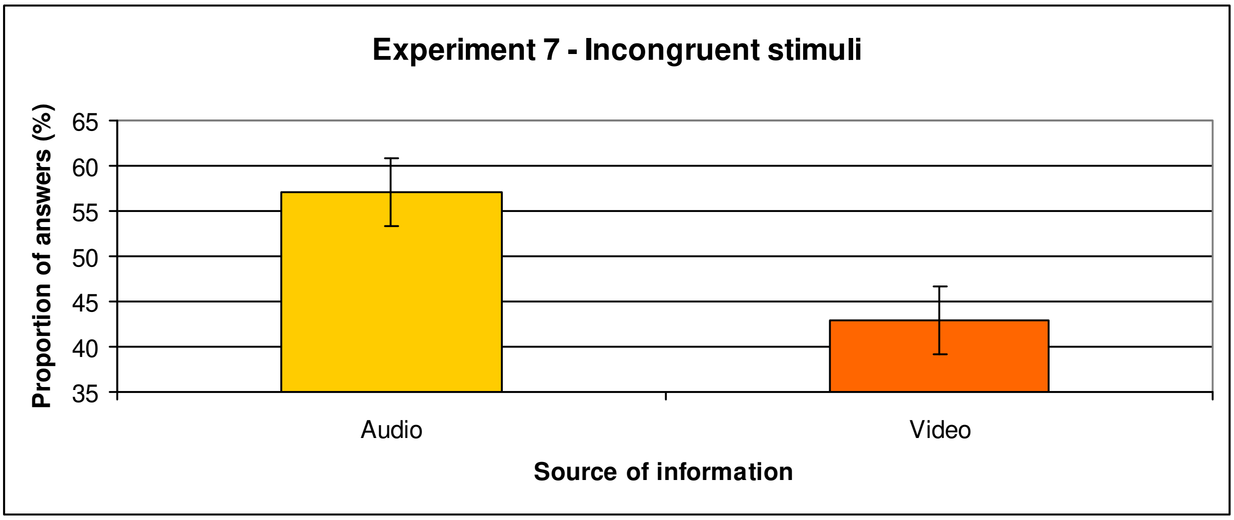


Figure 25. Proportion of predictions on the basis of the two sources of information for the incongruent stimuli. Error bars show the standard error of the mean.

4.2.3 Discussion

The aim of Experiment 7 was to investigate the relevance of early auditory and visual information in anticipating volleyball serves. To this purpose, participants were asked to predict the landing zone of overhand serves on the basis of their length. In half of the stimuli, auditory and visual information were congruent, while in the other half, auditory and visual information were incongruent; as a consequence, thanks to the latter group of stimuli it was possible to evaluate which of the two sources of information participants mostly relied on to make their predictions.

As concerns the congruent stimuli, the results revealed that participants' prediction accuracy was not different from chance; this was reasonably due to the difficulty of the task, whose accurate execution might require more information than the early one provided to the participants in the present experiment. Concerning the response times, the results highlighted that, as hypothesized, participants were slower in making their predictions for the incongruent stimuli compared to the congruent ones; this was reasonably due to the conflict between auditory and visual information. Finally, as concerns the incongruent stimuli, the results revealed that, as hypothesized, participants relied more on early auditory information than on the respective visual information to make their predictions.

Taken together, the results of Experiment 7 suggest that for anticipating the landing zone of overhand serves, athletes would rely more on auditory information than on visual information. However, early information seems to be insufficient to promote a prediction accuracy above the chance level.

4.3 Experiment 8

Experiment 8 was conceived to better understand the contribution of early auditory and visual information to the anticipation of volleyball serves. To this purpose, participants were required to perform the same task of Experiment 7, but in this case relying either only on auditory information or only on visual information. In light of the results of Experiment 6, we hypothesized to observe both faster and more accurate predictions when participants could rely on auditory information than when they could rely on visual information.

4.3.1 Materials and methods

Participants

Twenty-one volleyball players (16 females, 5 males) took part in the experiment. They had an average age of 24.2 years (SD = 5.8) and an average playing experience in amateur leagues of 9.5 years (SD = 4.2); nineteen of them were right-handed, and two were left-handed. All participants had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimuli

The same 20 serves considered for Experiment 7 were also considered for the present experiment. However, in this case the audio and video files were edited separately, thus creating two kinds of stimuli – auditory and visual – for each serve. Moreover, the files of 2 serves among the non-selected ones were used to create the stimuli for the practice trials. Like in the previous experiment, every stimulus lasted 1250 ms, including the whole serve movement and the first portion of the ball flight.

Task and procedure

Participants' task was the same as for Experiment 7, i.e. predicting the landing sector of each serve. Every experimental session started with 2 practice trials, and then consisted of two blocks, each composed of 20 test trials. The experimental conditions were two: Audio (only audio files), and Video (only video files). A within subjects experimental design was used, with the two conditions carried out in a counterbalanced order among participants. The dependent variables measured were response accuracy and response time.

The procedure was similar to that of the previous experiment. Upon their arrival, participants were asked to seat in front of the laptop and to wear the headphones (also in the Video condition, so that they were in the same situation in both conditions). Then, the experimenter launched the first experimental session; the second session was administered 5 minutes after the conclusion of the first one, to provide participants with an appropriate rest.

4.3.2 Results

For the response accuracy (figure 26) a set of one sample t-tests revealed that participants performed significantly above the chance level only in the Audio condition [$t(20) = 5.286$; $p < 0.001$; $d = 1.15$] and not in the Video condition. Moreover, a paired samples t-test revealed that response accuracy was significantly higher in the Audio condition compared to the Video condition [$t(20) = 2.289$; $p < 0.05$; $d = 0.81$].

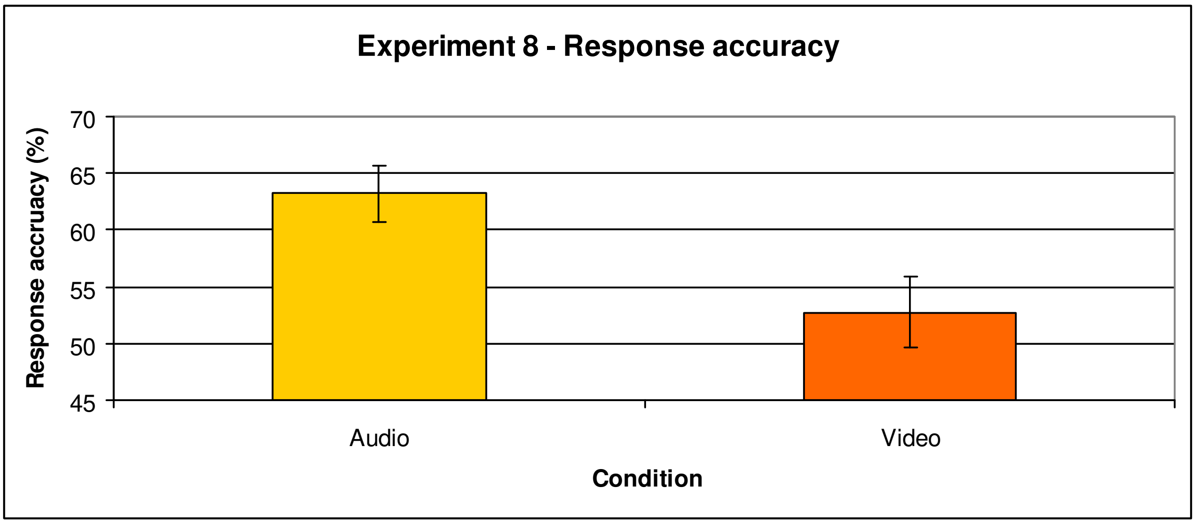


Figure 26. Response accuracy in the two conditions. Error bars show the standard error of the mean.

As concerns response times (figure 27), only those of correct responses were considered. A paired samples t-test revealed no significant difference between the two experimental conditions.

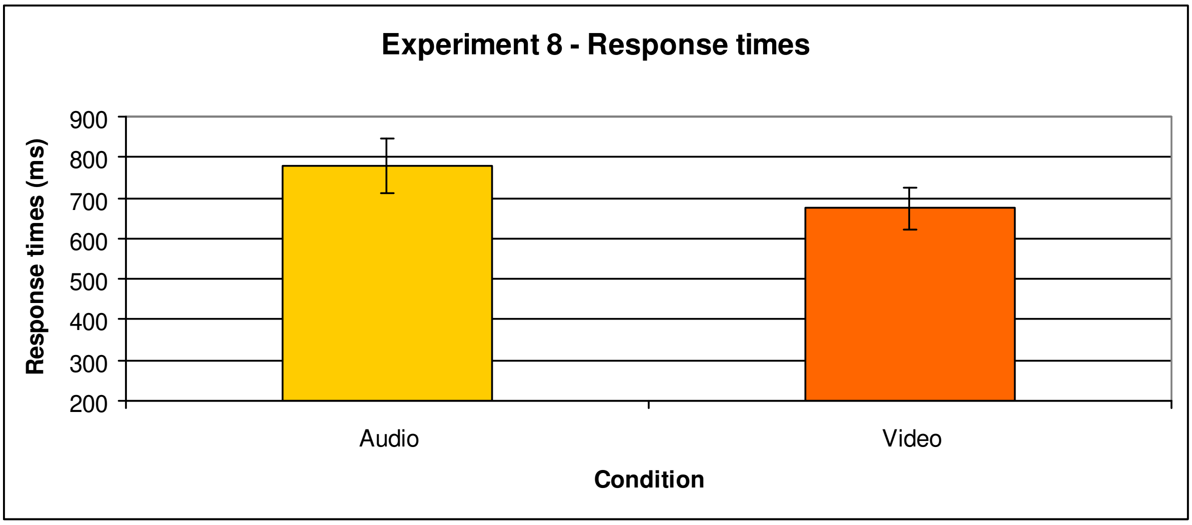


Figure 27. Response times in the two conditions. Error bars show the standard error of the mean.

4.3.3 Discussion

The aim of Experiment 8 was to further deepen the outcomes observed in the previous experiment. To this purpose, participants were forced to rely either only on early auditory information or only on early visual information to make their predictions; by doing so, it was possible to separately evaluate the contribution of the two sources of information in the anticipation of the landing zone of the serves.

As concerns the response accuracy, the results highlighted that, as hypothesized, participants were more accurate when they could rely on auditory information than when they could rely on visual information; moreover, in the former case the performances were also above the chance level, while in the latter case they were not. As concerns the response times, differently from what was hypothesized, the results revealed no difference between the two conditions.

Taken together, the results of Experiment 8 suggest that, at a comparable elaboration time, early auditory information would provide more relevant cues than the respective visual information to predict the landing zone of overhand serves on the basis of their length. In particular, the former seems to provide enough information to promote a better than chance prediction accuracy, while the latter seems to be insufficient to reach such a performance level.

4.4 Experiment 9

Experiment 9 is a repetition of Experiment 8, but considering also serves landing in the middle sector, in order to have a task resembling even more closely the field situation. In light of the results of Experiment 8, we hypothesized to observe more accurate predictions when participants could rely on auditory information than when they could rely on visual information, without any difference concerning response times. Moreover, it was reasonable to hypothesize that accuracy would not have been different from chance in the Video condition, while it was not possible to make a prediction in this regard concerning the Audio condition.

4.4.1 Materials and methods

Participants

Seventeen volleyball players (7 females, 10 males) took part in the experiment. They had an average age of 26.3 years (SD = 6.8) and an average playing experience in amateur leagues of 8.7 years (SD = 4.8); sixteen of them were right-handed, and one was left-handed. All participants had normal or corrected-to-normal vision, and reported no hearing disturbances. Written informed consent was obtained prior to the beginning of the experiment.

Stimuli

As mentioned above, in the present experiment also the middle sector was taken into consideration. Thus, besides the 10 short serves and the 10 long ones considered for the previous experiments, 10 serves landing in the middle sector were also selected, always with the criterion of the technical similarity among them. The audio and video files of these 10 more serves were edited as for Experiment 8, i.e. creating two kinds of stimuli – auditory and visual – for each serve. Moreover, the files of 1 more serve among the non-selected ones were used to create the stimuli for the practice trials. Like in the previous experiments, every stimulus lasted 1250 ms, including the whole serve movement and the first portion of the ball flight.

Task and procedure

Participants' task was the same as for the previous experiments, i.e. predicting the landing sector of each serve. They were required to do so by pressing one of three keys, i.e. "8", "5" or "2" on the keypad of a QWERTY keyboard (see figure 28 for the correspondence between the sectors and the keys).

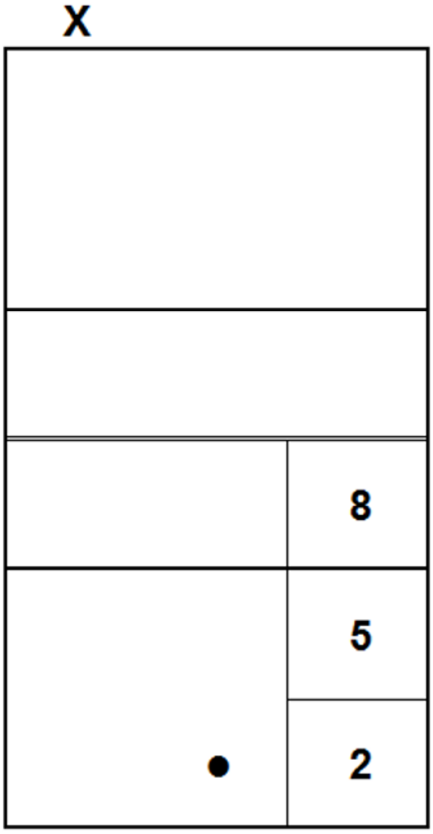


Figure 28. Correspondence between the sectors and the response keys on the keypad. This image was included in the instructions.

Every experimental session started with 3 practice trials, and then consisted of two blocks, each composed of 30 test trials. The experimental conditions and design, the dependent variables, and the procedure were the same as for Experiment 8.

4.4.2 Results

For the response accuracy (figure 29) a set of one sample t-tests revealed that participants performed significantly above the chance level only in the Audio condition [$t(16) = 5.504$; $p < 0.001$; $d = 1.33$] and not in the Video condition. Moreover, a paired samples t-test revealed that response accuracy was significantly higher in the Audio condition compared to the Video condition [$t(16) = 3.951$; $p < 0.01$; $d = 1.36$].

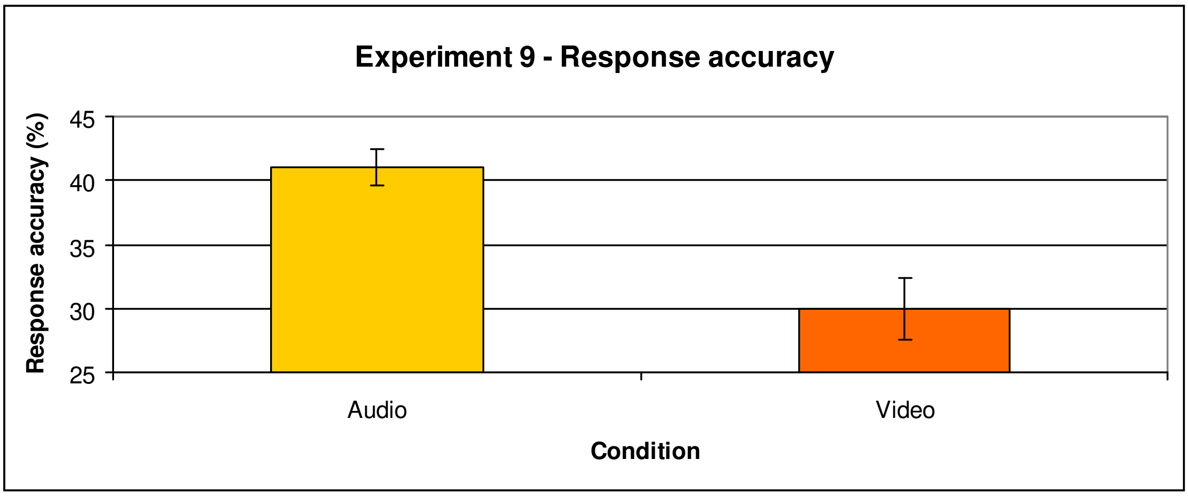


Figure 29. Response accuracy in the two conditions. Error bars show the standard error of the mean.

As concerns response times (figure 30), only those of correct responses were considered. A paired samples t-test revealed no significant difference between the two experimental conditions.

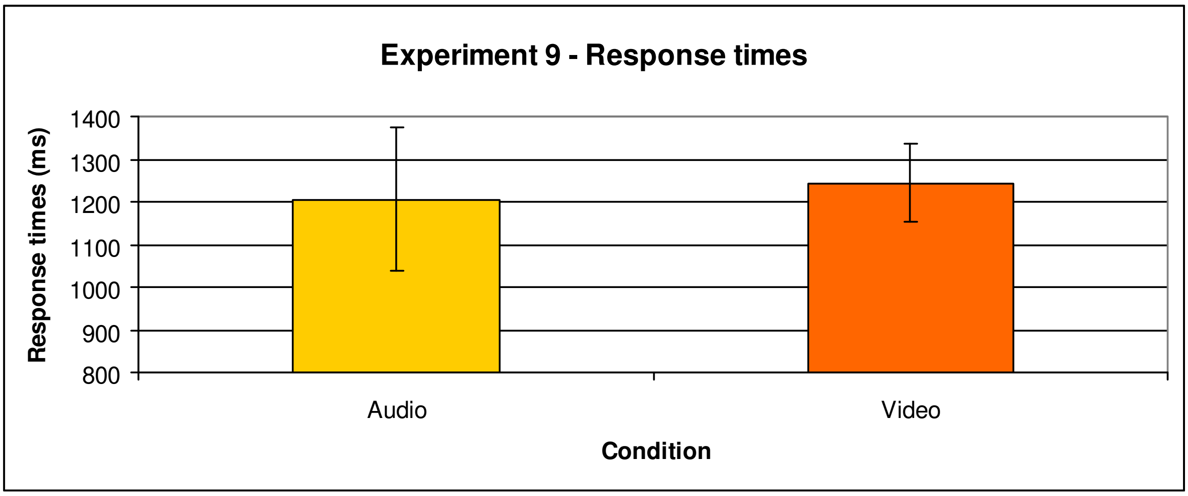


Figure 30. Response times in the two conditions. Error bars show the standard error of the mean.

4.4.3 Discussion

The aim of Experiment 9 was to evaluate whether, when taking into consideration also the middle sector, the outcomes observed in Experiment 8 could be replicated. In light of the results, this was the case, as participants performed better in the Audio condition than in the Video condition, without any difference concerning response times; moreover, also in the present experiment the performance in the former condition was above the chance level, while in the latter condition it was not.

Taken together, the results of Experiment 9 bring further support to the claim that, at a comparable elaboration time, early auditory information would be more relevant than the respective visual information for anticipating the landing zone of volleyball serves on the basis of their length. In particular, the former would provide enough information to reach a better than chance performance, while the latter seems to be insufficient to reach such a level of prediction accuracy.

4.5 General discussion

Notwithstanding previous research almost exclusively focused on the visual domain to study the perception of ball motion in sport (Davids et al., 2002; Mann et al., 2007; Vickers & Adolphe, 1997), in Chapter 3 we saw that, to discriminate the power of soccer penalty kicks and volleyball smashes, early auditory cues would be more informative than the respective visual cues. However, these results were obtained through an atypical task for athletes, i.e. expressing a judgement over the comparison of two similar situations. Rather, while competing, athletes need to react as appropriately and as fast as possible to the circumstances of a specific situation. As a consequence, the aim of the present chapter was to investigate whether the outcomes of experiments 5 and 6 could be replicated when participants are involved in a task that more closely resembles a field performance situation, i.e. predicting the landing zone of volleyball serves on the basis of their length.

To reach this aim, in Experiment 7 participants were provided with stimuli that were characterized either by the congruence between auditory and visual information, or by the incongruence between them; thus, in the latter case it was possible to evaluate which of the two sources of information participants mostly relied on for their predictions. The results highlighted a prevalence of predictions made on the basis of auditory information over those made on the basis of visual information; however, the accuracy in response to congruent stimuli was not different from chance, thus suggesting that early information might not be sufficient to perform this task effectively.

To better understand the contribution of early auditory and visual information, in experiments 8 and 9 participants were forced to rely either on the former or on the latter at a time to make their predictions. The results revealed not only that auditory information promoted a higher response accuracy compared to visual information, but also that in the former case the accuracy was above chance while in the latter case it was not. As a consequence, it is possible to claim that early auditory information alone would be sufficient to accurately anticipate the length of overhand serves.

There is an apparent inconsistency between the results of Experiment 7 and those of experiments 8 and 9. In the congruent trials of the former, participants could rely on both sources of information, and the sectors considered were two; given these conditions, prediction accuracy was not different from chance. Instead, in the latter experiments participants could only rely on one source of information at a time, and in Experiment 9 the sectors considered were three; in spite of this greater difficulty, by means of auditory information the prediction accuracy was above chance (while by means of visual information it was not). As a consequence, rather than an inconsistency, it is possible to claim that the results observed in Experiment 7 may have been due to a detrimental effect of visual information on auditory information. Such an effect would have been quite strong, as it was present despite the tendency of participants to rely more on auditory information (as it was observed thanks to incongruent stimuli).

There are at least two hypotheses concerning the low informativeness of the visual information considered in the present experiments. The first one is that, for the specific required task, such an early information, i.e. the kinematics of the server and the first portion of the ball flight, may still be ambiguous with respect to the outcome of the action; this seems not to be the case for early auditory information, i.e. the impact with the ball and its echo. The second hypothesis concerns how visual information was provided, i.e. by means of a laptop display: this has obvious implications on information richness – the loss of the third dimension, i.e. depth, and the shrinking of the remaining two – yet in experiments 5 and 6, visual information alone was sufficient to promote better than chance performances. This discrepancy may be due to the larger distance between the impact point and the recording point in the present experiments (17.3 m) compared to the respective distances in the previous experiments (11.1 m for penalties and 11.8 m for smashes). Instead, auditory information seems not to be affected, reasonably because of its lower loss of richness when it is synthetically reproduced. Obviously, it is also possible that the low richness of the visual information was due to the combination of these two hypotheses.

Except for field experiments, the richness of visual information represents a critical issue for all the studies mentioned in the present thesis. Some researchers tried to tackle this problem, for example by using wide screens (e.g., Savelsbergh et al., 2002): thanks to them it is possible to preserve real dimensions, but it is not possible to reproduce the third dimension, i.e. depth, which may have a relevant role. On the other hand, the main downside of field studies is that they allow for a lower level of control of the experimental situation compared to laboratory studies, thus making it harder to distinguish the effects of the variable(s) under investigation from those of potentially confounding variables; moreover, field studies also require more time to be carried out. For example, it would be very complicated to replicate on the field the experiments described in the present chapter, both for the difficulty to reproduce the conditions/stimuli (or its impossibility, as concerns the incongruent stimuli), and for the issues related to the server, i.e. her/his fatigue and the need to have her/him present to test each participant, just to mention a few.

A solution to combine the rigorousness of laboratory experiments with the ecologicity of visual information is represented by the new technologies that allow for the three-dimensional recording and reproduction of videos (Craig, 2013). Indeed, thanks to such instruments it is possible to provide participants with stimuli that are at the same time manipulated as desired and ecological, thus allowing for the evaluation of the actual relevance and contribution of visual information in the situation under investigation.

To sum up, the results of the three experiments described in the present chapter highlighted that, to anticipate the landing zone of overhand serves, athletes would rely more on early auditory information than on early visual information and that, at a comparable elaboration time, the former would provide more relevant perceptual cues than the latter, promoting a higher prediction accuracy. However, the considerations made upon the informativeness of visual information need to be carefully kept in mind; in this regard, future studies aimed at further investigating within this field of research should take advantage of the innovative instruments that allow for the three-dimensional reproduction of visual stimuli, so that their role can be better understood.

Beyond continuing to investigate the relevance and the contribution of auditory and visual information in the anticipation of sport actions, from an applied point of view it would be both interesting and potentially useful to develop and test the effectiveness of various kinds of perceptual-motor training based on the outcomes of basic research. If one or more of these training protocols would prove to improve athletes' performances to a significant extent, they could be integrated in the training regime of the athletes themselves, in order to regularly monitor their effects also on a long term period, e.g. during an entire season.

Chapter 5
Conclusions

In light of the growing interest towards the role of auditory information in sport, the aim of the present thesis was to investigate its contribution to the perception of opponent's actions in two ball sports – soccer and volleyball – and to compare this contribution with that of the respective visual information. To reach this aim, it has been necessary to adopt an approach that differs from the one characterizing most of the studies conducted on the relation between sound and sport to date, moving the focus from auditory information related to the self to that produced by other people, namely the opponents.

In Chapter 1, an overview of the studies that adopted the traditional approach was provided. Laboratory experiments highlighted that the auditory system is apter than the visual one in identifying the rhythmic features of simple, precisely timed gestures/movements; this, in turn, promotes a more accurate reproduction of the gesture/movement under investigation when participants can rely on an auditory model than when they can rely on a visual model. Field experiments extended the validity of these observations to the complex movements that characterize sport competitions, revealing that the use of auditory information, either as an augmented feedback or as a model, promotes significant performance improvements in various disciplines.

The empirical foundation of this connection between sound and movement has been identified in the tight relationship between the neural mechanisms underlying auditory perception and motor production. Such a relationship was observed thanks to neurophysiological studies, which highlighted that various kinds of sound related to movement promote the activation not only of perceptual areas of the brain, but also of premotor and motor ones. These observations, as well as those mentioned in the previous paragraph, can be framed within two theoretical frameworks that are not mutually exclusive, i.e. the mirror neuron system and the theory of event coding. The former is focused on the physical part of stimuli processing, highlighting that specific populations of neurons are activated both when an action is performed and when the sounds deriving from it are heard. Instead, the TEC is focused on the conceptual part of stimuli processing, postulating a common representational system shared by the processes underlying perception and action.

In the very last part of the first chapter, the few studies that adopted the approach focusing on the relevance of the sounds produced by the others were mentioned, to introduce the experiments that characterize the present thesis. Specifically, in Chapter 2 a preliminary set of four simple reaction time experiments was described, whose aim was investigating whether the results observed in previous studies in response to pure tones could be replicated with ecological sounds; in particular, foot-ball impacts of soccer penalty kicks were used as stimuli. Altogether, the results revealed that the natural loudness difference among different foot-ball impacts would not be sufficient to promote a variation in the reaction time in response to them. However, by artificially manipulating the loudness of the stimuli it was possible to obtain the general phenomenon observed with pure tones, i.e. an inverse relation between loudness and reaction time. Beyond the effects (or their absence) of the stimuli on the reaction time, participants were able to perceive that the stimuli themselves were different among each other.

In chapters 3 and 4, five experiments were described in which this ability to discriminate qualitatively similar auditory stimuli was implied. Specifically, in Chapter 3 the contribution of early auditory and visual information to the discrimination of shot power in soccer and volleyball was investigated. The results highlighted that, compared to early visual information, early auditory information associated with penalty kicks and smashes would provide more relevant perceptual cues, which would be faster to process and, in the case of smashes, also more informative. Thus, it seems that the power of shots can be more easily inferred from early auditory cues than from early visual cues.

To test whether this superiority of auditory information was also present in a task that more closely resemble a field performance situation, in Chapter 4 the role of early auditory and visual information in anticipating the landing zone of volleyball serves was investigated. The results revealed that athletes would rely more on auditory information than on visual information and that, at a comparable elaboration time, the former would be more informative than the latter, promoting a higher prediction accuracy.

Taken together, the outcomes observed in the present thesis highlight that athletes would be able to distinguish sport related sounds that are slightly different among each other; this, in turn, would allow them to explicitly and implicitly discriminate shot power on the basis of early auditory information, in some cases also more effectively than when relying on the respective visual information. Previous research already highlighted that the auditory modality outperforms the visual one in various tasks, like for example in simple reaction time and in temporal intervals discrimination; however, we claim that the mechanisms that are responsible for the effects observed here are different, and plausibly of a higher complexity, as the processing of a limited amount of information was needed to appropriately perform the required tasks.

In the interpretation of the present results, it is fundamental to remember the considerations concerning the richness of visual information made in the general discussion of the previous chapter. Indeed, administering visual stimuli by means of a laptop display necessarily affects their informativeness to a significant extent; instead, when auditory stimuli are synthetically reproduced, the loss of their informativeness is less pronounced. As a consequence, it would be risky to claim – exclusively on the basis of the experiments described here – that early auditory information provides more relevant perceptual cues than early visual information to discriminate shot power in soccer and volleyball. However, what it is possible to claim on the basis of the observations made in the present thesis is that early auditory information significantly contributes to this ability; to the best of our knowledge, this is a claim that has never been done before.

5.1 Future directions

Considered the novelty of the approach used for the present experiments, as well as that of the results observed thanks to it, there is much room for future research aimed at investigating both the same issues studied here and related ones. In particular, two are the main directions to be followed: one is basic research, the other is applied research.

Specifically, as concerns basic research, first of all it should be better understood the actual relevance and contribution of visual information in the situations under investigation. As already mentioned, this can be done by using the innovative instruments that allow for the three-dimensional recording and reproduction of videos; in this way, the loss of information richness would be significantly less pronounced than that due to the reproduction of videos on a two-dimensional display. As a consequence, the comparison between the role of auditory and visual information would be more realistic, thus more meaningful. Moreover, always concerning basic research, it would be interesting to investigate whether the relevance of early auditory information here observed in soccer and volleyball is also present in other sports; in this regard, the use of experimental tasks that closely resemble field performance situations is strongly suggested.

This suggestion is given in order to build a direct bridge between basic and applied research, so that the observations deriving from the former could provide information that are actually useful, and immediately usable, for the latter. Specifically, the main aim of applied research investigating on these issues should be that of developing and testing the effectiveness of perceptual-motor training, which could promote significant improvements in athletes' performances. If some training protocols would prove to be effective to this purpose in the short term, they could complement athletes' normal training regime, so that their effects could be evaluated also on a long term.

Concluding, the present thesis highlighted that early auditory information contributes to a significant extent to the perception of opponent's action in soccer and volleyball, in terms of discrimination of shot power. The observed results encourage to further investigate in this direction; on the basis of the outcomes of future studies pursuing the above mentioned aims, innovative protocols to improve athletes' performances may be developed, thus having a relevant impact from an applied point of view.

References

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, *30*(2), 233-252.

Abernethy, B., & Russell, D. G. (1987). Expert-novice differences in an applied selective attention task. *Journal of Sport Psychology*, *9*, 326-345.

Abernethy, B., Wood, J. M., & Parks, S. (1999). Can the anticipatory skills of experts be learned by novices? *Research Quarterly for Exercise and Sport*, *70*(3), 313-318.

Agostini, T., Righi, G., Galmonte, A., & Bruno P. (2004). The relevance of auditory information in optimizing hammer throwers performance. In P.B. Pascolo (ed.), *Biomechanics and sports*. Vienna: Springer, pp. 67-74.

Aziz-Zadeh, L., Iacoboni, M., Zaidel, E., Wilson, S., & Mazziotta, J. (2004). Left hemisphere motor facilitation in response to manual action sounds. *European Journal of Neuroscience*, *19*(9), 2609-2612.

Bar-Eli, M., Azar, O. H., Ritov, I., Keidar-Levin, Y., & Schein, G. (2007). Action bias among elite soccer goalkeepers: The case of penalty kicks. *Journal of Economic Psychology*, *28*(5), 606-621.

Bengtsson, S. L., Ullén, F., Ehrsson, H., Hashimoto, T., Kito, T., Naito, E., ... Sadato, N. (2009). Listening to rhythms activates motor and premotor cortices. *Cortex*, *45*(1), 62-71.

Bood R. J., Nijssen M., van der Kamp J., & Roerdink M. (2013). The power of auditory-motor synchronization in sports: Enhancing running performance by coupling cadence with the right beats. *PLoS ONE 8*(8), e70758.

Brown, A. M., Kenwell, Z. R., Maraj, B. K., & Collins, D. F. (2008). "Go" signal intensity influences the sprint start. *Medicine and Science in Sports and Exercise*, *40*(6), 1142-1148.

Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., ... Rizzolatti, G. (2004). Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study. *Journal of Cognitive Neuroscience*, *16*(1), 114-126.

Camponogara, I., Rodger, M., Craig, C., & Cesari, P. (2017). Expert players accurately detect an opponent's movement intentions through sound alone. *Journal of Experimental Psychology: Human Perception and Performance, 43*(2), 348-359.

Caramazza, A., Anzellotti, S., Strnad, L., & Lingnau, A. (2014). Embodied cognition and mirror neurons: A critical assessment. *Annual Review of Neuroscience*, *37*, 1-15.

Cesari P., Camponogara I., Papetti S., Rocchesso D., & Fontana F. (2014). Might as well jump: Sound affects muscle activation in skateboarding. *PLoS ONE*, *9*(3), e90156.

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cerebral Cortex, 18*, 2844-2854.

Chocholle, R. (1940). Variation des temps de réaction auditifs en fonction de l'intensité à diverses fréquences. *L'année psychologique*, *41*(1), 65-124.

Chollet D., Madani M., & Micallef J. P. (1992). Effects of two types of biomechanical bio-feedback on crawl performance. In D. MacLaren, T. Reilly, A. Lees (eds.), *Biomechanics and medicine in swimming. Swimming science VI*. London: E & FN Spon, pp. 57-62.

Chollet D., Micallef J. P., & Rabischong P. (1988). Biomechanical signals for external biofeedback to improve swimming techniques. In B.E. Ungerechts, K. Wilke, K. Reishle (eds.), *Swimming Science V*. Champaign, Illinois: Human Kinetics Books, pp. 389-396.

Collier, G. L., & Logan, G. (2000). Modality differences in short-term memory for rhythms. *Memory and Cognition, 28*(4), 529–538.

Craig, C. (2013). Understanding perception and action in sport: how can virtual reality technology help? *Sports Technology*, *6*(4), 161-169.

Darwin, C. J., Turvey, M. T., & Crowder, R. G. (1972). An auditory analogue of the Sperling partial report procedure: Evidence for brief auditory storage. *Cognitive Psychology*, *3*, 255-267.

Davids, K., Savelsbergh, G. J., Bennett, S., & van der Kamp, J. (Eds.). (2002). *Interceptive Actions in Sport: Information and Movement*. London and New York: Routledge.

Diaz, G. J., Fajen, B. R., & Phillips, F. (2012). Anticipation from biological motion: the goalkeeper problem. *Journal of experimental psychology. Human Perception and Performance*, *38*(4), 848–864.

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception & Psychophysics, 72*(3), 706-720.

Doody, S. G., Bird, A. M., & Ross, D. (1985). The effect of auditory and visual models on acquisition of a timing task. *Human Movement Science*, *4*(4), 271–281.

Dowrick P.W. (1999). A review of self modeling and related interventions. *Applied and Preventive Psychology*, *8*(1), 23-39.

Dubus G. (2012). Evaluation of four models for the sonification of elite rowing. *Journal on Multimodal User Interfaces*, *5*(3-4), 143-156.

Dubus, G., & Bresin, R. (2013). A systematic review of mapping strategies for the sonification of physical quantities. *PLoS ONE*, *8*(12), e82491.

Effenberg, A. O. (1996). *Sonification – Ein akustisches Informationskonzept zur menschlichen Bewegung*. Schorndorf: Hofmann.

Effenberg, A. O. (2005). Movement sonification: Effects on perception and action. *IEEE Multimedia, 12*(2), 53-59.

Effenberg, A. O., Fehse, U., Schmitz, G., Krueger, B., & Mechling, H. (2016). Movement sonification: Effects on motor learning beyond rhythmic adjustments. *Frontiers in Neuroscience*, *10*, 219.

Elliott, R. (1968). Simple visual and simple auditory reaction time: a comparison. *Psychonomic Science, 10*, 335-336.

Farrow, D., & Abernethy, B. (2002). Can anticipatory skills be learned through implicit video based perceptual training? *Journal of Sports Sciences*, *20*(6), 471-485.

Ferguson, E., & Gallagher, L. (2007). Message framing with respect to decisions about vaccination: The roles of frame valence, frame method and perceived risk. *British Journal of Psychology*, *98*(4), 667-680.

Flach R., Knoblich G., & Prinz W. (2004). Recognizing one's own clapping: The role of temporal cues. *Psychological Research*, *69*(1-2), 147-156.

Florentine, M., Buus, S., & Rosenberg, M. (2004). Reaction-time data support the existence of softness imperception in cochlear hearing loss. In D. Pressnitzer, A. de Cheveigné, S. McAdams, L. Collet (eds.), *Auditory Signal Processing: Physiology, Psychoacoustics, and Models*. New York: Springer Verlag, pp. 30-39.

Frame, J. D. (2012). *Framing decisions: Decision making that accounts for irrationality, people and constraints*. San Francisco, CA: Jossey-Bass.

Fujioka, T., Trainor, L. J., Large, E. W., & Ross, B. (2012). Internalized timing of isochronous sounds is represented in neuromagnetic beta oscillations. *The Journal of Neuroscience*, *32*(5), 1791-1802.

Galmonte A., Righi G., Agostini T. (2004). Stimoli acustici come nuovo elemento per il miglioramento della performance nel nuoto. *Movimento, 20*, 73-78.

Gazzola, V., Aziz-Zadeh, L., & Keysers, C. (2006). Empathy and the somatotopic auditory mirror system in humans. *Current Biology*, *16*(18), 1824-1829.

Glenberg, A. M., & Jona, M. (1991). Temporal coding in rhythm tasks revealed by modality effects. *Memory & Cognition*, *19*(5), 514-522.

Glenberg, A. M., Mann, S., Altman, L., Forman, T., & Procise, S. (1989). Modality effects in the coding and reproduction of rhythms. *Memory & Cognition, 17*, 373–383.

Glenberg, A. M., & Swanson, N. G. (1986). A temporal distinctiveness theory of recency and modality effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*(1), 3–15.

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. *Journal of Cognitive Neuroscience*, *19*(5), 893-906.

Grassi, M., & Casco, C. (2010). Audiovisual bounce-inducing effect: When sound congruence affects grouping in vision. *Attention, Perception, & Psychophysics*, *72*(2), 378-386.

Grassi, M., & Darwin, C. J. (2006). The subjective duration of ramped and damped sounds. *Attention, Perception, & Psychophysics*, *68*(8), 1382-1392.

Grondin, S., & McAuley, J. D. (2009). Duration discrimination in crossmodal sequences. *Perception, 38*, 1542–1559.

Han, D. W., & Shea, C. H. (2008). Auditory model: Effects on learning under blocked and random practice schedules. *Research Quarterly for Exercise and Sport, 79*(4), 476-486.

Haazebroek, P., Raffone, A., & Hommel, B. (2016). HiTEC: a connectionist model of the interaction between perception and action planning. *Psychological Research*. doi:10.1007/s00426-016-0803-0

Hermann, T., Hunty, A., & Neuhoff, J. G. (2011). *The sonification handbook*. Berlin: Logos Publishing House.

Hickok, G. (2009). Eight problems for the mirror neuron theory of action understanding in monkeys and humans. *Journal of Cognitive Neuroscience*, *21*(7), 1229-1243.

Hickok, G., Farahbod, H., & Saberi, K. (2015). The rhythm of perception: Entrainment to acoustic rhythms induces subsequent perceptual oscillation. *Psychological Science, 26*(7), 1006-1013.

Hommel, B. (2015a). Embodied cognition according to TEC. In Y. Coello, M. Fischer (eds.), *Foundations of embodied cognition*. New York: Psychology Press.

Hommel, B. (2015b). The theory of event coding (TEC) as embodied-cognition framework. *Frontiers in Psychology*, *6*, 01318.

Hommel, B., Müsseler J., Aschersleben G., & Prinz W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849-878.

Hopwood, M., Mann, D., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers? *International Journal of Sports Science and Coaching*, *6*(4), 523-536.

Humes, L. E., & Ahlstrom, J. B. (1984). Relation between reaction time and loudness. *Journal of Speech, Language, and Hearing Research*, *27*(2), 306-310.

Hummel, J., Hermann, T., Frauenberger, C., & Stockman, T. (2010). Interactive sonification of German wheel sports movement. In R. Bresin, T. Hermann, & A. Hunt (Eds.), *Proceedings of ISon 2010 – Interactive Sonification Workshop: Human Interaction with Auditory Displays*. Stockholm: KTH School of Computer Science and Communication (CSC), pp. 17-22.

Hunt, N., McGrath, D., & Stergiou, N. (2014). The influence of auditory-motor coupling on fractal dynamics in human gait. *Scientific Reports*, *4*, 5879.

Jain, A., Bansal, R., Kumar, A., & Singh, K. D. (2015). A comparative study of visual and auditory reaction times on the basis of gender and physical activity levels of medical first year students. *International Journal of Applied and Basic Medical Research*, *5*(2), 124.

Julin, A. L., & Dapena, J. (2003). Sprinters at the 1996 Olympic Games in Atlanta did not hear the starter's gun through the loudspeakers on the starting blocks. *New Studies in Athletics*, *18*(1), 23-28.

Justen, C., Herbert, C., Werner, K., & Raab, M. (2014). Self vs. other: Neural correlates underlying agent identification based on unimodal auditory information as revealed by electrotomography (sLORETA). *Neuroscience*, *259*, 25-34.

Karageorghis, C. I., & Jones, L. (2014). On the stability and relevance of the exercise heart rate–music-tempo preference relationship. *Psychology of Sport and Exercise*, *15*(3), 299-310.

Karageorghis C. I., & Priest, D.-L. (2012a). Music in the exercise domain: a review and synthesis (Part I). *International Review of Sport and Exercise Psychology*, *5*(1), 44–66.

Karageorghis C. I., & Priest, D.-L. (2012b). Music in the exercise domain: a review and synthesis (Part II). *International Review of Sport and Exercise Psychology*, *5*(1), 67–84.

Keele, S. W., Pokorny, R. A., Corcos, D. M., & Ivry, R. (1985). Do perception and motor production share common timing mechanisms: A correlational analysis. *Acta Psychologica, 60*, 173-191.

Kennel C., Hohmann T., & Raab M. (2014). Action perception via auditory information: Agent identification and discrimination with complex movement sounds. *Journal of Cognitive Psychology*, *26*(2), 157-165.

Kennel, C., Pizzera, A., Hohmann, T., Schubotz, R. I., Murgia, M., Agostini, T., & Raab, M. (2014). The perception of natural and modulated movement sounds. *Perception*, *43*(8), 796-804.

Kennel C., Streese L., Pizzera A., Justen C., Hohmann T., & Raab M. (2015). Auditory reafferences: The influence of real-time feedback on movement control. *Frontiers in Psychology*, *6*, 69.

Keysers, C., Kohler, E., Umiltà, M. A., Nanetti, L., Fogassi, L., & Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Experimental Brain Research*, *153*(4), 628-636.

Kirby, R. (2009). Development of a real-time performance measurement and feedback system for alpine skiers. *Sports Technology, 2*(1–2), 43–52.

Kohfeld, D. L., Santee, J. L., & Wallace, N. D. (1981a). Loudness and reaction time: I. *Perception & Psychophysics*, *29*(6), 535-549.

Kohfeld, D. L., Santee, J. L., & Wallace, N. D. (1981b). Loudness and reaction time: II Identification of detection components at different intensities and frequencies. *Perception & Psychophysics*, *29*(6), 550-562.

Kohl, R. M., & Shea, C. H. (1995). Augmenting motor responses with auditory information: Guidance hypothesis implications. *Human Performance, 8*, 327-343.

Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). Hearing sounds, understanding actions: Action representation in mirror neurons. *Science, 297*, 846-848.

Kühberger, A. (1998). The influence of framing on risky decisions: A meta-analysis. *Organizational behavior and human decision processes*, *75*(1), 23-55.

Lahav, A., Saltzman, E., & Schlaug, G. (2007). Action representation of sound: Audiomotor recognition network while listening to newly acquired actions. *Journal of Neuroscience*, *27*(2), 308-314.

Lai, Q., Shea, C. H., Bruechert, L., & Little, M. (2002). Auditory model enhances relative timing learning. *Journal of Motor Behavior, 34*, 299-308.

Lai, Q., Shea, C. H., & Little, M. (2000). Effects of modeled auditory information on a sequential timing task. *Research Quarterly for Exercise and Sport, 71(4),* 349-356.

Larsson, M. (2014). Self-generated sounds of locomotion and ventilation and the evolution of human rhythmic abilities. *Animal Cognition*, *17*, 1–14.

Lingnau, A., Gesierich, B., & Caramazza, A. (2009). Asymmetric fMRI adaptation reveals no evidence for mirror neurons in humans. *Proceedings of the National Academy of Sciences*, *106*(24), 9925-9930.

Loffing, F., & Hagemann, N. (2014). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychology of Sport and Exercise*, *15*(3), 260-267.

Loffing, F., Hagemann, N., Schorer, J., & Baker, J. (2015). Skilled players' and novices' difficulty anticipating left- vs. right-handed opponents' action intentions varies across different points in time. *Human movement science*, *40*, 410-421.

Magill R. (2010). *Motor learning and control: Concepts and applications.* New York: McGraw-Hill.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*(4), 457.

Marshall, L., & Brandt, J. F. (1980). The relationship between loudness and reaction time in normal hearing listeners. *Acta oto-laryngologica*, *90*(1-6), 244-249.

McCullagh, P., & Little, W. S. (1989). A comparison of modalities in modeling. *Human Performance*, *2*(2), 101–111.

Merker, B. H., Madison, G. S., & Eckerdal, P. (2009). On the role and origin of isochrony in human rhythmic entrainment. *Cortex*, *45*, 4-17.

Morgan, C. L. (1893) Primitive music: an enquiry into the origin and development of music, songs, instruments, dances, and pantomimes of savage races. *Nature*, *48*, 290-291.

Murgia M., Bresolin G., Righi G., Galmonte A., & Agostini T. (2011). The effect of visual and auditory models on golf swing. *Journal of Sport and Exercise Psychology*, 33 supplement, S91.

Murgia, M., Corona, F., Pili, R., Sors, F., Agostini, T., Casula, C., ... Guicciardi, M. (2015). Rhythmic Auditory Stimulation (RAS) and motor rehabilitation in Parkinson's disease: new frontiers in assessment and intervention protocols. *The Open Psychology Journal*, *8*, 220-229.

Murgia, M., Forzini, F., & Agostini, T. (2014). *Migliorare le prestazioni sportive. Superare il doping con la psicologia sperimentale applicata al movimento.* Milano: Franco Angeli.

Murgia, M., Hohmann, T., Galmonte, A., Raab, M., & Agostini, T. (2012). Recognising one's own motor actions through sound: The role of temporal factors. *Perception*, *41*(8), 976-987.

Murgia, M., Santoro, I., Tamburini, G., Prpic, V., Sors, F., Galmonte, A., & Agostini, T. (2016). Ecological sounds affect breath duration more than artificial sounds. *Psychological Research*, *80*(1), 76-81.

Murgia, M., Sors, F., Muroni, A. F., Santoro, I., Prpic, V., Galmonte, A., & Agostini, T. (2014). Using perceptual home-training to improve anticipation skills of soccer goalkeepers. *Psychology of Sport and Exercise*, *15*(6), 642-648.

Murgia M., Sors F., Vono R., Muroni A. F., Delitalia L., Di Corrado D., & Agostini T. (2012). Using auditory stimulation to enhance athletes' strength: An experimental study in weightlifting. *Review of Psychology, 19*, 13-16.

Novembre, G., & Keller, P. E. (2014). A conceptual review on action-perception coupling in the musicians' brain: what is it good for? *Frontiers in Human Neuroscience*, *8*, 603.

Oller, D. K., & Eilers, R. E. (1988). The role of audition in infant babbling. *Child Development*, *59*, 441-449.

Panchuk, D., Davids, K., Sakadjian, A., MacMahon, C., & Parrington, L. (2013). Did you see that? Dissociating advanced visual information and ball flight constrains perception and action processes during one-handed catching. *Acta psychologica*, *142*(3), 394-401.

Patel, A. D., & Iversen, J. R. (2014). The evolutionary neuroscience of musical beat perception: the Action Simulation for Auditory Prediction (ASAP) hypothesis. *Frontiers in Systems Neuroscience*, *8*, 57.

Pazzaglia, M., Pizzamiglio, L., Pes, E., & Aglioti, S. M. (2008). The sound of actions in apraxia. *Current Biology*, *18*(22), 1766-1772.

Pfingst, B. E., Hienz, R., Kimm, J., & Miller, J. (1975). Reaction− time procedure for measurement of hearing. I. Suprathreshold functions. *The Journal of the Acoustical Society of America*, *57*(2), 421-430.

Piéron, H. (1920). Nouvelles recherches sur l'analyse du temps de latence sensorielle et sur la loi qui relie ce temps à l'intensité d'excitation. *L'année psychologique*, *22*(1), 58-142.

Piras, A., & Vickers, J. N. (2011). The effect of fixation transitions on quiet eye duration and performance in the soccer penalty kick: instep versus inside kicks. *Cognitive processing, 12*(3), 245-255.

Pizzamiglio, L., Aprile, T., Spitoni, G., Pitzalis, S., Bates, E., D'Amico, S., & Di Russo, F. (2005). Separate neural systems for processing action-or non-action-related sounds. *Neuroimage*, *24*(3), 852-861.

Pizzera, A., & Hohmann, T. (2015). Acoustic Information During Motor Control and Action Perception: A Review. *Open Psychology Journal*, *8*, 183-191.

Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann, W. Prinz (eds.), *Relationship between perception and action.* Berlin: Springer-Verlag, pp. 167-201.

Prpic V., Murgia M., Feduzi S., Bolognini A., Zavagni M., Righi G., Agostini T. (2010). Modelli acustici applicati ai calci di punizione nel gioco del calcio. *Movimento, 26*, 74-78.

Put, K., Wagemans, J., Jaspers, A., & Helsen, W. F. (2013). Web-based training improves on-field offside decision-making performance. *Psychology of Sport and Exercise, 14*(4), 577-585.

Ramezanzade H., Abdoli B., Farsi A., & Sanjari M. A. (2014). The impact of sonification modelling on perception and accuracy of performing jump shot basketball. *International Journal of Sport Studies, 4*(11), 1388-1392.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review*, *12*, 969–992.

Repp, B. H., & Penel, A. (2002). Auditory dominance in temporal processing: New evidence from synchronization with simultaneous visual and auditory sequences. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(5), 1085–1099.

Repp, B. H., & Penel, A. (2004). Rhythmic movement is attracted more strongly to auditory than to visual rhythms. *Psychological research*, *68*(4), 252-270.

Repp, B. H., & Su, Y.-H. (2013). Sensorimotor synchronization: A review of recent research (2006-2012). *Psychonomic Bulletin & Review*, *20*(3), 403-452.

Righi G., Ferletic E., Furlan D., Pin A., & Gherzil A. (2007). Are visual models the best models to learn a specific task in sport training? *Perception 36, ECVP Abstract Supplement*, 179.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*, 131-141.

Ryu, D., Kim, S., Abernethy, B., & Mann, D. L. (2013). Guiding attention aids the acquisition of anticipatory skill in novice soccer goalkeepers. *Research quarterly for exercise and sport*, *84*(2), 252-262.

Sanchez, X., Moss, S. L., Twist, C., & Karageorghis, C. I. (2014). On the role of lyrics in the music–exercise performance relationship. *Psychology of Sport and Exercise*, *15*(1), 132-138.

Santoro, I., Murgia, M., Tamburini, G., Prpic, V., Sors, F., Galmonte, A., & Agostini, T. (2015). Panic disorder patients and healthy people differently identify their own heart frequency through sound. *Psihologija*, *48*(3), 279-287.

Savelsbergh, G. J., Williams, A. M., van der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of sport sciences, 20*(3), 279-287.

Schachner, A. (2013). The origins of human and avian auditory-motor entrainment. *Nova Acta Leopoldina NF*, *111*(380), 243-253.

Schaffert N., & Gehret R. (2013). Testing different versions of functional sonification as acoustic feedback for rowing. In *Proceedings of the 19th International Conference on Auditory Display*. Łódź, pp. 331-335.

Schaffert N., & Mattes K. (2012). Acoustic feedback training in adaptive rowing. In *Proceedings of the 18th International Conference on Auditory Display*. Atlanta, pp. 83-88.

Schaffert, N., Mattes, K., & Effenberg, A. O. (2010). Listen to the boat motion: acoustic information for elite rowers. In R. Bresin, T. Hermann, & A. Hunt (Eds.), *Proceedings of ISon 2010 – Interactive Sonification Workshop: Human Interaction with Auditory Displays*. Stockholm: KTH School of Computer Science and Communication (CSC), pp. 31-38.

Schaffert, N., Mattes, K., & Effenberg, A. O. (2011). An investigation of online acoustic information for elite rowers in on-water training conditions. *Journal of Human Sport and Exercise, 6*(2), 392-405.

Scharf, B. (1978). Loudness. In E.C. Carterette, M.P. Friedman (eds.), *Handbook of Perception. Vol IV*, New York: Academic, chapter 6.

Schmidt R. A., & Wrisberg C. A. (2008). *Motor learning and performance: A situation-based learning approach.* Champaign, Illinois: Human Kinetics.

Schmitz G., & Effenberg A. O. (2012). Perceptual effects of auditory information about own and other movements. In *Proceedings of the 18th International Conference on Auditory Display*. Atlanta, pp. 89-94.

Schmitz, G., Mohammadi, B., Hammer, A., Heldmann, M., Samii, A., Münte, T. F., & Effenberg, A. O. (2013). Observation of sonified movements engages a basal ganglia frontocortical network. *BMC Neuroscience*, *14*(1), 32.

Schubotz, R. I., Friederici, A. D., & von Cramon, D. Y. (2000). Time perception and motor timing: a common cortical and subcortical basis revealed by fMRI. *Neuroimage*, *11*(1), 1-12.

Shea, C. H., Wulf, G., Park, J.-H., & Gaunt, B. (2001). Effects of an auditory model on the learning of relative and absolute timing. *Journal of Motor Behavior, 33(2),* 127-138.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W. S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of motor behavior*, *37*(2), 164-175.

Sigrist R., Rauter G., Riener R., & Wolf P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review*, *20*(1), 21-53.

Sors, F., Gerbino, W., & Agostini, T. (2014). Auditory modeling in sport: Theoretical framework and practical applications. In P. Bernardis, C. Fantoni, & W. Gerbino (Eds.), *TSPC2014. Proceedings of the Trieste Symposium on Perception and Cognition, November 27-28.* Trieste: EUT Edizioni Università di Trieste, pp. 35-37.

Sors, F., Murgia, M., Santoro, I., & Agostini, T. (2015). Audio-Based Interventions in Sport. *The Open Psychology Journal, 8*, 212-219.

Ste-Marie, D. M., Law, B., Rymal, A. M., O, J., Hall, C., & McCullagh, P. (2012). Observation interventions for motor skill learning and performance: An applied model for the use of observation. *International Review of Sport and Exercise Psychology, 5*, 145-176.

Stone, J. A., Maynard, I. W., North, J. S., Panchuk, D., & Davids, K. (2015). (De)synchronization of advanced visual information and ball flight characteristics constrains emergent information–movement couplings during one-handed catching. *Experimental brain research*, *233*(2), 449-458.

Stone, J. A., Panchuk, D., Davids, K., North, J. S., & Maynard, I. (2014). Integrating advanced visual information with ball projection technology constrains dynamic interceptive actions. *Procedia Engineering*, *72*, 156-161.

Takeuchi, T. (1993). Auditory information in playing tennis. *Perceptual and motor skills*, *76*, 1323-1328.

Thaut, M. H., McIntosh, G. C., & Hoemberg, V. (2015). Neurobiological foundations of neurologic music therapy: rhythmic entrainment and the motor system. *Frontiers in Psychology*, *5*, 1185.

Trainor, L. J. (2015). The origins of music in auditory scene analysis and the roles of evolution and culture in musical creation. *Philosophical Transactions of the Royal Society B, 370*, 20140089.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*(4481), 453–458.

Utley A., & Astill S. (2008). *Motor control, learning and development.* BIOS Instant Notes. New York: Taylor & Francis.

van der Kamp, J. (2006). A field simulation study of the effectiveness of penalty kick strategies in soccer: late alterations of kick direction increase errors and reduce accuracy. *Journal of sports sciences*, *24*(5), 467-477.

van Vugt, F. T. (2013). *Sounds on time: auditory feedback in motor learning, re-learning and over-learning of timing regularity*. Neuroscience. Université Claude Bernard - Lyon I, 2013. English. <tel-00915893>

van Vugt, F. T., & Tillmann, B. (2015). Auditory feedback in error-based learning of motor regularity. *Brain Research*, *1606*, 54-67.

VandenBos, G. R. (2007). *APA Dictionary of Psychology*. Washington, DC: American Psychological Association.

Vansteenkiste, P., Vaeyens, R., Zeuwts, L., Philippaerts, R., & Lenoir, M. (2014). Cue usage in volleyball: A time course comparison of elite, intermediate and novice female players. *Biology of sport*, *31*(4), 295-302.

Vickers, J. N., & Adolphe, R. M. (1997). Gaze behaviour during a ball tracking and aiming skill. *International Journal of Sports Vision*, *4*(1), 18-27.

Weissensteiner, J., Abernethy, B., Farrow, D., & Müller, S. (2008). The development of anticipation: A cross-sectional examination of the practice experiences contributing to skill in cricket batting. *Journal of Sport and Exercise Psychology*, *30*(6), 663-684.

Wagner, E., Florentine, M., Buus, S., & McCormack, J. (2004). Spectral loudness summation and simple reaction time. *The Journal of the Acoustical Society of America*, *116*(3), 1681-1686.

Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of sport & exercise psychology*, *31*(6), 761-775.

Woods, E. A., Hernandez, A. E., Wagner, V. E., & Beilock, S.L. (2014). Expert athletes activate somatosensory and motor planning regions of the brain when passively listening to familiar sports sounds. *Brain and Cognition*, *87*, 122-133.

Wundt, W. (1874). *Grundzüge der Physiologischen Psychologie*, 2nd edition. Engelman: Leipzig.

Yamamoto G., Shiraki K., Takahata M., Sakane Y., & Takebayashi Y. (2004). Multimodal knowledge for designing new sound environments. In *Proceedings of the 6th International Conference on Human Computer Interaction with Mobile Devices and Services*. Glasgow: Citeseer, pp. 31-36.

Zmigrod, S., & Hommel, B. (2009). Auditory event files: Integrating auditory perception and action planning. *Attention, Perception & Psychophysics, 71*, 352-362.