Psychology of Sport and Exercise 31 (2017) 44–51

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

journal homepage: www.elsevier.com/locate/psychsport

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

Fabrizio Sors [a,*,1], Mauro Murgia [a,1], Ilaria Santoro [a], Valter Prpic [a,b], Alessandra Galmonte [c], Tiziano Agostini [a]

[a] University of Trieste, Department of Life Sciences, Italy
[b] De Montfort University, Division of Psychology, United Kingdom
[c] University of Trieste, Department of Medicine, Surgery and Health Sciences, Italy

ARTICLE INFO

Article history:
Received 10 December 2016
Received in revised form
27 March 2017
Accepted 3 April 2017
Available online 5 April 2017

Keywords:
Early information
Auditory information
Visual information
Shot power
Discrimination

ABSTRACT

Objective: It is well-established that early visual information has an important role in human ability to play ball sports, as its correct interpretation promotes accurate predictions concerning the ball motion. Other research highlights that auditory information provides relevant cues in various sport situations. The present study combines these two lines of research with the aim to investigate the contribution of early auditory and visual information to the discrimination of shot power in sport-specific situations.
Design: Two experiments were run, one concerning soccer penalty kicks and the other concerning volleyball smashes. In both experiments there were three conditions: Audio, Audiovideo, and Video; a within subjects design was used, with the three conditions carried out in three different days and in a counterbalanced order among participants.
Method: Participants' task was to discriminate the power of two penalties/smashes presented in rapid sequence, on the basis of a two-alternative forced choice paradigm.
Results: The results revealed that, for both penalties and smashes, response accuracy was above chance level in all the three conditions; moreover, while for the penalties no difference among the conditions was observed, for the smashes participants were more accurate in the Audio and Audiovideo conditions compared to the Video condition. As concerns the response times, for both penalties and smashes participants were faster in the Audio and Audiovideo conditions compared to the Video condition.
Conclusions: Taken together, the results suggest that the discrimination of shot power was more easily performed on the basis of early auditory information than on the basis of the respective visual information.

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, Williams, Ward, & Janelle, 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, Gill, Parks, & Packer, 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,

* Corresponding author. University of Trieste, Department of Life Sciences, Via Weiss 21 — Building W, 34128 Trieste, Italy.
E-mail address: fabrizio.sors@libero.it (F. Sors).
[1] Fabrizio Sors and Mauro Murgia contributed equally.

http://dx.doi.org/10.1016/j.psychsport.2017.04.005
1469-0292/

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 (e.g., Camponogara, Rodger, Craig, & Cesari, 2017). This is quite surprising, as there is a growing body of research that highlights the relevance of the auditory information in sport (Murgia & Galmonte, 2015; Sors, Murgia, Santoro, & Agostini, 2015).

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 revealed that, when playing in the auditory deprivation condition, players obtained less points, losing more games compared to the normal condition. Further analyses highlighted 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 more recent years, other field experiments further revealed that auditory information can affect sport performance. For instance, Brown, Kenwell, Maraj, and Collins (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, Righi, Galmonte, and Bruno (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, Mattes, and Effenberg (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, Hernandez, Wagner, and Beilock (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 et al. 2014; Murgia, Hohmann, Galmonte, Raab, & Agostini, 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, Maynard, North, Panchuk, & Davids, 2015; Stone, Panchuk, Davids, North, & Maynard, 2014). 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 1 concerns soccer penalty kicks, while Experiment 2 concerns volleyball smashes.

1. Experiment 1− soccer penalty kicks

In Experiment 1, 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; Wilson, Wood, & Vine, 2009; van der Kamp, 2006).

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.

2. Methods

2.1. 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.

2.2. 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.

2.3. Stimuli recording

The stimuli were recorded on a regular soccer pitch. The action camera and the stereo microphone were placed on a tripod in the middle of the goal line, 1.35 m high; this position reproduced an average goalkeeper perspective before a penalty kick, as goalkeepers are slightly bent on their knees to be as explosive as possible in diving toward the corners of the goal. A wooden panel of 90 × 90 cm was attached to the bottom of a target wall, and placed below the camera on the goal line; moreover, to avoid the tripod and the instruments from being hit by mistargeted shots, a plastic panel and another wooden panel were attached to the target wall, below and above the instruments themselves respectively (see Fig. 1).

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 wooden panel. Overall, 100 penalty kicks were recorded.

2.4. Stimuli editing

The first operation made on the penalty kicks database was to discard those that did not hit the wooden panel, as well as those that had a disturbance either in the video file (e.g., the presence of other people beyond the kicker) or in the audio one (e.g., wind noise).

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 small, we used the distance from the penalty spot to the centre of the wooden panel, i.e. 11.009 m, as a standard distance for all the penalties[2]. The travel time was calculated through the analysis of the audio files, measuring the interval between the foot-ball contact and the ball-panel one, both clearly audible in the recordings. The obtained speed values were further transformed to km/h units by multiplication by 3.6.

Out of the 34 penalty kicks, 11 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[3].

The video and audio files of these penalties were edited through the above mentioned software, and we created three kinds of stimuli – visual, auditory, 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: at this point, the video files were occluded with a black screen, and the audio files were interrupted.

2.5. 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 Fig. 2) 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 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.

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. The dependent variables used to evaluate participants' performance were response accuracy and response times of the test trials.

As concerns the procedure, participants were tested individually in a quiet room. Upon their arrival, they were asked to sit in front of the laptop and to wear the headphones (this was required 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.

2.6. Statistical analyses

First of all, a set of one sample t-tests was conducted to compare participants' response accuracy in the three conditions against the chance level. Then, we ran a repeated measures ANOVA in which the condition (three levels) was the independent variable, and the response accuracy was the dependent variable. A similar ANOVA was run also on response times. When a significant main effect emerged, a set of paired samples t-tests was conducted to compare

[2] It is noteworthy that differences in the range of 1–2 cm 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.

[3] 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.

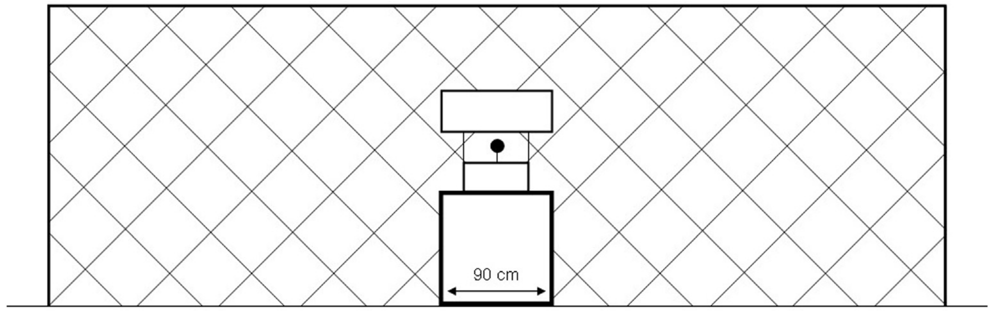

Fig. 1. Reproduction of the recording setting from the perspective of the penalty taker. The square in the middle of the goal represents the 90 × 90 cm wooden panel where penalties were directed. The dot indicates where the camera and the microphone were placed; the rectangles below and above it represent the protective plastic and wooden panels respectively.

the conditions among each other.

3. Results

As concerns response accuracy (Fig. 3a) participants performed significantly above the chance level in all three conditions: Audio (M = 63.51%, SD = 5.81%) [t (17) = 9.858; $p < 0.001$; $d = 2.32$]; Audiovideo (M = 64.54%, SD = 7.17%) [t (17) = 8.583; $p < 0.001$; $d = 2.02$]; Video (M = 64.47%, SD = 4.55%) [t (17) = 13.480; $p < 0.001$; $d = 3.18$]. No difference among conditions emerged.

As concerns response times (Fig. 3b), the ANOVA highlighted a significant main effect of the Condition [$F(2, 34) = 4.843$; $p < 0.05$; $\eta_p^2 = 0.22$]. The subsequent t-tests revealed that, compared to the Video condition (M = 745.22 ms, SD = 368.02 ms), response times were significantly faster both in the Audio (M = 604.00 ms, SD = 237.07 ms) [t (17) = 2.364; $p < 0.05$; $d = 0.46$] and Audiovideo (M = 581.17 ms; SD = 235.56 ms) [t (17) = 2.310; $p < 0.05$; $d = 0.53$] conditions; no significant difference was observed between the Audio condition and the Audiovideo condition.

4. Discussion

The aim of Experiment 1 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.

5. Experiment 2– volleyball smashes

In Experiment 2 we decided to focus on the volleyball smash. Like soccer, also volleyball is 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 1 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.

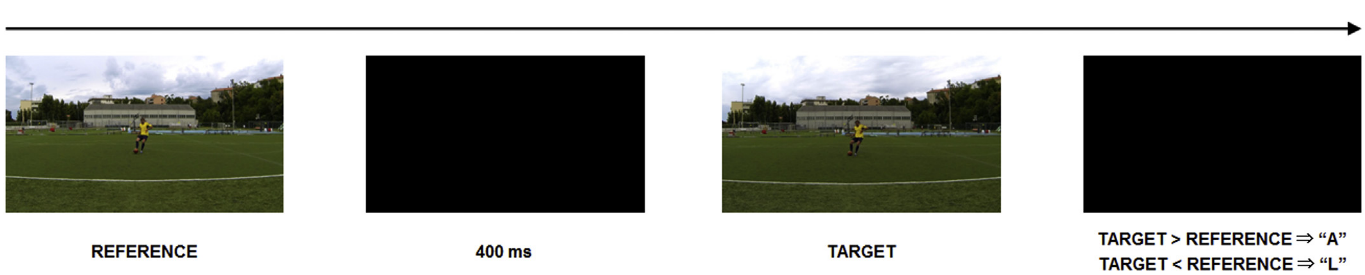

Fig. 2. A prototypical trial of the experimental task in the Video condition. Both reference and target were videos showing the run-up of the kicker until the foot-ball impact (the last frame of each video is here shown). A black screen between the reference and the target was shown for 400 ms; after 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.

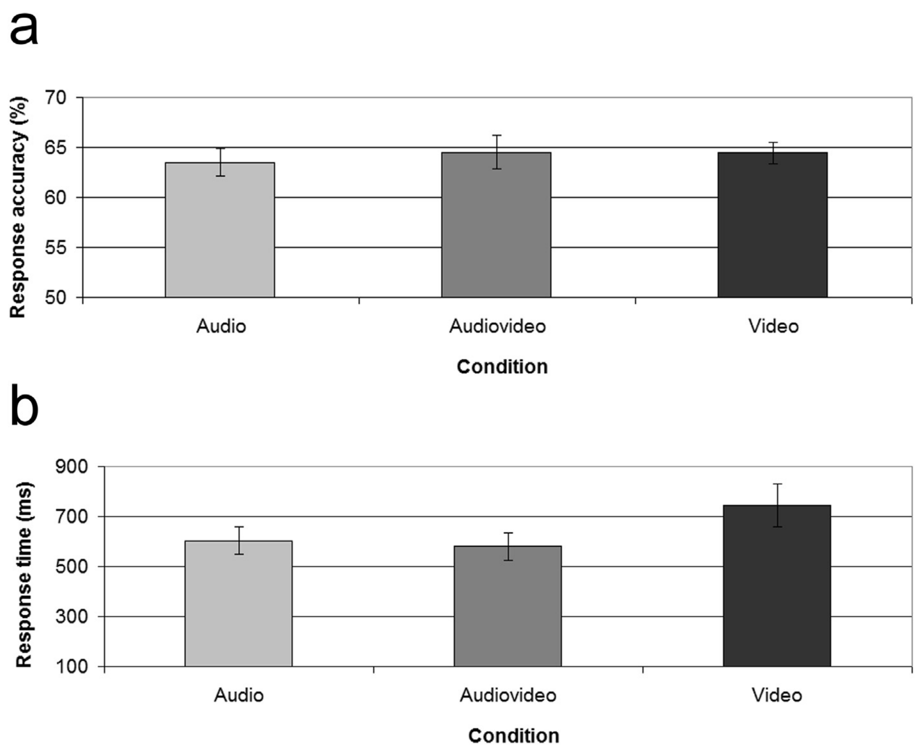

Fig. 3. Response accuracy (a) and response times (b) in the three conditions. Error bars show the standard error of the mean.

6. Methods

6.1. 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.

6.2. Apparatus

The instruments and software used were the same as for Experiment 1.

6.3. Stimuli recording

The stimuli were recorded on a regular volleyball court. Observing Fig. 4, 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 × 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.

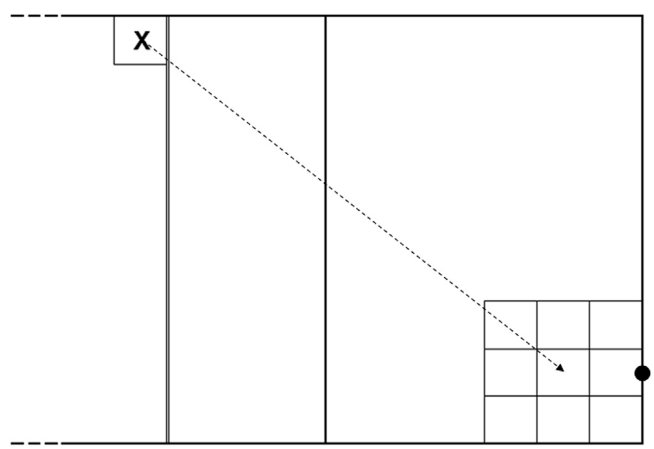

Fig. 4. Reproduction of the recording setting. The "X" represents the smashing point, and the arrow indicates the direction of the smashes. The nine squares represent the sectors used to determine the landing point of the ball; the dot indicates where the camera and the microphone were placed.

6.4. Stimuli editing

The editing phase was very similar to the one described for Experiment 1. 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 anomalous impacts with the ball.

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 video and audio files of these smashes were edited through the above mentioned software, and we created three kinds of stimuli – visual, auditory, 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: at this point, the video files were occluded with a black screen, and the audio files were interrupted.

6.5. 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, the dependent variables, and the procedure were the same as for Experiment 1.

6.6. Statistical analyses

The analyses conducted were the same as for Experiment 1.

7. Results

As concerns response accuracy (Fig. 5a) participants performed significantly above the chance level in all three conditions: Audio (M = 63.85%, SD = 6.50%), [t (16) = 8.785; $p < 0.001$; $d = 2.13$]; Audiovideo (M = 63.86%, SD = 8.35%) [t (16) = 6.846; $p < 0.001$; $d = 1.66$]; Video (M = 57.64%, SD = 6.99%) [t (16) = 4.504; $p < 0.001$; $d = 1.09$]. The repeated measures ANOVA highlighted a significant main effect of the Condition [F (2, 32) = 10.382; $p < 0.001$; $\eta_p^2 = 0.39$]. The subsequent 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.

As concerns response times (Fig. 5b), The ANOVA highlighted a significant main effect of the Condition [F (2, 32) = 13.725; $p < 0.001$; $\eta_p^2 = 0.46$]. The subsequent t-tests revealed that, compared to the Video condition (M = 875.12 ms, SD = 501.87 ms), response times were significantly faster both in the Audio (M = 512.35 ms, SD = 619.27 ms) [t (16) = 3.631; $p < 0.01$; $d = 0.64$] and Audiovideo (M = 462.71 ms, SD = 472.04 ms) [t (16) = 4.814; $p < 0.001$; $d = 0.85$] conditions; no significant difference was observed between the Audio condition and the Audiovideo condition.

8. Discussion

The aim of Experiment 2 was to investigate the contribution of early auditory and visual information to the discrimination of volleyball smashes power, and to evaluate whether the results obtained in Experiment 1 could be observed 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

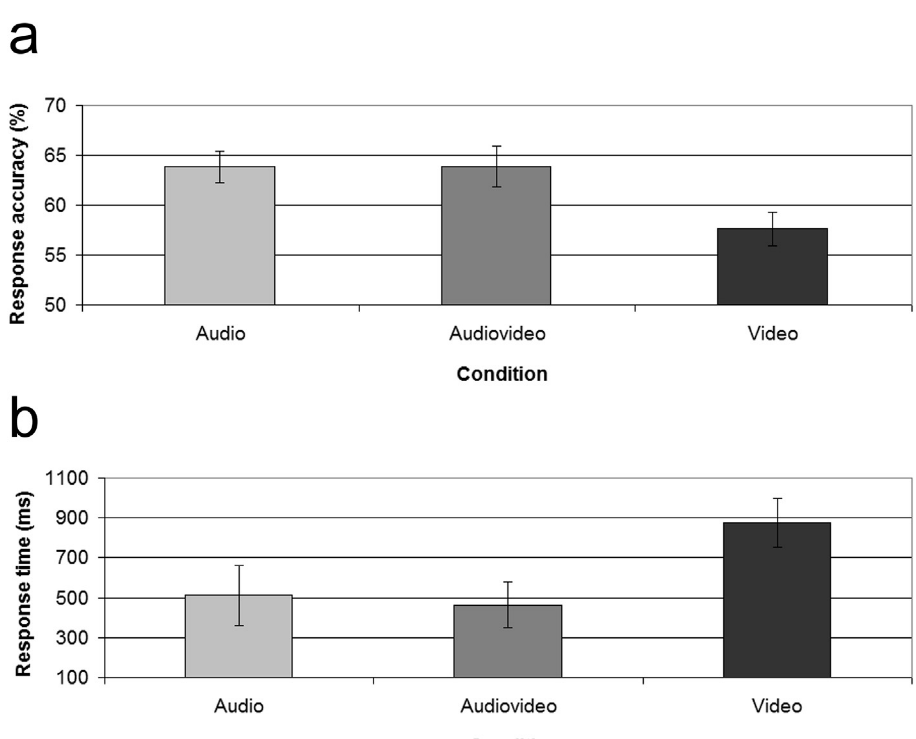

Fig. 5. Response accuracy (a) and response times (b) in the three conditions. Error bars show the standard error of the mean.

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 1, 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 2 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.

9. 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 (Murgia & Galmonte, 2015; Pizzera & Hohmann, 2015; Sors et al., 2015), to the best of our knowledge no study has ever investigated the role of sound in the ball motion perception. 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 is 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, the early auditory information associated with soccer penalty kicks and volleyball smashes would provide more relevant perceptual cues, which are faster processed and – in the case of volleyball – would determine an advantage also in terms of discrimination accuracy. 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, Bansal, Kumar, & Singh, 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.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.psychsport.2017.04.005

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. http://dx.doi.org/10.1068/p2872.

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* (pp. 67–74). Vienna: Springer. http://dx.doi.org/10.1007/978-3-7091-2760-5_9.

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. http://dx.doi.org/10.1016/j.joep.2006.12.001.

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. http://dx.doi.org/10.1249/MSS.0b013e318169770e1.

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. http://dx.doi.org/10.1037/xhp0000316.

Davids, K., Savelsbergh, G. J., Bennett, S., & van der Kamp, J. (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. http://dx.doi.org/10.1037/a0026962.

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. http://dx.doi.org/10.3758/APP.72.3.706.

Elliott, R. (1968). Simple visual and simple auditory reaction time: A comparison. *Psychonomic Science, 10*, 335–336. http://dx.doi.org/10.3758/BF03331548.

Farrow, D., & Abernethy, B. (2002). Can anticipatory skills be learned through implicit video based perceptual training? *Journal of Sport Sciences, 20*(6), 471–485. http://dx.doi.org/10.1080/02640410252925143.

Grondin, S., & McAuley, J. D. (2009). Duration discrimination in crossmodal sequences. *Perception, 38*(10), 1542–1559. http://dx.doi.org/10.1068/p6359.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielson, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers? *International Journal of Sports Science and Coaching, 6*(4), 523–535. http://dx.doi.org/10.1260/1747-9541.6.4.523.

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. http://dx.doi.org/10.4103/2229-516X.157168.

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. http://dx.doi.org/10.1080/02640410500190841.

Kennel, C., Pizzera, A., Hohmann, T., Schubotz, R. I., Murgia, M., Agostini, T., et al. (2014). The perception of natural and modulated movement sounds. *Perception, 43*(8), 796–804. http://dx.doi.org/10.1068/p7643.

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. http://dx.doi.org/10.1016/j.psychsport.2014.01.006.

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. http://dx.doi.org/10.1016/j.humov.2015.01.018.

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), 457–478. http://dx.doi.org/10.1123/jsep.29.4.457.

Murgia, M., & Galmonte, A. (2015). The role of sound in motor perception and execution. *The Open Psychology Journal, 8*, 171–173. http://dx.doi.org/10.2174/1874350101508010171.

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. http://dx.doi.org/10.1068/p7227.

Murgia, M., Sors, F., Muroni, A. F., Santoro, I., Prpic, V., Galmonte, A., et al. (2014). Using a perceptual home-training to improve anticipation skills of soccer goalkeepers. *Psychology of Sport and Exercise, 15*(6), 642–648. http://dx.doi.org/10.1016/j.psychsport.2014.07.009.

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. http://dx.doi.org/10.1016/j.actpsy.2013.01.014.

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. http://dx.doi.org/10.1007/s10339-011-0406-z.

Pizzamiglio, L., Aprile, T., Spitoni, G., Pitzalis, S., Bates, E., D'Amico, S., et al. (2005). Separate neural systems for processing action-or non-action-related sounds. *Neuroimage, 24*(3), 852–861. http://dx.doi.org/10.1016/j.neuroimage.2004.09.025.

Pizzera, A., & Hohmann, T. (2015). Acoustic information during motor control and action perception: A review. *Open Psychology Journal, 8*, 183–191. http://dx.doi.org/10.2174/1874350101508010183.

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. http://dx.doi.org/10.1016/j.psychsport.2013.03.005.

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. http://dx.doi.org/10.1080/026404102317284826.

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. http://dx.doi.org/10.4100/jhse.2011.62.20.

Sors, F., Murgia, M., Santoro, I., & Agostini, T. (2015). Audio-based interventions in sport. *The Open Psychology Journal, 8*, 212–219. http://dx.doi.org/10.2174/1874350101508010212.

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. http://dx.doi.org/10.1007/s00221-014-4126-3.

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. http://dx.doi.org/10.1016/j.proeng.2014.06.027.

Takeuchi, T. (1993). Auditory information in playing tennis. *Perceptual and Motor Skills, 76*, 1323–1328. http://dx.doi.org/10.2466/pms.1993.76.3c.1323.

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. http://dx.doi.org/10.5604/20831862.1127288.

Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology, 31*(6), 761–775. http://dx.doi.org/10.1123/jsep.31.6.761.

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. http://dx.doi.org/10.1016/j.bandc.2014.03.007.