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The influence of auditory information on performance in table tennis

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Abstract: It is well-known that visual information is essential for anticipation in table tennis but it not clarified whether auditory cues are also used. Therefore, we performed two in-situ studies, in which novices (study A) and advanced players (study B) responded to strokes of a real opponent or a ball machine by returning with forehand counters (study A) and forehand top spins (study B) to a given target area on the table. We assessed the parameters "hit quality" and "subjective effort". In study A, we provided four conditions: normal, a noise-cancelling headphone and earplugs to dampen auditory information, other noise-cancelling headphones and earplugs to remove almost all environmental sounds, and the same head-phones with additional bright noise to remove all sounds. In study B, we performed three tests (irregular play and regular play with an opponent and response to regular balls of a ball machine) under two conditions: normal and noise-cancelling headphones with the additional bright noise. In both studies, no significant differences between all conditions for "hit quality" and "subjective effort" (all p>0.05) were found. We conclude that auditory information, as well as their volume, have no influence on the hit quality in table tennis for novices and advanced players.

Keywords: in-situ table tennis study, hit quality, subjective effort, auditory information, anticipation

1. Introduction

It is well-known that anticipation, thus forecasting future events, and decision making are crucial in many sports, such as combat sports, racquet sports and ball sports. For correct anticipation, skilled athletes use kinematic and context information (for review of anticipation with focus on visual cues, see Loffing & Cañal-Bruland, 2017 and Morris-Binelli & Müller, 2017). Kinematic cues reveal information of the movement and the body posture itself, as well as of movement changes (e.g. different velocities over the time in different body segments). Context information can be information about the position of the players in the field, the score, the knowledge about movement preferences (Loffing & Cañal-Bruland, 2017), or the interpersonal distance between athletes (e.g. Petri et al., 2016). Such context information are perceived all the time, while kinematic information become more important around ball contact or ball release (Runswick, Roca, Williams & McRobert, 2018). Latest research concerning expert anticipation and decision making in sports, as well as training of anticipation using video material and virtual environments, are summarized in a recent book (Williams & Jackson, 2019a) and a review (Williams & Jackson, 2019b). For review of perceptual-cognitive skills in combat sports, we refer to

Russo and Ottoboni (2019), as well as Martínez de Quel and Bennett (2019).

There are several studies analyzing visual anticipatory cues in racquet sports (e.g. tennis, Abernethy, Zawi & Jackson, 2008, Murphy, Jackson & Williams, 2018, and badminton (Wright, Bishop, Jackson & Abernethy, 2010, Abernethy & Russel, 1987), but only a few studies are available in table tennis. Streuber, Mohler, Bülthoff and de la Rosa (2012) let table tennis players respond to strokes of a virtual opponent and a racquet, as well as only to the racquet, and found that information of the opponent's body and ball flight information are crucial for successful motor response (Streuber, Mohler, Bülthoff & de la Rosa, 2012, Russo & Ottoboni, 2019). In another study in table tennis, Zhao, Lu, Jaquess and Zhou (2018) used the occluder paradigm (kinematic information with congruent or incongruent ball flight information), and found that anticipation in racquet sports is crucial with time constraints and high ball velocities. Experts were significant better in anticipation when ball trajectories and body kinematic information are congruent, but are not better than advanced players or novices when both information are incongruent. Thus, anticipation in table tennis is dependent on motor and visual expertise rather than completeness of kinematic information (Zhao, Lu, Jaquess & Zhou, 2018). Although there is a large body of literature in the fields of anticipating visual cues and studies in table tennis, the influence of auditory information on the performance in sports, also in table tennis, is investigated insufficiently.

The majority of studies in the field of acoustics in sports takes place in the field of the creation of optimal sports environments (e.g. Yoo, Ronzio & Courtois, 2015), for the creation of auditory feedback and sonification (e.g. Schaffert, Engel, Schlüter & Mattes, 2019, Sigrist et al., 2015) and multimodal feedback in virtual reality applications (e.g. Brunnett, Rusdorf & Lorenz, 2006, Sigrist et al., 2015), as well as in unspecific sensorimotor synchronization experiments, such as finger tapping to auditory information (Repp & Su, 2013). In two simulator studies, visual and auditory modality was presented for driving scenarios, and it was found that visual information supports better driving performance whereas auditory information leads to quicker response. Thus, both information complement each other (Park, Kim, Kwon & Christou, 2016). However, the extend of auditory information on anticipation is not often analyzed. Auditory information are only implemented in experimental seet-ups in virtual reality or video footage to enhance the degree of realism rather than for analysis of their extend on perception, anticipation and motor response.

Findings in other field of research might indicate that auditory information is also important in sports scenarios and is essential for correct movement outcome. In a study when conducting musicians and non-musicians using a virtual conductor, it could be shown that music (as auditory stimulus) helps increasing anticipation and movement coordination and synchronization, but especially the visual cues from the conductor (gestures) were important for the prediction of the right timing and synchronization of the beat and the movement (Colley, Varlet, MacRitchie & Keller, 2018). Also, speech can be used for information intake, forecasting and responding in everyday life and in sports situations, although the content is realized a little later (Schreiber & McMurray, 2019). In a review concerning the perception of music, rhythms and speech, Rajendran, Teki and Schnupp (2018) demonstrated that auditory scene analyses, pattern detections and speech perceptions can be used for perception and anticipation. Auksztulewicz et al. (2019) analyzed brain areas being responsible for "what" and "when" information and showed that auditory information are processed in the prefrontal cortex, as it is the case with some visual information.

Previous research revealed that auditory stimuli might be of importance for anticipation, and thus for the performance in sports, but there are too few studies available in that field. In a recent study in fencing, Allerdissen, Güldenpenning, Schack and Bläsing (2017) analyzed the response behavior to visual, auditory and both information together, and observed that visual information is more important than auditory information, but experts are better in using auditory information than lower skilled athletes. Sors et al. (2017) analyzed visual and auditory information in soccer and volleyball, and found that although auditory signals led to earlier reactions (thus, acoustics can be processed faster than visual input), such information were not used to predict motion outcomes (Allerdissen, Güldenpenning, Schack & Bläsing, 2017, Sors et al., 2017). That is in line with a study of Wang, Liao, Lundgren Lyckvi and Chen (2016). In that study with table tennis players, strokes with different spins were shown in temporal occluded videos and the seated participants had to predict the strokes using a keypad. Increased visual information helped to improve the prediction whereas increased auditory information did not. However, best performance was obtained with visual and auditory information together. Thus, adding auditory information to visual signals helped better predicting outcomes in table tennis (Park, Kim, Kwon & Christou, 2016, Wang, Liao, Lundgren Lyckvi & Chen, 2016). Furthermore, auditory information contributes to the identification of ball spins (Santos et al., 2017). These findings are supported by Bischoff et al. (2014), who analyzed anticipation of novices to table tennis strokes shown in occluded videos. Best anticipation was achieved when visual and auditory information were consistent and complementary instead of conflicting (e.g. time delay between both information, Bischoff et al., 2014).

Runswick, Roca, Williams and McRobert (2018) highlighted the importance of context information. Such information in table tennis may contain noises of the ball (ball contact on the racquet and the table), foot strikes, noises of the clothes (slight rustles), respiration, speech and noises from the environment (e.g. other people and instructions from the coach). Here, we focus on the ball contacts on the racquet and the table. We chose an in-situ approach because the conditions are quite close to reality and the possibility of sports specific response behavior is provided. Currently, such in-situ studies to analyze performance in table tennis are quite rare. That is supported by a recent review of Avilés, Navia, Ruiz and Martínez de Quel (2019), in which it was found that only a few studies exist in racquet sports with high degree of representativeness. However, the importance of auditory information was not assessed in those studies.

The aim of the current paper is to analyze the effect of auditory information on the performance in the racquet sports table tennis using an in-situ paradigm. Thus, we extend existing knowledge, which was generated mostly by unspecific reactions (pen and paper or key press) towards manipulations in video materials, by investigations allowing natural movement and response behavior.

In the present paper, we perform two in-situ studies (study A with novices and study B with advanced table tennis players), in which the participants respond sports specifically by strokes with a table tennis racquet. We analyze the influence of auditory information on the performance, measured by the parameters "hit quality" and "subjective effort" in both studies. We examined the "subjective effort" because it might be possible to use increased attention to balance other missing inputs, such as auditory or haptic information, and thus, to keep the good performance at the expense of a higher cognitive load (Grandjean, Quoilin & Duque, 2019). Based on previous literature (e.g. Bischoff et al., 2014), we expect that with reduction of auditory information, the "hit quality" decreases while the "subjective effort" increases because the visual cues are not accompanied by the congruent auditory information.

2. Materials and Methods

Both studies (A and B) were performed in agreement with the ethical standards of the responsible human experimentation committee (institutional or regional) and with the 1975 Declaration of Helsinki, revised in 2000. All participants took part on voluntary basis. They were informed about the aim and the procedures and gave their written consent. Study design and data acquisition was performed after consultation of a skilled table tennis player with 12 years of competition experience of regional league level in Germany to ensure realistic scenarios and movement executions in both studies.

Study A – Analysis of novices' hit quality due to four different auditory conditions

We let novices respond to strokes of a real opponent in four different auditory conditions due to different noise-cancelling headphones. Thus in every condition, opponent kinematics and ball flight information were provided, but the volume level of the auditory information was manipulated: normal, dampened, almost mute and no auditory information. We aimed to analyze the influence of different volume levels of relevant table tennis acoustics (ball contacts on the racquet and the table) on the "hit quality" and the "subjective effort" of novices. We further used that study to decide which conditions we will provide in study B.

Participants

Fifteen novice sports students (all male, age: M = 22.3 years, SD = 3.3 years) with no or only few (some months) previous table tennis experience took part on voluntary basis and responded to strokes of an advanced table tennis player (age of 22 years with 10 years table tennis experience of regional league level in Germany).

Procedure

The advanced table tennis player served forehand passes with forward spin, and the participants had to respond with forehand strokes (counter strokes with few forward spin, which is one of the first strokes to be learnt in table tennis). That player served all balls for all other participants. The task was very easy so we could exclude any fatigue effects. Furthermore, another advanced player (author TS) surveilled the procedure and thus ensured that all forehand services were performed properly. We chose to use only one serving player to avoid different movement execution effects.

Thus, both players played cross forehands with a normal white table tennis ball at a standardized table tennis table. Each participant responded to ten strokes in four conditions each. These conditions were played consecutively in randomized starting order to exclude any learning effects. The four conditions were:

- 1: normal: all auditory information were provided
- 2: damped: the responding athlete wore noise cancelling headphones (Boltune, 5.0) and earplugs (35 dB), and the auditory information were softly but still audible
- 3: almost mute: the responding athlete wore noise cancelling headphones (Bose Quiet Comfort 35 II) and earplugs (35 dB), and the auditory information were almost completely masked
- 4: no further ball and environmental auditory information: the responding athlete wore noise cancelling headphones (Bose Quiet Comfort 35 II), on which an additional sound (bright clean background noise) was played to mask the ball and environmental noises.

In each condition, each participant had to respond to two target areas on the opponent's table. Each area had a width of 40 cm and the complete table length. Area 1 in each condition was the middle of the opponent's table (each 20 cm to both sides from the midline). The serving player was instructed where to serve the ball, and was also aware about the aim of the study and the different conditions. Area 2 in each condition was the diagonal corner (see also Figure 1). Each participant played 80 balls (20 balls per condition). All movements were recorded using a digital camera (25 Hz). That study simulated a typical scenario for technique training and warm-up.

Afterwards, the participants rated the effort in each condition on a scale from 0 points (no effort) to 5 points (large effort). Furthermore,

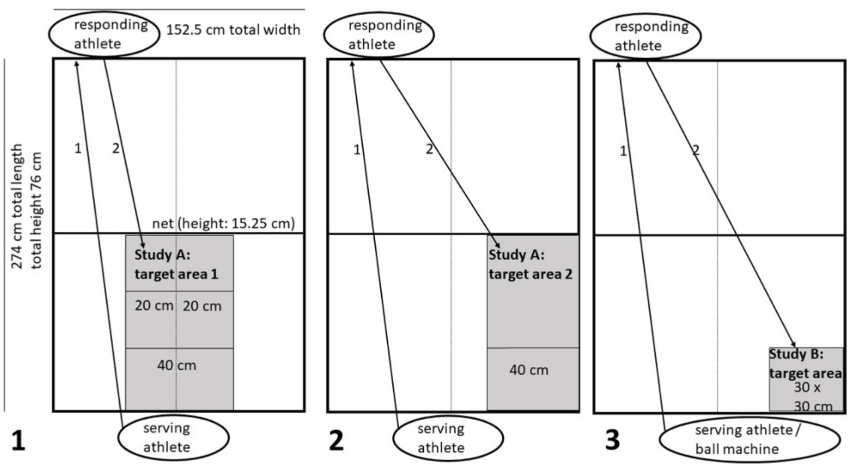

Figure 1. Schematic figure depicting the target areas from top view on the table and the players in study A (1, 2) and study B (3).

answering open questions, they gave written feedback about how they rated the importance of auditory information in table tennis, which condition was the easiest one, and which condition was the most stressful one.

Data analysis

The parameter "hit quality" was assessed by the video software Kinovea (version 0.8.15). Because response quality or accuracy are often analyzed by a score system (e.g. for analysis of decision making, see Milazzo, Farrow, Ruffault & Fournier, 2016, or investigation of response behavior, see Petri et al., 2019a,b), we also developed a score system (0-2 points). The responding athlete achieved 0 points if he did not hit the ball on his racquet. He got 1 point if he hit the ball on the racquet but missed the target area. In case of hitting the ball on the racquet and the correct target area, the participant got 2 points. 80 returns per participant, thus, 1200 videos, were analyzed.

The parameter "subjective effort" was analyzed according to a feedback questionnaire in which the participants ranked the single conditions on a scale from 0 points (no effort) until 5 points (high effort). For each condition (no headphones, noise dampening, almost mute, and no auditory feedback due to the provision of a bright background noise – all for target area 1 (middle of the table) and 2 (diagonal in the corner)), and each parameter ("hit quality" and "subjective effort"), we carried out non-parametric Friedman tests due to the violation of variance homogeneity and normal distribution. Furthermore, Wilcoxon-tests were performed to analyze differences between each headphone condition and the normal condition. The level of significance was set to α=0.05. For each analysis, we used the statistic program SPSS (IBM, version 25). The feedback questionnaires with open questions were analyzed descriptively.

Study B – Analysis of advanced table tennis players hit quality due to two different auditory conditions

We let advanced table tennis players respond to strokes of a real opponent and a ball machine in two conditions each: without manipulations (visual (body kinematics and ball trajectory information) and auditory information are provided), and noise cancelling headphones with additional background sound (occlusion of auditory information, such as the ball contact on the table and on the racquet, as well as environmental noises, e.g. other people).We chose these two conditions based on the results of study A, in which no significant differences in "hit quality" and "subjective effort" were found between the different manipulations in auditory signals (different volume levels). The bright sound, which was used in study A, was also utilized in study B due to the positive feedback of the participants. The bright sound occluded all surrounding auditory information but did not distract the participants. We aimed to analyze if the occlusion of the relevant auditory ball contact information and environmental noises affect the performance of advanced table tennis players in different tests which are close to training and competition scenarios.

Participants

Thirteen advanced table tennis players (11 male, 2 female, age: M= 39.5 years, SD = 19 years) took part in study B. They played regular table tennis since several years (M = 15.4 years, SD = 14.7 years of table tennis experience) and had at least 3 years of competition experience of regional league level in Germany.

Procedure

The procedure was similar to study A. The athletes had to respond to strokes (top spins) with forehand top spins. We chose that kind of response because it is the most frequently played stroke in expert table tennis matches. All top spins should be returned to a given target area (30x30cm at the cross corner). The three tests were as follows:

- test 1: irregular scenario. A real opponent, another athlete from the participant pool, played around 30 tops spins in the forehand or backhand, from which we analyzed 7 well-played forehand top spins. Here, all auditory and visual information (kinematic information and ball flight information) were provided. That condition is quite close to training and competition, and anticipation is needed.
- test 2: regular scenario. The responding athlete had to react to strokes of a real opponent, another athlete from the participant pool, who played 10 forehand top spins on the forehand of the responding athlete. Here, all kinematic information and ball flight information are provided but no anticipation is needed.
- test 3: a ball machine (Tibhar RoboPro Genius (Contra, Hamburg, Germany) with a moderate speed and a ball frequency of around 1 ball per 1-2 seconds as it is common in table tennis training) served the strokes on the forehand side (regular scenario). Thus, any kinematic information from the opponent were removed. Only ball flight information were provided.

We chose these tests because the irregular scenario simulated a typical training scenario close to competition preparation. The regular scenario displayed a warm-up scenario, and the ball machine is often used for technical training to improve stroke execution. In test 1, 30 balls were played each but we only analyzed 7 forehand top spins. In that test, around 10 to 16 balls were played in the forehand. Out of these, one author (TS) who is an advanced table tennis player chose the 7 best returned balls to ensure that we analyzed a quite natural returning behavior. In test 2 and 3, ten forehand top spins were played and analyzed each. Every test was played in the normal condition (no head-phones, thus all auditory and visual information were provided congruently) and in the condition with complete occlusion of all auditory information (environmental noises and ball contacts on the racquet and the table) due to noise-cancelling headphones (Bose 700) and additional background sound as used in study A condition 4. All six conditions (three tests with each normal and no-auditory information) were provided in randomized order to prevent any learning effects. All movements were recorded using a normal digital video camera (25 Hz).

We analyzed and compared the parameters “hit quality” and “subjective effort” in all conditions. Similar to study A, we used a scoring system for the “hit quality”. However, the score system was more precise (0-5 points). The player received 0 points if the ball was not hit at all on the racquet, and 1 point if the ball was hit on the edge of the racquet. S/he received 2 points if the ball was hit properly on the racquet but not on the table and 3 points, if the ball was returned on the table but not in the given target area (30 x 30 cm). 4 points were achieved if the ball was hit on the margin of the target area, and 5 points were given if the ball was hit into the target area. For further information, see also Figure 1.

After the completion of the study, the athletes rated the effort for each condition on a scale from 0 (no effort) until 5 (high effort), as it was already performed in study A. Additionally, they could give further feedback in a questionnaire with open questions.

Data analysis
702 videos were analyzed. However, due to technical problems, the data set of one participant had to be removed for the parameter "hit quality" but the data from all participants were available for the parameter "subjective effort". Similar to study A, Friedman Tests (α=0.05) were applied for both parameters "hit quality" as the performance to return strokes with a forehand topspin properly into a given target (analyzed again with the software Kinovea and a score system from 0 to 5 points), and "subjective effort" measured on a scale from 1 (no effort) to 5 points (high effort) to analyze differences between the conditions. In case of significant differences, Bonferroni post-hoc-tests were conducted, and effect sizes were estimated using Pearson's correlation coefficient being defined as r=0.1 small, r=0.3 moderate and r=0.5 large effect. Furthermore, Wilcoxon tests were applied for detection of differences between the visual + auditory conditions and the visual only conditions (when the participant wore the noise-cancelling headphones) within each test (irregular test and regular play with an opponent, and regular play with a ball machine). For all statistical analyses, we used the software SPSS (IBM, version 25) with a level of significance of α=0.05. The feedback questionnaires were analyzed descriptively.

3. Results

First, we will present the results of study A (novices), and afterwards the results of study B (advanced table tennis players).

Study A – Analysis of novices' performance due to four different auditory conditions
Friedman tests and Wilcoxon tests to analyze the parameters "hit quality" and "subjective effort"
We assessed the parameters "hit quality" and "subjective effort" as depending variables and found no significant differences between the four conditions (normal and three different volume levels) in both parameters (all p>0.05). The hit quality was good with almost 2 points (thus maximum) in each condition. The subjective effort was moderate with around 2 points (maximum effort 5 points). For further detail, we refer to Table 1.
We also analyzed differences between the four conditions four each target area, and also found no significant difference for the parameter "hit quality (1: middle of the table with χ^2 (3) = 1.432, p=0.698, and 2: diagonal with χ^2 (3) = 3.595, p=0.309), and "subjective effort" (1: middle of the table with χ^2 (3)=2.353, p=0.502, and 2: diagonal with χ^2 (3)=1.555, p=0.670. Thus, no differences between the different auditory conditions were detected.
Wilcoxon tests for detection of differences between each noise-cancelling headphone and the normal condition (no headphone) also found no significant differences for the parameters "hit quality" and "subjective effort". Comparing the headphones from Boltune (condition 2, dampening of auditory information) with the normal condition, no significant differences were found for target area 1 and 2 in "hit quality" (W=45.50, p=1, W=19.50, p=0.764) and "subjective effort" (target area 1: W=48, 00, p=0.464, target area 2: W=30.00, p=0.849). The same results were found for the headphones Bose Quiet Comfort 35 (condition 3, almost mute) in "hit quality" (target area 1: W=35.50, p=0.811, target area 2: W=76.00, p=0.375) and "subjective effort" (target area 1: W=30.00, p=0.802, target area 2: W=33.50, p=1), and for the headphones with additional bright background sound (condition 4) in "hit quality" (target area 1: W=53.50, p=0.598, target area 2: W=65.50, p=0.170) and "subjective effort" (target area 1: W=31.00, p=0.536, target area 2: W=23.00, p=0.666).
In summary, no significant differences between any conditions were observed. Thus, for our sample, the acoustic information and their volume level did not influence the performance in table tennis.

Furthermore, no difference was observed between the two chosen target area.

Further feedback

Although most of the participant were of the opinion that auditory information, especially ball contacts on the racquet and the table, are important in table tennis, half of the athletes later preferred conditions with manipulations of these information. Seven out of fifteen participants preferred the noise cancelling headphones Boltunes and Bose without further sound. In these conditions, the ball contacts on the table and the racquet were dampened but still softly audible. The participants stated that the reduction of the auditory information helped to better concentrate and focus on the task. Six participants preferred the normal condition, and the remaining two participant did not prefer any condition. All athletes confirmed that only the noise cancelling headphones with the additional noise completely removed any auditory information. When comparing the three conditions with the noise cancelling headphones, four participants preferred the condition with the additional sound due to better concentration on the relevant visual cues. The other 11 participants preferred the conditions where the sound was only dampened but not completely removed. That helped them to focus on the task but the condition was not too unnatural for them. Only two of the 15 athletes stated that the additional sound was disturbing or exhausting.

Therefore, we conclude that for complete occlusion of any auditory information in table tennis, an additional background noise is necessary. Most of the athletes felt comfortable with it.

Study B – Analysis of advanced table tennis players' performance due to two different auditory conditions in three tests

Friedman tests and Wilcoxon tests to analyze the parameters "hit quality" and "subjective effort"

Similar to study A, we assessed the parameters "hit quality" and "subjective effort" as depending variables, and found no significant differences between all conditions (normal and occlusion of auditory information) in both parameters (all $p>0.05$). We also analyzed differences between the three tests within the normal condition (no noise-cancelling headphones) and the condition where no auditory information were provided (with noise-cancelling headphones). The performance in "hit quality" was moderate with 3 points (maximum score 5 points), and the subjective effort was also moderate with 2-3 points (maximum effort 5 points). For further information, see Table 2.

Similar to study A, in the condition without auditory information, also no significant differences were found for the parameters "hit quality" (χ^2 (3)=1.319, p=0.685) and "subjective effort (χ^2 (3)=4.333, p=0.0.115) using Friedman tests when comparing the three tests (irregular play, regular play and ball machine). However, in the normal condition (visual and congruent auditory information), we found a significant difference for "subjective effort" between the three tests (χ^2 (3)=7.600, p=0.022). Bonferroni post-hoc tests revealed a significant difference between test 2 (regular play) and test 3 (irregular play) with p=0.018 and r=0.69 (large effect), but not between test 1 and test 2 (p=0.721), and between test 1 and test 3 (p=0.078). The effort to hit the target area properly was significantly higher in the irregular play compared to the regular play in the condition where both visual and auditory information were provided. However, for the parameter "hit quality", no significant difference was found between the three tests in the condition without auditory information (χ^2 (3)=1.319, p=0.685). That result is in line with the statement of Grandjean, Quoilin and Duque (2019).

Using Wilcoxon tests, we also analyzed differences between the normal condition (visual and auditory stimuli provided) and the conditions with the noise cancelling headphones (only visual stimuli provided) in each of the three tests and also found no significant differences in the "hit quality" (test 1: W=50.00, p=0.410, test 2: W=45.50, p=0.284, test 3: W=50.50, p=0.388) and in the "subjective effort" (test 1: 25.00, p=0.273, test

Table 1. Results of Study A (novices): Mean (M) ± standard deviation (SD) of the parameters "hit quality" and "subjective effort" for the four conditions and each target area.

parameter	target area	condition 1: normal (no noise-cancelling headphones) M ± SD	condition 2: dampening of the auditory information (noise-cancelling headphones, Boltune) M ± SD	condition 3: almost mute (noise-cancelling headphones, Bose) M ± SD	condition 4: no auditory information (noise-cancelling headphones with additional sound (bright background noise), Bose) M ± SD	significance (between all eight conditions using Friedman tests)
„hit quality" according to a score system. 0 points: the ball was not hit on the racquet. 1 point: the ball was hit on the racquet but not on the correct target area. 2 points: the ball was hit on the racquet and the correct target area	1: middle of the table	1.77 ± 0.15	1.76 ± 0.28	1.80 ± 0.13	1.73 ± 0.25	χ^2 (7) = 3.574, **p = 0.827**
	2: diagonal	1.79 ± 0.14	1.79 ± 0.21	1.75 ± 0.21	1.73 ± 0.21	
„subjective effort" according to a score system using feedback questionnaires with a scale of 1 (no effort) until 5 (high effort) for the four conditions and each target area	1: middle of the table	2.20 ± 1.08	1.93 ± 0.60	2.27 ± 1.03	2.40 ± 0.63	χ^2 (7) = 9.292, **p = 0.232**
	2: diagonal	2.46 ± 1.13	2.27 ± 0.70	2.4 ± 0.74	2.60 ± 0.74	

2: 18.00, p=0.347, test 3: W=20.00, 0.803). Thus, no significant differences were observed between the visual + auditory condition and the visual condition only when analyzing the irregular play and regular play with an opponent and the regular play with ball machine.

Further feedback

Five of the thirteen athletes preferred the conditions in which auditory information were removed because of better possibilities to concentrate. Seven athletes preferred the normal condition and one athlete had no preference. However, all athletes stated that they use only visual information to forecast strokes. These visual cues were namely the opponent's movements, racquet position and racquet movement, as well as the ball flight. None of the athletes reported to use any auditory information

4. Discussion

The advantage of the current studies is the representative learning design (Pinder, Davids, Renshaw & Araújo, 2011). The sports specific response quality is measured based on the hit quality according to the guidelines set by Avilés, Navia, Ruiz and Martinez de Quel (2019): the type of the stimulus is a real

Table 2. Results of study B (advanced players): Mean (M) ± Standard deviation (SD) of the parameters "hit quality" and "subjective effort". Irregular: players respond to irregular strokes of an opponent. Regular: players respond to regular strokes of an opponent. Ball machine: players respond to standardized strokes without kinematic information of the opponent.

parameter	**condition**	**test 1: irregular with opponent** (M ± SD)	**test 2: regular with opponent** (M ± SD)	**test 3: ball machine** (M ± SD)	**significance** (between all six conditions using Friedman tests)
„hit quality" according to a scoring system. 0 points (bad) until 5 points (very good) for each condition and test	**normal**: without head-phones	3.41 ± 0.69	3.45 ± 0.33	3.37 ± 0.61	$\chi^2(5) = 4.744$, **p = 0.448**
	no auditory signals: noise-cancelling headphones with additional sound (bright background noise, Bose)	3.32 ± 0.45	3.23 ± 0.44	3.25 ± 0.46	
„subjective effort" according to a score system using feedback questionnaires with a scale of 1 (no effort) until 5 (high effort) for each condition and test	**normal**: without head-phones	2.00 ± 1.08	1.92 ± 0.64	2.62 ± 0.87	$\chi^2(5) = 10.253$ **p = 0.068**
	no auditory signals: noise-cancelling headphones with additional sound (bright background noise, Bose)	2.15 ± 1.07	2.38 ± 1.19	3.08 ± 1.19	

opponent or a ball machine which is an often-used instrument in table tennis training, the type of response is sports specific as in training and competition, the moment of response is concurrent, and the information of response is immediately seen by the ball contact on racquet and table.

Perception of ball trajectories and movements of the opposing player as visual cues, as well as spin of ball as auditory cue, and adequate response with speed and accuracy, thus quality, are crucial in table tennis (Santos et al., 2017, Streuber, Mohler, Bülthoff & de la Rosa, 2012). In the current study, we extend the results from previous studies analyzing the importance of auditory information in sports, and especially table tennis, by separating visual and auditory cues, and examining the response behavior (quality of the return to a given target area) of two expertise levels (novices and advanced table tennis players) under quite natural conditions (two in-situ studies). In both studies, we could not find any differences between the normal conditions (visual and auditory information available) and the conditions without auditory information (visual information only when wearing noise-cancelling headphones). Thus, based on our results, we assume that manipulations in volume level or remove of auditory information does not influence the parameters "hit quality" or the "subjective effort" in table tennis. Although auditory cues are important in many daily life situations, and auditory information can be processed faster that visual information

(Santos et al., 2017), visual information seem to be more important in table tennis.

Previous studies showed that auditory information, when congruent to visual information, aids theses visual information (Bischoff et al., 2014, Wang, Liao, Lundgren Lyckvi & Chen, 2016), but in the current study, manipulations of the congruent auditory information had no effect on the performance. Therefore, we need to reject our assumption that the remove of auditory information leads to a decrease in "hit quality" and an increase in the "subjective effort". In contrast, based on our results, we can speculate removing auditory information in real training can help to focus on relevant visual information.

No significant differences in "hit quality" were found between the conditions with the ball machine and the regular and irregular play in study B when auditory information was removed. That finding supports the results of Streuber, Mohler, Bülthoff and de la Rosa (2012) who found that the ball is the most important visual cue, especially at the time of ball release or contact with the racquet (Avilés, Navia, Ruiz & Martinez de Quel, 2019, Streuber, Mohler, Bülthoff & de la Rosa, 2012) because the ball was the only visual cue always visible in each condition and test scenario.

The results of the feedback questionnaires of study A showed that although most of the participants were of the opinion that auditory information is important in table tennis, they preferred the conditions with the dampening or occlusion of these information. Many of both novices and advanced players stated that the reduction of auditory information helped to better concentrate and focus on relevant information during task completion. The report of the advanced players that they rely only on visual cues are in line with our finding in "hit quality". Based on our results, visual cues are more important than auditory cues both for novices and advanced table tennis players.

The results of the present studies with novices and advanced players are in line with previous research in which it was found that visual information, especially kinematic information, are more important than auditory information (e.g. in fencing, Allerdissen, Güldenpenning, Schack & Bläsing, 2017 or conducting, Colley, Varlet, MacRitchie & Keller, 2018). Santos et al. (2017) could only show that auditory information can be used to perceive flat hits in table tennis but auditory information alone is not usable to differentiate between fast, moderate or slow rotations. Although it is possible that the missing auditory information will lead to a higher cognitive load (Grandjean, Quoilin & Duque, 2019), no differences in the subjective effort were seen in study A (novices) and study B (advanced players) when analyzing the different conditions with manipulations of auditory information. However, when comparing the normal conditions in study B, where both visual and auditory information were provided, a significant difference with a large effect size was found between the regular and the irregular play. That finding underlies results of the importance of visual cues for correct and early anticipation of future strokes (Loffing & Cañal-Bruland, 2017, Morris-Binelli & Müller, 2017).

It is well-known that compared to novices, skilled athletes are better in forecasting future actions (also based on very early information, e.g. Loffing, Sölter, Hagemann & Strauss, 2017) and accurate decision making, as well as reacting to relevant stimuli due to their better visual pattern recognition (Gutiérrez-Davila, Rojas, Gutiérrez-Cruz & Navarro, 2019, Wang, Ji & Zhou, 2019), in case of an existence of patterns (structured patterns, Sherwood, Smith & Masters, 2019). However, skilled athletes are worse in cases of unstructured patterns, incongruent information (Sherwood, Smith & Masters, 2019, Zhao, Lu, Jaquess & Zhou, 2018) or response inhibition (Gutiérrez-Davila, Rojas, Gutiérrez-Cruz & Navarro, 2019). Experts are more robust against deceptive movements but they expect more feints due to their larger movement experiences (Güldenpenning, Kunde & Weigelt, 2017). Wright, Bishop, Jackson and Abernethy (2013) showed gender differences in expecting feints. Men expected more feints compared to women but further research is desired in that field (Wright, Bishop, Jackson & Abernethy, 2013). In our study, we only presented structured patterns and congruent information. It would be interesting to repeat our studies and to include more scenarios with irregular play and different stroke types to analyze anticipation in an-situ study closer to competition and not only to training as it was the case here.

Studies with eye tracking showed that information intake occurred due to a visual pivot, which is often a central point on the body (often the trunk or the head) of the opponent, or a functional space between several athletes and the ball, as well as due to peripheral vision (Vater, Williams & Hossner, 2019). In combat sports, such as karate kumite, Petri, Bandow, Salb and Witte (2018) demonstrated that the head, thus facial expressions and movements of the eyes, did not reveal relevant information und also underlined the importance of peripheral vision for information intake and processing of relevant visual kinematic information. That dominance of visual information was also found in our studies.

It would be interesting to perform a study similar to the one from Streuber, Mohler, Bülthoff and de la Rosa (2012), in which a user played table tennis strokes against a virtual opponent. In such a virtual environment, many manipulations of visual cues, e.g. bodily movements of the opponent, different ball spins or ball trajectories, could be performed to further understand which visual cues are used to anticipate strokes correctly. Furthermore, visual and auditory information could be manipulated (both information can be shown congruently or incongruently, e.g. with a time delay between visual and auditory information, or a wrong auditory information), to further understand how visual and auditory information interplay. Analyses of auditory cues for information intake, integration and processing could be tested under realistic but standardized conditions. Already Michalski et al. (2019) demonstrated that virtual reality interventions can be used to improve real world table tennis skills. In a review, Craig (2014) showed how virtual reality can be utilized to analyze perception and decision making in sports.

However, we need to mention some limitations of the current paper. First, the sample sizes are not very large. And especially in study B, it would be desirable to include more participants with an even more homogenous level. It would further be interesting to include more high-skilled athletes of national and international competition experience. Though, the current study is a valuable pilot study which can push new studies. Second, it is possible that the tasks were too easy and too short (each single task lasted not longer than 1-2 minutes). That could explain, why the subjective effort failed the level of significance and was just a trend ($p=0.068$) in the auditory conditions in study B. Thus, we recommend to repeat our studies and to include further strokes and either additional tasks or longer test protocols. Furthermore, it would be desirable to analyze further parameters, such as ball or arm velocities using acceleration sensors at the hand or arm of the athlete. It could be possible that – although we did not find any cues for that in the video materials- the velocity decreases in the conditions with occlusion of the auditory information to ensure a good hit quality. Furthermore, the technique execution might change, e.g. the range of movements might decrease to ensure good hit quality under more controlled (thus smaller) movement executions. Therefore, we recommend to perform further research in that field.

We conclude that auditory information is less important than visual information in table tennis. However, the relevant visual cues need to be conclusively clarified in future studies. For real table tennis training, it could be beneficial to include practical exercises with such noise-cancelling headphones that players, especially beginners, learn to concentrate on the relevant visual cues and to not get subtracted from environmental auditory information.

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References

Abernethy, B. & Russel, D.G. (1987). The relationship between expertise and visual search strategy in a racquet sport. Human Movement Science, 6, 283-319. DOI: 10.1016/0167-9457(87)90001-7

Abernethy, B, Zawi, K. & Jackson, R.C. (2008). Expertise and attunement to kinematic constraints. Perception, 37, 931-938. DOI: 10.1068/p5340

Allerdissen, M., Güldenpenning, I., Schack, T. & Bläsing, B. (2017). Recognizing fencing attacks from auditory and visual information: A comparison between experts and novices. Psychology of Sport and Exercise, 31, 123-130. DOI: 10.1016/j.psychsport.2017.04.009

Auksztulewicz, R., Schwiedrzik, C.M., Thesen, T., Doyle, W., Devinsky, O., Nobre, A.C., Schroeder, C.E., Friston, K.J. & Melloni, L. (2018). Not all predictions are equal: "What" and "When" predictions modulate activity in auditory cortex through different mechanisms. The Journal of Neuroscience, 38 (40), 8680-8693. DOI: 10.1523/JNEUROSCI.0369-18.2018

Avilés, C., Navia, J. A., Ruiz, L. M. & Martinez de Quel, Ó. (2019). Do expert tennis players actually demonstrate anticipatory behavior when returning a first serve under representative conditions? A systematic review including quality assessment and methodological recommendations. Psychology of Sport and Exercise, 43 (July), 16-26. DOI: 10.1016/j.psychsport.2018.12.015

Bischoff, M., Zentgraf, K., Pilgram, S., Stark, R., Krüger, B. & Munzert, J. (2014). Anticipating action effects recruits audiovisual movement representations in the ventral premotor cortex. Brain and Cognition, 92, 29-47. DOI: 10.1016/j.bandc.2014.09.010

Brunnett, G., Rusdorf, S. & Lorenz, M. (2006). V-Pong: An Immersive Table Tennis Simulation. IEEE Computer Graphics and Applications, 4, 10-13. DOI: 10.1109/MCG.2006.92

Colley, I.D., Varlet, M., MacRitchie, J. & Keller, P.E. (2018). The influence of visual cues on temporal anticipation and movement synchronization with musical sequences. Acta Psychologica, 191, 190-200. DOI: 10.1016/j.actpsy.2018.09.014

Craig, C. (2014). Understanding perception and action in sport: how can virtual reality technology help? Sports Technology, 6 (4), 161-169. DOI: 10.1080/19346182.2013.855224

Grandjean, J., Quoilin, C. & Duque, J. (2019). Investigating the effect of anticipating a startling acoustic stimulus on preparatory inhibition. Neurophysiologie Clinique, 49 (29), 137-147. DOI: 10.1016/j.neucli.2018.11.002

Güldenpenning, I., Kunde, W. & Weigelt, M. (2017). How to trick your opponent: a review article on deceptive actions in interactive sports. Frontiers in Psychology, 8:917. DOI: 10.3389/fpyg.2017.00917

Gutiérrez-Davila, M., Rojas, F. J., Gutiérrez-Cruz, C. & Navarro, E. (2019). Components of attack response inhibition in fencing. European Journal of Sport Science, 19 (5), 628-635. DOI: 10.1080/17461391.2018.1539122

Loffing, F. & Cañal-Bruland, R. (2017). Anticipation in sport. Current Opinion in Psychology, 16, 6-11. DOI: 10.1016/j.copsyc.2017.03.008

Loffing, F., Sölter, F., Hagemann, N. & Strauss, B. (2017). On-court position and handedness in visual anticipation of stroke direction in tennis. Psychology of Sport and Exercise 27, 195-204. DOI: 10.1016/j.psychsport.2016.08.014

Martínez de Quel, M. & Bennett, S.J. (2019). Perceptual-cognitive expertise in combat sports: a narrative review and a model of perception-action. Revista Internacional de Ciecias del Deporte, 58 (15), 232-338. DOI: 10.5232/ricyde2019.05802

Michalski, S.C., Szpak, A., Saredakis, D., Ross, T.J., Billinghurst, M. & Loetscher, T. (2019). Getting your game on: Using virtual reality to improve real table tennis skills. PLoS ONE, 14 (9): e0222351. DOI: 10.1371/journal.pone.0222351

Milazzo, N., Farrow, D., Ruffault, A. & Fournier, J.F. (2016). Do karate fighters use situational probability information to improve decision-making performance during on-mat tasks? Journal of Sports Sciences, 34 (16), 1547-1556. DOI: 10.1080/02640414.2015.1122824

Morris-Binelli, K. & Müller, S. (2017). Advancements to the understanding of expert visual anticipation skill in striking sports. Canadian Journal of Behavioral Science, 49, 262-268. DOI: 10.1037/cbs0000079

Murphy, C.P., Jackson, R.C. & Williams, A.M. (2018). The role of contextual information during skilled anticipation. Quarterly Journal of Experimental Psychology, 71 (10), 2070-2087. DOI: 10.1177/1747021817739201

Park, S. H., Kim, S., Kwon, M. & Christou, E.A. (2016). Differential contribution of visual and auditory information to accurately predict the direction and rotational motion of a visual stimulus. Applied Physiology, Nutrition, and Metabolism, 41(3), 244-248. DOI: 10.1139/apnm-2015-0390

Petri, K., Bandow, N., Salb, S. & Witte, K. (2018). The influence of facial expressions on attack recognition and response behaviour in karate kumite. European Journal of Sports Science, 19 (5), 1-10. DOI: 10.1080/17461391.2018.1536170

Petri, K., Emmermacher, P., Danneberg, M., Masik, S., Eckardt, F., Weichelt, S., Bandow, N. & Witte, K. (2019a). Training using virtual reality improves response behavior in karate kumite. Sports Engineering, 22:2. DOI: 10.1007/s12283-019-0299-0

Petri, K., Lichtenstein, M., Bandow, N., Campe, S., Wechselberger, M., Sprenger, D., Kaczmarek, F., Emmermacher, P. & Witte, K. (2016). Analysis of anticipation by 3D motion capturing – a new method presented in karate kumite. Journal of Sports Sciences, 35 (2): 130-135. DOI: 10.1080/02640414.2016.1158851.

Petri, K., Masik, S., Danneberg, M., Emmermacher, P. & Witte, K. (2019b). Possibilities to use a virtual opponent for enhancements of reactions and perception of young karate athletes. International Journal of Computer Science in Sport, 18 (2) (Special Edition), 20-33. DOI: 10.2478/ijcss-2019-0011

Pinder, R.A., Davids, K., Renshaw, I. & Araùjo, D. (2011). Representative learning design and functionality of research and practice in sport. Journal of Sport and Exercise Psychology, 33 (1), 146-155. DOI: 10.1123/jsep.33.1.146

Rajendran, V.G., Teki, S. & Schnupp, J.H. H. (2018). Temporal processing in audition: Insights from music. Neuroscience, 389, 4-18. DOI: 10.1016/j.neuroscience.2017.10.041

Repp, B.H., & Su, Y. H. (2013). Sensorimotor synchronization: A review of recent research (2006-2012). Psychonomic Bulletin & Review, 20 (3), 403-452. DOI: 10.3758/s13423-012-0371-2

Runswick, O.R., Roca, A., Williams, A.M. & McRobert, A. (2018). The temporal integration of information during anticipation. Psychology of Sport & Exercise, 37, 100-108. DOI: 10.1016/j.psychsport.2018.05.001

Russo, G. & Ottoboni, G. (2019). The perceptual-cognitive skills of combat sports athletes: A systematic review. Psychology of Sport & Exercise, 44, 60-78. DOI: 10.1016/j.psychsport.2019.05.004

Santos, D.P.R., Barbosa, R.N., Vieira, L.H.P., Santiago, P.R.P., Zagatto, A.M. & Gomes, M.M. (2017). Training level does not affect auditory perception of the magnitude of ball spin in table tennis. Journal of Human Kinetics, 55, 19-27. DOI: 10.1515/hukin-2017-0003

Schaffert, N., Engel, A., Schlüter, S. & Mattes, K. (2019). The sound of the underwater dolphin-kick: developing real-time audio feedback in swimming. Displays, 59, 53-62. DOI: 10.1016/j.displa.2019.08.001

Schreiber, K.E. & McMurray, B. (2019). Listeners can anticipate future segments before they identify the current one. Attention, Perception & Psychophysics, 81, 1147-1166. DOI: 10.3758/s13414-019-01712-9

Sherwood, S., Smith, T. & Masters, R. S. W. (2019). Pattern recall, decision making and talent identification in rugby union. European Journal of Sport Science, 19 (6), 834-841. DOI: 10.1080/17461391.2018.1545051

Sigrist, R., Rauter, G., Marchal-Crespo, L., Riener, R., & Wolf, P. (2015). Sonification and haptic feedback in addition to visual feedback enhances complex motor task learning. Experimental Brain Research, 233 (3), 909–925. DOI: 10.1007/s00221-014-4167-7

Sors, F., Murgia, M., Santoro, I., Prpic, V., Galmonte, A. & Agostini, T. (2017). The contribution of early auditory and visual information to the discrimination of shot power in ball sports. Psychology of Sport and Exercise, 31, 44-51. DOI: 10.1016/j.psychsport.2017.04.005

Streuber, S., Mohler, B.J., Bülthoff, H.H. & de la Rosa, S. (2012). The influence of visual information on the motor control of table tennis strokes. Presence, 21 (3), 281-294. DOI: 10.1162/PRES_a_00113

Vater, C., Williams, A.M. & Hossner, E.-J. (2019). What do we see out of the corner of our eye? The role of visual pivots and gaze anchors in sport. International Review of Sport and Exercise Psychology. DOI: 10.1080/1750984X.2019.1582082

Wang, Y., Ji, Q. & Zhou, C. (2019). Effect of prior cues on action anticipation in soccer goalkeepers. Psychology of Sport and Exercise, 43 (July), 137-143. DOI: 10.1016/j.psychsport.2019.02.001

Wang, M., Liao, Y., Lundgren Lyckvi, S. & Chen, F. (2019). How drivers respond to visual vs. auditory information in advisory traffic information systems. Behavior & Information Technology. DOI: 10.1080/0144929X.2019.1667439

Williams, A.M. & Jackson, R.C. (2019a). Anticipation and decision making in sports. New York, NY, USA: Routledge, 397 pages. ISBN: 978-1-138-50483-7 (hbk)

Williams, A. M. & Jackson, R. C. (2019b). Anticipation in sport: Fifty years on, what have we learned and what research still needs to be undertaken? Psychology of Sport and Exercise, 42 (May), 16-24. DOI: 10.1016/j.psychsport.2018.11.014

Wright, M.J., Bishop, D.T., Jackson, R.C. & Abernethy, B. (2010). Functional MRI reveals expert-novice differences during sport-related anticipation. Neuroreport, 21(2), 94-98. DOI: 10.1097/WNR.0b013e328333dff2

Wright, M.J., Bishop, D.T., Jackson, R.C. & Abernethy, B. (2013). Brain regions concerned with the identification of deceptive soccer moves by higher-skilled and lower-skilled players. Frontiers in Human Neuroscience, 7: 851. DOI: 10.3389/fnhum.2013.00851

Yoo, J.W., Ronzio, F. & Courtois, T. (2019). Road noise reduction of a sport utility vehicle via panel shape and damper optimization on the floor using genetic algorithm. International Journal of Automotive Technology, 20 (5), 1043-1050. DOI: 10.1007/s12239-019-0098-4

Zhao, Q., Lu, Y., Jaquess, K.J. & Zhou, C. (2018). Utilization of cues in action anticipation in table tennis players. Journal of Sports Sciences. DOI: 10.1080/02640414.2018.1462545