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Original Article

Sport experience and visual motor reaction time of boxers

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Abstract
Adequate evaluation of the situation and timely reaction are crucial for the performance in sports such as boxing. There are few studies on the visual motor reaction time of boxers. The aim of this study was to evaluate the visual motor reaction time of boxers during a complex dynamic cognitive task, depending on their sport experience. This study included 20 male boxers, all right-handed. They were divided into two groups according to their boxing experience: 1–3 years (mean age of 21.2 ± 5.45 years) and more than 5 years (mean age of 24.4 ± 6.92 years). The boxers did not have any significant differences in their anthropometric measurements. They were instructed to press as fast as possible buttons that were flashing red or green in random order and position with their dominant and non-dominant hand, depending on the color of the button. Hits were analyzed as "jab" (forward) or "cross" (diagonal) according to the arm movement required to reach the button. The visual motor reaction times of the group with more than 5 years of experience were shorter than those of the other group. The "jab" hits were faster than the "cross" ones in both groups. Sport experience had greater effect on the "jab" reaction times than on the "cross" ones. In both groups of boxers, the visual motor reaction times with the dominant hand were shorter than those with the non-dominant hand. Owing to the specific training of boxers, their automatic reaction abilities during a task-specific cognitive load increase more prominently for the "jab" hits. Despite sport experience, the effects of hand laterality on the visual motor reaction times are preserved. Greater experience in boxing significantly shortens the overall response time and leads to specific differences in the motor response of the performing arm depending on the stimulus/target position. The developed methodology is suitable for assessing the progress and selection of athletes as well as for developing better training programs.
Key Words: **boxing, punch, choice reaction time, upper extremity VMRT, cognitive function, hand dominance**

Introduction

Motor skills, such as fast response and good inhibitory control are crucial for achieving high athletic performance (Van de Water et al., 2017), especially in combat sports, such as boxing (Dincer et al., 2022). Boxing is a sport in which the athletes are at a short distance from each other, which requires the ability to quickly assess the situation and the possible trajectory of the opponent's strike and to initiate adequate and effective motor response. There is evidence that the speed of visual motor processes is determined especially by the functioning of the central nervous system (Ando et al., 2001; Zwierko et al., 2008). In combat sports, such as boxing, the sudden and rapid displacement of the body, combined with simultaneous hand movements during defence and attack are factors, related to reaction time (RT) (Dincer et al., 2022).

Visual motor reaction time (VMRT) is defined as the time, required to recognize and respond to a sequence of appearing visual stimuli and often involves the ability to make quick and accurate response to a stimulus with movement of the hands (Wilkerson et al., 2015; Brinkman et al., 2020). It is a measure of the ability to make a quick processing of the visual and cognitive information for the execution of an accurate perceptual-motor response. According to the cognitive complexity of the task there are three main types of RT that are measured in studies: Simple reaction (single stimulus that produces known response when it appears); Choice reaction (multiple stimuli and each stimulus requires a different response) and Discrimination reaction (multiple stimuli, but a response only to one of the stimuli) (Miller & Low, 2001; Baayen & Milin, 2010).

In the literature there are not many visual motor reaction time studies of boxers, especially with a cognitive task of choice. A recent study measured the visual simple RT of boxers and wrestlers, and found that boxers had shorter visual simple RT compared to wrestlers (Dincer et al., 2022). Other studies assessed simple and complex VMRTs in boxers in relation to gender and found no differences in the visual RT (Bianco et al., 2011). Few studies compare the visual RT of boxers with different levels of competitive experience. For example Darby et al. measured the speed of verbal response to visual stimuli of boxers and found that finalists in

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a boxing tournament had significantly shorter VRT than those who did not reach the finals, while Bianco et al. did not find significant differences in the RTs of amateurs and competitors by measuring VMRT using a computer keyboard (Bianco et al., 2008; Darby et al., 2014). Those contradicting results are probably due to the specifics of the tasks, which are not related to the formation of motor response with the whole arm, as in boxing. Loturco et al. investigated the VMRT in elite boxers while performing specific movements, characteristic for the boxing technique (straight and cross punches) and found that the VMRT was shorter during straight punches, compared to cross punches (Loturco et al., 2015).

As the methods for evaluating motor reaction time differ in regard of the complexity of the motor task (inclusion of more segments of the body in the motor response), the time for the motor response increases, which is why it is difficult to directly compare the results from the different studies with different motor tasks.

Also, the visual motor reaction time with a cognitive choice strongly depends on the complexity of the decision-making task and the subject's cognitive abilities and experience. In the context of boxing, the cognitive choice is critical for split-second decision making in the ring as the boxer must quickly process visual cues from their opponent, assess the situation, and choose between different defensive or offensive dual-task maneuvers. Therefore for evaluation of boxers' reaction time the most suitable one is the Choice reaction time to visual stimuli.

The aim of our study was to evaluate the effect of sport experience on the visual motor reaction time of choice (VMRTC) of boxers, by using a two-choice decision-making task with motor actions close to the real boxing punches.

Material & methods

Participants

A total of 20 boxers took part in the present study. The participants were divided into two groups, depending on their sports experience: intermediate (active boxing 3 times a week, up to 3 years) and highly skilled boxers (competitors and champions of National and European championships). All subjects were right-handed males. Before the study an interview was conducted and the medical history of the boxers was assessed. Exclusion criteria were the presence of sports injuries in the last month, as well as injuries related to loss of consciousness, balance issues or neurological disorders in the last 6 months. All subjects had rested and were examined a minimum of 24 hours after the last sport practice. Prior to the study, the boxers were given standardized instructions about the purpose and the way of performing the tasks, ensuring that the presented information was the same for all participants. All subjects gave written informed consent to participate in the study. They were free to withdraw from the study at any time. The study was approved by the Bioethics Committee of the Institute of Neurobiology and was in accordance with the Declaration of Helsinki. Table 1 presents the main anthropometric characteristics of the participants.

Table 1. Anthropometric data of the boxers, participating in the study, presented as mean values and standard deviations.

Measure	Group1 Sport experience < 3 years	Group2 Sport experience > 5 years
Number of subjects	10	10
Age (years)	21.2 ± 5.45	24.4 ± 6.92
Height (cm)	175.56 ± 9.6	175.4 ± 6.01
Weight (kg)	70.18 ± 7.55	75.84 ± 9.38
BMI (kg/m^2)	22.75 ± 1.27	24.71 ± 3.33
Foot length (cm)	27.01±1.39	26.86 ± 1.11
Height / Foot length	6.41 ± 0.19	6.43 ± 0.15

Equipment and measurements

To measure the VMRTC of the boxers, a computerized apparatus, developed at the Institute of Neurobiology – BAS, was used. It contains a board with 13 radially located light buttons, each one selectively lightened in red or green (Fig. 1), a laptop and a video camera. The choice reaction time was studied by using a visual stimulus to which the athlete responded with a selective response by hitting a button with maximally fast movement of the right or left hand without changing the position of the body. The task included a total of 50 light stimuli – 25 red and 25 green, presented in random order. We used red and green colors of the stimuli, because some studies show that red and green stituli provoke the same visual choice reaction time (Balakrishnan et al., 2014). The buttons are 32 x 32 mm in size, corresponding to a low spatial frequency and resulting in fixed stimulus detection time (Mitov and Totev, 2010). Boxers were instructed to respond with hitting the lighted button to switch it off, respectively, the red stimuli with the dominant right hand and the green stimuli with the non-dominant left hand. This task was tailored to the performance of punches, specific to the boxing technique – straight punch, not crossing the vertical axis of the board (jab) and punch, crossing the vertical axis of the board (cross). Thirty-two jabs (16 with dominant right and 16 with non-dominant left hand) and 16 cross punches (10/6) were analyzed. The VMRTC was measured in milliseconds. It was calculated from the moment of

illumination of the respective button to the moment of its switching off. The interstimulus interval was 350ms (time to return the arm to the starting position). The first two hits were for getting acquainted with the task and were not included in the analysis. The performance was recorded with a web camera to exclude any errors from the analysis (buttons pressed with the wrong hand or not starting the movement from the required standardized position). VMRTCs with an excessive delay (over 1000ms) were also removed from the analysis.

Procedure

The position of the boxers was as standardized as possible. They stood facing the light board, positioning their body directly opposite the center button, located at eye level. The distance of the person from the light board was determined so that he could reach the buttons located in the upper diagonals of the light board with his arm outstretched. In the starting position, the hands were placed next to the cheeks, in front of the ears and returned back there after each hit.

A sound signal determined the start of the task. The task was performed two consecutive times with an interval of 45 minutes between them. The two measurements of each boxer for each punch technique were averaged and considered for further analysis.

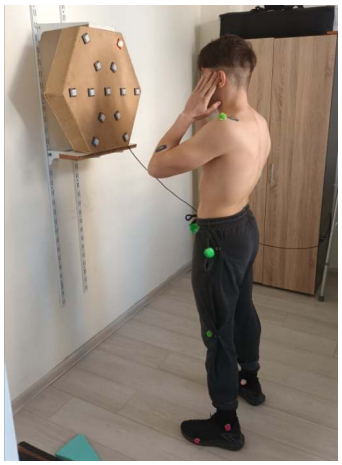

Fig.1 Position of the subject to the light board for the measurement of VMRTC

Statistical analysis

Descriptive statistics were applied to the analysis of anthropometric indicators and VMRTC data in the two studied groups of boxers. The type of data distribution was assessed with the Kolmogorov–Smirnov test for normality of distribution. The Student's t-test was used to compare the anthropometric parameters of the two groups of boxers, while the Mann-Whitney U test was used to compare the VMRTC between the groups, and the Wilcoxon rank test was used between the types of punches and between left and right hands. The analyses were made using the computer software Statistica 8.0 for Windows (Stat Soft Inc. USA). $P < 0.05$ was considered statistically significant.

Results

Statistically significant differences in the anthropometric measures between the two groups of boxers were not found (Student's t-test, at level of significance $p<0.05$) (Table 1).

Nonparametric statistical analysis was applied to evaluate the differences of VMRTCs between groups and execution of the punches. Table 2 shows the VMRTCs in the two groups of boxers when performing jab and cross punches with the left and right hand.

The VMRTCs of the intermediate boxers (Group 1) were found to be longer, compared to the highly skilled boxers (Group 2) for both types of punches, performed with both left and right hands. Statistically significant differences between the groups were found in the execution of jabs with both hands and cross punches with the right hand (Mann-Whitney U test, $*p<0.05$), while in the cross punches with the left hand statistically significant difference between the groups was not found (Table 2).

The highly skilled boxers (Group 2) showed significantly longer values of VMRTC in the cross punches than the jabs, executed with right and left hands, while for the intermediate boxers (Group 1) significant difference between jab and cross punch was observed in the execution with right hand only (Wilcoxon rank test, $\#p<0.05$). The VMRTCs of the left hand jabs were significantly longer than the right hand jabs in both groups of boxers, while for the cross punches this was found only in the highly skilled boxers, but not in the intermediate group (Wilcoxon rank test, $\hat{}p<0.05$) (Table 2).

Table 2. VMRTC values of the two groups of boxers when performing straight and cross punches with the dominant (right) and non-dominant (left) hands, where # $p<0.05$, Wilcoxon rank test - significant difference between straight and cross punches; ^ $p<0.05$, Wilcoxon rank test, significant difference between right and left hands, *$p<0.05$, Mann-Whitney U test - significant difference between Group 1 and Group 2. Data are presented by median and interquartile range (25^{th}, 75^{th} percentiles).

Type of punch	Group1	Group2
Dominant arm (Right)		
jab	611.42 (601.5, 640.5) #	570.53 * (512.4, 610.4) #
cross	673.7 (636.3, 706.9) ^	642.40 * (616.2, 676.7) ^
Non-dominant (Left)		^
jab	660.81 (631.4, 710.9)	619.1 * (571.6, 645.6) #
cross	676.32 (638.6, 755.5)	656.4 (638.6, 755.5)

Discussion

Reaction time (RT) is one of the simplest ways to assess a person's sensory and motor performance (Antonova et al., 2016). Some researchers suggest that the RT depends on the speed of the sensorimotor cycle including the detection of the stimulus, the information transfer through the afferent nerves, the generation of the motor response from the central nervous system and the final response (Adleman et al.,2016; Greenhouse et al., 2017).

The aim of the study was to evaluate the visual motor reaction times of choice with both hands in intermediate and highly skilled boxers and to evaluate the effects of sport experience by inter-group comparisons. As some studies show significant differences between right-handed and left–handed individuals in terms of visual choice reaction time (Awamleh et al., 2013; Hiraoka et al., 2017), while other investigators debate whether women have longer RTs (Neto et al., 2009; Bianco et al., 2011; Loturco et al., 2015, Chouamo et al., 2020), in the current study only right-handed males were included.

The duration of choice reaction time depended of the difficulty of the task, as evidence suggests that more complex cognitive tasks activate more areas in the brain cortex (Antonova et al., 2016).

Our results showed that the level of experience has a significant effect on the VMRTCs of boxers and leads to a decrease in the response times for both investigated types of punches, performed with both left and right hands, except for the cross punches with the non-dominant hand.

We found that the dominant hand was faster compared to the non-dominant hand. This finding was in accordance with previous research which established similar results but obtained when studying simple reaction times (Rabbitt, 1978; Chouamo et al., 2020). The functional dominance of the right hand was significantly more expressed for the highly skilled boxers than the intermediate boxers. The VMRTCs of both jabs and cross punches with the right hand were shorter than those with the left hand, while in the intermediate boxers hand lateralization was expressed for jabs only.

A possible reason is the fact that boxers responded to the stimuli with movements specific for boxing. Jabs are the most common and most practiced punches in boxing, which creates a certain automaticity in their execution. We hypothesize that this automaticity shortens the motor time that is a component of VMRTC and is achieved with much training. In addition to this suggestion is the finding of Çakmakçı et al. that even once a week boxing training for 12 weeks can improve individuals' simple reaction time (Çakmakçı et al. 2019), supported also by other studies showing that upper limb training leads to improved cognitive and visual motor response to choice reaction time (Wilkerson et al., 2017, 2021; Engeroff et al., 2019, Friebe, et al., 2021).

In our investigation we found that cross punches in general had significantly longer values of VMRTC than jabs. The results are in line with Loturco et al., who measured simple RTs for jab and cross punches against a body opponent bag (Loturco et al., 2015). We suggest that a possible reason is the higher decision-making complexity of the task. According to Henry and Rogers' "memory drum" theory of neuromotor reaction, differences in the complexity of rapidly executed large scale arm movements would affect the RT for their initiation, because a more comprehensive stored program would need to be retrieved from memory (Fischman et al., 2008). In our study the VMRTCs of cross punches were longer with the left hand than those with the right hand in the group of highly skilled boxers, while such lateralization was not observed for the intermediate boxers. Moreover, the VMRTCs of cross punches with the non-dominant (left) hand of intermediate boxers were

similar to their cross punches with the dominant hand and were the longest VMRTCs measured in our study. A possible explanation is that cross punches require faster visual desion-making and overall better eye-hand coordination and that we observed in all results.

When the target is further from the center, the reaction times increase, while a study of Nougier et al. shows that elite athletes do better on this task than untrained individuals (Nougier et al., 1989; Antonova et al., 2016). In our case, we observed a similar result between the intermediate and the high-trained boxers. The lack of difference in the VMRTCs of the left and right cross punches of the intermediate boxers can be explained with the fact that stimuli in the right visual field are processed faster due to the fact that both hemispheres are involved in the processing, while stimuli in the left visual field activate cortical representations only in the right hemisphere (Antonova et al., 2016). It is possible that the faster processing of the information from the right visual field significantly compensates for the otherwise expected slower left-handed response in Group 1 and evens out the VMRTCs of their left and right hand cross punches. However, they remain the longest RTs measured in the present study. The fact that in the highly skilled boxers we observed shorter VMRTCs of the cross punches with the left hand, and even shorter VMRTCs with the right hand than Group 1, suggests a paralel improvement in the coordination of both hands and probably a refinement of some aspects of spatial orientation in this group.

Conclusions

We observed that the greater sport experience and improved boxing technique lead to a significant shortening of the overall response time and a greater reduction in the RT of jabs compared to cross punches, probably due to the faster achievement of automaticity of the jabs. In both groups of boxers, we observed shorter visual motor reaction times with the dominant hand than the time of the non-dominant hand, i.e. hand laterality was preserved. The cross punches seem to improve more slowly than the jabs, probably because they require better eye-hand coordination and therefore more practice.

The methodology of our research would be suitable for assessing the progress and selection of athletes in sports that require fast reactions to visual stimuli, such as combat sports. Furthermore, analyzing the VMRTCs of the different types of boxing punches, presented by elite boxers, can be used to speculate on the influence of the training practices on the RTs of specific boxers and to develop better training programs. It can be expected that athletes systematically applying VMRT training with cognitive choice can improve their spatial orientation, accuracy and reaction speed abilities more quickly.

Conflicts of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

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