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High perceptual sensitivity to global motion in badminton players

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Global motion perception (GMP) is a fundamental aspect of visual perception. Previous studies found that action video gamers had better GMP. However, it is still under debate whether ball playing, particularly badminton playing, can improve the sensitivity of GMP. To address this issue, 24 professional badminton players, 24 sprinters and 24 non-player controls were recruited to perform a GMP task, in which participants were asked to identify the global motion direction (leftward/rightward, upward/downward, contraction/expansion, or clockwise/anticlockwise) of randomly-presented dot kinematograms. Results showed that badminton players had lower motion coherence threshold than the other two groups in radial, rotational and up/down motion forms. In left/right motion form, the threshold was lower for the badminton players than for the non-players, but the difference was not significant between badminton players and sprinters. The findings suggest that badminton training may improve the sensitivity of GMP, and this increased sensitivity is irrelevant to general physical exercise.

KEY WORDS: Badminton playing; Global motion perception; Perceptual learning.

Introduction

We often judge the global direction of a group of objects, with most members moving in the same direction and some other members in different directions (e.g., a flock of birds). This judgment relies on global motion perception (GMP). GMP, referring to the process of combining local motion

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signals into a global perception to obtain speed and direction information (Narasimhan & Giaschi, 2012), is one of the fundamental aspects of visual perception. Investigation of GMP might contribute to our survival in a dynamic environment.

GMP is typically investigated by using the random dot kinematograms (RDK) paradigm (Williams & Sekuler, 1984). In this paradigm, there are numerous dots in the display area. Some proportions of the dots move coherently along the same direction (signal dots), while the remaining dots are replotted randomly (noise dots). Generally, the sensitivity of GMP is often evaluated by motion coherence threshold (for the sake of brevity, we sometimes refer to it simply as threshold), which refers to the minimum percentage of signal dots in the total number of dots that subjects require to determine the overall motion direction (Britten, Shadlen, Newsome, & Movshon, 1992; Newsome & Paré, 1988).

Up to date, it has been shown that the sensitivity of GMP is improved by laboratory training, such as typical perceptual training (e.g., Ball & Sekuler 1986; Chen, Bi, Zhou, Li, Liu, & Fang, 2015; Chen, Cai, Zhou, Thompson, & Fang, 2016; Norton, Mcbain, Öngür, & Chen, 2011). For example, in the study of Norton et al. (2011), healthy adult participants were asked to perform six sessions of tasks on six separate days. The first five sessions included both training and testing sessions, and the sixth session only contained one testing session. In both the training and testing sessions, participants were required to perform a direction discrimination task. The training and testing sessions differed in motion coherence levels. The results showed that the motion coherence threshold was 21% lower after training, suggesting that GMP could be enhanced through perceptual learning.

Moreover, researchers have also investigated whether the sensitivity of GMP is influenced by casual training, such as action video game (AVG) and ball training (Green, Pouget, & Bavelier, 2010; Hutchinson & Stocks, 2013; Pavan, Boyce, & Ghin, 2016; Overney, Blanke, & Herzog, 2008; Kong et al., 2012). For AVG training, Green et al. (2010) asked AVG and non-AVG players to view a random dot motion display (motion coherence level: 0.8%, 1.6%, 3.2%, 6.4%, 12.7%, 25.6%, 51.2%) and indicate the net direction of motion (left or right). Results showed that AVG players had shorter response times in the visual motion direction discrimination task than non-AVG players. However, two other studies did not show an effect of AVG experience on response times even similar tasks were used (Hutchinson & Stocks, 2013; Pavan et al., 2016). This might because that Hutchinson and Stocks (2013) and Pavan et al. (2016) used parafoveal stimuli, and these stimuli required longer latency in response selection and implementation (Ando, Kida, & Oda, 2002). The AVG playing might be not enough to speed up response time for such complex peripheral tasks. Nevertheless, Hutchinson and Stocks (2013) found that AVG players exhibited lower thresholds than non-AVG players and moreover, this effect took place only when participants were discriminating contracting elements but not when they were discriminating expanding elements. Pavan and colleagues (2016) observed that AVG players exhibited lower thresholds for translational motion than non-AVG players and even non-video game players (e.g., Sims and FIFA). However, for all these studies (Green et al., 2010; Hutchinson & Stocks, 2013; Pavan et al., 2016), there were no effects of training in rotational motion.

Regarding ball training, while previous studies had investigated the effect of training on the behavioral performance of GMP, not all of the findings showed the significant effect. Overney et al. (2008) varied RDKs at high (i.e., 15%), moderate (i.e., 10%) and low (i.e., 5%) motion coherence of left/right translation and asked the participants to judge the overall (global) direction. The results did not show any differences in perceptual sensitivity between tennis players and non-tennis players, at 15%, 10% or 5% motion coherence levels. However, when collapsing the data from the three levels of coherence, tennis players showed higher accuracy than non-players. Using a similar paradigm, Kong et al. (2012) found that badminton players performed more accurately than non-players when RDKs were at the moderate coherence (25.6%), whereas this difference was not shown for RDKs at the high (51.2%) or low (12.8%) motion coherence levels.

The findings in the studies of Overney et al. (2008) and Kong et al. (2012) might imply that the effect of ball training on GMP was influenced by the coherence level. Using extremely high and low motion coherence levels might produce the ceiling and floor effects, respectively, which generally reduced the differences between ball players and non-players. Thus, looking for appropriate motion coherence levels might be important in understanding the effect of ball training on GMP. More importantly, no studies - to the best of our knowledge - had investigated whether the effect of ball training on GMP could be generalized to other motion directions (e.g., radial and rotational motions). Besides, previous studies investigated the effect of ball training by observing the differential behavioral responses between ball players and non-players. However, using this design did not clarify whether the effect of training was associated with ball playing or general physical activities.

Thus, the present study was designed to further investigate the effect of badminton training (a type of racquet sports) on behavioral performance associated with GMP. To address this question, badminton players, sprinters and non-players were recruited as participants in the present study. The recruitment of badminton players was because our previous study showed the effect of badminton playing on GMP (Kong et al., 2012). Using these players as participants helped in combining the findings in the present study with previous studies. Since badminton playing also had a large amount of speed physical exercise (Jin, Xu, Zhang, Gao, & Lin, 2011; Ba kosz, Nawara, & Ociepa, 2013; Devarmani, 2015), the sprinters were recruited as a sport control group to rule out the effect of physical activities experience. All participants were asked to indicate the directions of RDKs with the signal dots moving along one of four motion forms - left/right and up/down translational motion, radial and rotational motion. To avoid the influence of task difficulty, we used an adaptive staircase that changed the proportion of signal dots according to participant's performance history (Edwards & Badcock, 1995; Lu & Dosher, 1998). Compared to sprinters and non-players, a long experience of the intensively dynamic visual information integration would benefit badminton players' GMP. Thus, we predict that badminton players would have lower motion coherence threshold in the RDKs task than the other two groups.

Method

Participants

Three groups (i.e., badminton players, sprinters and non-players) of 72 participants took part in this study, with 24 participants for each group. Badminton players (13 males, 18-24 years, $M \pm SD = 21.09 \pm 1.67$ years) and sprinters (13 males, 19-23 years, $M \pm SD = 20.81 \pm 0.94$ years) were included by the following criteria: 1) at least 5 years' training experience; 2) at least three 2h training sessions per week in the last 2 years. Non-players (14 males, 19-24 years, $M \pm SD = 21.45 \pm 1.01$ years) had no habits of playing or watching ball games in their leisure time, or had no training experience in badminton or other ball games. All participants were right-handed, as determined by the Edinburgh Handedness Inventory (Oldfield, 1971). Participants had normal or corrected-to-normal vision and did not report a history of neurological illness. All participants provided written informed consent prior to the testing. The study was approved by a local ethical committee.

Stimuli

Stimuli were left/right and up/down translational, radial and rotational RDKs (Newsome & Paré, 1988). The RDKs included 100 white dots (2 pixels/dot) that were presented within a circular aperture with a diameter of 5 deg (density: 5.09 dots/deg^2) at the center of the display. All dots moved at 5 deg/s against a black background with a limited lifetime of 50ms. After 50ms or when it dropped off the edge of the circular display window, the dot would be replaced by a new dot at a different randomly selected position within the circular window.

As illustrated in Figure 1, the RDKs contained a portion of dots moving coherently ranging from 0% to 100% in a certain direction ('signal' dots) and another portion moving in random directions ('noise' dots). In the case of the left/right translational motion form, signal dots moved either leftward or rightward on each trial with equal probability. The direction of signal dots was upward or downward for up/down translation. Signal dots were displayed

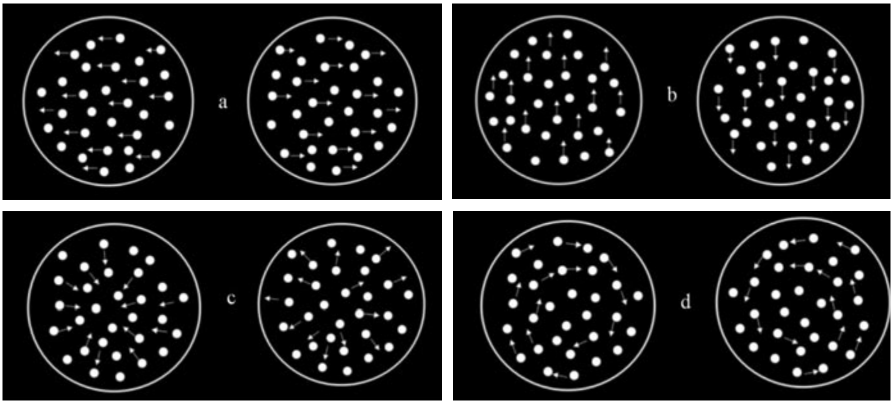

Fig. 1. - RDKs used in the experiment: (a) left/right translation, (b) up/down translation, (c) radial motion and (d) rotation. Note that arrows indicate the moving direction of the dots rather than the stimuli *per se*.

along either expansion or contraction trajectories for radial motion, and rotated either clockwise or anticlockwise for rotation.

Procedure

After informed consent had been given, participants were asked to sit in a comfortable chair in a dimly illuminated room at a viewing distance of 60-70 cm from a 21-inch computer monitor which resolution was 1600×900 pixels with a refresh rate of 60 Hz. Stimulus presentation and behavioral data collection were controlled by MATLAB 8.0 (http://www.mathworks.com/) based Psychtoolbox extension (Brainard, 1997; Pelli, 1997).

Global motion coherence thresholds were measured by using two-alternative, forced-choice, direction discrimination procedure. Performance was measured separately for each of the motion types and the testing order was counterbalanced across participants. Participants had to complete four task blocks, i.e., a left/-right translational block, an up/down translational block, a radial block and a rotational block. Each block contained 5 sessions, with the first one as the practice and the other four as the actual experiment. The data of the practice session were discarded. For each session, the proportion of signal dots was manipulated using a 3-down, 1-up adaptive staircase routine that varied the proportion of signal dots presented on each trial, according to the observers' latest response history, tracking the global motion coherence threshold value of 79.4% correct performance level (Edwards & Badcock, 1995; Lu & Dosher, 1998). The staircase began at 100% coherence and had a proportional step size of 15% until the fourth reversal and 10% thereafter. The staircase was terminated after 9 reversals and the threshold was calculated by averaging the last 4 reversals with the step size of 10% in the last four sessions (Slaghuis, Holthouse, Hawkes, & Bruno, 2007).

Each trial started with a fixation of 1000 ms. Subsequently, a RDK was presented for 1000 ms. Participants were instructed to judge the direction of the signal dots in each stimulus presentation (i.e., the overall direction of a RDK) as accurately as possible by pressing one of the keys on the keyboard (e.g., "F" for left and "J" for right movement). After each block, there was a break, which duration was controlled by participants.

Results

Average global motion coherence thresholds for the overall direction of radial, left/right, rotational and up/down motions in each group were shown in Table I and Figure 2. A 3 (group) × 4 (motion form) repeated measure analysis of variance (ANOVA) was performed with group (badminton players, sprinters, non-players) as a between-subject factor and motion form

TABLE I
Thresholds for badminton players, sprinters and non-players in different motion forms (M±SD, %)

	Radial	Left/Right	Rotational	Up/Down
Badminton players	9.15±1.92	17.02±4.63	21.48±4.12	18.88±9.12
Sprinters	17.96±8.27	19.21±4.77	31.53±9.18	26.42±7.59
Non-players	13.61±2.54	26.32±7.47	28.72±9.04	31.60±8.91

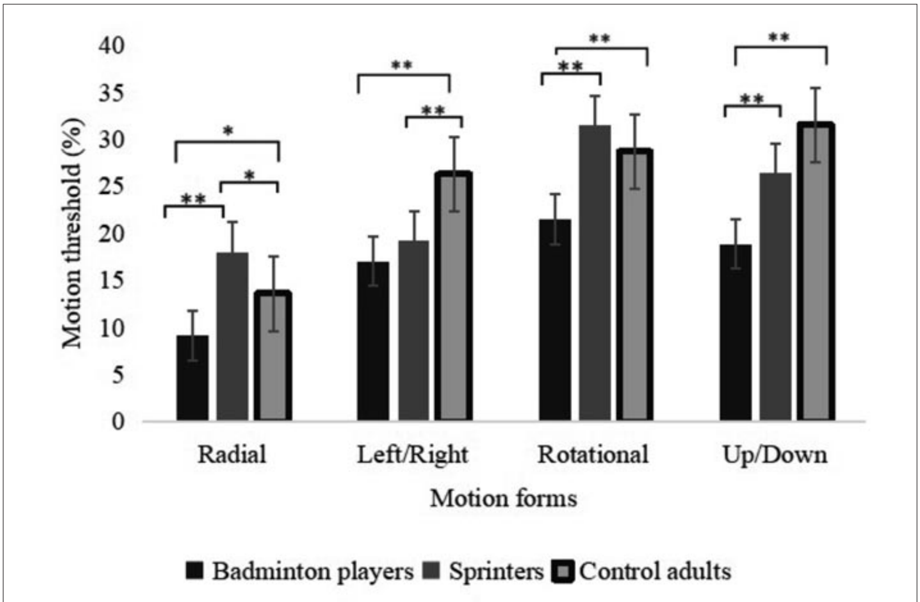

Fig. 2. - Average global motion coherence thresholds for determining the direction of radial, left/right, rotational and up/down motions for badminton players, sprinters and non-players. Error bars represent the standard error of the means and * indicates a significant difference revealed by group comparisons in each motion form. Note: * means $p < 0.05$; ** means $p < 0.01$.

(radial, left/right, rotational, or and up/down) as a within-subject factor. Statistical analyses were performed using IBM SPSS 20.0 Statistics software (SPSS INC., an IBM company, Chicago, Illinois). Greenhouse-Geisser corrections were applied to correct degrees of freedom and p values where appropriate. Bonferroni corrections were used to correct post-hoc t-tests.

In general, the statistical results showed a significant main effect for group (F (2, 69) = 23.69, $p < 0.01$, η_p^2=0.41), indicating that the threshold for badminton players was generally lower than that for sprinters and non-players. A significant effect of motion form (F (3, 207) = 86.48, $p < 0.01$, η_p^2=0.56) was also observed, suggesting the lowest threshold for the radial motion condition.

More importantly, there was a significant interaction between the two factors (F (6, 207) =7.24, $p < 0.01$, η_p^2=0.17). Note that as our purpose was to explore whether badminton playing can improve the sensitivity of GMP, we further conducted simple effect analysis with motion form as a fixed variable here, and compared the differences of motion coherence threshold among the three groups under each motion condition. These results showed the significant effect of group for all motion forms, though to different extents. For the radial condition, the thresholds among the three groups were significantly different from each other (F (2, 69) =17.82, $p < 0.01$, η_p^2=0.34). The radial threshold for badminton players was smaller than non-players ($p < 0.05$), and the latter lower than the sprinters ($p < 0.05$), leading to a significant effect between the badminton players and the sprinters ($p <$ 0.01). In the left/right condition, there was also a significant effect of group (F (2, 69) =17.02, $p < 0.01$, η_p^2=0.33). Both badminton players and sprinters had lower left/right threshold than non-players ($p < 0.01$), but there was no differential threshold between badminton players and sprinters ($p > 0.05$). In both rotational and up/down conditions, the group effect was significant (rotational: F (2, 69) =10.59, $p < 0.01$, η_p^2=0.24; up/down: F (2, 69) =17.19, $p < 0.01$, η_p^2=0.33). The badminton players had lower threshold than the other two groups ($p < 0.01$), but there were no differential thresholds between sprinters and non-players ($p > 0.05$). These results generally illustrated that badminton players required less signal dots to discriminate the direction of global motion and the extents were modulated by motion form.

Discussion

The present study investigated the effects of badminton training on the motion coherence threshold associated with GMP. Results showed that the thresholds were lower for badminton players than for the other two groups in the radial, rotational and up/down conditions. For the left/right condition, badminton players had lower threshold than non-players, whereas there was no differential threshold between badminton players and sprinters. Therefore, the findings in the present study suggest that badminton training may generally improve the sensitivity to GMP and, the improvement may be associated with ball training rather than simply physical exercise, at least in discriminating of radial, rotational and up/down motion directions in GMP tasks.

It had been reported that perceptual learning improved the discrimination ability of visual motion stimuli. Participants who had been trained to discriminate a small difference between two similar motion directions showed increased sensitivity to the trained direction, but not to the untrained motion directions (Ball & Sekuler, 1982). Norton et al. (2011) found that both schizophrenia patients and healthy controls showed decreased perceptual threshold in a motion direction discrimination task after a period of perceptual learning, whereas this decrease was not shown for perceptual-unrelated discrimination tasks (e.g., a speed discrimination task). Nevertheless, some other studies observed that perceptual training increased the ability in perceptual-unrelated domains, particularly when the training task was more complicated than the testing task (Fahle, 2005; Green & Bavalier, 2003). For example, the AVG training, which training program included visual attention (Chisholm & Kingstone, 2015), contrast sensitivity function (Li, Polat, Makous, & Bavelier, 2009), and GMP (Pavan et al., 2016), increased behavioral performance in a simple GMP task. Similar to AVG training, badminton training in the present study also included complicated training programs, in particular the program associated with GMP. For instance, the players had to be trained about the integration of dynamic information (e.g., the movement direction and posture of the opponent and the trajectory of a flying shuttle). In this case, the sensitivity of GMP might be improved for badminton players, even compared to sprinters, whose training programs included general physical exercise. Furthermore, compared to video game playing, badminton playing may be a better choice for perception training in terms of physical and psychological fitness (Chekroud et al., 2018).

The findings in the present study were partially in line with our previous study (Kong et al., 2012), in which badminton players made more accurate responses than non-players in the RDKs task at a moderate coherence level (i.e., 10%) of translational motion. Different from the present study, however, our previous study did not find any effects of badminton training in the high and low motion coherence levels. Besides, the study by Overney et al. (2008) did not find any effects of tennis training at each motion coherence level. The motion coherence levels used in Kong et al.'s (2012) and Overney et al.'s (2008) studies were constant and the perceptual sensitivity was assessed by accuracy at the fixed coherent level in the motion direction discrimination task. In contrast to the dependent variable of motion coherence threshold, the accuracy might not be sensitive to reflect the variance of GMP. More importantly, the fixed coherence levels used in previous studies might result in the involvement of task difficulty. Thus, we adopted an adaptive staircase procedure to increase detection sensitivity. The changes in index and experimental procedure might strengthen the effect of badminton training.

In addition, our results also revealed that the motion coherence threshold of radial motion was significantly lower than the threshold of the other three motion forms irrespective of the group. To explain this interesting result, the relationship between radial motion and our daily life might be taken into account. Forward or backward moving is the most common motion type in our daily life. During forward/backward moving, the surrounding scene around us is moving in radial expansion/contraction ways. Hence, the GMP sensitivity of radial motion is bound to improve for long-time routine training and thus, the sensitivity of radial motion is higher than the sensitivity of other motions. This explanation might be in line with the studies of Allen, Hutchinson, Ledgeway and Gayleian (2010) and Billino, Bremmer and Gegenfurtner (2008), in which the differences of GMP between young and elderly persons were investigated. Both these two studies found that the GMP sensitivity of radial motion in the elderly showed no declining compared to left/right motion, rotation or other motion forms. For this result, the authors explained that this might because that radial motion was common enough in our daily life, and such long-time routine training resulted in good sensitivity to GMP related to radial motion, not only for young adults but also for the elderly.

Finally, we would like to mention two limitations in the present study. First, the present study did not provide evidence for a causal relationship between badminton training and GMP, as the current design cannot exclude the influence of innate factors, e.g., badminton players may be born with higher sensitivity to GMP than others. Future studies might use a longitudinal within-subjects design by tracking badminton players, sprinters and non-player controls for the change of GMP before and after training to further investigate the related issue. In addition, it is unknown whether professional ball training influences neural responses to GMP. Future studies could investigate the related issue for more details.

Conclusion

The present study investigated the effect of badminton playing on GMP sensitivity. Results showed that badminton players had lower motion coherence threshold than sprinters and non-players in radial, rotational and up/down motion direction discrimination tasks. In the left/right condition, the threshold of badminton players was lower than the threshold of non-players, but was not significantly different from that of the sprinters. In general, the findings suggested that badminton playing may improve the sensitivity of GMP, and this improvement is irrelevant to physical exercise, at least when GMP is with respect to radial, rotational and up/down motion directions. Furthermore, this study provides evidence that long-term ball training involving rich dynamic visual information can improve individuals' sensitivity to GMP.

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Conflict of interest

The authors report no conflict of interest.

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