Athletic training in badminton players modulates the early C1 component of visual evoked potentials: A preliminary investigation

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One basic question in brain plasticity research is whether individual life experience in the normal population can affect very early sensory–perceptual processing. Athletes provide a possible model to explore plasticity of the visual cortex as athletic training in confrontational ball games is quite often accompanied by training of the visual system. We asked professional badminton players to watch video clips related to their training experience and predict where the ball would land and examined whether they differed from non-player controls in the elicited C1, a visual evoked potential indexing V1 activity. Compared with controls, the players made judgments significantly more accurately, albeit not faster. An early ERP component peaking around 65 ms post-stimulus with a scalp topography centering at the occipital pole (electrode Oz) was observed in both groups and interpreted as the C1 component. With comparable latency, amplitudes of this component were significantly enhanced for the players than for the non-players, suggesting that it can be modulated by long-term physical training. The results present a clear case of experience-induced brain plasticity in primary visual cortex for very early sensory processing.

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1. Introduction

One of the exciting topics in brain plasticity research is how individual life experience changes brain structures and functions, and in particular, whether such changes can occur for early sensory processing. Much related work has focused on the effects of musical training on the auditory cortex and auditory processing indexed with auditory evoked potentials (Recanzone et al., 1993; Schlaug et al., 1995; Zatorre, 1998; Pantev et al., 1998; Ohnishi et al., 2001; Gaser and Schlaug, 2003; Wong et al., 2007; Musacchia et al., 2007; Murray et al., 2008; Bermudez et al., 2009). Relatively less research has examined experience-induced changes in the dominant visual modality. Plasticity research of the visual cortex has been mainly with the blind population or the animal models often under very unnatural situations, such as monocular deprivation or retinal damage (Hubel and Wiesel, 1970; Calford et al., 2003; Feller and Scanziani, 2005; Karmarkar and Dan, 2006). Some recent studies with normal participants, however, were concerned with cross-modal interaction and did not address the visual modality per se (Amedi et al., 2003; Schmithorst and Holland, 2003; Saito et al., 2006; Huang et al., 2010).

Athletes provide a possible model to explore the plasticity of the visual cortex. Albeit its emphasis on the motor system, athletic training in confrontational ball games is quite often accompanied by training on the visual system. In the case of badminton, for proper response selection and action implementation, players must integrate perceptual processing. Athletes provide a possible model to explore plasticity of the visual cortex as athletic training in confrontational ball games is quite often accompanied by training of the visual system. We asked professional badminton players to watch video clips related to their training experience and predict where the ball would land and examined whether they differed from non-player controls in the elicited C1, a visual evoked potential indexing V1 activity. Compared with controls, the players made judgments significantly more accurately, albeit not faster. An early ERP component peaking around 65 ms post-stimulus with a scalp topography centering at the occipital pole (electrode Oz) was observed in both groups and interpreted as the C1 component. With comparable latency, amplitudes of this component were significantly enhanced for the players than for the non-players, suggesting that it can be modulated by long-term physical training. The results present a clear case of experience-induced brain plasticity in primary visual cortex for very early sensory processing.

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Athletes provide a possible model to explore the plasticity of the visual cortex. Albeit its emphasis on the motor system, athletic training in confrontational ball games is quite often accompanied by training on the visual system. In the case of badminton, for proper response selection and action implementation, players must integrate a great amount of dynamic visual information, including flight information of the ball and kinetic information of the opponent. Given the fast speed of the ball (as fast as more than 250 km/h) and the need for quick motion around a large spatial area, these visual processes must be completed very rapidly before the ball falls to the ground. It is quite possible that extensive experience with badminton playing may induce adaptive changes in the visual cortex.

There have been a few studies with athletes regarding training effects on the motor cortex. Wei et al. (2009), for example, reported greater gray matter density of pre-central gyrus for professional divers than non-athletic controls. There are also studies on visual processing in athletes, which however did not use sports-related stimuli (Ozmerdivenli et al., 2005; Delpont et al., 1991; Taddei et al., 1991; Nakata et al., 2010). Generic visual stimuli, such as checkerboards, may not be the most sensitive in probing training-related functional changes that can possibly be specific to a player's training experience. Several studies did use training-related materials as stimuli, but they have so far been concerned only with late ERP components such as P300 (Rossi and Zani, 1991; Rossi et al., 1992; Radlo et al., 2001; Taliep et al., 2008).
In the current study, we presented professional badminton players and non-player controls with video clips taken from actual badminton games and asked them to judge where the ball would land. We intended to see whether training experience in badminton would modulate C1, an ERP component indexing early visual processing.

C1 is the very first visual evoked potential (VEP) component peaking between 60 and 90 ms post-stimulus with a midline occipito-parietal scalp distribution (Jeffreys and Axford, 1972). It is generally considered to reflect initial activation of the primary visual cortex (Hillyard and Anllo-Vento, 1998; Martinez et al., 1999; Di Russo et al., 2003; Simpson et al., 1995; Gomez-Gonzalez et al., 1994; Clark and Hillyard, 1996). Early studies failed to find attentional modulation of C1 (Gomez-Gonzalez et al., 1994; Martinez et al., 1999; Fu et al., 2001; Di Russo et al., 2003), but recent work suggested otherwise. Several recent C1 studies have shown that C1 might be modulated by endogenous processes, such as attention (Kelly et al., 2008; Rauss et al., 2009; Fu et al., 2009, 2010). For example, Kelly et al. (2008) controlled inter-subject variability and reported modulation of C1 by spatial attention. There is also evidence that C1 is affected by the emotional valence of the stimulus (Halgren et al., 2000; Eger et al., 2003; Pourtois et al., 2004; Stolarova et al., 2006). That is, C1 is not purely exogenous and only sensitive to the physical properties of a stimulus. Possibly it can be affected by endogenous processes and shaped by experience. Although C1 changes have been suggested to indicate V1 plasticity (Pourtois et al., 2008), whether C1 is modulated by individual experience has not yet been explicitly investigated.

2. Methods

2.1. Participants

Eighteen badminton players (9 female, mean age ± SD = 21.9 ± 2.0 years, age range = 18–25 years) and eighteen non-badminton players (9 female, mean age ± SD = 22.8 ± 2.2 years, age range = 18–27 years) participated in this study with informed consent, each receiving monetary compensation for 50 RMB (about 5 US dollars). All were right-handed, with normal or corrected-to-normal vision and normal color vision. None had any neurological or psychiatric disorders, or used any neuroleptics.

Participants were all college students selected prior to this study based on responses to a questionnaire about their sports experience. Players satisfied all of the following inclusion criteria: 1) currently playing provincial/municipal badminton team; 2) qualified as National Player at Second Grade or above; 3) 5 or more years of professional training experience; 4) practising more than three times a week for 2 or more hours in the last 2 years. Non-players, matching the players in age and education, did not have any previous experience of playing badminton or tennis. Further, none of them watched badminton or tennis games more than occasionally.

2.2. Stimuli

Stimuli were color video clips (wmv format, 25 frames per second) of single matches in world tournaments illustrated with an example in Fig. 1. Other than participant group, task difficulty was manipulated to reveal more information by setting the clip length at four different levels from 400 to 1280 ms. For a 400 ms clip, the clip ended about 80 ms (−2 frames) before the ball contacted the racquet; for a 480 ms clips, the clip ended right when the ball contacted the racquet; for a 600 ms clip, the clip ended about 120 ms (+3 frames) after the contact point; and for a 1280 ms clip, the clip ended about 800 ms (+20 frames) after the contact point. For the 600 ms and 1280 ms clips, the ball finished about 1/3 or 2/3 of its trajectory (from contacting the racquet to touching the group), respectively.

Based on pilot data, the 400 ms and 600 ms clips were selected to contain little information about the ball’s final location to participants who lacked badminton playing experience. For these clips, the non-players were expected to be purely guessing regardless of their actual responses being correct or incorrect. Comparison across the correct and incorrect trials would then allow us to see whether C1 changes can result from higher-level decision-making factors unrelated to training experience. Containing more relevant information, the increasingly longer scripts were supposedly less difficult when used to judge the landing position of the ball. The clip subtended a visual angle of 14.2° horizontally and 11.4° vertically.

There were a total of 220 test clips, containing 40 1280 ms clips and 60 clips for each of the other three lengths. Due to practical reasons in material preparation, there happened to be fewer clips at the 1280 ms level. Within each type of clips, the ball landed actually equally likely in one of four locations, left forehead, right forehead, left backcourt, and right backcourt. This was also the case for the four clips used for practice. None of the clips had been viewed by any of the participants prior to the study.

Note that the present paradigm involving real life video clips carries a disadvantage in that it does not permit a strict control of stimulus location. C1 was observed in some classic studies to be highly dependent on the stimulated part of the visual field (e.g., Jeffreys and Axford, 1972), which has been corroborated in later studies (e.g., Pourtois et al., 2008). Ideally, one would hope to be able to present the stimuli randomly in the upper or lower half of the visual field to better identify C1.

2.3. Procedure

Participants were tested individually in a dimly illuminated, sound-attenuated room. They were first informed about the nature of the task and then seated in a comfortable armchair 1 m away from a computer monitor. They were instructed to avoid head movement and eye blinks, especially during clip presentation.

Each trial started with a fixation cross at the center of the screen for 1000 ms, followed by a clip displayed for one of the four lengths randomly intermixed. The inter-trial interval was jittered between 1000 ms to 1500 ms. The task was to view each clip with full attention and to judge as quickly and accurately as possible whether the ball would finally land at the forecourt or the backcourt, regardless of the left or right side.

Half of the participants pressed the ‘I’ key in the keyboard with their right index finger to indicate a forecourt location, and the ‘V’ key with their left index finger to indicate a backcourt location. For counterbalancing, the other half pressed the ‘M’ key with their right index finger to indicate a backcourt location, and the ‘R’ key with their left index finger to indicate a forecourt location.

Participants performed four practice trials with clips not used for testing and then completed 220 test trials involving the same number of clips. Behavioral responses were recorded by computer. There were two self-paced breaks during testing. The entire recording session lasted approximately 20 min. To control for biological rhythmical factors, all data collection was conducted from 7 to 10 PM in the evenings and completed within a month.

2.4. EEG recording and data analysis

EEGs were recorded and analyzed with Scan 4.3 using a 32-channel Ag–AgCl electrode cap following the 10–20 convention (NeuroScan Inc., Compumedics, Australia). All scalp electrodes were referenced online to the left mastoid (A1) and re-referenced offline to averaged mastoids. Bipolar horizontal and vertical EOGs were simultaneously recorded at a 500-Hz sampling rate. Electrode impedances were kept below 5 kΩ. Band-pass filtering was applied ranging from 0.1 to 100 Hz with a 50 Hz notch filter. Eye movement artifacts were automatically corrected using the Scan software (amplitude threshold set at ±100 μV).
The continuous EEGs were epoched of baseline from −200 ms to 800 ms with time 0 corresponding to clip onset. The prior-onset interval was used for baseline correction. These epochs were then averaged for each participant by condition and by response type, i.e., whether participants made the correct response or not. For each participant, a low-pass filter (<20 Hz) was applied to averaged epochs, followed by a re-reference based on the grand average of all electrodes. Peak amplitudes of C1 from three most representative electrodes (O1, O2, and Oz) were analyzed with ANOVAs including a between-subject factor, group: players vs. non-players, and three within-subject factors, response type: correct vs. incorrect, electrode site, O1, Oz, and O2, and task difficulty, 400, 480, 600, and 1280 ms. Traditionally, C1 has been shown to have larger amplitude at Oz compared with the two lateral electrodes O1 and O2 (Hillyard and Anllo-Vento, 1998). The electrode location was included as a factor to validate the C1 component to be inspected. C1 latencies were analyzed similarly except without using the electrode factor as latencies from the three sites, being minimally different from each other, were pooled. Greenhousee Geisser correction was applied where necessary and uncorrected degrees of freedom and corrected p values were reported.

3. Results

3.1. Behavioral results

Data from one player were missing due to computer breakdown. For the remaining 17 players, mean accuracies across the four difficulty levels (400, 480, 600, and 1280 ms) were 0.58 (0.12), 0.59 (0.07), 0.62 (0.05), and 0.81 (0.11), respectively. Numbers in brackets show standard deviations. Mean accuracy at every level was
significantly above the 0.5 chance level (from 400 to 1280 ms, t(16) = 2.74, 5.21, 5.51, and 11.12, p < 0.05, 0.0001, 0.00005, and 0.000000005, respectively). For the 18 non-players, the corresponding results were 0.50 (0.08), 0.50 (0.05), 0.54 (0.06), and 0.73 (0.10). Mean accuracies were significantly above chance at the 600 and 1280 ms levels (t(17) = 3.10, 9.40, p < 0.01, p < 0.0000005, respectively) but not at the 400 and 480 ms levels (t(17) = −0.0006 and 0.37, p = 0.99 and 0.71, respectively). Mean response times (RT) are shown in Table 1, separately for correct and incorrect trials.

A 2 × 4 ANOVA (group × task difficulty) on the accuracy data showed significant main effects for group (F(1, 33) = 15.7, p < 0.001) and task difficulty (F(3, 99) = 71.2, p < 0.001) but no interaction between the two (F(3, 99) = 0.06, p = 0.5). The players judged the landing location of the ball more accurately than the non-players (0.65 vs. 0.57). Post-hoc paired t-tests indicated higher accuracies at the 1280 ms level than each of the 400, 480, and 600 ms levels (0.77 vs. 0.54, 0.55, and 0.58, ps < 0.001), at the 680 ms level than both the 400 ms (p = 0.05) and 480 ms levels (p = 0.05). The 400 ms and 480 ms levels were no different from each other (p = 0.5).

A 2 × 4 × 2 ANOVA (group, task difficulty, and response type) on the RT data did not reveal any significant main effects nor any two-way or three-way interaction effects (Fs < 1).

3.2. ERP results

EEG data were missing from one player due to computer breakdown. Data from other three participants, including one player and two non-players were discarded due to excessive motion artifacts. Grand-averaged ERPs for each group and response type are shown in Fig. 2 showing a clear C1 component around 65 ms after target onset. Fig. 2 also plots C1 scalp topographies at peak time point for the two types of responses in each group, indicating an occipital locus.

Analysis based on the remaining participants, 16 in each group, did not reveal any significant main effect for task difficulty nor for its interaction with any other factor or combination of factors (Fs < 1). The four difficulty levels were then collapsed to produce a 2 × 2 × 3 ANOVA involving group, response type, and electrode site. For peak amplitudes of C1, this ANOVA revealed significant main effects for group (F(1, 30) = 5.9, p < 0.05) and electrode site (F(2, 60) = 15.1, p < 0.001), but not for response type (F(1, 30) = 2.5, p = 0.1) nor the three-way interaction (F < 1). Mean C1 amplitudes were larger for the players than the non-players (−2.61 vs. −1.46 μV). Mean C1 amplitude was larger for the OZ site than for the other two sites (−1.72, −1.99, and −2.39 μV for O1, O2, and Oz, respectively). The group by response type interaction was significant (F(1, 30) = 5.3, p < 0.05). C1 amplitude was larger for the correct responses than the incorrect ones (t(15) = −3.5, p < 0.005) for the players but no different for the non-players (t(15) = 0.4, p > 0.1). For peak latencies of C1, a 2 × 2 ANOVA involving group and response type did not reveal any significant effect.

4. Discussion

In this study, we used the ERP methodology to address a basic question in brain plasticity research, which is whether individual life experience in the normal population can affect very early sensory-perceptual processing. Using athletes as a plasticity model and focusing on the visual modality, we presented professional badminton players with video clips related to their training experience and asked them to predict the landing position of a flying ball.

Compared with the non-player controls, the players made the location judgments significantly more accurately, albeit not faster. This was true for all the four levels of task difficulty. In particular, the players performed significantly above chance at the two short clip lengths of 400 ms and 480 ms when the non-players were essentially guessing. Apparently, the more accurate performance in the players was not caused by speed-accuracy tradeoff. The results suggest that the players may be able to extract more information from the visual display or have more knowledge in aiding their decision-making, but they may not necessarily extract early visual information more rapidly than the non-players. Ripoll et al. (1995) studied boxers of various levels of expertise in a video problem-solving paradigm similar to ours and also found response accuracy to be more indicative of expertise level than response time. This pattern of the accuracy results is what would be expected given the extensive training the players had.

For both groups, the ERP results clearly revealed an early peak with a latency around 65 ms post-stimulus and with a scalp topography centering at the midline occipital region. This component was interpreted as the C1 component as its latency and scalp topography were in line with previous studies on C1 (e.g., Hillyard and Anllo-Vento, 1998). While C1 latency was comparable across the two groups, its amplitude was significantly larger for the players than for the non-players. Consistent with our above discussion of the behavioral results, the absence of between-group differences in C1 latency suggests that athletic training changes the processes by which early visual information is extracted though not their time course. This critical result on C1 amplitude suggests that C1 can be modulated by long-term physical training, in particular, by athletic training in ball games that presumably places high demand on visual perceptual processing. Given the nature of C1, we propose that this finding presents a clear case of experience-induced brain plasticity in primary visual cortex for very early sensory processing. Note that our results are preliminary and the associated conclusions are tentative in that there is a possibility that the early ERP component we observed was not a genuine C1. This is because previous studies of C1 have used relatively simple physical stimuli with the most complex being faces, compared to the video clips used here with highly complex and dynamic visual stimulation. It would be necessary to confirm in future studies that the early component we observed and interpreted as C1 here indeed shows characteristics of the classical C1 component, e.g., being affected by manipulations of physical properties such as stimulus clarity, visual field position.

A secondary finding was that for the players, C1 amplitude in trials with a correct judgment was higher than that in incorrect trials, but no different for the non-players. As mentioned earlier, the non-players were essentially performing at chance level for the 400 ms and 480 ms length clips and response accuracy was just a matter of random guessing, and it follows naturally that C1 in such a situation did not differ by response type. However, at the 600 ms and 1280 ms

### Table 1

<table>
<thead>
<tr>
<th>Response type</th>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty level</td>
<td>400 ms</td>
<td>480 ms</td>
</tr>
<tr>
<td>Players mean RT (ms)</td>
<td>1223</td>
<td>1213</td>
</tr>
<tr>
<td>SD for players RT</td>
<td>622</td>
<td>713</td>
</tr>
<tr>
<td>Non-players mean RT (ms)</td>
<td>1200</td>
<td>1201</td>
</tr>
<tr>
<td>SD for non-players RT</td>
<td>524</td>
<td>526</td>
</tr>
</tbody>
</table>

Note: Correct for correct trials and incorrect for incorrect trials.

Difficulty level was reduced as clip length increased from 400 ms to 1280 ms.
levels, the non-players were performing above chance level and the correct trials were meaningfully different from the incorrect trials in that there was likely more useful visual information picked up or utilized during the correct trials than the incorrect trials. That C1 in such a situation was still unaffected by response accuracy in the non-players suggests that it is not sensitive to the amount of perceptual information used for the decision-making processes. Therefore, enhanced C1 in the players for the correct trials than the incorrect trials is unlikely to reflect some generic differences between the two types of trials.

There is no evidence in the literature that C1 could be affected by decision-making. So it is not quite clear why C1 differed between correct and incorrect trials for the players but not for the controls. We speculate that this pattern may be related to the training experience of the players. Begleiter and Porjesz (1975) showed that when a flash medium brightness was judged as “bright”, it elicited early ERPs (P1 and N1 as early as 100 ms post-stimulus) different from when the same flash was judged as “dim”. They suggested that these differential ERP responses to a sensory stimulus may reflect the activation of memory traces about a specific experience. In light of their explanation, for our player participants, a larger C1 could be elicited by some of the clips that may have activated specific training-related memory episodes facilitating an eventually correct decision. In comparison, clips that could not trigger such episodes would be relatively less likely to yield a correct response, everything else being equal. Such a correlation between early C1 responses and later decision-making outcomes would not be present for the non-players who did not have the training-related memory traces. Consistent with this possibility, recent research has indicated that elite performance is linked to the capabilities of anticipatory information pick-up supported by the development of a large bank of suitable instances in a domain-specific memory store in the athletes (Yarrow et al., 2009).

The C1 effects we observed could not be attributed to task difficulty, i.e., the task was more difficult for the non-players than for the players. This is because although behavioral performance varied in line with our task difficulty manipulation, C1 was not affected by such a manipulation at all for either of the two participant groups. This may not be surprising because the different levels of difficulty was manipulated by increasing the clip duration from 400 ms to 1280 ms and the four levels would differ from each other at least 400 ms after stimulus offset, which was much later than the C1 onset time window from 40 to 60 ms. Neither could these effects be attributed to attentional factors as examination of the typical ERP components indexing attention such as P1 and N2 (Hillyard and Anllo-Vento, 1998) revealed no differences across the two groups of participants.

There is a possibility that C1 amplitude differences across the two groups reflect different pre-stimulus activity, e.g., experienced players may be able to anticipate the stimulus onset more efficiently than the controls. Apparently, if the pre-stimulus activity differed by a fixed signal shift across the two groups, it would have been corrected in the baseline correction step and not confound the later C1 differences. If, on the other hand, there was a trend that the ERP signals became increasingly more negative as the anticipated stimulus onset was approaching, and the slope of this trend was different across the two groups (i.e., a larger increment rate for the players somehow due to their better ability to anticipate the stimulus than the controls), such differences may carry over to the post-stimulus onset period and have produced the more negative C1 in the players than the controls. For example, in Fig. 2, the ERP waveforms for the players at O1 and O2 electrodes seem to increase more rapidly with time (towards being more negative) during the 200-ms pre-stimulus window, compared with the non-players.

This explanation, however, is based on between-group factors and cannot account for the differential C1 responses across the correct and incorrect trials within the player group. Further, in O2 where C1 was largest in amplitude, the players and the non-players seem to differ little in signal trend prior to stimulus onset, particularly for the correct trials. This was confirmed in two-sample t-tests on slope values obtained from linear regressions of the ERP signals within the −200 to 0 ms time window conducted for each individual participant. For the correct trials, mean slopes at O2 were −0.003 (μV/ms) for the players and −0.002 for the controls, t(30) = 0.89, p = 0.38. For the incorrect trials, the corresponding values were −0.004 and −0.001, t(30) = 1.84, p = 0.075. Therefore, although pre-stimulus activity may differ across participant groups, we tentatively think that it is unlikely to fully explain the C1 effects we identified.
Previous electrophysiological studies have documented significant differences between athletes and non-athletes in ERP responses to simple visual stimuli (e.g. checkerboards) (for a review, see Nakata et al., 2010). For example, shortened P1 latency was observed for tennis players compared with rowers and non-players (Delpont et al., 1991). Differences in N145 latency and P100 amplitude were found between volleyball players and non-players (Özmerdivenli et al., 2005) but not between cyclists and controls (Magniet al., 1998). In line with these studies showing that long-term ball game training can modulate the early components of visual evoked potentials, the present study using training-related stimuli for the first time reports a modulation of the very first visual evoked potential by athletic training experience in the healthy population.

Our results are different from Pourtois et al. (2008) who found C1 amplitude reduction in adult participants following a 90-min visual texture discrimination training. The training involved in our players is clearly much more complex than simple discrimination and includes, for example, integration of perceptual information and retrieved memory of previous experience. Further, the training examined here has been ongoing for at least several years and the effects of training may depend on when they are measured. Qu et al. (2010) trained college students on perceptual discrimination of line orientations three times in a one-week period and observed that the amplitude of N1 decreased in the 3rd session. However, when the same group of participants performed the same task again six months later, they showed increased N1 amplitude.

Alternative to the straightforward interpretation that enhanced C1 amplitude reflects changes in visual processing in early visual cortex as one form of cortical plasticity, the finding may be attributed to increased feedback from higher-level cortices to the early visual cortex in the players, as previously suggested by some researchers (Martinez et al., 2001; Foxe and Simpson, 2002). That is, while non-players use only perceived visual information, players may draw on more higher-level contextual knowledge based on similar episodes from previous game playing to exert top-down influences on early visual processing. According to this interpretation, the result that correct trials elicited a larger C1 for the players compared with incorrect trials would require fast-activating feedback loops from the later decision-making processes to the early perceptual processes. It is still unclear whether this is neuro-physiologically feasible. For example, Martinez et al. (1999) showed a feedback process occurring at approximately 150 ms, too late for the C1 latency of around 80 ms. However, Schroeder et al. (1998) found in macaque monkeys that information transmission from V1 to the highest level of the ventral visual stream (inferotemporal cortex, IT) takes only 23 ms, implying a theoretical possibility of very early feedback effects.

This ambiguity in data interpretation is not unique to the present study. For example, there are imaging results showing increased BOLD signal changes in V1 following perceptual training with associated performance improvement. Such results can be explained based on plasticity or understood as enhanced processing in V1 due to increased feedback (Furmanski et al., 2004). However, the two types of interpretations may not really conflict with each other. Given the highly interactive nature of visual processing where top-down and bottom-up processes are closely intertwined, it may be conceptually difficult, if not impossible, to define what is intrinsic to V1 processing. Backward projections that allow top-down influence on V1 can be an integral part of the V1 neural network. If so, experience-induced changes of the efficiency of such projection pathways can be taken either as top-down effects or as cortical plasticity of V1. While future research may lead to better ways distinguishing the two views, they may alternatively show that the concept of an intrinsic local V1 network is a fuzzy one.

Overney et al. (2008) showed that expert tennis players detected tennis balls more accurately than non-players against tennis court background but not landscape background and the two groups were no different in basic perceptual processes, such as detecting coherent motion from random dot matrices and attentional blink. Our results are in line with this study emphasizing the importance of training-related stimuli. However, a valuable future study would be to use non-trained stimuli to see whether professional training of badminton can improve general sensory perceptual processing, or is only specific to what have been trained.

5. Conclusion

Briefly, the present study provides a novel piece of evidence indicating that long-term physical training involving rich visual perceptual information can modulate very early sensory processing in the normal population. It also demonstrates the value of using athletes as a model of brain plasticity.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.ijpsycho.2010.09.005.

References


