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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 37(0)

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Publication Date

2015

Peer reviewed

How do different training tasks modulate our perception and hemispheric lateralization in the development of perceptual expertise?

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Abstract

Holistic processing (HP) and hemispheric lateralization are both expertise markers of object recognition. For example, expertise in face and sub-ordinate object perception is shown to be associated with HP and stronger right hemispheric lateralization. However, HP is modulated by experiences of selective attention to parts such as writing experiences of Chinese characters (Tso, Au, & Hsiao, 2014) and drawing experiences of faces (Zhou et al., 2011). Meanwhile, hemispheric lateralization is associated with the decoding strategy employed in object recognition, such as left hemispheric lateralization for reading alphabetic scripts and right hemispheric lateralization for reading logographic scripts. This study aims at training participants to recognize the same sets of artificially-created scripts using either whole-word (Logographic) or grapheme-to-phoneme (Alphabetic) approaches. We found that both approaches induced strong HP, though the alphabetic approach induced stronger left hemisphere advantage than the logographic approach. This training study demonstrates that HP and hemispheric lateralization are separate processes that are associated with different perceptual mechanisms.

Keywords: Perceptual expertise, holistic processing, hemispheric asymmetry, reading, writing,

Background

The concept of holistic processing (HP) is derived from Gestalt psychology, which refers to the tendency to integrate separate features of an object and perceive them as a single unit that is qualitatively different from the sum of its parts (Köhler, 1929). HP is a perceptual marker of visual expertise in subordinate-level object recognition. It is a perceptual phenomenon commonly observed in face perception in which all facial parts are integrated and viewed as a whole (Bukach et al., 2006; though it was suggested to be an expertise marker limited to face recognition, c.f. Mckone, Kanwisher, & Duchaine). For example, training participants to recognize novel artificial symmetric objects ("Greebles"), Gauthier and colleagues (1998) found a positive correlation between HP and expertise in within-category object recognition. Consistently, Wong, Palmeri and Gauthier (2009) showed that participants had an increase in HP when trained to individualize an artificial object type ("Ziggerins").

To demonstrate HP for faces, the composite face illusion can be induced with the composite paradigm: when the bottom halves of two faces are from different faces, the two identical top halves of the faces are judged as different (Rossion, 2013 for a review). This illusion suggests an obligatory attention to all facial parts and results in failure of selectively attending to parts (Richler, Wong, & Gauthier, 2011). The composite paradigm demonstrates one type of configural processing according to Maurer et al. (2002; or processing objects as a Gestalt, Pomerantz & Portillo, 2011). Using the complete composite paradigm, Tso, Au, and Hsiao (2014) revealed an inverted U-shape pattern in HP in learning to read Chinese characters: they showed that compared with novice, expert readers with limited writing experiences showed increased HP, while expert readers with writing experiences showed a reduced holistic effect. This difference in HP between Chinese readers with and without writing experiences could mainly be explained by writing performance, given that reading performance variables had been statistically controlled. These findings hint at an increase in HP of Chinese character recognition at the initial stages of learning, with subsequent writing experiences reducing the HP. Consistently, artists with face-drawing experiences also had reduced holistic face processing compared with ordinary people (Zhou et al., 2012). These effects thus suggest that HP is modulated by drawing/writing experiences in which local components are selectively attended.

Hemispheric asymmetry may be another expertise marker for object recognition. Neuroimaging studies generally showed stronger activation in the right occipitotemporal area for face recognition (Rossion, Hanseeuw, & Dricot, 2012). Complementing this finding, Gauthier and colleagues (1998) found that as participants were trained to individualize Greebles, they showed stronger activation in the right occipitotemporal regions (fusiform face areas). EEG/ERP studies also showed reliable hemispheric asymmetries of visual expertise in object perception such as words/characters (see Hsiao, Shillcock, & Lee, 2007) and faces, particularly in the ERP components N170 (e.g., Maurer et al., 2005; Scott & Nelson, 2007). While alphabetic word recognition was shown to be more left-lateralized, the Chinese language—a logographic script—was found to induce either a strong bilateral or right-lateralized activation in the brain (Tan et al, 2001; Hsiao, Shillcock, & Lee, 2007). The above neuroimaging findings are consistent with behavioural data of a left visual field (LVF) (i.e., right hemisphere, RH) advantage in recognizing

Chinese characters and faces, and a right visual field (RVF) (left hemisphere, LH) advantage for alphabetic word recognition (Hsiao & Lam, 2013). Consistent with this lateralization effect, in eye movement studies, viewers also have a tendency to look at the left side of a face more often than the right side when processing faces (Leonards & Scott-Samuel, 2005; Mertens, Siegmund, & Crusser, 1993), and the left side of a Chinese character more than the right side when processing Chinese characters (Hsiao & Cottrell, 2009). Moreover, a LVF/RH advantage has been consistently observed when processing upright faces (e.g., Hsiao & Liu, 2012; Leehey et al., 1978; Young, 1984) as well as for Chinese characters (Tzeng et al., 1979; Cheng & Yang, 1989). These effects all suggest the involvement of the RH in face and character recognition (Hsiao, Shieh, & Cottrell, 2008; Burt & Perrett, 1997). This difference between alphabetic and logographic script processing suggests that hemispheric lateralization may depend on the decoding strategy employed in object recognition.

It remains unclear why Chinese character recognition differs from the recognition of words in alphabetic languages in terms of hemisphere lateralization particularly in the visual system. One account is that this LH advantage in alphabetic languages is due to the LH lateralization in phonological processing (Rumsey et al., 1997), or more specifically, the grapheme-to-phoneme mapping (i.e. mapping each letter onto a sound) that is heavily involved in alphabetic word decoding (Voyer, 1996; Maurer and McCandliss, 2007). Though reading Chinese characters also involves mapping each character to its pronunciation at the syllable level, the grapheme-to-phoneme mapping requirement is less pronounced in reading Chinese script (Hsiao & Lam, 2013).

Indeed, fMRI studies showed that English readers recruit brain areas different from those of Chinese readers during reading processes (e.g., Perfetti et al., 2007), and that dyslexia in an alphabetic language and in the Chinese script are marked by different brain abnormalities (e.g. Siok et al., 2005). Hsiao and Lam (2013) simulated this asymmetry by applying a hemispheric processing model of face recognition to visual word recognition; the model implements a theory of hemispheric asymmetry in perception that hypothesizes low spatial frequency biases in the RH and high spatial frequency biases in the LH (Ivry & Robertson, 1998). They found that the requirement to decompose words into graphemes for grapheme-phoneme mapping requires more high spatial frequency/LH processing than logographic reading. They also found that stronger left-lateralization correlates with increase lexical visual similarity. This model provides a computational explanation for the difference in lateralization between English and Chinese orthographic processing.

An inverted U-shape development pattern in HP was discovered for Chinese characters (Tso et al., 2014), but it remains unclear for alphabetic languages. Since alphabetic reading involves decomposing a word into graphemes (Hsiao & Lam, 2013) for grapheme-phoneme mapping, this decomposition may require more local attention to parts, and thus may have similar effects as writing experience does to reduce HP. However, prior studies of real life object recognition relied on perception of objects with distinctive shapes and features (e.g., English words of a linear shape in contrast to Chinese characters of a square configuration), which were confounding factors to drawing conclusions on perceptual differences between the recognition of different objects. Hence, this study aims at training participants to recognize the same sets of artificially-created characters to investigate the perceptual changes after learning the characters. Participants learned the scripts using either whole-word (logographic) or grapheme-to-phoneme (alphabetic) approach. If perceptual and hemispheric lateralization changes occur after the training, the effect should mainly come from learning the decoding methods (logographic vs. alphabetic). This is the first of similar training studies to investigate HP and its association with hemispheric lateralization of reading alphabetic and logographic language script.

Methods

Materials

Artificial Korean-like Characters A total of 30 components were created, all of which were used to make 80 Artificial Korean-like Characters (AKC). The AKCs were of a top-bottom configuration with two top components and one bottom component in each character—this arrangement simulated the top-heavy configuration of faces. In the *Alphabetic* condition, each component in an AKC corresponded to a phoneme. Each AKC mapped onto a syllable with its combination of components following a *consonant-vowel-consonant* (CVC) phonological rule. In the *Logographic* condition, each AKC was randomly assigned a syllable pronunciation that appeared in the Alphabetic condition. If a component appeared in one position, it would not appear in other positions in an AKC (i.e., the components in the AKCs were position-specific; see Fig. 1).

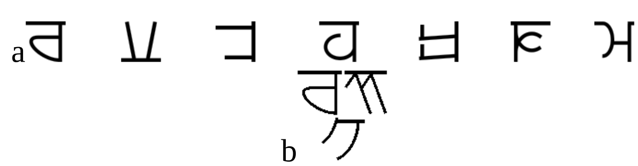

Fig. 1 Examples of (a) AKC components and (b) an AKC

Participants

6 Cantonese-speaking Chinese participants aged 18 to 23 from the University of Hong Kong were recruited. All participants had no prior knowledge to Korean hanguls. They were right-handed according to the Edinburgh Handedness Inventory with normal or corrected to normal vision. Half of them were assigned to the logographic condition while half of them were assigned to the alphabetic condition.

Procedures

Training Phase Each participant learned all 80 AKCs during 3 learning sessions in 3 consecutive days. Each learning session consisted of two blocks with 40 AKCs learned in each block. Two learning blocks in each learning session allowed participants to be exposed to all 80 AKCs per day.

3 Participants were randomly assigned to the Logographic and 3 to the Alphabetic conditions. In the logographic condition, each AKC was shown as a whole character for four times in each trial, accompanying a pronunciation for that specific AKC in each display on the computer screen. The first three screens were displayed for 500ms and the last display in each trial stayed on the screen for the participants to familiarize with for 5 seconds until the start of the next trial for the next AKC.

In the alphabetic condition, each AKC was also shown as a whole character for four times in each trial. A different component was highlighted in each of the first 3 displays, accompanied by the pronunciation of the component in each display, for 500ms. The last display of the AKC is accompanied by the pronunciation of the whole AKC and stayed on the screen for the participants to familiarize with for 5 seconds until the start of the next trial for the next AKC.

Forced-Choice Quiz. To test for learning progress, after each learning session, participants completed a Forced-Choice Quiz. In each trial, two AKCs were displayed on the screen accompanied by a syllable sound—the sound matched one of the AKCs. Participants chose the AKC that matched the sound by pressing the corresponding buttons on a response box. There were a total number of 160 trials with each AKC-sound pair appearing twice. A feedback on the correctness with the accumulated percentage of correct responses was given immediately after making a judgment before the start of the next trial.

Pretest and Post-test 1) *Complete Composite Task:* To measure HP of AKCs, procedures were adopted from Tso *et al.* (2014). In each trial, we presented participants with two AKCs and instructed them to attend to only half (either top or bottom) of each AKC and judge whether they were the same or different. In each of the four conditions—same in congruent trials, different in congruent trials, same in incongruent trials, and different in incongruent trials—twenty pairs were presented. We adopted the complete composite paradigm so that in congruent trials, both attended and irrelevant halves corresponded to the same response while in incongruent trials, the attended and irrelevant halves corresponded to different responses (Gauthier & Bukach, 2007). The performance difference between the congruent and incongruent trials measured HP, reflecting the extent of interference of the irrelevant parts on the attended parts. This paradigm reduces the influence of response biases in assessing the HP effect, in contrast to the partial composite design,in which the irrelevant halves are always different (Richler, Cheung, & Gauthier, 2011; see Fig. 2a)

Each trial started with a 1,000 ms of central fixation. A pair of AKCs was then displayed simultaneously, with one above and one below the initial fixation point.

During the 500 ms presentation time, participants looked at each AKC once and responded as quickly and accurately as possible by pressing corresponding buttons to judge if the character parts were the same or different. There were 2 blocks; participants were instructed to either attend to the top halves or the bottom halves of each AKC pairs in each block. We measured the response time difference between incongruent trials and congruent trials (i.e., Holistic RT); a stronger HP effect is marked by a more positive value (Fig. 2b).

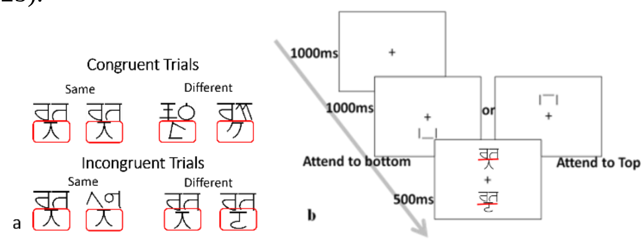

Fig. 2. (a) Illustration of stimulus pairs in the complete composite paradigm; the attended components are circled in red. (b) Trial sequences.

2) *Divided Visual Field Sequential Matching Task:* Each trial started with a 500 ms fixation. Then participants were presented with an AKC briefly for 150 ms at the center. The screen then turn blank for another 400 ms until a second AKC was presented either in the participant's left visual field or right visual field, at 1.5° of visual angle away from the center (with each stimuli subtending a visual angle of 1.5°). Participants judged whether the two stimuli were the same or different by pressing a button on the response box. The stimuli presented were the AKCs that appeared in the training sessions. There were a total of 160 trials, half of which the pairs of AKCs were different. The response time was recorded for the judgment of each stimulus. A faster response time for characters presenting in the left visual field than the right visual field indicates a right-hemisphere advantage, and vice versa for a left hemisphere advantage (See Fig. 3).

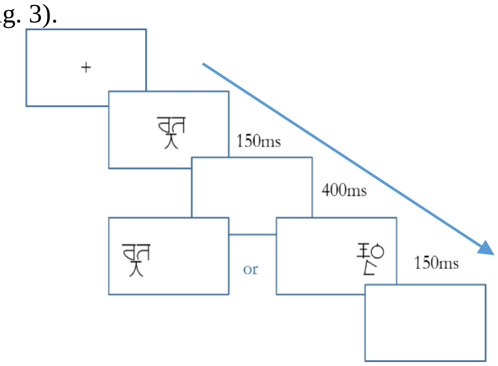

Fig. 3. The test sequence in the Divided Visual Field Sequential Matching Task

Post-test only 1) *Forced-Choice Quiz.* To test for recognition accuracy after training, participants completed a Forced-Choice Quiz identical to the one completed after each training session. No feedbacks were given.

2) *Lexical decision task.* After a 500 ms fixation, participants were presented with an AKC and judged

whether it was a valid character or not by pressing buttons. We used 40 AKC appeared in the training sessions (real AKCs), 40 AKC consisted of learned components appearing at correct locations in the AKC, but of a novel combination (Pseudo-AKCs), and 40 AKC consisted of components appearing at locations that had not appeared in AKCs in the training sessions (Non-AKCs). This task is to test for participants' orthographic awareness: the more participants judged 'yes' for Pseudo-AKCs compared with non-AKCs, the stronger the awareness of the orthographic structures of the AKCs.

Results

Holistic Processing

Repeated-measures ANOVA was used to investigate HP effects measured in the Complete Composite Task (congruency: congruent vs. incongruent x condition: Logographic vs. Alphabetic). For holistic RT in the pretest, there was no main effect of congruency, $F(1, 4) = 2.359$, $p = .199$, no main effect of condition, $F(1, 4) = .646$, $p = .466$, and no interaction between congruency and condition, $F(1, 4) = .562$, $p = .495$. For holistic RT in the post-test, there was a main effect of congruency, $F(1, 4) = 20.87$, $p = .01$, but no main effect of condition, $F(1, 4) = .090$, $p = .779$, and no interaction between congruency and condition, $F(1, 4) = .175$, $p = .697$. Post-hoc pair-wise comparison showed that participants responded significantly more slowly in incongruent trials (M = 464.6ms) than in congruent trials (M = 426.9ms) in the post-test, $t(5) = 4.999$, $p = .004$. This suggested that participants in both the logographic and alphabetic conditions perceived AKCs more holistically in the post-test compared with the pretest (See Fig. 4).

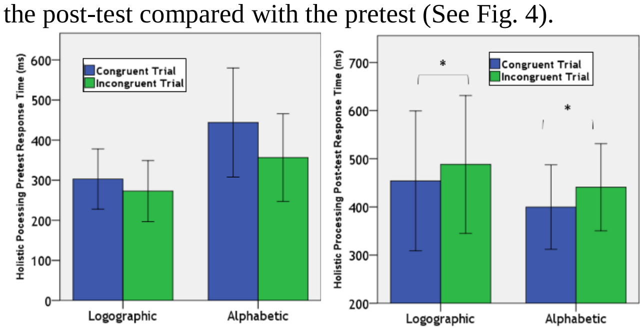

Fig.4. Response time in congruent and incongruent trials of the HP task in Pretest (left) and Post-test (right; $^{**}p < .05$).

Hemispheric lateralization

Repeated-measures ANOVA was used to investigate hemispheric lateralization measured in the Divided Visual Field Sequential Matching Task (Visual field: left vs right x condition: Logographic vs Alphabetic). In the pretest, no main effect was observed for visual field $F(1, 4) = .155$, $p = .71$, no main effect in condition, $F(1, 4) = .161$, $p = .709$, nor an interaction effect between visual field and condition, $F(1, 4) = .114$, $p = .753$. In the post-test, a significant main effect was found in visual field, $F(1, 4) = 16.398$, $p = .015$, while a marginal effect was found in condition, $F(1,4) = 7.393$, $p = .053$. There was a significant interaction effect between visual field and condition, $F(1, 4) = 26.729$, $p = .007$. Post-hoc pair-wise comparisons showed a right visual field advantage in the alphabetic condition in post-test, $t(2) = 5.747$, $p = .029$, while no significant difference in response time between the left and right visual fields was found in the logographic condition, $t(2) = .938$, $p = .447$ (See Fig. 5).

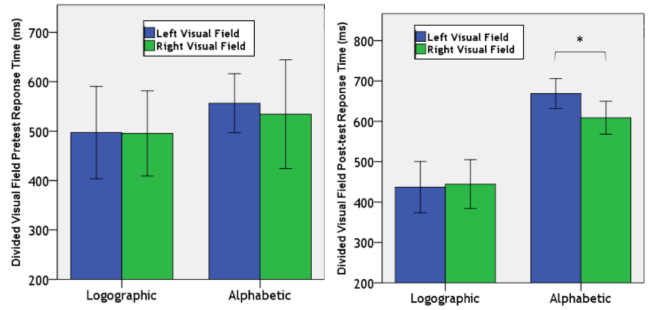

Fig.5. Response time LVF and RVF trials of the Divided Visual Field Sequential Matching Task in Pretest (left) and Post-test (right; $^{*}p < .05$).

Naming Accuracy and Orthographic Awareness

Participants in both the alphabetic and logographic condition had an AKC naming accuracy over 80%, though the accuracy was marginally higher in the alphabetic than in the logographic condition, $t(5) = 2.667$, $p = .056$.

In the lexical decision task, Repeated-measures ANOVA (character type: real vs pseudo vs non-AKCs x condition: logographic vs alphabetic) revealed a significant main effect in character type, $F(2, 5) = 236$, $p = .000086$, but no main effect was found in condition $F(2, 5) = 1.195$, $p = .336$, and no interaction effect was found between character type and condition, $F(2, 5) = .015$, $p = .909$.

Post-hoc pairwise t-tests showed that non-AKCs were more likely rejected than real, $t(5) = 17.53$, $p = .000011$, and pseudo-AKCs, $t(5) = 14.60$, $p = .000027$. Participants could identify both real and pseudo-AKCS as valid AKCs with similar accuracies, $t(5) = 2.030$, $p = .098$. This suggests that participants in both logographic and alphabetic conditions have similar orthographic awareness (See Fig. 6).

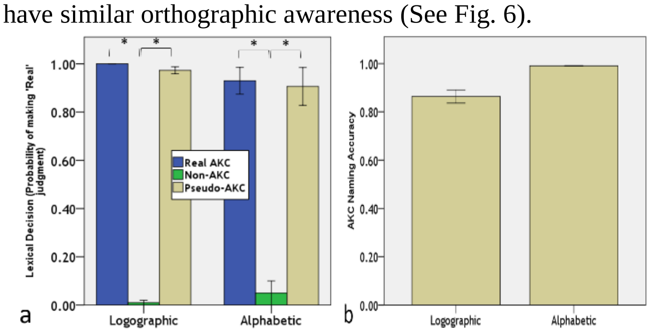

Fig.6. (a) Probability of acceptance of AKC as valid in the Lexical Decision task, and (b) accuracy in the AKC naming task ($^{*}p < .05$).

Discussions

This paper investigated how different learning strategies modulated two perceptual expertise effects: holistic processing (HP) and hemispheric lateralization. More specifically, we examined how learning a set of artificially created characters (the AKCs) with either a grapheme-phoneme (alphabetic) approach or a whole-word (logographic) approach modulated these effects. Consistent with the expertise hypothesis based on face/object perception research, participants in the alphabetic and logographic conditions perceived AKCs more holistically after training. HP thus seems to be a consistent expertise marker independent of the decoding strategies employed by participants to recognize AKCs. This is consistent with Tso, Au and Hsiao's (2014) finding that HP is an immediate perceptual expertise marker. Perhaps learning to recognize words at the initial stage requires HP to process both featural and configural information. The results of Tso et al. (2014) suggest that perhaps HP will then decrease as participants become experienced in AKCs, especially with writing experience. The perceptual effect of writing AKCs can be further investigated. Note, however, that learning to read AKCs in the grapheme-phoneme approach led to a marginally higher naming accuracy than in the whole word approach. This effect is consistent with the beneficial effects of orthographic transparency: regularity in orthographic patterns facilitates learning of the script (Ellis et al., 2004). Nevertheless, participants in both the Alphabetic and Logographic conditions could identify real and pseudo-AKCs as legitimate AKCs and rejected non-AKCs with similar accuracy. This similarity in orthographic awareness in participants under both conditions suggested a mental categorical representation of AKCs despite learning under different decoding strategies. The enhanced knowledge of orthography in AKCs is analogous to the own-race advantage in face perception. Since participants in both Alphabetic and Logographic conditions showed similar HP after training, perhaps the increase in HP is associated with an enhanced categorical representation of visual objects. This speculation is consistent with studies of face processing showing that a stronger HP is associated with own-race face recognition (Tanaka, Kiefer, Bukach, 2004).

Participants in the alphabetic condition showed an increase in LH/RVF advantage after the training session, while participants in the Logographic condition did not show significant changes in the lateralization pattern. Increase in HP in object recognition was suggested to correlate with RH lateralization (Gauthier & Tarr, 2002). However, although the Alphabetic approach increased HP, it induced a LH lateralization—a stronger phonological involvement in object recognition led to a stronger left-lateralization.

Thus, in contrast to a prior belief that HP and RH lateralization are associated (Gauthier et al, 1998; Gauthier et al, 1999), it seems that they may be two distinctive processes involving different perceptual mechanisms: HP is modulated by experiences in selectively attending to parts and features while hemispheric asymmetry is associated with the decoding strategy in object recognition. Through computational modeling, Galmar and Hsiao (2013) showed that when a face recognition task depended only on featural information, HP and RH lateralization correlated negatively. In contrast, when face recognition relied solely on configural information, there was a positive correlation both HP and RH lateralization. AKCs learned using the alphabetic approach may depend more on featural information than in the logographic approach due to the requirement of letter identification. According to Galmar and Hsiao (2013), this may lead to a negative correlation between HP and RH lateralization, consistent with the current finding that the alphabetic group showed increased HP and a RVF/LH advantage. Similarly, Hsiao and Cottrell (2009) showed that Chinese character expertise is associated with reduced HP and increased left side bias/RH lateralization; Tso et al. (2014) showed that writing experience modulates HP effects but not left side bias/RH lateralization. Together with these findings, our results suggested that RH lateralization and HP are separate processes that coincide with each other, as one becomes an expert in the recognition of most object types such as faces or Chinese characters.

This is the first training study to report on the changes in both HP and hemispheric lateralization in learning to read an artificial script under different decoding methods (i.e., logographic vs. alphabetic). The hemispheric lateralization effect of learning scripts using a whole-word, logographic approach is more bilateral, whereas learning a script using a grapheme-to-phoneme correspondence approach induced a stronger RVF advantage/LH lateralization. Nevertheless, both learning approaches induced a similar level of HP effects, suggesting that HP may be an initial expertise marker for visual recognition at an early learning stage regardless of the decoding method involved. This study suggests that HP and RH lateralization are not always associated. HP may be induced by a categorical representation of objects and can be modulated by sensorimotor experience/online attentional mechanisms, while hemispheric lateralization may be related to perceptual representations developed through experience and thus can be modulated by the decoding method used for recognition. This study offers a window onto how the nature of learning experiences may modulate major markers of expertise in complex object recognition.

Acknowledgement

We are grateful to the Research Grant Council of Hong Kong (project code: HKU 745210H to J. Hsiao). We are also grateful to Remy Schmitz, Aria Chen, Joey Ma, Micaela Tang and Wendy Zhang for their input in the experiment preparation.

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