How Strong is Automaticity of Ensemble Encoding? Empirical Evidence from Ensemble Orientation and Facial Emotion

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ABSTRACT

Ensemble encoding abstracts multiple bits of information efficiently. Some researchers have found that ensemble encoding occurs automatically, while others have found the process is not automatic, because it involves both feedforward and feedback loops. We explored the automaticity in ensemble encoding under the adaptation paradigm by examining whether the orientation and emotion averaging were resistant to task load and attention distribution. In the adaptation stage, multiple orientations (Experiment 1) or emotions (Experiment 2) with different combinations of stimulus variance and intensity (manipulated task load) were presented either in the foveal or peripheral field of vision (manipulated attention distribution), and participants were asked to estimate the test stimulus. The combination of high variance and low perceived stimulus intensity reduced the extent to which these individual features contributed to estimates of both average orientation and emotion, and thus were applied to manipulate the task load. The visual system obtained varied attention among stimuli in the different fields of vision, which were used to manipulate attention distribution. Contrary to previous findings, the orientation ensemble was more easily influenced by task load and was not immune to the interaction between task load and attention distribution, while the process of emotion ensemble was nearly free from those restrictions and was also influenced to only a small degree by individual positive or negative emotional valence, implying higher automaticity in ensemble encoding of social information. Our findings support the domain-specific proposal, implying that automaticity might stem from the initial informational registration and happen in the early perceptual course.

KEYWORDS

ensemble encoding
automatic process
orientation
facial emotion
task load
attention distribution

INTRODUCTION

When dealing with redundant information, the human perceptual system has limited ability and leaves low-detail and less-robust traces rather than high-fidelity representations of individuals (Goldenberg et al., 2020). Those coarse traces in perception are produced by ensemble encoding, also known as feature averaging. The ability to conduct ensemble encoding is supposed to develop within the first nine months of life (Zosh et al., 2011). It is a crucial factor in discovering how our visual system constructs a subjectively rich impression of the environment (Gross, 2017). Critically, ensemble encoding can abstract a large amount of available information that preserves behaviorally relevant data and subsequently minimizes computational load. Ensemble encoding has also been proposed as a foundational role in early visual perception as well as in later conscious processes (Ackermann & Landy, 2014; Alvarez, 2011), thus facilitating the sustaining of visual stability (Corbett & Melcher, 2014) and expanding working memory capacity (Brady & Alvarez, 2015).

Nevertheless, there appears to be a startling dissociation in ensemble encoding. That is, does the visual system automatically perform ensemble encoding without conscious intention and effort or does it compute voluntarily based on deliberate top-down control (Alvarez, 2011)? This statement assumes a distinction between automatic and voluntary process mechanisms. Yet, some researchers have answered this question by positing different degrees of automaticity rather than a strict dichotomy (Klümper et al., 2020). According to the dual-process theory (Grayot, 2020) and relevant social cognition research, automatic processes do not require conscious choice, intention, or intervention to become active and run to completion. Most critically, the automatic cognitive process is not restricted by task load (Omer & Braw, 2021) and attention (Stolte & Ansorge, 2021). Related studies were used to support the automaticity of ensemble encoding based on the swiftness of the ensemble process. For example, unlike the individual object process, the average estimates (one statistic produced by ensemble encoding) were found to be formed accurately even at a very short presentation of 50 ms (Chong

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& Treisman, 2003). Importantly, this ensemble encoding proceeds relatively early in the course of visual perception, in contrast to the process of object identification (Alvarez & Oliva, 2008). Some studies also found a lack of selective attention in ensemble encoding (Bronfman et al., 2014), which indicates the automaticity of ensemble encoding. In the light of the feedforward theory, this early ensemble process was attributed as being feedforward, and usually happens before visual signals converge to a common brain area (Hochstein et al., 2015). However, advances in neuroscience indicate that the activation of perception is caused not only by feedforward signals from the retina but also by iterative re-entrant exchanges among multiple visual areas (Crouzet et al., 2017). In line with the latter finding, some studies claimed that feature averaging could benefit from the late visual stage. Relevant studies also found that estimates of average size and orientation were susceptible to object substitution masking, revealing the influence of the later stage of the visual process (Jacoby et al., 2013), thus implying less automaticity and more controlled and voluntary ensemble encoding.

All these studies have attempted to generalize the automaticity of ensemble encoding for various levels of features to a similar degree, consistent with the domain-consistency perceptive (Balas et al., 2009). However, a domain-specific perspective and many studies have revealed that there are different processes for different levels of traits, implying different automaticity. Indeed, consensus on the processing mechanism fails to take shape even for ensembles of the same features in different studies. For example, according to studies applying the adaptation paradigm, low-level features (like average orientation) were a fundamental and adaptable dimension processed by neurons with selective preference. It is the case that the purer automatic process existed in orientation averaging (Jacoby et al., 2013). However, a refined study demonstrated that orientation averaging mainly benefited from the later stage of the process after the initial registration of featural information, indicating that the top-down control took a role in average extraction primarily in a less automatic encoding (Pilling et al., 2019).

Similarly, the evidence of ensemble encoding for middle- and high-level traits showed that size averaging could be represented across retinotopic and spatiotopic coordinates (Corbett & Melcher, 2014). This implies a subtle and sophisticated process that is less automatic (more voluntary). But other research demonstrated a spontaneous process for similar sizes (Chong & Treisman, 2003). Therefore, it is essential to compare the low-level features (e.g., orientation) and the superior-level features (e.g., emotion) for their automaticity under the same experimental conditions and examine the effects of experimental conditions and methods. This is one of the innovations of the current study.

There are additional innovations in this study to systematize the previous divergences. First, the accuracy of average feature estimate (Chong & Treisman, 2005; Haberman et al., 2009) and the point of subjective equality (PSE, Jacoby et al., 2013) were often employed to explore the automaticity of ensemble encoding. These two indicators are not appropriate since they both include more complicated perception encoding and are easily influenced by the distribution of attention (Chong & Treisman, 2005). Adaptation size could be used to solve this problem because it is commonly accepted that adaptation can happen with little or no attention. It was initially regarded as a particular visual phenomenon, reflecting the automatic neuromechanism selectively sensitive to limited features (Campbell & Kulikowski, 1966). In addition, as an indicator of visual stability (Melcher & Colby, 2008), the adaptation size of ensemble encoding helps infer the exact automatic mechanism of ensemble encoding. Second, previous studies have seldom paid attention to the influence of task load (the immunity from the task load is a critical indicator of automaticity) on ensemble encoding. This omission is surprising because stimulus intensity tends to change the uncertainty in average abstraction and the variance among stimuli intervenes in the perception of individual items (Öhman et al., 2001).

Social cognition researchers provide compelling evidence on the higher automaticity of social information, such as emotion (Bargh & Ferguson, 2000). Consistent with this automatic nature of social cognition, we propose that the automaticity of low- and high-level feature averaging is different. The averaging for the latter would be encoded automatically, while the automatic portion would be smaller for the former.

To test this hypothesis, task load (composed of variance and perceived intensity) and attention distribution (manipulated by different visual fields) were manipulated in the present study to examine the automaticity of different ensemble encoding (feature level: orientation and emotion). The high variance among items decreased average computation efficiency and was regarded as a task load for ensemble encoding (Haberman et al., 2015; Luo & Zhou, 2018). Combined with low intensity, which causes a vague perception of stimuli (Balas et al., 2009), less similar (high variance) stimuli could negatively influence average abstraction. In this regard, the combination of high variance and low intensity can be used as a comprehensive task load to examine the automaticity of ensemble encoding (Vul & Rich, 2010). Moreover, examining the immunity of ensemble encoding to attention distribution is also helpful in determining the automaticity of ensemble encoding. The amount of attention in the center field of vision would be more and would be centralized, while the amount of attention on the periphery would be less. We varied the presentation positions of stimuli to manipulate the attention distribution. In the present study, the adaptation paradigm was applied to compare the adaptation size for a series of orientations and emotions appearing in the fovea or periphery with different combinations of stimulus variance and intensity.

EXPERIMENT 1. THE INFLUENCE OF TASK LOAD AND ATTENTION DISTRIBUTION ON ORIENTATION ENSEMBLE

The goal of Experiment 1 was to assess whether the ensemble of orientation is free of the restriction from task load and attention distribution. The task load was manipulated by the combination of intensity and variance of stimuli, and attention distribution was manipulated by the attention distribution(fovea/periphery). The immunity from task load would match the criterion of automaticity, and the automaticity of ensemble encoding would be more valid when the degree of influence from attention distribution was discovered.

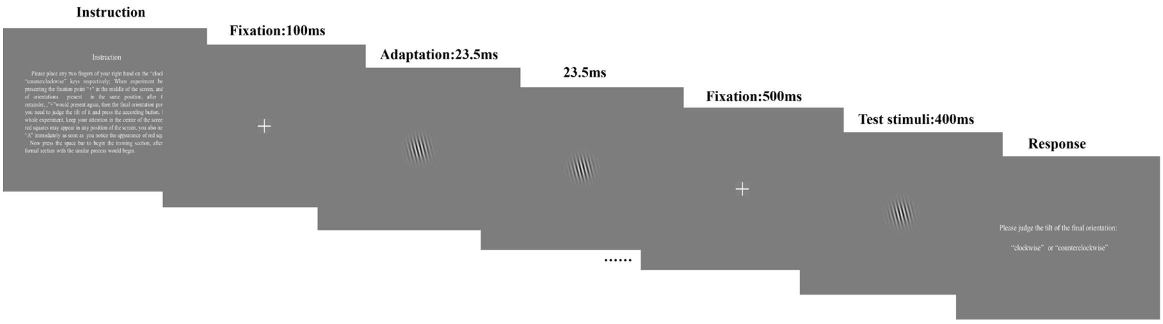

FIGURE 1.

Schematic diagram of the procedure in Experiment 1. In the adaptation period, participants viewed a series of orientations, and these stimuli would appear in the fovea (or peripheral) position of the visual field with high intensity and low variance (or low intensity and high variance) in a rapid serial visual presentation (RSVP). Each display lasted for 23.5 ms. In the test period, they judged the angle (clockwise or counter-clockwise) of the test orientation.

Method

PARTICIPANTS

Nineteen participants (eleven males, eight females, M_{age} 20.67 ± 1.71 years) with right-hand dominance and (corrected) normal vision were paid for participation. All procedures were conducted following the principles expressed in the Declaration of the International Psychological Committee and were approved by the Zhejiang University Ethics Committee.

MATERIALS AND DESIGN

The experimental stimuli were generated using Matlab_R2016b (The MathWorks, Natick, MA) and were presented on a 17 in. CRT monitor (1024 × 768 resolution, 80 Hz refresh rate).

The stimuli applied in the adaptation and test sections both consisted of a series of Gabor patches, each of them measuring 2.77° in diameter. Since the intensity and variance of similar stimuli were found to exert different loads on average computation, we combined stimulus intensity and variance to differentiate the task load. Namely, low task load would occur when orientations were presented in the form of high intensity and low variance. In contrast, high task load was produced when orientations had low intensity and high variance values.

In the adaptation phase, by dividing the average tilted angle of orientation stimuli by 15° (high intensity) and 30° (low intensity), each with a small numerical jitter of 10° (high variance) and 5° (low variance), four groups of stimuli were generated. Two that had high intensity with low variance and low intensity and high variance were ultimately used as adaptive stimuli. Average orientation groups with lower intensity (30°) and higher variance (10°) had a high task load. That is, orientations in the high task load group were tilted clockwise or counter-clockwise at 15°, 25°, 35°, and 45°. Average orientation groups with high intensity (15°) and lower variance (5°) had a low task load, and orientations tilted clockwise or counter-clockwise at 0°, 5°, 10°, 15°, 20°, 25°, and 30° in this group. Although the number of stimuli was different between the two groups, it was found that the number of stimuli beyond four was too high to influence the average computation (Alvarez, 2011). In the test phase, the Gabor patches were tilted clockwise or counter-clockwise by 0°, 2°, 4°, and 6°, respectively. The sample materials are shown in Figure. 2.

The adaptive orientations were presented either in the fovea or peripheral location of the visual field to distinguish the attention distribution. Stimuli appearing successively in the fovea were efficiently allocated more attention, yet those that appeared in the periphery (measured 7.88° from the central fixation) spontaneously obtained less attention. The average orientation was proven to be adaptable. The magnitude of adaptation after-effect size was an indicator of ensemble encoding (Gibson & Radner, 1937) and thus was continuously applied in this study.

In summary, this experiment applied the within-subject design with two factors (task load and attention distribution), separately manipulating the task load and attention distribution, and consisted of adaptation and test sections. There were four conditions, each including two blocks, with clockwise and counter-clockwise adaptative orientations, respectively. There were thus eight blocks in total, each including 56 trials, with 448 trials in total. Trials in each block were randomly arranged.

PROCEDURE

During the entire experiment, participants viewed the stimuli from a distance of 60 cm while sitting straight and looking at the center of

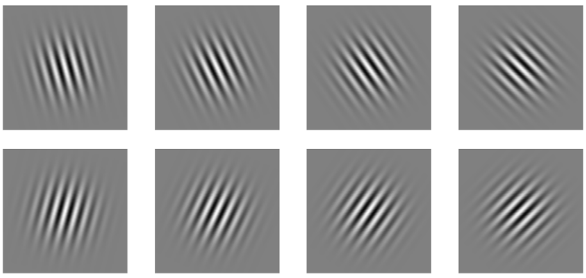

FIGURE 2.

Example images of Gabor patches in Experiment 1. The Gabor patches in the top line are tilted counter-clockwise at 15°, 25°, 35° and 45° in the high task load group, the Gabor patches in the bottom line are tilted clockwise at 15°, 25°, 35° and 45° in the high task load group.

the screen, and keeping their bodies still. In the adaptation section, participants were instructed to pay attention to the center of the screen, and orientations were presented with different combinations of task load and attention distribution. After adaptation, participants would be asked to judge the test orientation illustrated in the center of the screen.

The details are shown in Figure 1. Initiated with six practice trials before each block, a fixed image appeared in the center of the screen for 1000 ms, followed by a variety of orientations rearranging the image with different intensity and variance, which were presented in a rapid serial visual presentation (RSVP) in the foveal or peripheral area of the screen, each randomly appearing 112 times and lasting for 23.5 ms, for 2632 ms in total (adaptation duration). After another appearance lasting 500 ms, the test orientation appeared for 400 ms, and participants were asked to determine the tilt direction of the test orientation using a binary choice, pressing "F" when the test orientation tilted toward counter-clockwise, and pressing "J" otherwise. In addition, when the RSVP appeared in the periphery, the images would randomly appear in the left or right area of the periphery, and participants were told to keep their attention on the center screen and avoid eye movement.

To guarantee participants' steady awareness and effort on the tasks they were asked to press the "A" key as soon as they detected red squares (probe stimuli). The probe stimuli were inserted six times in each block. According to the previous routine (Yigui et al., 2012), two-thirds of probe stimuli appeared in the central field of vision, while the remainder were presented in the periphery. This performance of probe stimuli was used to test the attention effort of participants and was not relevant to the data indicator.

Results and Discussion

All data were retained for final analysis because of the 0.73 hit rate and 0.08 false alarm rate to task-irrelevant probes. The threshold difference was applied to measure adaptation aftereffect size in ensemble encoding (Lai et al., 2012). It amounted to a subtraction between the hit rate of one condition where the mean value was perceived as "different" (of adaptation and test sections) and the hit rate of another condition where the average is reported as "same" (of adaptation and test sections). It returned a larger adaptive aftereffect size along with more significant results as long as they appeared above zero (Caughlan & Jiang, 2014). Negative values indicate a worse adaptation, lower values indicate less adaptation. In this experiment, the ratio of the test stimulus judged to be counter-clockwise (clockwise) under the counter-clockwise condition (clockwise) adaptation was subtracted from the ratio of the test stimulus judged to be counter-clockwise (clockwise) under the clockwise (counter-clockwise) adaptation. As an index of adaptation effect size, the threshold differences under each condition were calculated.

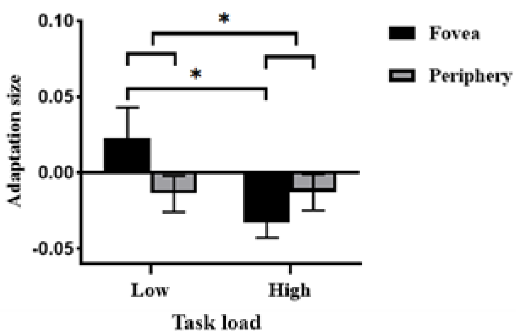

FIGURE 3.

Interaction effect of the task load and attention distribution. For orientations presenting in the fovea, the adaptation size was notably less biased in favor of the low task load condition than the high task load condition.

The size of adaptive aftereffect was subjected to a 2 × 2 within-subjects analysis of variance (ANOVA) with factors of task load (low vs. high) and attention distribution (foveal vs. periphery). There were significant adaptation effects in each condition. The main effect of task load was statistically significant, $F(1, 18) = 4.694$, $p = .044$, $\eta_p^2 = 0.207$, and the adaptation effect of low task load ($M = 0.005$, $SE = 0.012$) was statistically significantly higher than that of high task load ($M = -0.023$, $SE = 0.009$). It was thus clear that the lower task load had significantly facilitated the ensemble encoding of orientations. The main effect of attention distribution was not statistically significant, $F(1, 18) = 0.402$, $p = .534$, $\eta_p^2 = 0.022$, while the interaction effect of the task load and the attention distribution was statistically significant, $F(1, 18) = 5.098$, $p = .037$, $\eta_p^2 = 0.221$. Pairwise comparisons between low and high task load, separately for foveal and peripheral fields of vision, were performed. The simple effect of task load was statistically significant for the foveal stimuli, $F(1, 18) = 7.036$, $p = .016$, $\eta_p^2 = 0.281$ (as shown in Figure 3), such that estimation of adaptation was less biased in favor of the low task load condition ($M = 0.023$, $SE = 0.020$) than in the high task load condition ($M = -0.033$, $SE = 0.010$). However, the simple effect of task load for the periphery did not appear significant. To summarize, the task load, especially for the orientations presented in the foveal field of vision, notably influenced the adaptation in ensemble encoding. Therefore, the direct neural encoding of low-level orientations did not make the ensemble encoding of orientations so automatic, although they were indeed partly immune from the attention distribution.

The previous study found that the higher mental processes (Bargh & Ferguson, 2000), like social interaction, evaluation, judgment, and the operation of internal goal structures can proceed without the intervention of conscious acts of will (a symbol of automaticity). Unlike the neutral-selective encoding for orientations, the high-level social information is in the form of trait-concept terms, and their abstraction degree is already very high (Fajkowska & Kreitler, 2018). We wondered whether further abstraction from ensemble encoding was free from the restriction of extra interference and attention distribution. Therefore, Experiment 2 explored whether the ensemble encoding of facial emotion, a sophisticated social attribute, has a similar degree of automaticity to the ensemble encoding of orientation in Experiment 1.

EXPERIMENT 2. THE INFLUENCE OF TASK LOAD AND ATTENTION DISTRIBUTION ON EMOTION ENSEMBLE

Experiment 2 employed the adaptation paradigm to examine the automaticity in ensemble encoding of facial emotion by manipulating task load and attention distribution. The valence of emotion (positive or negative) was also considered as an independent variable.

Methods

PARTICIPANTS

Twenty-six participants (fourteen males, twelve females, M_{age} = 20.96 ± 1.79 years) with right-hand dominance and (corrected) normal vision were paid for participation. Similar to Experiment 1, all procedures were conducted following the principles expressed in the Declaration of the International Psychological Committee and were approved by the Zhejiang University Ethics Committee.

MATERIALS AND DESIGN

The instruments used were similar to those used in Experiment 1. Experimental materials in adaption and test sections were made from the Chinese Affective Face Picture System (Wang et al., 2002). Two positive (happiness) and two negative (anger) facial emotion photos were carefully chosen. With the background removed, the facial area of these photos was retained in the formulation of an image of 86 × 86 pixels.

The Magic Morph was applied to synthesize these images with neutral emotion to create a series of facial emotions with varying intensity. Similar to Experiment 1, it was assumed that stimuli intensity (positive or negative valence of 30 or 60%) would affect average emotional uncertainty, while stimuli variance (valence variance of 20 or 10%) would influence the individual perception of facial emotions. Emotion groups with weaker intensity (30%) and stronger variance (20%) would have a high task load, while emotion groups with stronger intensity (60%) and weaker variance (10%) were provided with a low task load. There were thus four groups of adaptative emotions, that is, the happiness of 30%with a variance of 20%(0% happiness, 20% happiness, 40% happiness, 60% happiness), the anger of 30% with a variance of 20% (similar to happiness), the happiness of 60% with a variance of 10% (30% happiness, 40% happiness, 50% happiness, 60% happiness, 70% happiness, 80% happiness, 90% happiness), and the anger of 60% with a variance of 10% (similar to happiness).

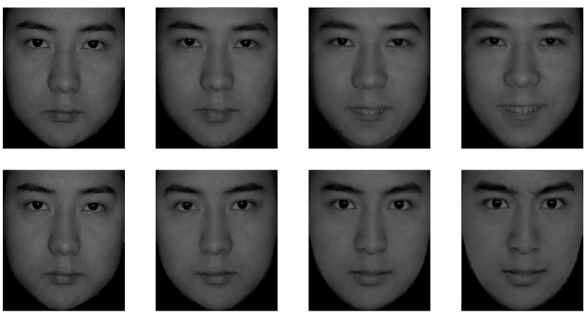

FIGURE 4.

Example images of facial expression in Experiment 2. The faces in the first line are the happiness of 30% with a variance of 20% , which are 0% happy, 20% happy, 40% happy, and 60% happy, respectively. The faces in the second line are the anger of 30% with a variance of 20% , which are 0% angry, 20% angry, 40% angry and 60% angry, respectively.

In the test period, seven stimuli, including three happy emotions (ranged 10% to 30% with intervals of 10%), three angry emotions (the same variance range as happy emotion), and one neutral emotion, wereseparately presented. The sample materials are shown in Figure 4.

In total, there were four conditions, each condition was divided into two blocks according to the emotional valence. Therefore, there were eight blocks in total, including 448 trials in total. The trials in each block were randomly arranged.

PROCEDURE

Commencing with six practice trials, a fixed cross was presented for 1000 ms in the formal experimental trial, followed by a series of adaptation stimuli with different intensity and variance, which appeared 112 times. Each adaptation stimulus lasted for 23.5 ms. When the adaptation RSVP was presented in the periphery, the facial emotion randomly appeared in the left or right area of the periphery while the participants kept their focus on the central location to avoid eye movement. After another fixed image appeared on the screen for 500 ms, a test face with a particular emotion was presented for 400 ms. The participants were instructed to perform a forced choice between two alternatives (positive or negative) for the emotional valence of the stimuli, which randomly appeared during the test period. The six emotions were also used to test the awareness and effort of participants during the experimental process.

Results and Discussion

Two participants' data were deleted because of low hit rates, while the remaining twenty-four participants (fourteen males, ten females, M_{age} = 20.96 ± 1.79 years) provided usable data (0.77 hit rate and 0.09 false alarm) for analysis. The size of the adaptation aftereffect was calculated using the same method as in Experiment 1.

There were significant adaptation effects in each condition. Adaption aftereffect size was then subjected to a 2 × 2 within-subjects ANOVA with the factors of task load (low vs. high) and attention distribution (foveal vs. periphery). The results showed that the main effect of the task load was not statistically significant, $F(1, 23) = 0.686$, $p = .416$, $\eta_p^2 = 0.029$. The main effect of the attention distribution was also not statistically significant, $F(1, 23) = 0.028$, $p = .869$, $\eta_p^2 = 0.001$. This means that there was a weak influence from the task load and attention distribution on the adaptation of ensemble emotion. We also found a statistically nonsignificant interaction effect between task load and attention distribution, $F(1, 23) = 2.025$, $p = .168$, $\eta_p^2 = 0.081$. Compared with the ensemble encoding of orientation in Experiment 1, the adaptation of ensemble emotion appeared more automatic, nearly free of the restriction from task load and attention distribution.

Some studies found that certain negative valence emotions (like fear and sadness) were mandatorily registered without top-down attention (Lavie et al., 2003; Vuilleumier et al., 2002) and would be subject to a mandatory process, especially for people with autism spectrum disorder (Fenker et al., 2010). It also appears that negative emotion with high intensity was subject to a firsthand and automatic process driven by bottom-up attention (Öhman et al., 2001) through a feedforward loop (Lipp & Waters, 2007). In such cases, we wondered whether the valences of emotion would influence their ensemble encoding, especially in different fields of vision. Therefore, the effect of emotional valence was analyzed as an independent variable, but it was found that neither the main effect of emotional valence, $F(1, 23) = 0.061$, $p = .808$, $\eta_p^2 = 0.033$, nor its interaction with attention distribution was statistically significant, $F(1, 23) = 0.498$, $p = .487$, $\eta_p^2 = 0.0021$. The overall detailed data are shown in Figure 5.

Surprisingly, we found a statistically significant interaction of emotional valence and task load, $F(1, 23) = 19.022$, $p < .01$, $\eta_p^2 = 0.453$, shown in Figure 6. The simple effect of task load was statistically significant for positive emotions, $F(1, 23) = 14.500$, $p = .001$, $\eta_p^2 = 0.387$, that is, adaptation size was less biased in the high task load condition ($M = 0.075$, $SE = 0.049$) than in the low task load condition ($M = -0.111$, $SE = 0.065$). The simple effect of task load for negative emotion was statistically significant as well, $F(1, 23) = 11.113$, $p = .003$, $\eta_p^2 = 0.326$, but in the opposite direction. Adaptive scores were less biased in the low task load condition ($M = 0.028$, $SE = 0.060$) than in the high task load condition ($M = -0.115$, $SE = 0.058$). There was no notable significance for the simple effect of task load on emotional valence.

In sum, Experiment 2 found that the ensemble encoding of facial emotion was free from the influence of task load and attention distribution, and the emotional valences were also unable to solely influence the emotion ensemble encoding.

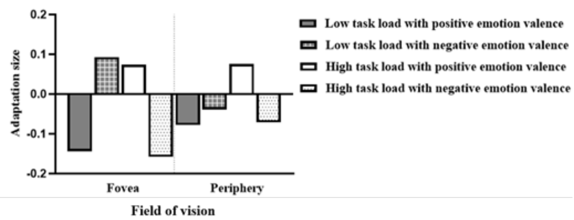

FIGURE 5.

Size of adaptation under different conditions. There was no significant difference in adaptation size when the emotions appeared in the foveal or the peripherical field of vision and also had nothing to do with the level of task load, suggesting cognitive load and attention distribution had no notable influence on emotion ensemble encoding. Besides, neither the main effect of emotion valence nor its interaction with the attention distribution was significant.

GENERAL DISCUSSION

The current study explored the automaticity of ensemble encoding. That is, we explored whether feature averaging is resistant to the task load and attention distribution. It was discovered that attention distribution defined by the visual fields (foveal and periphery) did not have a notable influence on the feature averaging of orientation and emotion. Nevertheless, the adaptation size of orientation ensemble encoding was influenced by task load and the interaction between task load and attention distribution. The further simple effect analysis revealed that the simple effect of the task load was significant for orientation stimuli appearing in the foveal rather than in the peripheral fields of vision. Specifically, the adaptation size of the orientation ensemble appeared higher when orientations with low task load were presented in the foveal field, which implied that the lower task load and higher attention resource jointly facilitated the ensemble encoding of orientation (Experiment 1). In Experiment 2, neither the main effect of the task load nor attention distribution nor their interaction was significant. Regardless of the attention distribution, emotional valence did not have a notable influence on the adaptation of emotional ensemble. Interestingly, a significant interaction effect of emotional valence and task load appeared. Emotions with positive valence and high task load and emotions with negative valence and low task load both had a higher adaptation effect.

Our study provides a special insight into the automaticity of ensemble orientation and facial emotion, corresponding to low-level and high-level features, respectively. In Experiment 1, the orientation ensemble was susceptible to the task load. The adaptation aftereffect size under high task load was significantly smaller than that under low task load. Moreover, combined with the lower attention, the high task load can bring about a notably smaller adaptation size and disturb the automaticity of the orientation ensemble. Those results imply that the ensemble encoding of orientations is not as automatic as previous research has asserted (Corbett & Melcher, 2014). In contrast, the emo-

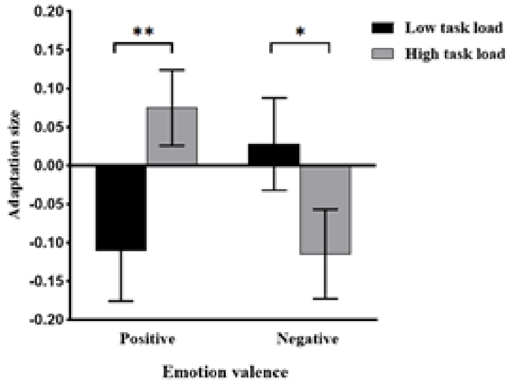

FIGURE 6.

Interaction effect of emotional valence and the task load. The size of emotional adaptation was biased against high task load and in favor of low task load when the adaptative emotion valence was positive, yet showed an opposite tendency under negative emotion valence.

tion ensemble was immune from the task load and attention distribution. Its automaticity thus appears more stable relative to that of the orientation ensemble. One of the critical criteria in the domain-specific proposal for ensemble encoding is the different automaticity for different level features. Considering the above statement, the domain-specific proposal for ensemble encoding is well-justified.

Consistent with previous research, our results indicate that the attention resource was not the principal limit of ensemble encoding. At the same time, our results also suggest that the task load can work separately or jointly with attention or some stimuli dimensions (like emotional valence) to intervene in the adaptation of ensemble encoding. Since low task load plays a significant role in the normal operation of working memory (WM), and possibly supports the well-being of the updating function in the central executive system (Friedman et al., 2006; Miyake et al., 2000). That is, the task load is believed to affect the updating process. In the present study, the high task load may have disturbed the executive control of ensemble encoding (Vandierendonck, 2016). In addition, we manipulated the task load through the intensity and variance of individual items, and this kind of load belongs to the early noise in the noisy and inefficient (but otherwise ideal) observer model (Solomon et al., 2011). As the results indicate, both the orientation ensemble and the emotion ensemble were absolutely or partly influenced by this task load, indicating that the ensemble encoding may happen in the early feature-registering stage.

Our results support the domain-specific proposal of ensemble encoding, although this proposal also needs to be viewed with caution. Confirmed by evidence from behavioral and neuroimaging research, the human face includes low-level traits such as texture (Cao et al., 2020), that are less useful than high-level features. Future studies must use other high-level features to examine whether it is warranted to conclude that there are different automatic mechanisms for simple and complex stimuli. Moreover, some researchers suggest that human vision can flexibly employ different attention distribution strategies and sampling methods to abstract the ensemble (Baek & Chong, 2020). Future studies can conduct further exploration.

CONCLUSION

Ensemble encoding of low-level features such as orientation is partly automatic, not fully influenced by attention distribution but susceptible to the task load and the joint effect of the task load and attention distribution. In comparison, ensemble encoding of facial emotion obtained a relatively higher degree of automaticity, indicated by the immunity from the task load, attention distribution, and emotional valence, but influence by the interaction of the task load and emotional valence. Those results of ensemble emotion imply high automaticity in social cognition. Our findings support the domain-specific perspective for ensemble encoding of different levels. The findings also indirectly imply that the automaticity of ensemble encoding may originate from the initial feature-registration stage belonging to the early part of the perceptual process.

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, Zhijun Zhang, or the fist author, Dan Han, upon reasonable request. Please feel free to get in touch for the supporting data. The email address of the corresponding author is zjzhang@zju.edu.cn; The email address of the first author is handan931124@zju.edu.cn.

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