2019

How visual confidence on global motion is affected by local motion ambiguity and type of motion noise, and its correlation with autistic trait tendency?

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Year 2017-18

SSC 4319 Senior Thesis

How visual confidence on global motion is affected by local motion ambiguity and type of motion noise, and its correlation with autistic trait tendency?

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Abstract

Perceptual confidence has been found to correlate with task performance in general, and is believed to be independent of stimulus features. However, certain stimulus feature could induce a subjective sense of uncertainty, which could potentially influence confidence judgments beyond task performance. The present studies aimed at assessing the effects of the ambiguity of local motion signals on perceptual confidence on a global-motion task. Participants first discriminated the global motion directions of two multiple-aperture, global-motion patterns, one generated using multiple Gabor elements and the other using multiple Plaid elements. They then performed a two-interval, forced-choice confidence task by choosing which of the two perceptual responses they were more confident in being correct. In Experiment 1, when perceptual performance was controlled by varying coherence, we found that participants chose plaids more often than Gabors, even with perceptual performance matched between the two patterns. In Experiment 2, when perceptual performance was controlled by varying luminance contrast of noisy pixels in every motion frame, such “plaid preference” in confidence bias was significantly weakened.

Besides, there has been numerous studies on visual perception of autistic individuals. But not many of them has looked into the relationship between their metacognition and perceptual judgement. This study aimed at assessing the relationship between the autistic trait tendency and metacognitive process about one’s perceptual performance. Our results show that, at the same level of objective task performance, subject perceptual confidence depends on both the ambiguity of local motion signals and the type of noise. Our results also shows that there is an association between the subject perceptual confidence and the autistic trait tendency.

Introduction

In everyday life, we are constantly receiving different visual information. They are then processed in a complex visual system, reaching to recognitions or judgements. When we see a moving car, our visual system is actually processing the information according to a hierarchy. Visual stimulus first enters the eyes through projection on the retina. Photoreceptors then transduce the signals and send to the brain through a region called lateral geniculate nucleus (LGN) in the thalamus. Once this has occurred, signals reach the visual cortex which locates in the occipital lobe, the most posterior region of the brain. The visual cortex is further divided into different distinct compartments. The earliest stage of visual processing has been identified in the primary visual cortex (V1), where the orientation- and spatial frequency-selective neurons can only cover a small receptive field (M Weliky, Bosking & Fitzpatrick, 1996; Duffy & Hube, 2007; Priebe, 2016). The more complex visual features are passed serially from one area to the next area, e.g. V2, V4, middle temporal visual area (MT) for further processing and object recognition. This is known as the hierarchical visual processing (Hubel and Wiesel, 1962).

V1 as the first visual processing stage, neurons are highly selective to orientations and simple features. Wiesel and Hubel (1959) have found cells called simple cell and complex cells in V1 that respond to edges and gratings of particular orientations and spatial frequencies primarily, such as Gabor. Basically, Gabor patch is a sine wave grating, or a series of black and white bars that can oriented into different degrees seen through a Gaussian window. Many static visual experiments have used it to test the receptive field properties of specific neurons (Takeuchi, 1998; Amano, 2009; Scarfe, 2011; Rider, 2014; Sherman, Seth, Barrett & Kanai, 2015). Gabor has also been increasingly used in visual motion experiment recently to test the differences between the local and global motion perception. Although motion has been found to have the highest neural activities in MT (Smith, 1998; Born &

Bradley, 2005), there has been some evidences showing that there are some direction-selective neurons in V1 and V2 responding to visual motion (Mather, Pavan, Campana & Casco, 2008; An, 2012). They can predominantly detect and signal the motion of 1D visual features. But deriving a true motion direction from the local spatial and temporal structure of the stimulus viewed through a small aperture, is very difficult and highly subjective to ambiguity (Rider, Nishida & Johnston, 2016). Therefore, Gabor as a one-dimensional (1D) visual feature is ambiguous in signaling global motion direction. This is known as the aperture problem (Shimojo, Silverman, Nakayama, 1989; Bruno & Bertamini, 2015) To solve the ambiguity, our visual system needs more information, for instance, by integrating motion signals of other orientations to become a two-dimensional (2D) motion feature, such as Plaid. Plaid combines two distinct gratings of orthogonal orientation to each other with same contrast. By integration, it consists of unambiguous local motion signals that allow observers to derive a true motion direction (Movshon, 1982).

The complexity of visual stimuli and size of receptive fields increased throughout the low-level to high-level visual processing (bottom-up processing) (Intaitė, 2013; Dijkstra, 2017). This allows us to see things better as we receive feedback from cells with larger receptive fields (Scarfe, 2011). But this is only halfway through the entire visual processing. To derive a visual judgement or a decision, information in the visual cortex is reached by the prefrontal cortex to process information. Our brain integrates the assumptions formed by prior experiences and knowledge (top-down processing) (Intaitė, 2013; Dijkstra, 2017) to enhance the visual processing. We are usually more aware and conscious of such kind of later stage information processing. Interestingly, we are conscious about comparing the visual information our brain obtained from the earlier stage of processing in the visual cortex. But it seems that we are unconscious of the origins of these visual information. So do we actually know what we see? What are we really conscious of? And can we make accurate judgement about what we see?

This leads us to a major question of "what is consciousness?" Consciousness is broadly defined as a state of being aware of external world and internal self (Van Gulick, 2004). It could be awareness, subjectivity and in many other terms. But when we make any judgement or decision, we need to regulate our cognition. Otherwise saying, we need to know what we know and what we are thinking. Therefore, we need information processing of even higher order that is beyond consciousness, which is the "metacognitive processes" or "metacognition" (Timmermans, 2012). It refers to the awareness of one's own knowledge, in other words, knowing of what one is thinking. There have been research findings showing the metacognition-related brain activities in the right rostrolateral prefrontal cortex (rlPFC) (Fleming, 2012). But how do we quantify metacognition? Some previous research suggest that confidence can to use to quantitatively measure metacognition (Maniscalco & Lau, 2012; Fleming, 2012, 2014; Santangelo, 2016). When ones know what they are aware of and thinking, they should be able to utilize their knowledge and be more confident in giving the correct response or judgement. Intuitively, confidence is an alternative measurement for metacognitive sensitivity (Fleming, 2014).

There are sufficient findings suggesting confidence is a "good" way to measure the metacognition. But is it the case? Although high perceptual confidence is usually coupled with better perceptual performance with high accuracy (Samaha, 2016), it is a self-reported rating which highly subjects to perceptual and response bias. There have been debates on whether individuals can indeed dissociate between their objective performance and subjective awareness since this is very important in terms of selecting a reliable mean to quantify metacognitive process (Peters, Kentridge, & Phillips, 2017; Phillips, 2017; Phillips & Block, 2016). To solve this issue, more computation approaches and alternatives have been developed recently (Maniscalco and Lau 2012; Fleming, 2017). Rather than confidence rating which has been found potentially susceptible to criterion bias (Hesselmann, Hebart, & Malach, 2011; Salti et al., 2015), two-interval forced-choice was shown to efficient in controlling the criterion bias (Peters & Lau, 2015).

Given the above distinctions in perception, do our metacognitive judgments differ between the perception of high-level stimuli vs the perception of low-level stimuli? In the following experiment of this study, we aim to compare and identify differences in the visual confidence judgements between perceptual task performances on a low-level stimulus and a high-level stimulus, and to understand the extent of metacognition on information processing hierarchy.

Speaking of information and perceptual processing, multiple researches have been done on the autistic individuals. The major reason is that autistic individuals has been found to have a very different perceptual system from the normal population (Dakin & Frith, 2005; Manning, Tibber & Dakin, 2017). Autism is also associated with social communication deficits, perceptual abnormalities or language delays (Baron-Cohen, 1995) with number of findings and evidence. Such assumption has been extended to individuals who possess high tendency of autistic traits, but without diagnose of autism. Therefore, the AQ representing the degree of autistic traits can be collected from the participants after the following experiments to explore more on the metacognition and perceptual confidence of autistic individuals.

Experiment 1

Participants

Thirty participants (twenty-two females, eight males) aged 18-25 years (M=21.3, SD=1.15), including the first author were recruited to participate in experiment 1 upon completion of a written informed consent. All participants had normal vision or corrected-to normal vision. All of them were either given course credit or paid HK$50 for their participation. The data of two participants were removed due to either computer program errors during the experiment or missing data. Data of two additional participants were also removed due to negative standard deviation (refer to the result section). Therefore, twenty-six participants (eighteen females, eight males) aged 18 – 25 years (M=21.2, SD=1.11) in total were included in the data analysis for experiment 1.

Apparatus & Stimuli

All stimuli were generated in MATLAB by using Psychophysics Toolbox extensions version 3 (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007). Stimuli were multiple-aperture arrays consisting of 188 randomly-oriented elements. Each element was either a Gabor element or an orthogonal plaid with a spatial frequency is 2 cycles per degree. The stimuli were presented at the center of the screen, and were viewed through a circular annulus that was 8 degree (visual angle) with an empty central region of 3.5-degree (visual angle) radius (See Figure 1 & 2).

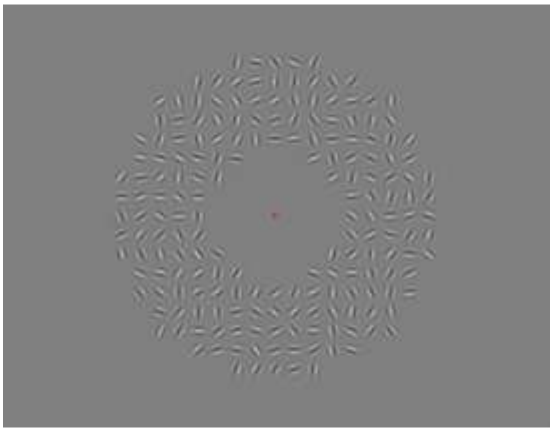

Figure 1. Stimulus sample in experiment 1: Gabor stimulus.

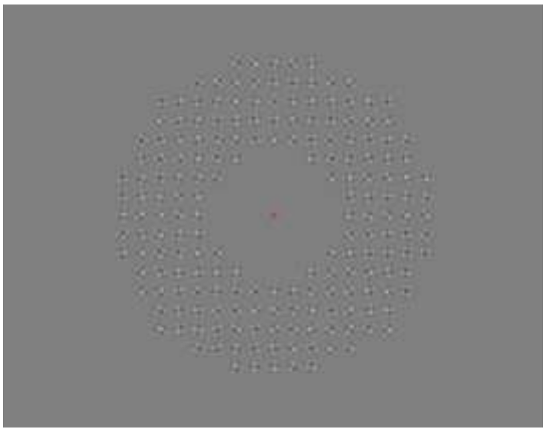

Figure 2. Stimulus sample in experiment 1: Plaid stimulus.

Stimuli were viewed binocularly in full-screen of 1920 x 1080 pixels and observers maintain focus on the central fixation point when viewing the stimuli. The viewing distance was fixed at 53 cm with a chin rest, making each element approximately 1.5 visual degrees in diameter. The overall Michelson's contrast of the stimuli was set constant at 0.2 on a background luminance level of 127.5.

In experiment 1, coherence of motion patterns was manipulated to alter the perceptual task difficulty. It was computed in terms of signal-to-noise ratio (SNR). The coherence SNR was defined as the ratio of the number of elements pooling into the target direction to the number of elements moving in random directions:

$$SNR = \frac{Number_{Signal}}{Number_{Noise}},$$

where signal is number of elements moving toward target direction, noise is number of elements moving toward random directions

For the main experiment, the coherence (SNR) was calibrated to achieve three fixed d' (0.8, 1.6, 2.4) levels as the perceptual task difficulty. An adaptive staircase using the accelerated stochastic approximation method in order to target three fixed levels of perceptual accuracy, which correspond to the three d' was adopted (Kesten, 1958). The initial coherence for each staircase is .99 and the initial step for the staircase is 15 in log unit of SNR. Such adaptive staircase aimed to calibrate the coherence level (SNR) at which an observer's performance for both Gabor and Plaid could be stabilized at 3 target levels of accuracy based on the 3 levels of d': 65.54% (d'=0.8), 78.81% (d'=1.6) and 88.49% (d'=2.4) in each condition. Observer would perform at a constant probability to give "correct" answers across conditions.

Therefore, a 3 × 3 × 2 factorial design was used in experiment 1 in which combinations of Gabor or Plaid patches and coherence at target d' levels were presented (See

Table 1). Each stimulus exposure duration was 250 ms in total length. The refresh rate was 144 Hz and 36 frames were presented each second of the stimulus. Each trial contained two stimulus intervals in random order: one was Gabor elements, and the other was Plaid elements. A coherent global motion of the stimulus moved either leftward or rightward with the drift speed of 2 degree per second.

Table 1.

Summary of d' for Gabor and Plaid treatment conditions.

Treatment Condition	Gabor	Plaid
A	0.8	0.8
B	0.8	1.6
C	0.8	2.4
D	1.6	0.8
E	1.6	1.6
F	1.6	2.4
G	2.4	0.8
H	2.4	1.6
I	2.4	2.4

Autism Spectrum Quotient (AQ-50)

Apart from the main experiment, all participants completed the Autism Spectrum Quotient (AQ) questionnaire. It consists of 50 items (statements) to measure five subdomains of autism spectrum: social skills, attention switching, attention to detail, communication and imagination. Subjects indicated their degree of agreement to the statement on a four-point scale from “definitely agree” to “definitely disagree”. Scoring 32 or above out of 50 is a very crucial indicator of high autistic tendency and being diagnosed with autism or related disorders. The Cronbach's alpha of each subdomain has been found to be moderate to high (Communication = .65; Social, = .77; Imagination = .65; Local Details = .63; Attention Switching = .67) suggests a moderate to high internal reliability. A high test-retest reliability of the AQ-50 has been established (r = .7, p = .002).

Procedure

In the main experiment, the motion direction discrimination tasks were first introduced in each trial. In each trial, a central fixation dot was presented for 500 ms, following by the presentation of the first target stimuli for 250 ms. Participants needed to discriminate (left or right) on a Gabor pattern and a Plaid pattern, one after another. They were then presented with a response prompt, asking them to make motion direction judgment for the target stimulus in a two-interval, forced-choice (2IFC) by pressing the arrow keys on a regular computer keyboard.

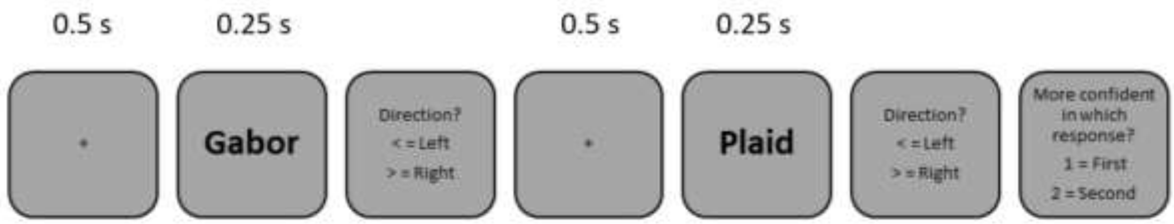

Figure 3. Task structure in each trial of the experiment.

After that, the same central fixation dot was presented for 500 ms before the presentation of second target stimuli for 250 ms. The same response prompt was presented again to the participants for a motion direction judgement for second target stimulus. Then, the participants were presented with another response prompt, asking them in 2IFC, to choose the stimulus in which they were more confident in their direction judgment by button press (1: first stimulus; 2: second stimulus). There was no time limit for participants to give their response on each response prompt. Their overall accuracy, accuracy for chosen stimulus as the more confident choice and accuracy for the unchosen stimuli was presented to them after they completed a whole block (24 trials) of the experiment. Participants were also informed to give their best guess even if they subjectively felt they could not see the motion direction in some target stimuli.

All participants completed a block of practice trials prior to the main experiment. The purpose of the practice trials was to familiarize the participant with the to the stimuli, task content and response keys. They were also used to check if the participants pass the adaptive staircasing staging. Structure of the practice trials and the trials in the main experiment were identical, except for the trial-by-trial feedback about the cumulative accuracy across blocks. The participants then entered the main experiment after completion of 24 practice trials. The main experiment consisted of 30 blocks. Each block contained 24 trials. There were 9 pairings condition of Gabor and Plaid coherent motion pattern set by the three fixed d' levels. The first 144 trials (6 blocks) were calibration trials. As there were two responses (one for Gabor, one for Plaid) in each trial, there were in total 288 perceptual responses (144 for Gabor, 144 for Plaid). For each Gabor and Plaid, the 144 trials were split into 3 independent staircase tracts with 48 trials for each. Therefore, there were 6 independent tracks of staircase running (48 trials), 3 for gabor (targeting d'=0.8, 1.6, and 2.4), 3 for plaid (also targeting d'=0.8, 1.6, and 2.4) during calibration. The order of the trials for the three Gabor staircases and the three Plaid staircases were randomized. As a result, Each calibrated trial consisted of a Gabor trial and Plaid trial, each randomly taken from one of their three staircases. So, there only 576 trials (24 blocks) for the main experiment, 64 trials for each of the nine conditions. There were no noticeable difference between the calibration and the main experiment trials as the blocks proceeded without letting the participants know. Therefore, each participant went through 720 trials in total. Breaks with no time limit were allowed between blocks in order to reduce fatigue. The feedback corresponding to their performance on the previous block was presented to the participants at this time. After completing the main experiment, participants were asked to complete an online version the Autism-Spectrum Quotient (AQ-50). They were then fully debriefed completing the questionnaire.

Data analysis

In the current study, both experiments aimed to investigate if we could find any difference in the relationship between objective performance and subjective awareness between the two motion patterns. The objective performance was defined in terms of how well participants could discriminate between left and right directions in Gabor or Plaid motion patches, whereas the subjective awareness was defined as the percentage of choosing Plaid. In each trial, we collapsed data of each subject across the stimulus order (Garbor-Plaid, Plaid-Gabor) and target motion direction order (right-left, left-right, right-right, left-left) for each combination of coherence levels (3 Gabor d' levels × 3 Plaid d' levels = 9 combinations). The motion direction performances (d') were matched between the target Gabor pattern and Plaid pattern. Calculation of the performance difference between target stimuli of coherence levels set at the three fixed target d' levels was done in the method of $d'_{Plaid} - d'_{Gabor}$. Hits were defined when the target stimulus moved rightward and the subject chose right. False alarms were defined when the target stimulus moved rightward but the subject chose left. In all the experiment, the hit rate and false alarm rate of 1 and 0 were converted 1 – (1/2 of number of trials in calculating d') and (1/2 of number of trials in calculating d').

The 9 coherence combinations were plotted and fitted into a cumulative normal distribution function to generate a psychometric curve for each subject, in terms of the proportion of trials where the Plaid pattern was rated as the more confident choice against the d' difference between the Gabor and Plaid motion patch. Assuming the relationship between the subjective awareness and the objective performance of Gabor stimulus is not different from that of Plaid stimulus, the participants should be betting equally on the two stimuli when the d' difference, also known as the point of subjective equality (PSE) is zero. Likewise, participants should have a 50% chance of choosing the Plaid stimulus, or the point of objective equality (POE) when the d' difference between the two target stimuli is zero. However, if such relationship is different between the two target stimuli, a shift of the psychometric function is observed in which the PSE and POE no longer equal to zero and 50% respectively.

PSE of each subject was obtained from their psychometric functions was compared against the d' difference between the Gabor motion pattern and the Plaid motion pattern at zero. The PSEs were then adjusted by using a standard correction of PSE / SD. To test the hypothesis, two-tailed one-sample t-tests were conducted in all experiments in this study. Repeated measures ANOVAs was conducted to test the effect of coherence on motion direction discrimination d'. Apart from the main analyses on the PSE, the relationship between the Autism Spectrum Quotient (AQ) and standardized PSE was also analyzed from all subjects. Correlational analysis was conducted in Jamovi.

Results

A repeated measures ANOVA (mixed ANOVA design), with within-subjects factors of coherence (three d' levels) and the stimuli (Gabor or Plaid) was conducted. A significant main effect of coherence on motion direction discrimination d' was found [$F(2, 50) = 49.370$, $p < .001$] (See Figure). This suggested that the direction judgment performance increased with coherence of elements in the stimuli. However, there was no main effect between stimuli [$F(1, 25) = .840$, $p = .364$], and no interaction effect between coherence and stimuli [$F(2, 50) = .155$, $p = .857$] being shown by the ANOVA. These results confirmed that (1) the performance between Gabor and Plaid were matched across coherence levels, and (2) the target d's used to calibrate the coherence between Gabor and Plaid were matched optimally in the experimental design.

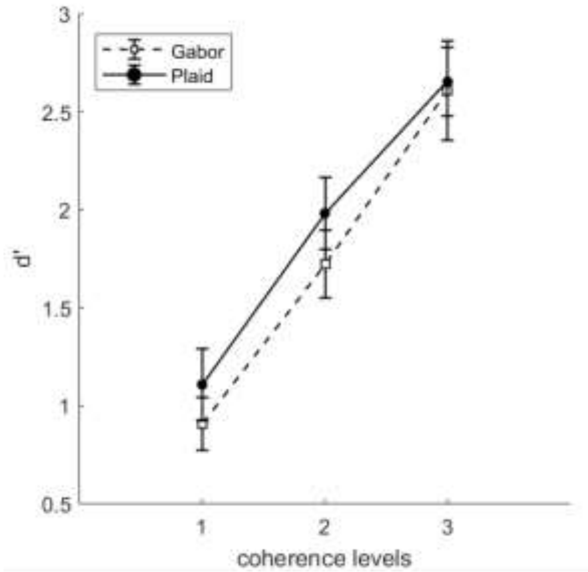

Figure 4. Results from Experiment 1. Direction discrimination performance (d') of Gobar and Plaid stimuli at each coherence level.

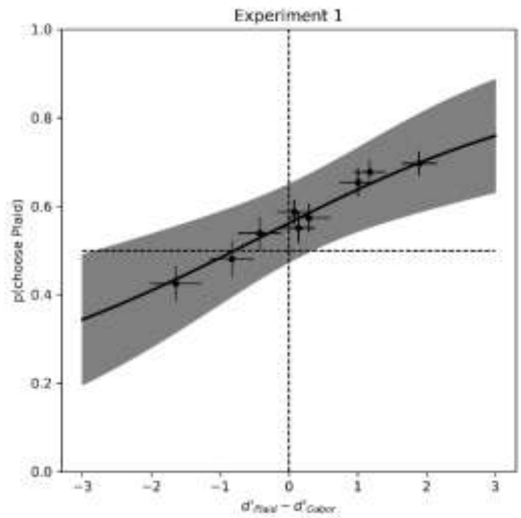

Figure 5. Results from Experiment 1. Average psychometric curve of the PSE/SD.

In the main analyses, two-tailed one-sample t-tests were conducted to test whether there are any difference, in other words, potential bias of the PSE being found from the d' difference between Gabor and Plaid. As mentioned before, the standardized PSE /SD was used to explore the potential bias of the PSE analyses in comparison to PSEs since it provide a more reliable index.

According to the test results, the mean PSE / SD is -0.177 (SD = 0.238) across all coherence levels respectively. The one-sample t-tests suggested that the standardized PSE / SD was found to be significantly different from zero [$t(20) = -3.45$, $p = .002$, 95% CI (-.257, -.065)] with sufficient evidence (See Figure 5). In general, there is a difference being found on the percentage of choosing Plaid from 50% when the objective performances under Gabor and Plaid patterns are matched. It is noteworthy that 21 participants responded in the negative direction, which they would equally choose between the two stimuli to be the more confident choice only when their performance on Gabor patch substantially surpass that on Plaid patch. They were more biased to choose Plaid pattern to be the more confident choice over Gabor pattern, even if they perform equally well on them. This shed light on explaining the effect of local signals' ambiguity on our confidence judgements.

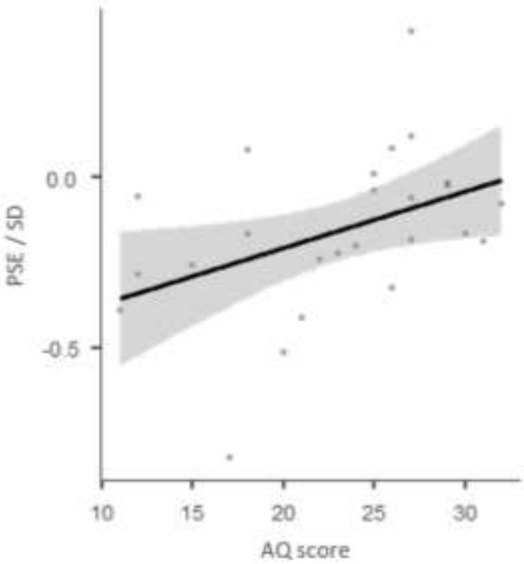

Figure 6. Result from experiment 1: Correlation between AQ score and PSE/SD

Apart from the main analyses, correlational analyses were used to explore the relationship between the AQ score and the standardized PSE values. Results of the Pearson's correlation shows that a significant positive correlation was found between the AQ score and the standardized PSE values [r(24) = .423, p = .031]. This suggests that the higher the autistic trait tendency is, the greater the PSE value is. In other words, individual who possess more autistic traits, they are less biased in choosing between Plaid or Gabor at equally uncertain circumstances. This is quite a surprising finding in this experiment, since it inverted some of the previous findings on the perception of autistic individuals.

Experiment 2

Participants

Twenty-six participants (fifteen females, eleven males, five experienced) aged 18-24 years (M=21.3, SD=1.38), including the first author participated in experiment 2 upon completion of a written informed consent. Five participants noted as "experienced" had previously participated in experiment 1 prior to experiment 2. All participants had normal vision or corrected-to normal vision, and were either given course credit or paid HK$50 for their participation. However, one participant disclosed that he didn't put on vision corrected glasses after the experiment and was removed from the data analysis. Therefore, twenty-five participants (fifteen females, ten males) were included in the data analyses for experiment 2.

Apparatus & Stimuli

The stimuli and apparatus in experiment 2 were the same as in experiment 1, except for the following modifications on the stimuli from those in experiment 1. Target stimuli were the same multiple-aperture arrays consisting of 188 randomly-oriented Gabor or Plaid elements. Unlike manipulating the coherence in experiment 1, the coherence of drifting elements in experiment 2 was set constant at 1. But the target stimuli were masked with Gaussian noise which were created in MATLAB (see Figure 7 & 8).

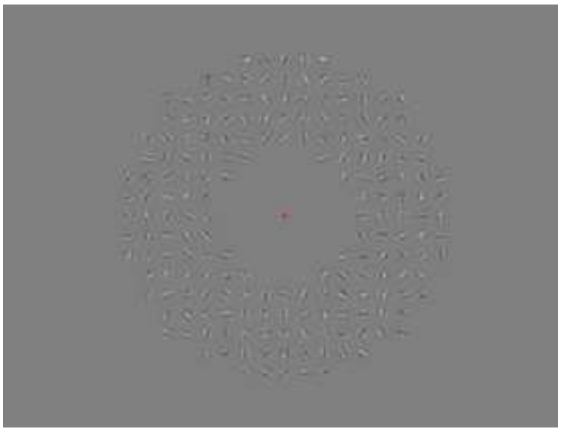

Figure 7. Stimulus sample in experiment 2: Gabor stimulus

Figure 8. Stimulus sample in experiment 2: Plaid stimulus

The pixel size of the noise was 2. The luminance contrast of noise to the contrast of the target stimuli represented the contrast signal-to-noise in experiment 2, and was controlled to manipulate the difficulty of perceptual tasks. The contrast SNR was defined as the ratio of the luminance contrast of noise pixel to the contrast of the Gabor or Plaid element:

$$SNR_{Gabor} = \frac{Contrast_{Signal}}{Contrast_{Noise}},$$

where signal is contrast of Gabor / Plaid element; noise is contrast of the luminance contrast of noise pixels

For the main experiment, the contrast SNR was calibrated to achieve the same fixed target d’ levels as in experiment 1 to control the perceptual task difficulty. An adaptive staircase method was used. The noise alpha for each staircase is 0.1 and the initial step for the staircase is 10 in log units of SNR. Therefore, a 3 × 3 × 2 factorial design was also used in experiment 2 in which combinations of Gabor or Plaid patches and luminance contrast at target d’ levels were presented.

Procedure & Data Analysis

The procedure and analysis procedure in experiment 2 were the same as that in experiment 1, except for some changes made to the data analysis. In each trial, we collapsed data of each subject across the stimulus order (Garbor-Plaid, Plaid-Gabor) and target motion direction order (right-left, left-right, right-right, left-left), but for each combination of luminance contrast levels of noise pixel (3 Gabor d' levels × 3 Plaid d' levels = 9 combinations) in experiment 2. Again, we plotted the 9 combinations, fitted them into a psychometric function for each subject. But in experiment 2, additional rules were added to better fit the data into the psychometric function. If the subject's thresholds for each luminance contrast level is in ascending order, the calibrations were accepted. But if only the threshold of the smallest and the greatest target d's are in ascending order, the threshold of the middle target d' is estimated by taking means. And if the thresholds are not in ascending at all, all three thresholds are then estimated by fitting the psychometric curve. The mean standardized PSE was calculated and obtained from the PSEs of each subject for further data analyses by running two-tailed one-sample t-tests, repeated measures, and correlational analysis.

Results

A repeated measures ANOVA (mixed ANOVA design), with within-subjects factors of luminance contrast of noise to signal (three d' levels) and the stimuli (Gabor or Plaid) was conducted to check for effects. It is noted that the coherence of the elements in each stimulus pattern were controlled at a constant level of 1. The main effect of the luminance contrast ratio of noise to signal on the motion direction discrimination d' was found to be significant [$F(2, 48) = 101.592$, $p < .001$] (See Figure). This indicates that the direction judgement performance increased with the contrast ratio in the stimuli. Similar to experiment 1, the main effect between Gabor and Plaid was found insignificant [$F(1, 24) = .026$, $p = .871$], and no interaction effect between the contrast ratios and the stimuli was found [$F(2, 48) = .190$, $p = .827$]. All the results of the ANOVA, again, confirmed that (1) the performance between Gabor and Plaid were matched across the luminance contrast ratio levels, and (2) the target d's used to calibrate the luminance contrast ratio indeed worked and achieve the optimal matching of d' between the Gabor and Plaid stimulus in the experimental design.

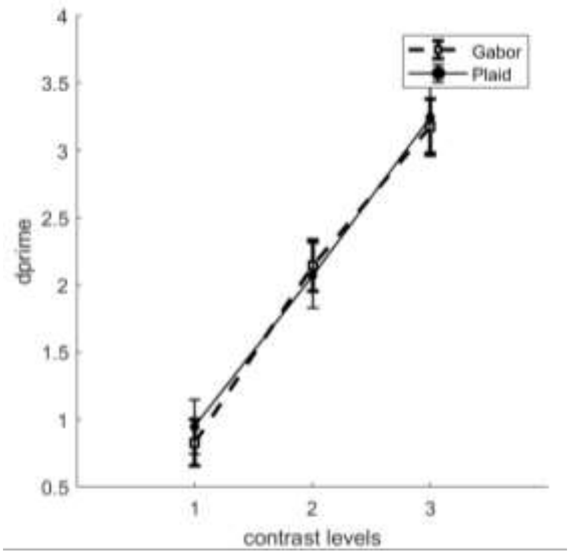

Figure 9. Results from Experiment 2. Direction discrimination performance (d') of Gobar and Plaid stimuli at each luminance contrast level.

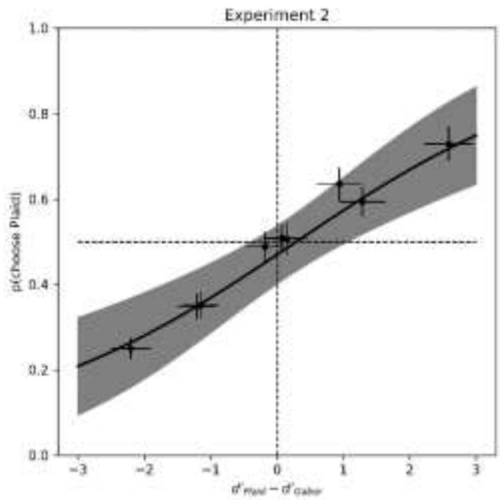

Figure 10. Results from Experiment 2. Average psychometric curve of the PSE/SD.

As for the main analyses, two-tailed one-sample t-tests were conducted to test if there are any difference being found in d' between the two stimuli (Gabor or Plaid), suggesting a potential bias of the PSE analyses. The mean standardized PSE / SD were 0.077 (SD = 0.179) across all contrast ratio levels respectively. The test results indicate that standardized PSE / SD was significantly different from zero [$t(24) = 2.11$, $p = .045$, 95% CI (.002, .144)] (See Figure 10). Since the standardized PSE values provide a more reliable index to explore the potential bias of the PSE analyses in comparison to PSEs, the test results are accepted. Overall, the test results suggest when the subjective awareness is matched, difference was found in the objective performance between Gabor and Plaid. To put it another way, the percentage of choosing Plaid is no longer 50% when the objective performances under Gabor and Plaid patterns are equal.

Interestingly, most of the participants responded in the positive direction which is unexpected with the original hypotheses, which is the tendency to choose Plaid over Gabor under equally uncertain circumstances can be eliminated by the type of motion noise. But it seems that participants tend to choose the Gabor stimulus, which consists of ambiguous local motion signals to be the more confident choice in signaling global motion direction over the Plaid stimulus, when they noticed differences between the two stimuli or they perform equally good or bad on them. Such unexpected findings reveal that there might be more in our brain and perceptual system affecting our confidence judgements other than just explicit knowledge about the difference in contrast and local signal ambiguity.

Moreover, two-sample t-tests were conducted in comparing the results of experiment 1 and experiment 2. The PSEs across the two experiment was found to be insignificantly different from each other [$t(50) = -1.4586$, $p = 0.151$, 95% CI (-2.7846, 0.4417)]. Yet, the findings significantly different standardized PSE/SDs across the two experiments [$t(50) = -4.0270$, $p = 0.0002$, 95% CI (-0.3505, -0.1172)] gave evidence to reject the null hypothesis, that is the difference in the results between the two experiment equals to zero.

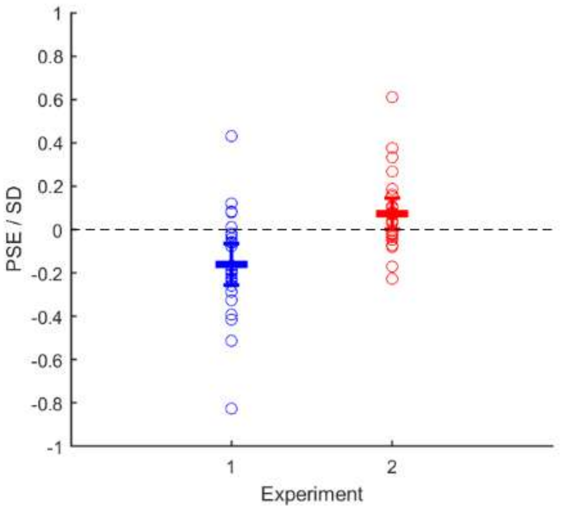

Figure 11. PSE/SD comparison between experiment 1 and experiment 2.

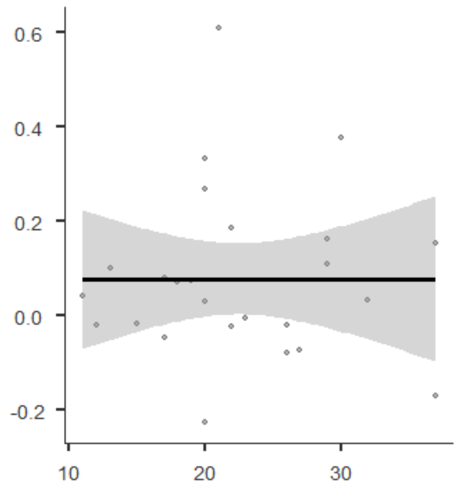

Figure 12. Result from experiment 2: Correlation between AQ score and PSE/SD

Apart from the main analyses, the relationship between the AQ score and the standardized PSE values was explored and tested by using correlational analyses. However, results of the Pearson’s correlation shows that there was no relationship being found between the AQ score and the standardized PSE values [r(23) = .001, p = .994] (See Figure 11). Unlike the findings in experiment 1, we do not find any association between the autistic trait tendency and the tendency to choose any of the two stimuli. The manipulation of contrast ratios and the control of motion coherence in this experiment may account for such findings.

Discussions

In experiment 1, a difference in the subjective awareness has been found between the Gabor and Plaid patches in signaling a global motion direction under manipulation of coherence. When an observer’s objective performance on Gabor motion patches is equally the same as that on Plaid motion patches, there is a tendency to choose on Plaid as the more confident choice rather than betting evenly on both stimuli. Such tendency, or bias may be explained by the different local features of the two stimuli. Gabor, as mentioned, consists of ambiguous one-dimensional (1D) local signals in signaling global direction. The contour of a 1D image is partially blocked when it is viewed through an aperture. Such visual blockage provides no time-varying cues that is parallel to the oriented image contour. Also, as the receptive field of neurons in early cortical areas are comparatively small and narrow in orientation tuning, they are incapable of processing the complex contour representation of a stimulus (Scarfe, 2011; Rider, Nishida & Johnston, 2016). As a result, there can be infinite directions the visual image is moving toward to under the two-dimensions, that is commonly known as the aperture problem. Each element in a Gabor patch may be perceived as signaling arbitrary motion directions. Therefore, synchronization of signals becomes difficult and is unable provide an unambiguous overall global direction unless the coherence of elements toward a specific perceived direction is very high. Otherwise the available visual information is insufficient for observers to derive a true motion direction. When observers cannot make certain judgements baaed on clear discrimination between direction, their confidence about their judgement decrease accordingly.

As opposed to Gabor, Plaid resolves the local signal ambiguity by combining different oriented gratings, usually perpendicular, into an overlapping visual pattern. Motion of such cross-orientation pattern now become a more detectable with its corner and line-end, as they provide additional information that is parallel to a moving contour (Welch, 1989). This allows a single neuron to uniquely identify and predict the direction and speed of a motion stimulus. Apart from this distinctive feature, Plaid motion patch is processed in two stages (Adelson and Movshon, 1982; Movshon etal., 1986; Welch, 1989). In the first stage of processing, components in Plaid are decomposed into two sliding transparent constituent gratings of different spatio-temporal frequencies. They are compared to each other in terms of relative contrast, spatial frequency and motion direction, and then recombined. The intersections between gratings provide relevant spatial information in discriminating an overall direction and generate unambiguous velocity signal (Welch, 1989; Lorenceau, 2010). The directional signals are further strengthened when elements in a Plaid patch are coherently moving toward a specific direction. Observers can better discriminate the unambiguous local signals and deriving a true global motion direction. So, it is more likely for them to bet on Plaid as a more confident choice of being correct. Only when their performance on Gabor patches substantially surpass that on Plaid patches in a trial, they will be aware of a difference in their performances between the stimuli. And they will be equally confident, or equally uncertain about their judgement. The PSE, therefore shifts leftward and demonstrate a bias toward Plaid patches.

Beside local signal features, our perceptual performance may be influence by the differences in neural firing between Gabor and Plaid. As we know, the visual cortex is in hierarchical structure and the visual processing feedforwards according to the hierarchy, so as the neural firing. When the properties of a visual stimulus lie within a neuron's receptive field, it will fire action potential and send signals. So, a neuron is more likely and frequently to fire if it has a larger receptive field that cover more subsets of stimuli. This may explain why we can see Plaid better than Gabor, and hence perceive Plaid as a more confident choice. Since neuronal tuning of neurons in early cortical areas, such as V1 and V2 areas is much simpler, they are only sensitive to specific subset of orientations or simple features. Gabor stimuli seem to elicit neural firing in those areas. In contrast to Gabor, Plaid as a cross-oriented grating pattern contains much complex features. The neurons in the later cortical areas such as V4 and MT seem to respond more to Plaid with their larger receptive field and complex tuning. Firing by a number of neurons, rather than single orientation-selective neuron is elicited by the visual complexity of Plaid. A stronger signal is eventually sent out for visual and information processing, and hence influence our objective perceptual performance and confidence judgement by making us aware of it.

While in experiment 2, the contrast SNR was manipulated to look for any difference in the subjective awareness between the Gabor and Plaid patches in signaling a global motion direction. Interestingly, an opposite pattern to experiment 1 was observed. Observers tend to choose Gabor as a more confident choice over Plaid when their objective performances on both stimuli are the same. Plaid, when comparing to Gabor, is under the later stage of visual processing that can be reached and accessed relative easier by the prefrontal cortex for information processing. To support this, existence of a mechanism is assumed to enhance direct projection and feedback between the prefrontal cortex and extrastriate visual cortex like V4 and MT. They can directly encode and project visual contents to prefrontal cortex for conscious information processing, and hence making contribution to consciousness (Banks, 2009). Several evidences have been found to support this assumption (Libedinsky & Livingstone, 2011; Zanto, Rubens, Thangavel & Gazzaley, 2011). In such wise, observers are supposed to be more aware of the direction signaling by Plaid instead of Gabor.

But luminance contrast noise has been added to interfere with the processing. Under luminance noise, the two-stage processing (Adelson and Movshon, 1982) of Plaid may be interrupted. The components in Plaid may not be decomposed. Instead, it seems that the cross-oriented gratings are now viewed as irregular pattern as the intersections between the two gratings are blurred. Spatial frequency and motion direction that provide time-varying cues are no longer available. So, it become difficult for observer to discriminate the motion direction since there are uncertainty caused by luminance contrast noise.

Unlike Plaid, Gabor seems to be less vulnerable to the luminance noise effect. Observers could still see the relatively blurred gratings tilted to a specific orientation under luminance contrast noise. Neurons which are selective to that particular orientation and location in V1 are elicited to fire action potential and send signals representing Gabor. As the tuning of V1 neurons covers a much smaller and specific receptive field, the inhibition of other active neural firing may be less capable of interfere with the signals. Therefore, observers can perceive a clearer stimulus with less noise interference. However, there are more groups of orientation-selective neurons being activated by grating patterns like Plaid. Otherwise saying, there may be more groups of neurons being activated to fire due to the similar tuning. These neural firings are more like the inhibitory signals, rather than additional excitatory one (Richardson & Swarbrick, 2010). The signals of the Plaid patch are now interfered by other disorderly inhibitory neural firings, which eventually weaken the visibility of the moving Plaid patch. As a result, observers cannot see and discriminate the motion direction clearly. Under such circumstances, our metacognitive system seems to respond more to and trust the less noisy signal, which is the Gabor stimulus, more than the noisier signal, which is the Plaid stimulus. Therefore, we seem to be more confident of our motion direction judgement on Gabor patches, rather than Plaid patches.

Apart from the investigation on the relationship between objective perceptual performance and subjective awareness, we looked for whether there is an effect of one's autistic traits tendency on their subjective awareness about their own judgement in the current study. Autistic individuals have been characterized with atypical visual perception, that is enhancement to see details, impairment to integrate information and inability to self-monitor their performance (Dakin & Frith, 2005; Annaz, 2010; Pellicano & Burr, 2012, Grainger, Williams & Lind, 2014; Manning, Tibber & Dakin, 2017).

However, in experiment 1 of the current study, the results suggest that participants with higher autistic trait tendency seems to be less biased to choose Plaid as the more confident choice. They seem to be able to discriminate their objective perceptual performance quite well, which counters to the previous findings that metacognition is relatively impaired in autistic individuals. A possible explanation would be the atypical visual processing actually enhances their visual acuity to simple visual stimuli. Components in or near the V1 or MT were found to be more responsive to a stimulus's simple features such as lines and spatial frequency (Milne, 2009). They are less affected by the ambiguity of motion direction signals as it depends more on these small details. Moreover, several findings have found that autistic individuals show superior performance in direction integration and discrimination tasks under noisy condition (Manning, Tibber & Dakin, 2017). Their higher tolerance of noise allows them to discriminate the direction better and hence, have higher confidence about their judgement. This may be a possible explanation of their less biased performance in experiment 1. Yet, the same effect was not found in experiment 2. Although this is a very interesting findings, the underlying mechanism is still unknown as there has not been many research on studying the low-level visual processing in autistic population that can support these findings. Also, all participants are not diagnosed with Autism. Only their autistic traits were measured to investigate the possible association. However, this could be an indicator for future research direction on the motion perception and metacognition among autistic individuals.

Conclusion

In conclusion, a difference was found in the relationship between the objective performance and subjective awareness for forced-choice motion direction discrimination between the Gabor and Plaid patch in the current study. The results have revealed that normal observers indeed possess certain degree of confidence bias toward Plaid motion patch when coherence, and toward Gabor motion patch when luminance contrast were manipulated. Whether this bias or tendency can be demonstrated in other low-level stimuli or high-level stimuli is subject to further studies in the future. Moreover, an unexpected relationship between autistic trait tendency and such confidence bias was found in the current study. This provides insights to further study the higher-order cognitive process that is the self-awareness of perceptual judgment among the autistic population.

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