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Self-reference modulates the perception of visual apparent motion

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Abstract

Visual apparent motion is a perceptual illusion where sequentially presented static stimuli containing no physically continuous motion are perceived as moving. In the current study, we examined whether and how self-reference, as a typical high-level information processing, could modulate perceptual categorization of the apparent motion in Ternus display, even when self-reference is task-irrelevant. Two frames were consecutively presented, with the first frame consisting of two identical stimuli (e.g., two rectangles) on the leftmost and the middle positions and the second frame consisting of two stimuli on the middle and the rightmost positions. Depending on the inter-stimulus interval (ISI) between the two frames, the display could be perceived as showing Element Motion (EM), with the peripheral stimulus moving from one side to the other while the middle stimulus remains stationary or flashes briefly at the middle position, or Group Motion (GM), with both stimuli appearing to move as a whole. Participants were tested in this configuration and then learned to associate different labels (Self, Friend, Stranger) with geometric shapes (Circle, Rectangle, Triangle). They were tested again in the new configuration. Results showed that after association (vs. before association), participants were more likely to perceive the Ternus display of self-associated shapes as GM, but this effect did not appear for friend-associated or stranger-associated shapes. Self-referential processing spatially "glues" the two stimuli in a frame with the concept of "Self," leading to a more dominant percept of GM.

Keywords Self-reference · Apparent motion · Ternus display

Introduction

Visual apparent motion is a perceptual illusion where sequentially presented static images containing no physically continuous motion are perceived as moving (Wertheimer, 1912). Among the kaleidoscope of apparent motions, Ternus display is one powerful paradigm in which two identical stimuli (e.g., two rectangles) flash twice with various sub-second inter-stimulus intervals (ISIs) between the two visual frames (He & Ooi, 1999; Ma-Wyatt et al., 2005; Pantle & Picciano, 1976; Petersik & Rice, 2006; Ternus, 1926). As shown in Fig. 1A, the two stimuli in the first frame are presented at the leftmost and the middle positions (Locations 1 and 2), followed by the two stimuli in the second frame presented at the middle and the rightmost positions (Locations 2 and 3). When the ISI between the two frames is short enough (e.g., less than 50 ms), the majority of observers would perceive Element Motion (EM) where the leftmost stimulus in the first frame appears to move to the rightmost position in the second frame while the middle stimulus (Location 2) remains stationary or flashing briefly. In this case, temporal grouping, i.e., grouping different visual elements as a whole according to temporal proximity, is dominant, such that the middle (overlapping) stimuli between the two frames are perceived as one stationary (flashing) stimulus while the two stimuli within a frame are not perceived as a group. However, with a long enough ISI (e.g., more than 260 ms), participants are more likely to perceive Group Motion (GM) where both stimuli appear to move from one visual frame to the other frame as a group (Fig. 1B). In this case, spatial grouping, i.e., grouping different visual elements in a frame as a whole according to spatial proximity, is dominant over temporal grouping between elements of different frames. Thus, temporal and spatial grouping processes are in competition

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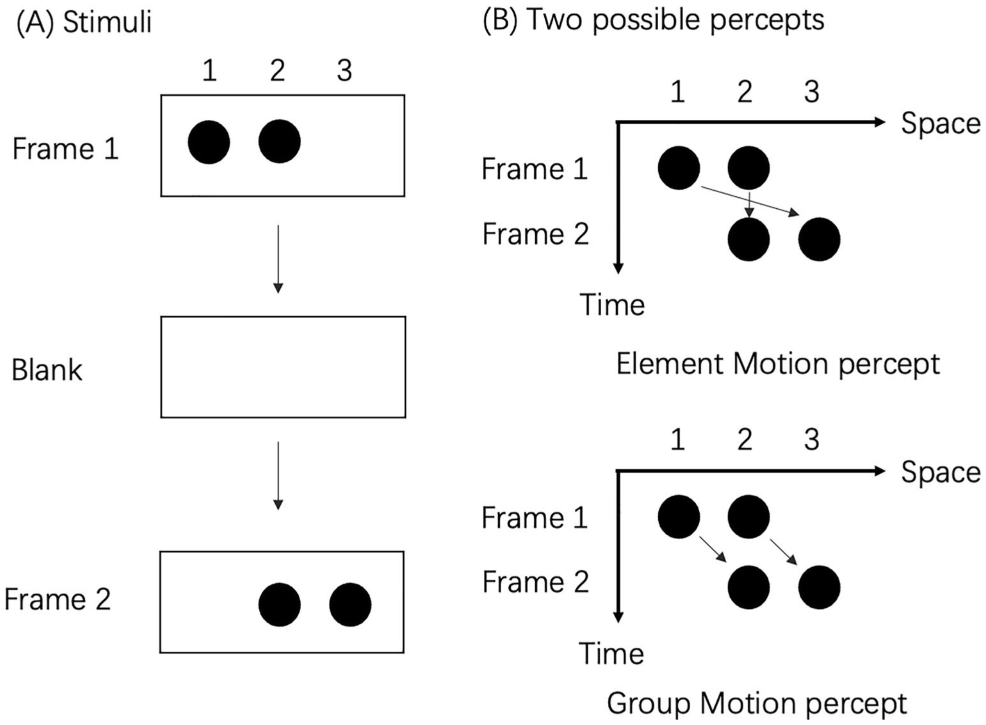

Fig. 1 Ternus apparent motion paradigm and exemplar stimuli. **A** The apparent motion stimuli consist of two frames presented sequentially, separated by an inter-stimulus interval (ISI). **B** Two possible percepts of Ternus display. "Element Motion" percept: The middle stimulus is perceived as staying or flashing briefly at the same location ("2") across the two frames, while the outer stimulus is perceived as moving from one location to the other (from "1" to "3"). "Group Motion" percept: The two stimuli are perceived as moving together in the manner of a coherent lateral displacement. The direction of motion is rightward in the above example. The leftward direction is also viable

with each other in different ISIs, resulting in either a dominant EM or a dominant GM percept (He & Ooi, 1999; Petersik & Rice, 2006). Investigating visual apparent motion could help us understand principles of perceptual organization as well as the *correspondence problem* in which how our visual system establishes correspondence between objects and maintains the identity of the object over time (see Dawson, 1991; Stepper et al., 2020).

Perception of visual apparent motion could be modulated by both bottom-up, stimuli-driven factors and top-down, semantics-driven factors. It has been shown that perception of motion is modulated by spatio-temporal information including inter-stimulus interval, frame duration (see He & Ooi, 1999; Petersik & Pantle, 1979) and by feature information including the similarity in size or luminance between elements of the Ternus display (see Hein & Moore, 2012, 2014; Hein & Schutz, 2019; Kramer & Yantis, 1997). For example, when the overlapping (middle) stimuli between the two frames share the same luminance information, they are more likely to be perceived as stationary, leading to EM percept (Hein & Moore, 2012).

Importantly for the present purpose, top-down or high-level information processing such as semantic context has also been shown to modulate the perception of Ternus Display (Chen & Zhou, 2011; Yu, 2000). Chen and Zhou (2011) embedded Chinese characters in the two circles in each frame. They found that when the two characters in each frame formed a meaningful compound word, the participants were more likely to perceive them as GM than when the two characters form a meaningless nonword. The authors argued that since compound words are represented as wholes in the lexicon (Zhou et al., 1999), the activation of these representations would serve as "glue" to bind the circular stimuli in a frame, leading to more reporting of GM. This top-down semantic guidance can derive not only from lexical semantics but also from general world knowledge (Hsu et al., 2015; Yu, 2000). For example, Yu (2000) presented observers with a cartoon of a walking person's feet (two circles) or of the wheels of a car before a Ternus display composed of circles. Observers reported more EM after seeing a walking person's feet than after seeing the wheels of a car, suggesting that the observers' world knowledge of human walking with one foot remaining static and the other moving, and the knowledge of wheels of a car moving as one unit affected the observers' perception of the Ternus display. Recently, Stepper and colleagues (2020) manipulated participants' experience with the objects used in the Ternus display such that these objects were encounted previously either as being spatiotemporally grouped together (common object history) or being spatiotemporally independent from each other (separate object history). They found that the objects with common object history were more likely to be pecieved as GM in the Ternus display than objects with a separate object history.

"Self" is related to all sorts of information an individual holds. Self-referential processing, which can serve as a top-down and semantics-driven factor, has been shown to affect response inhibition (Golubickis et al., 2021), working memory (Yin et al., 2021; Yin et al., 2019), attention (Macrae et al., 2018), and visual perception (Humphreys & Sui, 2015; Macrae et al., 2017; Sui & Humphreys, 2015a) such as prioritizing access to visual awareness (Macrae et al., 2017). In Macrae et al. (2017), for example, participants first performed an associative learning task in which they were required to associate specific geometric shapes (i.e., circle, triangle, square) with three labels: self, a best friend, and an unfamiliar stranger (Sui et al., 2012). Then these shapes presented to one eye were rendered invisible by continuous flash suppression (CFS) at the other eye and the participants were asked to report the presence (or absence) of a specified shape according to its corresponding label as soon as a stimulus became visible (due to the weakening of CFS). Results showed that compared with geometric shapes referenced to either a friend or a stranger, shapes previously associated with the self were more easily to become visible and be reported.

The empirical question for the present study is whether the association with self would affect the processing of apparent motion in the Ternus display. Understanding this question will shed light on how the visual system solves the motion correspondence problem as well as the pervasiveness of self in human life. To this end, we implemented a 3 (Association: Self vs. Friend vs. Stranger) × 2 (Test Sequence: pre-test vs. post-test) within-subject design in which before and after participants learned to associate specific shapes (i.e., circle, triangle, or rectangle) with self, a friend, or a stranger, they were tested with the Ternus stimuli composed of the shapes. If the association with self serves as a top-down factor in spatially grouping the two stimuli in a frame, we would expect to observe more GM in the post-test (i.e., after the associative learning) than in the pre-test, and this "sequence" effect should be larger for the self-related stimuli than for the friend- or stranger-related stimuli. However, if the association with self serves as a top-down factor in temporally grouping the two middle stimuli between the two frames, this interaction between association type and test sequence should be observed on EM, rather than on GM.

Methods

Participants

Forty-six undergraduate and graduate students took part in the study. The sample size was determined by a priori power analysis using G*power 3.1 (Faul et al., 2007), with power = 0.95, $\alpha = 0.05$, and a medium effect size to detect an interaction in the 3 (Association: Self vs. Friend vs. Stranger) × 2 (Test Sequence: pre-test vs. post-test) within-subjects design. Addressing the lexical semantic impact on the perception of a Ternus display, Chen and Zhou (2011) obtained an effect size of 0.436. Here we assumed a more conservtive effect size of 0.2 to examine the potential interaction between assocation type and test sequence. This calculation showed that 43 participants are needed. In our sample, eight participants failed to meet our criteria for data quality and were therefore excluded (see *Data analyses* below). The remaining 38 participants, including 16 males, had an age range of 18–30 years (mean age = 22.18 years, SD = 2.80 years). All participants were naïve to the research question. They received monetary compensation for their participation. Informed consent was obtained from participants prior to the commencement of the experiment, and the protocol was reviewed and approved by the Committee for Protecting Human and Animal Subjects, School of Psychological and Cognitive Sciences, Peking University.

Procedure and materials

Participants were tested individually. After a participant came to the lab, he/she was first given instructions concerning the tasks and procedures of the study. He/she performed the Ternus apparent motion task for the pre-test. Then he/she was instructed to form associations between particular geometric shapes (Triangle, Rectangle, or Circle) and social labels (him/herself, a good friend, or an unfamiliar stranger), respectively, with the shape-label associations counter-balanced across participants. After the associative learning, the participant performed the same Ternus apparent motion task again. The entire experiment took approximately 40 min to complete.

Visual stimuli were presented on a 21-in. SONY CRT monitor (refresh rate: 100 Hz, resolution: 1,024 × 768) connected to a DELL computer. Stimulus presentation and participant's response recording were controlled by Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) with MATLAB. The participant viewed the monitor from a distance of approximately 60 cm in a dimly lit and quiet room, and the head position was stabilized with a chinrest.

The Ternus apparent motion task

The Ternus apparent motion task started with the presentation of a central fixation cross for 300–500 ms. Then each of the two visual frames was presented for 50 ms, with one of the seven levels of inter-stimulus interval (ISI; 50, 80, 110, 140, 170, 200, or 230 ms) between the two frames. Each frame was composed of the same two black (RGB: [0, 0, 0]) shapes (Triangle, Rectangle, or Circle, 1.5° × 1.5°) on a gray (RGB: [127,127,127]) background. One shape was presented at the center of the screen, and the other shape was presented 3.6° left or right of the center of the screen in the first frame or 3.6°

right or left of the center in the second frame. Following the stimulus presentation, a question mark appeared in the center of the screen to instruct the participant to make a forced choice by pressing a keyboard button (i.e., J or K, counter-balanced across participants) indicating whether they had perceived EM or GM in the current trial. Once a decision had been made, after 300–500 ms, the next trial began. There were ten trials for each combination of label and ISI level, giving 210 trials in total in either the pre-test or the post-test. Trials of different conditions were randomly mixed and presented.

Before the formal experiment, participants completed a 40-trial practice block with only two levels of ISI (50 ms, 260 ms). For the ISI of 50 ms, the display was expected to be perceived as EM; for the ISI of 260 ms, the display was expected to be perceived as GM. Feedback was displayed on the screen if the participant made an incorrect response. After practice, the participant moved on to the formal experiment unless his/her response accuracy was below 90%; in the latter case he/she would repeat the practice block.

The shape-label association tasks

The procedural scheme of shape-label association tasks was adapted from Liu and Sui (2016). In this task, a participant was prompted to establish the one-to-one association between the three personal labels (Self, Friend, Stranger) and three geometric shapes (Circle, Rectangle, Triangle) through associative learning. The shape-label associations were counter-balanced with a Latin square design across participants, and the assignment of participants to the associations was still balanced after the eight participants were eliminated from data analysis. Participants were first told to remember the shape-label associations and then asked to complete a learning task and a matching task to ensure that they had learned the associations well.

In the learning task, each trial began with the presentation of a central fixation cross for 800 ms. Then one shape (triangle, rectangle, or circle, 1.5° × 1.5°, the same as in the Ternus apparent motion task) and three labels in Chinese characters referring to “myself,” “good friend,” and “stranger” were presented simultaneously above and below the central fixation, respectively. The center of the bottom edge of the shape was 3.2° away from the center of the screen; the three labels appeared 3.2° below the center in random sequence. The participant was asked to judge as quickly as possible (within 2,000 ms, the longest possible duration of stimulus presentation) which of the three labels matched the given shape by pressing one of the three buttons on the keyboard (i.e., J, K, and L) using the index, middle, and ring fingers of the right hand. Feedback (i.e., correct, incorrect response, or timeout) was given on the screen for 500 ms once the participant had made his/her judgment, and the overall accuracy was displayed at the end of the task. There were 54 trials in this task, with each shape presented 18 times. This task was terminated when the overall accuracy was above 90%, indicating that the association had been learned; otherwise, participants were to repeat this task.

For the matching task, each trial began with the presentation of a central fixation cross for 800 ms, followed by the pairing of a shape and a label above and below the center of the screen, respectively, for 100 ms. After stimulus presentation, a question mark was presented on the screen and the participant was asked to report as quickly as possible (within 2,000 ms) whether the shape-label pairing was correct or not, based on the associations learned previously, by pressing one of the two buttons on the keyboard (i.e., N and M) using the index or middle finger of the right hand (Sui et al., 2012). Feedback (i.e., correct, incorrect response, or timeout) was given on the screen for 500 ms after the response. There were 135 trials in this task, with each shape presented 45 times.

Data analyses

For both the shape-label association learning task and the shape-label association matching task, we conducted one-way repeated-measures analyses of variance (ANOVAs) for accuracy and reaction time (RT). Trials more than 2.5 standard deviations above or below each participant's mean of each cell (learning task: 2.10% of all the trials; matching task: 1.29% of all the trials) were removed from the RT analysis. For the shape-label association matching task, we focused on the match trials (i.e., trials with the associative meanings of the shape and the label being matched; see Sui et al., 2013).

For the apparent motion task (including the pre-test and the post-test), the percentage of GM reports was computed for each level of ISI. The seven data points, one for each ISI, were fitted into the psychometric curve using a logistic function (Treutwein & Strasburger, 1999) for each participant (see Fig. 2 for an example). The PSE (point of subjective equality) was calculated by estimating the time point on the fitted curve at which GM and EM would be reported with equal probability. Note that the lower the PSE was, the more likely the display was to be perceived as GM. Participants with PSE 2 steps (60 ms) below or over the expected PSE (140 ms, estimated from previous studies on Ternus apparent motion) in the pretest were excluded from all the data analyses. These participants had a strong perceptual bias towards either EM or GM. Then, a 3 (Label: Self, Friend, Stranger) × 2 (Test Sequence: pre-test or post-test) repeated-measures analysis of variance (ANOVA) was conducted. Eight participants were excluded because their PSE was two steps (60 ms) below or over the expected PSE (140 ms) in the pretest.

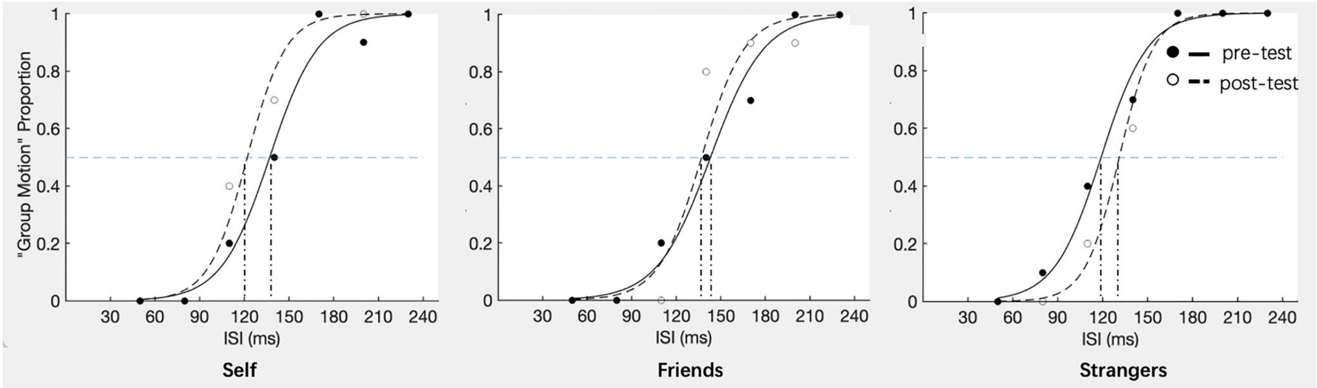

Fig. 2 Psychophysical curves and points of subjective equality (PSEs) of a typical participant: PSE as a function of label (Self, Friend, Stranger) and test sequence (pre-test, post-test). Each dot represents an inter-stimulus interval (ISI; 50, 80, 110, 140, 170, 200, 230 ms). The filled dots and lines denote the pre-test, and the hollow dots and dashed lines denote the post-test

Results

The shape-label association tasks

For the association learning task, ANOVAs revealed a null effect of label (association) in accuracy, $F(2,74) = .23$, $p = .80$, $\eta^2_p = .01$, but a significant effect in RTs, $F(2,74) = 9.80$, $p < .001$, $\eta^2_p = .21$. Bonferroni-corrected post hoc comparisons showed that RTs to the shape-self association (1,010 ± 143 ms) and to the shape-stranger association (1,034 ± 141 ms) were both significantly faster than RTs to the shape-friend association (1,117 ± 155 ms): $t(37) = -4.66$, $p < .001$, Cohen's $d = -.97$; $t(37) = -3.30$, $p = .006$, Cohen's $d = -.75$. No significant difference was found between the two former associations: $t\ (37) = -.88$, $p = 1.00$, Cohen's $d = .22$.

For the association matching task, ANOVAs did not find a significant effect in accuracy, $F(2,74) = 1.87$, $p = .16$, $\eta^2_p = .05$, but an effect in RTs, $F(2,74) = 12.64$, $p < .001$, $\eta^2_p = .26$. Bonferroni-corrected post hoc comparisons showed that this effect was driven by faster RTs to the shape-self trials (617 ± 162 ms), relative to RTs to the shape-friend trials (694 ± 184 ms, $t\ (37) = -3.76$, $p = .002$, Cohen's $d = .86$) and RTs to the shape-stranger trials (715 ± 173, $t\ (37) = -5.13$, $p < .001$, Cohen's $d = 1.10$). The latter two types of trials did not differ from each other, $t\ (37) = .97$, $p = 1.00$, Cohen's $d = .24$.

Overall, the shape-label association tasks demonstrated the beneficial effects of self referential processing in the shape-label association tasks, in line with previous studies (e.g., Sui et al., 2012). The high response accuracy in all the conditions of the tasks indicated that the participants had learned the associations between social labels and shapes well.

Apparent motion task

A 3 (Label: Self, Friend, Stranger) × 2 (Test Sequence: pre-test or post-test) repeated-measures analysis of variance (ANOVA) on PSE revealed no main effect of label, $F(2,74) = 2.44$, $p = .09$, $\eta^2_p = .06$, or test sequence, $F(1,36) = 3.80$, $p = .06$, $\eta^2_p = .09$. However, the interaction between the two factors was significant, $F(2,74) = 4.80$, $p = .01$, $\eta^2_p = .12$. Further simple effects analysis showed that in the Self condition, PSE in the post-test (124 ± 18 ms) was lower than in the pre-test (134 ± 20 ms), $t(37) = -3.00$, $p = .005$, Cohen's $d = -.50$, but this difference was not found in the Friend (pre:125 ± 21 ms, post:130 ± 20 ms; $t(37) = -1.53$, $p = .14$, Cohen's $d = -.25$) or the Stranger (pre:133 ± 21 ms, post: 133 ± 24 ms; $t(37) = -.22$, $p = .82$, Cohen's $d = -.03$) conditions (Fig. 3). Out of the 38 participants, 29 showed a PSE decrease after associating the visual shapes with "Self", but only 21 and 19 showed PSE decrease after associating the shapes with "Friends" and "Strangers," respectively. An additional analysis testing the linear trend of the PSE difference (pre-test minus post-test) found a significant effect of Label, $F(1,114) = 4.28$, $p = .04$, $\eta^2_p = .04$, indicating that the label (association) effect

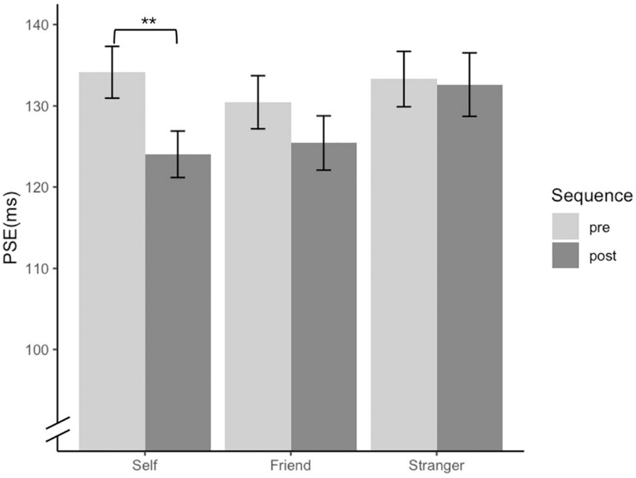

Fig. 3 Results of the apparent motion task: points of subjective equality (PSEs) as a function of label and test sequence. Each dot with the bar represents an individual participant's PSE. Asterisks denote statistically significant differences between pairs of conditions (**: $p < 0.01$). Error bars denote standard errors of the means across participants

decreased over label conditions in a linear trend (largest in Self, medium in Friend, weakest in Stranger).

Discussion

Replicating previous studies of self-reference (e.g., Humphreys & Sui, 2015; Sui et al., 2012) , we observed beneficial effects (e.g., faster RTs) of self-association in shape-label association tasks. Importantly, consistent with previous studies on the top-down semantic impacts upon visual apparent motion (Chen & Zhou, 2011; Hsu et al., 2015; Yu, 2000), we showed that self-referential processing can also modulate the perception of a Ternus display. Participants had enhanced GM perception for self-associated shapes but not friend- or stranger-associated shapes in the post-test, relative to the pre-test, in the apparent motion categorization task.

There could be two explanations for the observed perceptual bias. The first one is that self-referential processing facilitates spatial perceptual integration between the two stimuli within a frame, such that the two stimuli within a frame are perceived as a group, appearing to move from one frame to the other. This observation is consistent with the argument that all the information related to self form a network and self-reference acts as an integrative hub for information processing, helping bind together different information, in a way that self-associated shapes are integrated into a single representation as "self Gestalt" (see Sui & Humphreys, 2015a), and leading to more reports of GM in the current study. Indeed, for a participant, there is only one "self" in the world but there are many "friends" and "strangers," which could increase uncertainty and make it harder for the participant to integrate the visual stimuli with "friends" and "strangers."

The above explanation is further supported by recent studies demonstrating that self-reference facilitates spatial grouping (e..g, Scheller & Sui, 2022; Sui & Humphreys, 2015b; Sui et al., 2015). For example, Sui and colleagues (2015b) investigated redundancy gain in a shape-label matching task. Participants first learned to associate two different shapes with either self or a best friend. Then they were presented with either a single shape or two shapes and were asked to judge whether the single shape or one of the shape pairs matches a given label. The authors found that compared with the single shape condition, responses to the shape pairs were faster for both the Self and the Friend conditions (i.e., a redundancy gain effect). Importantly, this redundancy gain was larger for the self-related stimuli than for the friend-related stimuli, reflecting the function of "self Gestalt."

Another possible but less supported explanation for the current finding argues for a role of self-referential processing in temporal resolution, rather than in spatial grouping. This account assumes that stimuli associated with self are more easily differentiated in time. When participants are presented with Ternus stimuli, the spatially overlapping stimuli in the two frames, i.e., the stimuli presented at the center of the screen in the first and second frames, normally perceived as being stationary or flashing, are more easily physically segregated if the two stimuli are associated with Self than with Friend or Stranger. This would lead to more spatial grouping of stimuli within a frame and more reports of GM for the self-associated trials than for the friend- or stranger-associated trials. Indeed, a recent study showed that training participants' interval discrimination ability by asking them to judge which of the two time intervals marked by two sound beeps is longer improves the participants' ability to separate the two visual frames in the Ternus display, leading to more reports of GM after training (Chen & Zhou, 2014). Another study using the temporal order judgment task also demonstrates that self-reference enhances temporal resolution to some degree (Constable et al., 2019). Constable and colleagues (2019) asked participants to report which object (the picture of the mug that belonged to the participant, or the one that belonged to the experimenter) appeared first in a temporal order judgment task while the ISI between the two objects was varied across trials. In a series of experiments, the authors found that participants were more likely to report their own mugs than the experimenter's mug across all ISIs. It seems that self-reference facilitates temporal processing.

Although the data in the current study do not allow us to choose between the two explanations, the current findings do extend our understanding of the relationship between visual perception and high-level information processing. In Chen and Zhou (2011), the compound words were embedded in the Ternus stimuli (i.e., circles), having no direct relation to the stimuli, and hence were completely task-irrelevant. In the current study, as in Yu (2000) and Stepper et al. (2020), the high-level information (self or the history of experience) was directly associated with the visual stimuli, even though it was still task-irrelevant. Nevertheless, the processing of all this high-level information gives rise to a modulatory effect on the correspondence problem probed by the Ternus display, demonstrating a general top-down impact on perceptual processing.

In the domain of self research, a large body of previous research has shown that visual perception is biased towards preferentially processing self-related information compared with information related to social identities or properties (e.g., Macrae et al., 2017; Sui & Humphreys, 2015b). However, these studies commonly used tasks that directly tap into self-referential processing, such as asking participants to associate shapes with the Self (vs. Friend vs. Stranger) label and then report the presence or absence of a specified shape based on a given label (Macrae et al., 2017). In the current study, although the participants were also asked to associate stimuli with different labels, the task they conducted to test the self-referential effect was self-irrelevant, providing novel evidence for the pervasiveness of Self in human life.

In conclusion, by associating geometric stimuli with different social labels, the present study demonstrated the effect of self-referential processing on visual apparent motion. Beyond low-level information such as spatio-temporal information, higher level information, including self-reference and other semantic properties, is utilized as a top-down constraint to guide the parsing of one form of apparent motion over the other.

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Author contributions All authors developed the study concept and contributed to the study design. Data collection and analysis were performed by JH. Manuscript preparation was carried out by JH, LC and XZ. All authors approved the manuscript for submission.

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