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Kanizsa-like illusory figures shorten simple manual reaction time

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Abstract

The present study provides evidence that simple manual reaction time (RT) can be shortened by task irrelevant Kanizsa-like illusory figures emerging as completed perceptual units in the observer's visual system. This type of behavioral effect allows to evaluate the role of a perceived figure constituted by brightness enhancement, illusory contours and depth stratification by maintaining constant retinal size and average luminance of the inducers in modulating RT. Using two different versions of the inducers, with the same retinal size and different average luminance, we found that simple RT was shortened by the presence vs absence of the figure with significant faster response in the illusory condition than no-illusory condition in the two versions of the inducers. These results confirm previous works that provide evidence on the relationship between simple RT and perceptual/phenomenal features.

Keywords

Kanizsa-like illusory figures, illusion, simple manual reaction time, lateral occipital complex, conscious vision, phenomenology

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Introduction

It is well known that simple manual reaction time (RT) is modulated by stimulus intensity (Piéron, 1914; Wundt, 1874; see also Pins & Bonnet, 1996, 2000). Sperandio et al. (2009) found that simple

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RT is also modulated by stimuli that have the same luminous flux and the same retinal size but differ in terms of perceived size. In this study luminance was adjusted to equate the luminous flux for stimuli of different size and RT to a stimulus perceived bigger than another resulted faster even if the two stimuli were equal in terms of luminous flux and retinal size. In other words, authors found that simple RT reflects scaling constancy. They also found (Sperandio et al., 2010) that simple RT can be modulated by visual illusions leading to a misperception of size. Specifically, the authors tested the Ebbinghaus-Titchener illusion, based on size contrast mechanism (Gregory, 2005), and Ponzo illusion based on constancy scaling mechanism. In the Ebbinghaus-Titchener illusion the finding was that the circle perceived as bigger was responded to faster than that perceived as smaller. Therefore, simple manual RT reflects perceived rather than retinal size (e.g., constancy scaling and size contrast).

These results are interesting because a physical index of a simple motor behavior, as the simple manual reaction to the detection of the stimulus onset, can reflect not only the physical parameters of the stimulus but also its perceptual, i.e., phenomenal features. Starting from the dissociation between "vision for perception" system (ventral stream, projecting from primary visual cortex to inferior temporal cortex), and "vision for action" system (dorsal stream, projecting from primary visual cortex to superior parietal cortex and intraparietal sulcus), Sperandio et al. (2010) argued that simple RT should be controlled by the dorsal stream and should not reflect perceptual mechanisms such as constancy scaling and size contrast. Indeed, these two systems subserve different kinds of visual information processing: the ventral stream is mainly involved in objects recognition and visual features analysis while the dorsal stream is mainly involved in visually guided actions (Milner & Goodale, 2008). On the basis of their findings, Sperandio et al. (2009), instead, hypothesized that a simple manual reaction is more likely subserved by the ventral "vision for perception" stream rather than by dorsal stream "vision for action". It is also possible that RT modulation could be related to perceived distance rather than constancy scaling and size contrast mechanisms, indeed object-observer relationship is essential in the "vision for action" system. Since perceived size, subserved by "vision for perception" ventral stream, and perceived distance, subserved by "vision for action" dorsal stream, are closely related, further experiments should be conducted in order to disambiguate the contribution of these two phenomena and their respective neural correlates.

The focus of the present work was to provide evidence of a simple RT shortening by two kinds of Kanizsa-like illusory figures derived from those described, in detail, by Kanizsa (1955) with four phenomenal properties as the following:

> *(I) In a particular region of the visual field, transformations of brightness and/or mode-of-appearance occur that phenomenally distinguish that region from contiguous regions, even though stimulation from all regions is the same. (II) Phenomenally, the region undergoes a displacement in the third dimension, and is seen as situated in front of or over the rest of the field. (III) The region possesses a more or less clear margin, which separates it from the contiguous areas, and also crosses regions where there is no quantitative or qualitative change in the stimulation. (IV) When conditions are optimal, all above interconnected phenomenal aspects (chromatic transformation, displacement in the third dimension, presence of the margin) are compelling and acquire a modal character that distinguishes them from the perception of merely virtual lines.*

Specifically, we tested two experimental conditions in which whether the inducers were rotated leading to the formation of the figure or not, the physical stimulation was the same both in terms of average luminance and retinal size of the single elements, therefore it was possible to evaluate only the role of the phenomenal illusory figure emerging from these specific stimulation configurations in shortening simple RT. The two kinds of Kanizsa-like figures used in the present study refer to two different types of inducers (see the Methods). The compelling perception of the illusory figure is the result of many perceptual processes that allow amodal margins of the illusory figure to become perceptually modal and the tendency of amodally completing the inducers "behind", because partially

"occluded" by the illusory figure, and boosting the illusory figure formation itself. The real portions of the margins in the inducers, requiring each other as is thought in the Gestalt theory, trigger the modal completion of the gap where no physical discontinuity exists but the phenomenal margin is extended and completed effortlessly to the point that it becomes compellingly real.

Several studies demonstrated how Kanizsa-like illusory figures were processed by the interplay between V1 and V2 visual areas and lateral occipital complex (L.O.C.) (Murray & Hermann, 2013, Poscoliero & Girelli, 2018, see also Seghier & Vuilleumier, 2006). Particularly, when the inducers leading to the illusion are arranged to create the illusory figure, L.O.C. activity is higher than when the inducers are rotated outward not to form the illusory figure. Since L.O.C. is located on the lateral bank of the fusiform gyrus projecting ventrally and dorsally (Grill-Spector & Kanwisher, 2001), before the distinction between ventral and dorsal visual stream (Milner & Goodale, 1995), it is possible to hypothesize that the higher neural activity in L.O.C., when a Kanizsa's illusory figure is perceived, might be a strong signal to pass forward to the dorsal stream for the "vision for action" cognitive operation to take place and consequently for speeding up simple RT. In a previous study, Poscoliero and Girelli (2018), although in a Yes/No paradigm, showed that the phenomenal illusory contour effect (IC-effect) was strongly represented by an early ERP component called Nc1 which has a latency of 230–280 ms post-stimulus and it is thought to originate from extrastriate visual areas, possibly resembling the LOC complex. It is therefore very likely that the LOC complex might provide a candidate area to boost the simple reaction time in humans when a meaningful phenomenal unit is formed and powerfully emerges from the background.

Experiment

In this experiment a simple manual RT paradigm was used in order to test a possible shortening by Kanizsa-like illusory figures. Shortening as opposed to lengthening of simple manual RT was expected because the illusory figure formation, although implied a depth stratification in order to take place, led to an immediate meaningful interpretation of the visual scene. Therefore it should be reacted to faster with respect to a simpler but meaningless two dimensional spatial arrangement of the very same visual elements randomly arranged that did not lead to a meaningful figure. Although the discrimination of the figure per se was not a task requirement. Thus a speeding up of simple RT was expected when participants reacted to the illusory figures than to the no-illusory figures. Two different versions of inducers, with different average luminance, the same retinal size but different support ratio, were used in order to disambiguate between physical and perceptual effect on simple RT. The support ratio, among others, is a physical feature which has a strong impact onto the perception of illusory figures, although some authors did not consider the support ratio as the relevant difference between Pacmen and Line Endings (see Maertens & Shapley, 2008) which were the two types of stimuli used in the present study (see Methods). Indeed, Dresp (1992) and Shipley and Kellman (1992) found that the brightness enhancement of the illusory figure increases linearly with the support ratio. The two types of inducers used in this experiment had two support ratios which were one almost six times the other. Such large difference provided two quite different physical stimulations which were thought to stress the difference between presence/absence of the illusory figures which remained the main experimental manipulation of the study.

Methods

Participants

Sixteen right-handed participants (8 females) (mean age: 26.1; S.D: 4.2) took part in the experiment. All participants had normal or correct-to-normal vision and no history of neurological or psychiatric

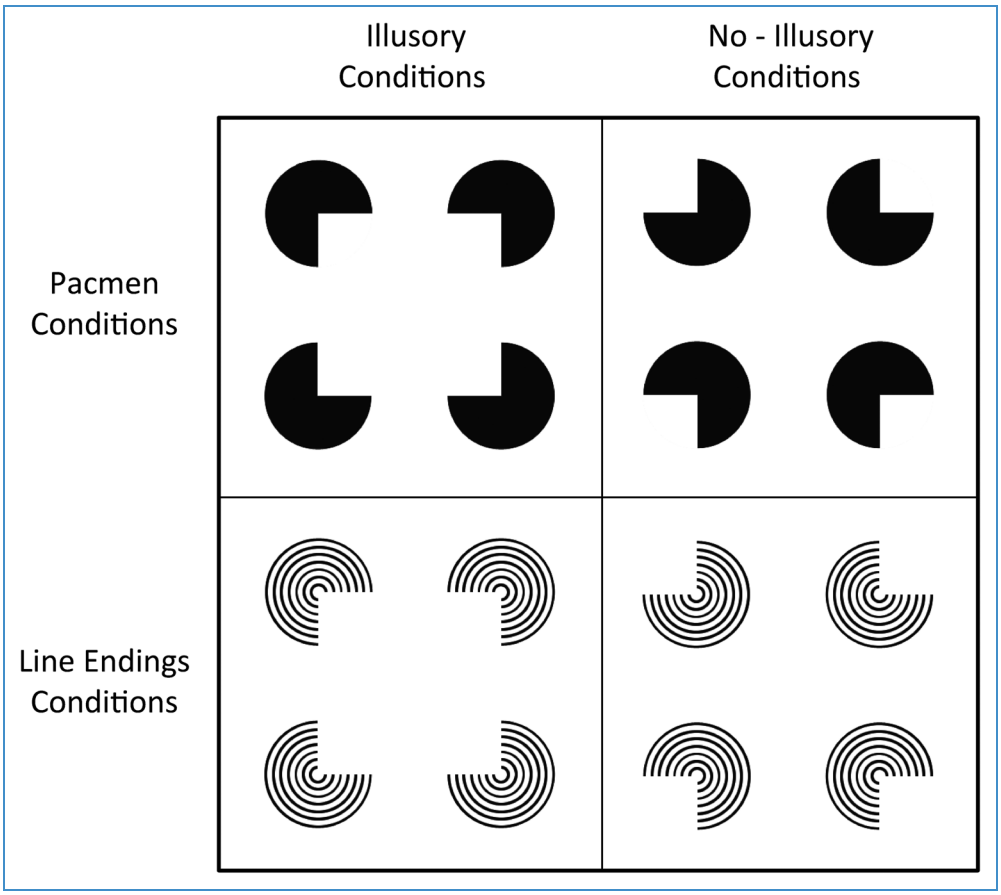

Figure 1. The four stimuli used in the experiment. Pacmen inducers (top row) consisted of an illusory figure made of black solid inducers: illusory condition (left column), no-illusory condition (right column). Line ending inducers (bottom row) consisted of an alternative version in which the inducers were made by seven concentric circles: illusory condition (left column), no-illusory condition (right column). See the description of stimuli in the method section for details.

diseases. They were paid for participating in the experiment and gave written informed consent in accordance with the Declaration of Helsinki.

Stimuli

Two versions of Kanizsa-like illusory figure were used: an illusory square composed by four Pacmen inducers (Pacmen square) and an illusory square composed by four line endings inducers (line endings square) (Figure 1). Evidently Pacmen inducers (solid black) had a lower average luminance than Line Endings inducers (thin black lines) due to the extended solid black area.

In the Pacmen square each of the four black inducers was composed by a circular sector of 270° subtending a visual angle of 2°. They could be arranged to form the illusory figure or rotated by 180° not to form the illusory figure. The four inducers were arranged so that, when forming the illusory figure, the sides of the illusory square subtended an angle of 2.7°. The support ratio (i.e., the ratio of the length of the real inducing figure relative to the total length of the illusory figure defined by

Shipley & Kellman (1992) as twice the radius of the inducers divided by twice the radius plus the gap) had a value of 0.75. This high value of support ratio was chosen in order to increase the illusory effect.

In the Line Endings square the four black inducers were replaced by seven partial concentric equally spaced circles each having a thickness of 0.05° of visual angle. The visual angle subtended by the biggest of the seven circles was equal to that of the black inducers (2°). As before, the inducers could be arranged to form the illusory figure with an edge subtending an angle of 2.7°, or rotated by 180° not to form the illusory figure. In this case the support ratio was defined as the line width multiplied by the number of lines and divided by twice the radius plus the gap, with width held constant (Lesher & Mingolla, 1993). Thus the value of support ratio was 0.13, roughly 1/6 of Pacmens'.

The four stimuli (Pacmen square, Pacmen no square, Line Endings square and Line Endings no square) were centrally presented and, given their small size, they fell into central vision. The luminance of each inducer was 0.7 cd/m^2 while that of the background was 95.7 cd/m^2. The stimuli were built using Adobe Photoshop CS6 and presented at the center of a 19" cathode ray tube monitor (Model: LG 901b). Refresh rate was 75 Hz, desktop size was 1280×1024 pixels. E-Prime software version 1.1 was employed to control stimulus presentation and to record participants' RTs.

Procedure and Task

Participants were seated in front of a Pc Monitor at a distance of 57 cm in a dimly lit room and were completely unaware of the purpose of the experiment. They were instructed to keep the gaze on the fixation point (visual angle: 0.1°–luminance: 0.7 cd/m^2) at the center of the screen (empty field luminance was 95.7 cd/m^2) and to respond, in a detection task, as fast as possible to the onset of the stimuli by pressing the space-bar of the Pc keyboard with their right or left index finger according to the instructions displayed on the monitor at the beginning of the trial block. An acoustic warning stimulus (duration 200 ms) warned the participants of the incoming visual stimulus. The interval between acoustic warning and visual stimulus onset was randomized within the temporal window of 500–700 ms. The duration of the stimulus was 100 ms. The overall Inter Trial Interval (ITI) was randomized within the time range: 800–1000 ms.

The experiment was divided into two sessions: 1) participants were shown a Pacmen square (illusory condition) or a Pacmen no square (no-illusory condition) using Pacmen inducers (Pacmen condition), 2) they were shown line endings square (illusory condition) or a line endings no square (no-illusory condition) using line endings inducers (line endings condition). The session order was randomized across participants. Each session included 12 blocks. In half of them participants were to respond with their right hand (right hand condition) while in the others with their left hand (left hand condition). Hand condition was introduced with the aim to control for a possible hemispheric lateralization effects and, within each session, the order of the responding hand was randomized. Each block included 25 trials randomly presented: 10 trials for the illusory condition, 10 trials for the no-illusory condition and 5 trials in which after the warning signal no stimulus was presented and participants were instructed not to respond (catch trials). Thus the experimental design was a $2 \times 2 \times 2$ within subjects design with "inducers version" (Pacmen vs line endings), "hand" (right vs left) and "illusion" (illusory vs no-illusory), as main factors. The overall number of presentations for each participant was 480 (60 trials for each of the eight conditions) plus 120 catch trials.

The range of accepted RTs was 140–650 ms. Participants who did not comply with this limit in more than 5% of the total trials were not considered for subsequent analysis. The same was true for participants who responded to more than 5% of catch trials. No participants exceeded these limits.

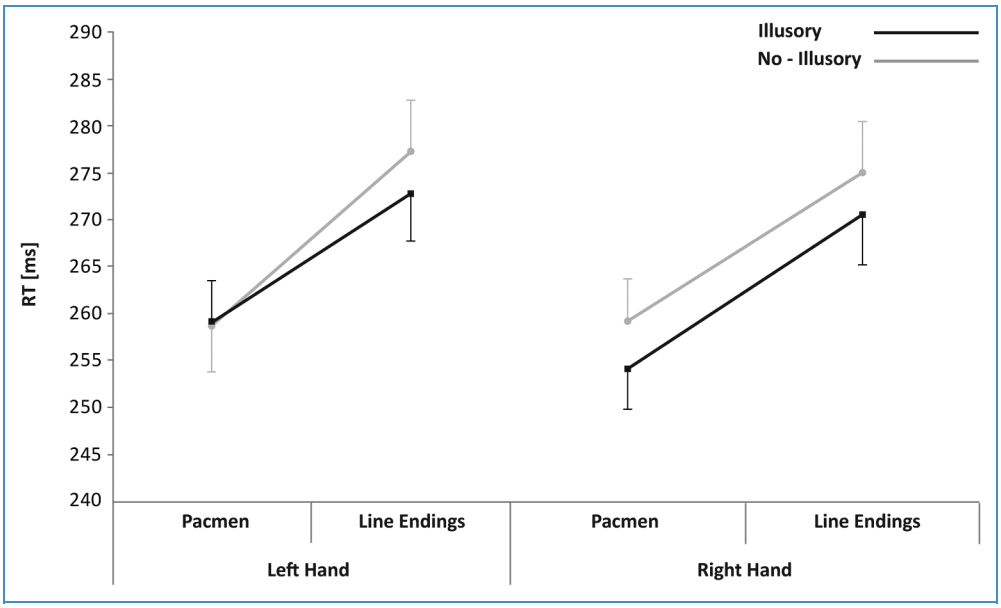

Figure 2. Mean simple RT and SEM relative to the eight experimental conditions. Left graph represents left hand condition and right graph represents right hand condition. Black lines represent illusory conditions: for both Pacmen and line endings conditions, as indicated on X axis. Grey lines represent no-illusory conditions: for both Pacmen and line endings conditions, as indicated on X axis.

It is worth pointing out that stimuli were not shown to the participants prior to the experiment. They were not asked to discriminate between the presence or absence of illusory figure but to press the space bar as quickly as possible following stimulus onset detection.

Results

A three-way repeated measures ANOVA on RT data was carried out with "inducers version" (Pacmen vs line endings), "hand" (right vs left) and "illusion" (illusory vs no-illusory) as main factors. Significant main effects were found for the "inducers version" main factor ($F(1,15) = 8.50$, $p < 0.05$) indicating slower RTs for line endings inducers (273.94 ± 10.12 ms) than for Pacmen inducers (257.76 ± 8.17 ms) and more importantly for the "illusion" main factor ($F(1,15) = 13.13$, $p < 0.01$) indicating faster RTs for illusory condition (264.13 ± 8.67 ms) than for no-illusory condition (267.56 ± 8.90 ms). The "hand" factor was not significant and no significant interactions, comprising the "hand" factor, were found as well: Hand ($F(1,15) = 1.45$, $p > 0.001$); hand × inducers version ($F(1,15) = 0.00$, $p > 0.001$); Hand × Illusion ($F(1,15) = 1.40$, $p > 0.001$), respectively. Figure 2

According with the experimental hypothesis tested here, simple RT was sensitive to the presence vs absence of an illusory figure and this holds for both Pacmen and line endings inducers since the interaction "illusion" × "inducers version" was not significant: ($F(1,15) = 1.09$, $p > 0.001$). Finally, the three-way interaction: hand × inducers version × illusion was not significant ($F(1,15) = 1.45$, $p > 0.001$).

The overall difference between line endings inducers and Pacmen inducers is likely due to their different overall average luminance with the line endings inducers yielding longer RTs because of their higher average luminance as compared with Pacmen inducers.

After the end of experiment, participants were asked about their subjective perceptual experience. Most of them reported that, while the majority of the images on the screen were composed by four

partial circles around the fixation point, some of them resembled a luminous square which appeared whiter than the background and it was surrounded by four partial circles. It was interesting to record the participants verbal report of their percept from the phenomenal point of view because what they reported followed from the phenomenal properties described by Kanizsa which corroborated the experimental hypothesis.

Discussion

The aim of the present work was to test whether the presence of Kanizsa-like illusory figures can shorten simple manual RT. Results showed that participants' response were faster when the illusory figure emerged from a particular configuration of the inducing elements with respect to when it did not, independently from inducers version and the responding hand. It is worth to stress here that it is likely the natural and immediate automatic modal completion of the anomalous margins leading to the emergence of the figure which yields the RT shortening. The configuration of elements (inducers) is peculiar to the compellingness of the emerging figure. The behavioral effect could potentially be represented in a lengthening of the manual simple RT instead of a shortening, as the results showed, so why the RT ended up to be shorter for the illusory effect might be due to the immediacy at which the whole process takes place in human visual system.

We opted for a detection paradigm, where simple RTs are measured, because it was the most straightforward way to test experimentally the immediacy of this perception without any conscious volitional cognitive operation such that taking place in a recognition/discrimination task. The illusory figure materialized in front of the participants spontaneously without any cognitive effort.

Poscoliero and Girelli (2018) conducted an ERP experiment with the same task of the present study where, in addition to a square, also a triangle and a pentagon shape were presented. In that study the same pattern of results was found only for the illusory square but not for the triangle and the pentagon. This last evidence might suggest that a square is a more regular geometric figure than a triangle or a pentagon but "regularity", as a phenomenal property was discarded by Kanizsa himself (Kanizsa, 1955) when he observed that the emergence of an illusory figure through amodal completion was possible also for non-regular figures. Further experiments should be conducted in order to indicate which perceptual features (e.g., symmetry, balance/unbalance distribution of inducers across upper and lower visual field, shape, support ratio etc.) are crucial to yield the RT effect. The present results confirm, as in Sperandio et al. (2009, 2010), that simple RT is sensitive to a particular set of phenomenal properties within a configuration leading to the emergence of a meaningful figure. The neurophysiological mechanism underlying this effect likely relies in the interplay between lateral occipital complex (L.O.C.) and V1, V2 visual cortices. This neural network is involved in object and gestalt processing (Murray & Hermann 2013; Poscoliero & Girelli, 2018). The crucial role of L.O.C. in the processing of illusory figure was highlighted by Stanley and Rubin (2003, 2005) and Hirsch et al. (1995). Likely, although participants were not asked to perform a discrimination task, the illusory figure modulated the activity of the L.O.C. providing a powerful signal leading to a faster response of the dorsal "vision for action" visual stream represented by faster simple RT. Given its value in terms of survivor, e.g., camouflage (see Nieder, 2002), Kanizsa-like illusory figures can be rapidly detected by the visual system at a mid-early stage before the classic distinction between ventral and dorsal visual stream (Milner & Goodale, 1995). From one hand the activity of L.O.C. is responsible for a "vision at a glance" (Hochstein & Ahissar, 2002) that conveys information to the ventral visual stream allowing subsequent more detailed perception and categorization. From another hand it conveys information to the dorsal visual stream leading to a faster motor response. This is in agreement with Poscoliero et al. (2013) where, by using a metacontrast masking paradigm, the authors showed that the salient region of an illusory figure (i.e., the portion of the visual field between the inducers) can lead to a priming effect to a real figure even though not

consciously processed, providing evidence that the visual system is highly sensitive to this kind of perceptual configuration. Neural dissociation between detection and discrimination of illusory figure was also confirmed by Murray et al. (2006). It is also important to note that, at a phenomenological level, participant's report after the experiment is in agreement with a "vision at a glance": A partial impression of the illusory figure that fits with a nearly analysis of the incoming information by the visual system. The relationship between neurophysiological and phenomenological level of explanation should be strongly considered in the future research (see Spillmann, 2009; Spillmann & Dresp, 1995) but the present study, showing only a behavioral effect without the measurement of a neurophysiological correlate, cannot provide a direct support to the above tentative interpretation.

In conclusion, the present experiment provides novel evidence that the compelling emergence of Kanizsa-like illusory figures can shorten simple manual reaction time confirming that a simple motor action, as required in a detection task, is not affected only by physical parameters but also by perceptual/phenomenal features which are completed in the extrastriate visual cortex very quickly and do not require a higher cognitive operation such as recognition/discrimination to release a programmed motor response.

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Tommaso Poscoliero: Conceptualization; Data curation; Methodology; Software; Writing – original draft; Writing – review & editing.
Massimo Girelli: Data curation; Methodology; Supervision; Writing – review & editing.

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