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Holistic processing of impossible objects: Evidence from Garner's speeded-classification task

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Holistic processing, the decoding of the global structure of a stimulus while the local parts are not explicitly represented, is a basic characteristic of object perception. The current study was aimed to test whether such a representation could be created even for objects that violate fundamental principles of spatial organization, namely *impossible objects*. Previous studies argued that these objects cannot be represented holistically in long-term memory because they lack coherent 3D structure. Here, we utilized Garner's speeded classification task to test whether the perception of possible and impossible objects is mediated by similar holistic processing mechanisms. To this end, participants were asked to make speeded classifications of one object dimension while an irrelevant dimension was kept constant (baseline condition) or when this dimension varied (filtering condition). It is well accepted that ignoring the irrelevant dimension is impossible when holistic perception is mandatory, thus the extent of Garner interference in performance between the baseline and filtering conditions serves as an index of holistic processing. Critically, in Experiment 1, similar levels of Garner interference were found for possible and impossible objects implying holistic perception of both object types. Experiment 2 extended these results and demonstrated that even when depth information was explicitly processed, participants were still unable to process one dimension (width/depth) while ignoring the irrelevant dimension (depth/width, respectively). The results of Experiment 3 replicated the basic pattern found in Experiments 1 and 2 using a novel set of object exemplars. In Experiment 4, we used possible and impossible versions of the Penrose triangles in which information about impossibility is embedded in the internal elements of the objects which participant were explicitly asked to judge. As in Experiments 1–3, similar Garner interference was found for possible and impossible objects. Taken together, these findings emphasize the centrality of holistic processing style in object perception and suggest that it applies even for atypical stimuli such as impossible objects.

1. Introduction

Humans readily perceive different elements of the visual scene such as object shape (Hochstein & Ahissar, 2002; Patterson et al., 2007), facial identity (Farah et al., 1998), gist of the visual scene (Oliva & Torralba, 2006), as well as other properties (Oliva & Torralba, 2006), by decoding the global structure of objects (i.e. holistic processing) rather than explicitly representing their local elements. Moreover, several studies demonstrated that holistic processing is mandatory, at least when perception is involved (Ganel & Goodale, 2003). For example, in an influential paper, Navon (1977) showed precedence for global over local features in a perceptual classification task such that when large letters were composed of small letters, the initial percept corresponded to the global letter embedded in the stimulus.

Another example for mandatory holistic processing comes from studies that used Garner's speeded-classification task (Garner & Felfoldy, 1970). This paradigm tests the ability to selectively attend to one dimension of an object (e.g. width) while ignoring an irrelevant dimension of the same object (e.g. height). Participants are asked to make speeded perceptual classifications of a specific dimension under two experimental conditions: In the baseline block, the irrelevant dimension is held at a constant value while in the filtering block, participants are again asked to classify a relevant dimension, but now the irrelevant dimension randomly varies. It has been consistently documented across many studies that performance is worse in the filtering compared to the baseline condition when classifying different dimensions belonging to the same object (e.g. Felfoldy, 1974; Ganel & Goodale, 2003). This finding indicates that the two dimensions are processed in an integral

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manner, implying that objects are processed in a holistic fashion (Pomerantz & Garner, 1973; Pomerantz & Pristach, 1989).

Different types of dimensions can produce different types of Garner interference effects. Some dimensions, referred to as integral dimensions, elicit Garner interference while others, considered as separable dimensions, do not elicit Garner interference (for further discussion Ganel, 2011; Ganel & Goshen-Gottstein, 2002). More pertinent to the current discussion are findings showing that even the same set of dimensions, under different processing styles, can either produce or not produce Garner interference effects, depending on the task at hand. There are many relevant examples to support this idea (e.g., Pomerantz & Pristach, 1989) in the case of the configuration of simple features. Other findings, conducted in our lab and replicated by others (Ganel & Goodale, 2003; Janczyk & Kunde, 2012; Kunde et al., 2007; Schum et al., 2012), suggest that the processing of a simple shape (i.e., a rectangle) is performed in a holistic manner (and hence produces a Garner interference effect) when subjects are asked to make perceptual estimations. In contrast, the same object is processed analytically (and does not produce a Garner interference effect) when visually-guided actions are involved and subjects are asked to grasp (rather than to make perceptual estimations of) the same rectangular objects. Another relevant example comes from studies of face perception that used Garner's paradigm. The same set of stimuli and dimensions were found to produce Garner interference when the faces are presented in an upright, standard orientation while no Garner interference effect was found when the same faces were inverted (Amishav & Kimchi, 2010). In a similar vein, unlike normal subjects, who show Garner interference when upright faces are presented, prosopagnosic individuals, that are impaired in their ability to process faces in a holistic manner, do not show Garner interference effect even when presented with upright faces (Kimchi et al., 2012). These findings provide additional support for the idea that Garner's paradigm can be used as an efficient marker of holistic processing.

In the current study, we explored whether holistic representation would be evident even in cases in which spatial information is distorted. We addressed this issue by utilizing *impossible objects* which constitute a class of visual illusions in which 2D line drawings seem to represent objects that could not exist in real 3D space (Penrose & Penrose, 1958). Using the seminal Garner interference paradigm (Garner, 1978), we probed the nature of the perceptual mechanisms mediating the representation of impossible objects.

Early studies utilized impossible objects as a tool for investigating spatial representations in *long-term memory* (e.g. Cooper et al., 1992; Schacter et al., 1991; Soldan, Hilton, & Stern, 2009; Williams & Tarr, 1997). Despite some discrepancies across different studies, it has been generally argued that impossible objects cannot be represented holistically in long-term memory because they lack a coherent 3D structure.

On the other hand, only few studies investigated the underling processes that mediate the representation of impossible objects. Early studies suggested that representation of possible and impossible objects rely on a piecemeal processing style (Hochberg, 1968). However, more recent studies have suggested a more complex relationship between the processes underlying the perception of possible and impossible objects. For example, Shuwairi (2009) and Shuwairi, Albert, and Johnson (2007) showed that babies at the age of 4-months exhibited a spontaneous preference for displays of an impossible compared to a possible cube. A similar line of results was obtained by Regolin et al. (2011) in newly hatched chicks. The results of these studies emphasize the sensitivity of the visual system for object impossibility. Critically however, this sensitivity was not dependent on local cues, thus suggesting the possibility that global processing mediated the perception of impossible shapes.

We recently provided additional evidence that the perception of possible and impossible objects is mediated by shared early perceptual representations, and that the observed differences between the two object categories may rely on higher cognitive mechanisms. In particular, we used fMRI adaptation and found similar adaptation levels for possible and impossible objects, alongside differences between the two object categories in the correlations between behavioral performance and the neural response (Freud, Ganel, & Avidan, 2013). Note, that although the spatial representation of impossible objects is quite ambiguous, the great majority of these objects still possesses intact shape attributes such as volume, closure and defined surfaces, which could support their intact object-based representation. Here we specifically address the nature of the processes that mediate the perception of possible and impossible objects.

2. Experiment 1

Based on the initial neuroimaging findings from our lab described above (Freud, Ganel, & Avidan, 2013), we hypothesized that possible and impossible objects would be perceived similarly in a holistic fashion. To test this assumption, we utilized the Garner speeded-classification task (Garner & Felfoldy, 1970). Participants were asked to classify an object (i.e. possible or impossible cubes, Fig. 1) based on its width while ignoring its height. The main prediction was that slower classifications would be observed when the irrelevant dimension randomly varies (i.e. filtering blocks) compared to when the irrelevant dimension is kept constant (i.e. baseline blocks) regardless of object possibility. Additional experiments were conducted to account for possible confounds.

2.1. Methods

2.1.1. Participants

Sixteen first and second year healthy psychology students (mean age: 24.5, seven females) with normal or corrected to normal vision participated in the experiment. They all provided informed consent to participate in the experiment and received the equivalent of $5 for their participation. All experimental procedures were approved by the ethics committee of the Psychology Department at Ben-Gurion University of the Negev.

2.1.2. Stimuli

A pair of possible and impossible cubes was used as experimental stimuli (Fig. 1). The impossible cube was adapted with permission from the "impossible world web site". The matched possible cube was identical except for two features which were inserted using Photoshop CS to make the object's global 3D structure possible. Four versions were created for each stimulus based on the factorial combination of width (44 mm vs. 52 mm) and height (46 mm vs. 56 mm). Stimuli subtended a visual angle of approximately 6.2° and were presented on a 19 in. computer screen (1024 × 768 resolution; refresh rate of 60 HZ).

2.1.3. Experimental design

Block (baseline, filtering) and object type (possible, impossible) served as within-subject independent variables. The order of the blocks was counterbalanced across subjects. In the baseline blocks, the relevant dimension (width) varied between trials while the irrelevant dimension (height) was kept constant (i.e. short or tall). In the filtering blocks, both the relevant (width) and the irrelevant (height) dimensions varied between trials in a random fashion and all possible combination were used (Fig. 1). Object type (possible/impossible) always varied randomly in both filtering and baseline blocks.

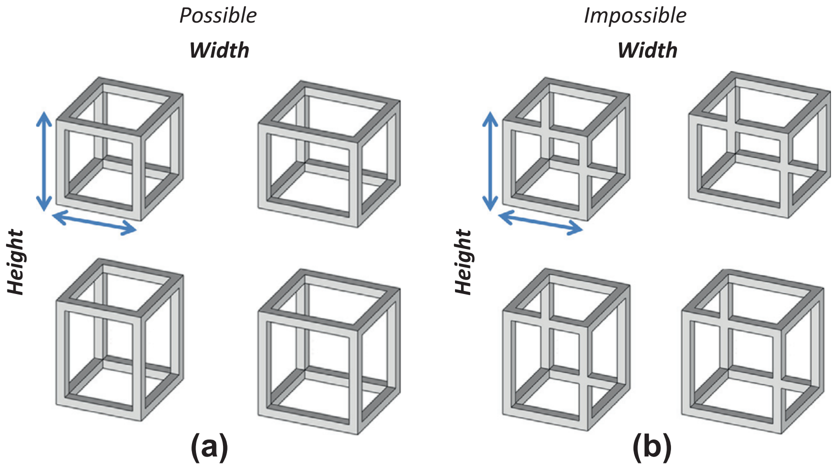

Fig. 1. Possible (left) and impossible (right) cubes that were presented in Experiment 1. Note, that the two sets of possible and impossible objects were controlled so that relatively small physical differences would establish a profound difference in the perception of spatial impossibility. Width and length were manipulated to create four versions of each stimulus.

Each stimulus was presented eight times in a random order in each block, resulting in a total of 32 presentations for each baseline block and 64 presentations for the filtering blocks. To prevent differences between blocks as a result of the different number of stimulus presentations within each block, the filtering blocks were divided into two equal parts (Ganel, 2011), each containing 32 stimuli. There were eight practice trials prior to the beginning of each experimental block which were excluded from any further analysis.

2.1.4. Procedure

Participants were asked to make speeded classifications (narrow vs. wide) of the width of the cube by pressing one of two corresponding keys on the keyboard ("f" or "k") as quickly as possible. Trials were self-generated. Each trial began with the presentation of 500-ms fixation point which was immediately followed by a 500-ms blank screen, and then followed by the stimulus, located at the center of the screen. The stimulus remained on the screen until a response was recorded. Reaction times and accuracy were recorded and served as dependent measures.

2.2. Results and discussion

Mean reaction time (RT) and accuracy were calculated for each participant. Mean error percentage was low (7.7%, range 1–25%, see Table 1) and no effects of object type or of block [all $Ps > 0.2$] were found for the accuracy data. Therefore, further analysis is focused on RTs for correct trials. For each participant, RTs slower or faster than 2.5 standard deviations than the mean were excluded from the analysis. A repeated measures analysis of variance (ANOVA) was conducted with object possibility and block as independent variables.

The reaction time data is presented in Fig. 2. As can be seen, faster RTs were found in the baseline blocks compared to the filtering blocks, as indicated by a main effect of block [$F_{(1,15)} = 28.84$, $p < 0.001$, $\eta_p^2 = 0.65$] with no interaction with object possibility [$F_{(1,15)} < 1$]. Planned comparisons revealed that the Garner interference effects were significant for both possible [$F_{(1,15)} = 23.77$, $p < 0.001$] and impossible objects [$F_{(1,15)} = 18.87$, $p < 0.001$]. No significant effects were found for the order variable (all $Ps > 0.05$).

The findings of Experiment 1 are straight forward: similar Garner interference effects were found for possible and impossible objects, indicating holistic perception of object shape for both object categories. Particularly, participants processed the relevant and the irrelevant dimensions in an integral fashion, as evident from the significant Garner interference effect (72 ms for possible objects and 76 ms for impossible objects). Experiments 2–4 examine potential confounds and further verify this basic finding.

3. Experiment 2

As noted above, the results of Experiment 1 imply that impossible objects are perceived in a holistic manner, similarly to possible objects. However, it is not clear whether the holistic processing observed in Experiment 1 can be attributed to 2D or to 3D form perception. For example, participants could have ignored the 3D structure of the cube and base their decision solely on the 2D layout of its forefront. Critically, the origin of impossibility lies in the processing of 3D monocular information embedded in these stimuli and in Experiment 1, we manipulated the height and width of the cube (2D plane) while depth (pictorial 3D plane) remained

Table 1
Mean (and standard deviation) accuracy performances in Experiments 1–4.

	Possible filtering	Possible baseline	Impossible filtering	Impossible baseline
Experiment 1	90%	95%	89%	94%
	(7%)	(12%)	(14%)	(7%)
Experiment 2	95%	95%	94%	95%
	(7%)	(6%)	(7%)	(6%)
Experiment 3	92%	93%	93%	94%
	(4%)	(5%)	(5%)	(5%)
Experiment 4	89%	89%	88%	89%
	(7%)	(8%)	(7%)	(7%)

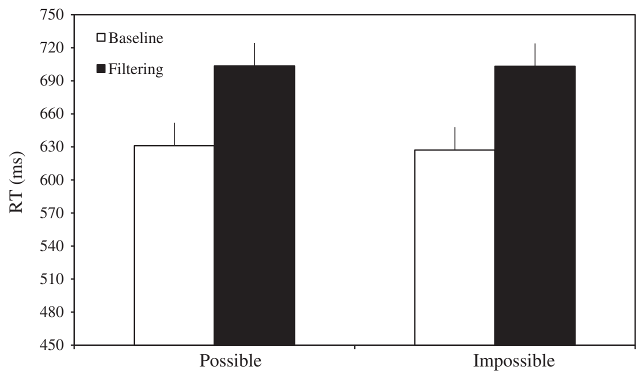

Fig. 2. Mean reaction times for width classifications in Experiment 1. Participants responsed faster in the baseline blocks compared to the filtering blocks (a Garner interference effect) regardless of object possibility. Error bars in this figure and all figures below represent confidence intervals as calculated for repeated measure ANOVAs (Jarmasz & Hollands, 2009).

constant. Thus, the Garner interference for impossible objects in Experiment 1 could have reflected holistic processing of 2D information alone regardless of impossibility. To rule out this alternative explanation, in Experiment 2 we ensured that pictorial, 3D depth is explicitly processed. Here, we tested the relationship between the perceived depth dimension of the cube and between width while height remained constant (see Fig. 3). Specifically, we examined whether objects would still be processed holistically when the irrelevant (or relevant) dimension include an explicit reference to 3D shape.

3.1. Methods

3.1.1. Participants

Sixteen first and second year healthy students with normal or corrected to normal vision participated in the experiment (none of whom participated in Experiment 1). Due to a technical failure the age and gender of the participants were not recorded, but they were all part of the same general population as in Experiment 1. They all provided informed consent to participate in the experiment and received 5$ equivalent for their participation. All experimental procedures were approved by the ethics committee of the Psychology Department at Ben-Gurion University of the Negev.

3.1.2. Stimuli

The stimuli were identical to Experiment 1 expect for the following changes: Height of the cube remained constant while four versions were created to each stimulus based on the factorial combination of width (44 mm vs. 52 mm) and perceived depth (34 mm vs. 44 mm) (Fig. 3).

3.1.3. Experimental design and procedure

To provide a more robust measure of classification performance, in Experiment 2 we tested the bi-directional relationship between width and depth, rather than focusing only on the irrelevant effects on one dimension as in Experiment 1 (see Melara & Algom, 2003). Task (depth classifications, width classifications), block (baseline, filtering) and object type (possible, impossible) served as within-subject variables. The order of the blocks and tasks were counterbalanced across subjects. In the baseline blocks, the relevant dimension (width/depth) varied between trials while the irrelevant dimension (depth/width respectively) was kept constant. In the filtering blocks, both the relevant and the irrelevant dimensions were varied and all possible combinations were used (Fig. 3). As in Experiment 1, object type (possible/impossible) was varied randomly in both filtering and baseline blocks. In all other aspects, the procedure was similar to the one used in Experiment 1.

3.2. Result and discussion

Mean reaction times (RT) and accuracy were calculated for each participant. As in Experiment 1, mean error rate was relatively low (6.1%, range 0–23%, Table 1). RTs were calculated for correct trials only. For each participant, RTs slower or faster than 2.5 standard deviations from the mean were excluded from the analysis. As can be seen in Fig. 4, a robust Garner interference effect was found in this experiment, with faster RTs in baseline compared to filtering blocks along all experimental conditions. A repeated measure ANOVA revealed a Garner interference effect (i.e. main effect of block) [$F_{(1,15)} = 6.99$, $p < 0.05$, $\eta_p^2 = 0.31$] with no interactions with object possibility [$Ps > 0.25$]. Planned comparisons showed that the Garner interference effect was significant for both possible [$F_{(1,15)} = 9.5$, $p < 0.01$] and for impossible objects [$F_{(1,15)} = 4.14$, $p = 0.05$]. Additionally, a main effect was found for task with faster reaction time for depth classification (598 ms) compared to width classification (655 ms) [$F_{(1,15)} = 8.05$, $p < 0.05$, $\eta_p^2 = 0.34$]. Importantly, there was no interaction of task with object's possibility

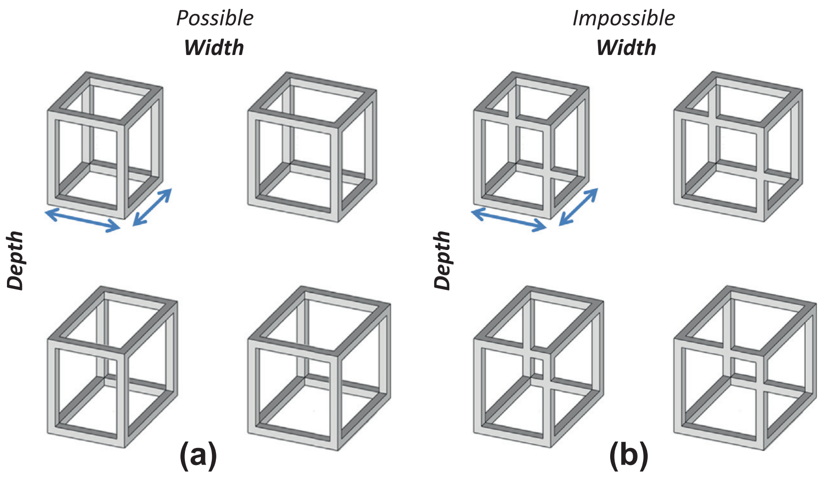

Fig. 3. Examples of stimuli presented in Experiment 2. Possible (left) and impossible (right) cubes. Width and depth were manipulated to create four versions of each stimulus.

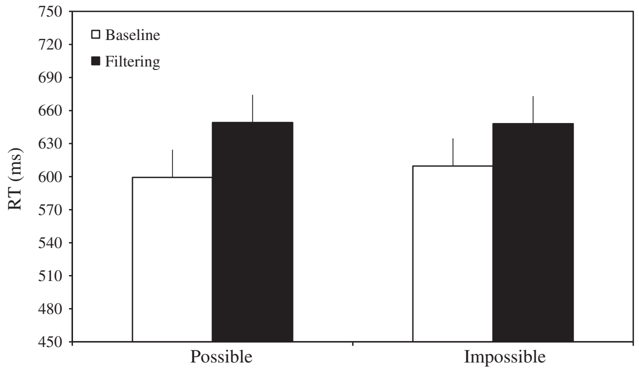

Fig. 4. Mean reaction times for width and depth classifications in Experiment 2. Participants responded faster in the baseline blocks compared to the filtering blocks (a Garner interference effect) regardless of object possibility or task.

[$F_{(1,15)} = 2.33$, $p > 0.14$] or main effect for object's possibility [$F_{(1,15)} = 1.18$, $p > 0.2$]. To exclude the option that object possibility interacted with order, we included an additional ANOVA analysis with order as a between subject variable. No main effects of order or interactions were found, with the exception of a three way interaction between block, order and the dimension of judgment [$F_{(1,15)} = 5.3$, $p < 0.05$, $\eta_p^2 = 0.57$]. Importantly, no interaction with object type was observed ($Ps > 0.2$).

These findings indicate that the two dimensions of the cube were processed in an integral fashion. In the current experiment, two sources of information were manipulated (2D and perceived 3D). Thus, in contrast to Experiment 1, here holistic processing was not restricted to the surface plane of the visual scene and the effects could be mediated by a 3D representation. Importantly, the Garner interference effect was found again for possible and impossible objects suggesting similar perceptual representations of the two object categories.

The results of the accuracy data were subjected to a repeated measure ANOVA. This analysis revealed a two-way interaction between object type and block [$F_{(1,15)} = 4.74$, $p < 0.05$, $\eta_p^2 = 0.24$]. However, planned comparisons revealed that for accuracy, Garner interference was not found for possible [$F_{(1,15)} < 1$] or for impossible objects [$F_{(1,15)} = 1.46$, $p = 0.24$]. Nevertheless, in the filtering blocks, superior performance was observed for possible objects [$F_{(1,15)} = 4.17$, $p = 0.05$]. This difference may be attributed to the greater level of complexity embedded in impossible objects.

4. Experiment 3

The results of Experiments 1 and 2 suggest that possible and impossible objects are perceived in a similar holistic fashion. Experiment 2 also implies that this processing style could not be attributed solely to the processing of 2D information while ignoring the ambiguity embedded in the 3D information.

Nevertheless, one potential difficulty related to the design of Experiments 1 and 2 is that we used only one, well-known exemplar of impossible objects – the impossible cube (note that this is a common practice in studies employing the Garner paradigm (e.g. Ganel, 2011; Ganel & Goodale, 2003; Pansky & Algom, 1999). In the context of the present study, one could argue that the familiarity of participants with the impossible cube may mediate their ability to encode this object holistically despite being impossible. Thus, the aim of Experiment 3 was to test whether the pattern of results obtained in Experiments 1 and 2 would also extend to a novel, non-familiar stimulus.

4.1. Methods

4.1.1. Participants

Twelve first and second year healthy students (mean age: 24, five females, none of whom participated in Experiments 1 or 2) with normal or corrected to normal vision participated in the experiment. They all provided informed consent to participate in the experiment and received 5$ equivalent for their participation. All experimental procedures were approved by the ethics committee of the Psychology Department at Ben-Gurion University of the Negev.

4.1.2. Stimuli

A pair of new possible and impossible objects was used as experimental stimuli (Fig. 5). The impossible object was adapted with permission from the "impossible world web site". The matched possible object was identical except for one feature inserted using Photoshop CS to make the object's global 3D

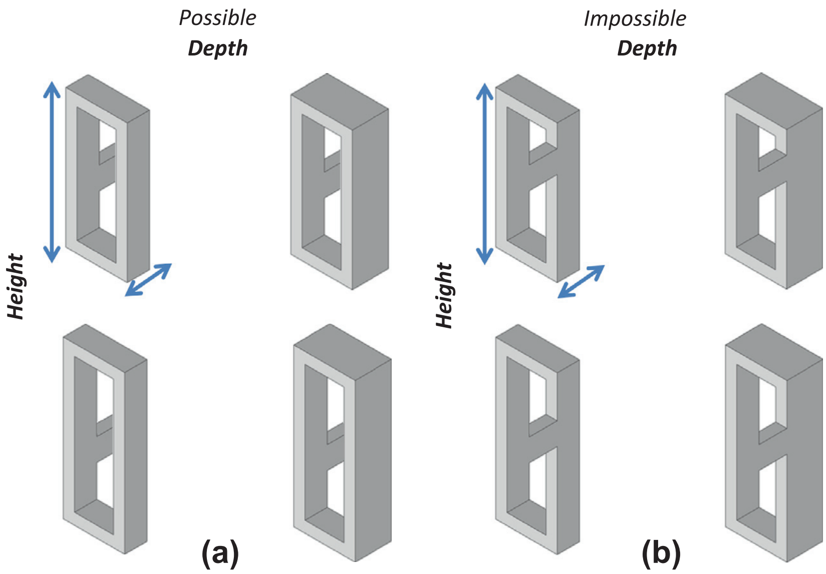

Fig. 5. Examples of stimuli presented in Experiment 3. Possible (left) and impossible (right) objects. Height and depth were manipulated to create four versions of each stimulus.

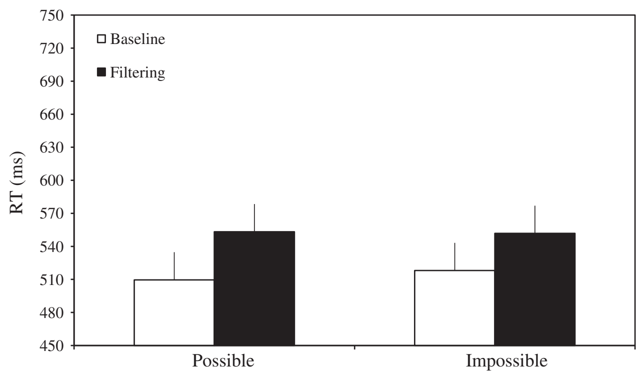

Fig. 6. Mean reaction times for height and depth classifications in Experiment 3. Participants responsed faster in the baseline blocks compared to the filtering blocks (a Garner interference effect) regardless of object possibility or task.

structure possible. Four versions were created for each stimulus based on the factorial combination of height (52 mm vs. 62 mm) and depth (7 mm vs. 12 mm).

4.1.3. Experimental design and procedure

Participants were asked to classify height and depth. In all other aspects, the procedure was similar to the one used in Experiment 2.

4.2. Result and discussion

Error percentage was low (6.1%, range 2–11%, Table 1) and no effects of object type or of block [all $Fs_{(1,11)} < 1$] were found for the accuracy data. Therefore, further analysis is focused on RTs for correct trials. For each participant, RTs slower or faster than 2.5 standard deviations from the mean were excluded from the analysis. A repeated measures analysis of variance (ANOVA) was conducted with object possibility, block and task as independent variables.

The reaction time data is presented in Fig. 6. Faster RTs were found in the baseline blocks compared to the filtering blocks, as indicated by a main effect of block [$F_{(1,11)} = 6.28$, $p < 0.05$, $\eta_p^2 = 0.36$] with no interactions with object possibility or task [$Fs_{(1,11)} < 1$]. Planned comparisons revealed that the Garner interference effects were significant for both possible [$F_{(1,11)} = 5.59$, $p < 0.05$] and impossible objects [$F_{(1,11)} = 5.07$, $p < 0.05$]. Similarly to Experiment 2, a main effect [$F_{(1,11)} = 13.2$, $p < 0.05$, $\eta_p^2 = 0.54$] was found for task with faster reaction times for depth classifictions (503 ms) compared to height classifictions (568 ms). Importantly, there was no interaction of task with object's possibility [$F_{(1,11)} < 1$] or main effect for object's possibility [$F_{(1,11)} < 1$]. When order was taken into account as a between subject variable, a two way interaction with Garner condition was found, indicating larger Garner interference when the experiment began with the filtering block [$F_{(1,11)} = 5.3$, $p < 0.05$, $\eta_p^2 = 0.66$]. No interactions were found with object type ($Ps > 0.2$).

The findings of Experiment 3 replicate and extend the results of Experiments 1 and 2. Particularly, similar effects of Garner interference were found for possible and impossible objects, indicating holistic perception of object shape for both object categories.

5. Experiment 4

The results of Experiments 1–3 provide evidence for holistic representation of impossible objects. However, it can be argued that in the previous experiments information on object impossibility was not directly attended-to during the task. In particular, in Experiments 1–3 the critical information about the impossibility of the objects was embedded in the internal region of the figures, while participants were asked to make judgments regarding the outside perimeter. Experiment 4 was designed to address this issue. To this end, we utilized the impossible and possible versions of the well-known Penrose triangle (Penrose & Penrose, 1958) (Fig. 7). Critically, the external perimeter was kept constant throughout the experiment and participants were asked to directly classify the width of an internal feature in which a structural violation occurs.

In Experiments 1–3 possible and impossible objects were presented in a random fashion within each block. Because the possible objects that were used were matched versions of the impossible objects, it is feasible that the intermixed design encouraged subjects to rely on memory representation of the possible versions of the impossible objects. This issue could be even more pronounced when performance directly relies on the critical regions of the stimulus that carry information on impossibility. Therefore, in Experiment 4, we used the more traditional block design (see Ganel, 2011) in which possible and impossible objects were separately blocked and block order was counterbalanced between subjects.[1]

5.1. Methods

5.1.1. Participants

Thirty-five first and second year healthy students (mean age: 23.5, sixteen females, none of whom participated in Experiments 1–3) with normal or corrected to normal vision participated in this experiment. Three participants were disqualified because they performed below 50% in at least one of the experimental blocks. All participants provided informed consent to participate in the experiment and received 5$ equivalent for their participation. All experimental procedures were approved by the ethics committee of the Psychology Department at Ben-Gurion University of the Negev.

5.1.2. Stimuli

A pair of possible triangle and the impossible-Penrose triangles (Fig. 7) was used. The impossible triangle was adapted with permission from the "impossible world web site". The matched possible object was identical except for one feature inserted using Photoshop CS to make the object's global 3D structure possible. Two internal features were manipulated based on the factorial combination of relevant feature (9 mm vs. 11 mm) and irrelevant feature (11 mm vs. 15 mm).

5.1.3. Experimental design and procedure

Participants were asked to classify the width of the internal feature. The order of the type of object presentation was counterbalanced across subjects. In all other aspects, the procedure was similar to the one used in Experiment 1.

5.2. Results and discussion

Error percentage was 11% (range 2.5–25%, Table 1) and no effects of object type or of block [all $Fs_{(1,29)} < 1$] were found for the accuracy data. Therefore, further analysis is focused on RTs for correct trials. For each participant, RTs slower or faster than 2.5 standard deviations from the mean were excluded from the analysis. A repeated measures analysis of variance (ANOVA) was

[1] To ensure that the effects we report in previous experiments were not mediated by the type of presentation (i.e., intermixed vs. block design) we ran an additional control experiment (16 subjects) with a similar design to the one used in Experiment 1, but now in a design in which possible and impossible objects were presented in separate blocks. Again, Garner interference effects were found for the possible and impossible cubes with no interaction between object type and Garner interference.

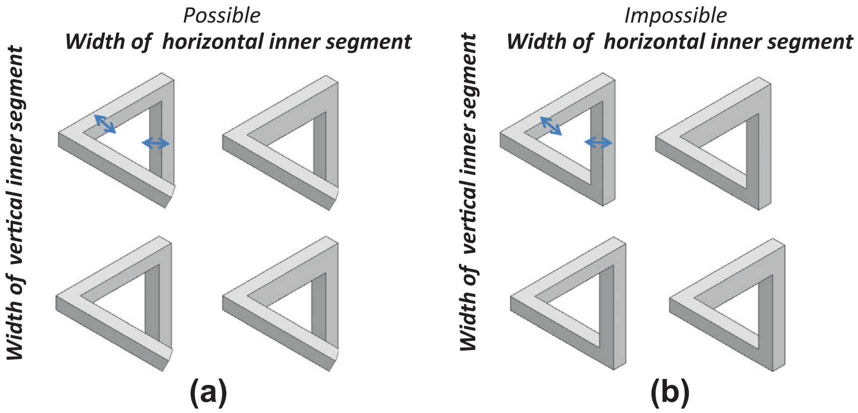

Fig. 7. Examples of stimuli presented in Experiment 4. Possible (left) and impossible triangles. Two internal features were manipulated to create four versions of each stimulus. Note, that the outer perimeter remained constant in all figures.

conducted with object possibility, and block as independent variables.

The reaction time data is presented in Fig. 8. Faster RTs were found in the baseline blocks compared to the filtering blocks, as indicated by a main effect of block [$F_{(1,29)} = 5.81$, $p < 0.05$, $\eta_p^2 = 0.16$] with no interactions with object possibility [$Fs_{(1,29)} < 1$]. Planned comparisons revealed that the Garner interference effects were significant for both possible [$F_{(1,29)} = 2.7$, $p = 0.05$, one tailed] and impossible objects [$F_{(1,29)} = 3.44$, $p < 0.05$, one tailed].

A repeated measure ANOVA with the order of presentation as between subject variable was conducted to test for possible effects of order. Importantly, no interaction was found between order, the Garner effect, and object possibility [$F_{(1,29)} < 1$]. This finding implies that the Garner interference effect for impossible objects is not due to prior exposure to their possible counterpart. A two way interaction was found between object possibility and order. Particularly, when possible triangles were presented at the first half of the experiment, longer RTs were observed for impossible triangle [$F_{(1,29)} = 5.07$, $p < 0.05$]. On the other hand, when impossible triangles were presented at the first half of the experiment, no differences between object types were found [$F_{(1,29)} < 1$]. Similarly to Experiment 2, this finding may reflect the ambiguity of the spatial layout embedded in impossible objects.

To conclude, the findings of Experiment 4 replicate and extend the results of the previous experiments. Particularly, similar effects of Garner interference were found for possible and impossible objects, indicating holistic perception of object shape for both object categories, even when internal features that contain impossible information were directly attended. Note that the overall

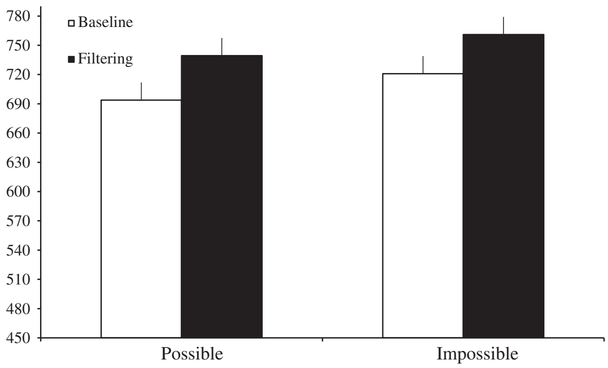

Fig. 8. Mean reaction times for internal feature judgments in Experiment 4. Participants responsed faster in the baseline blocks compared to the filtering blocks (a Garner interference effect) regardless of object possibility.

Garner effect seems to be weaker in comparison to previous studies. This could be due to the particular task demands in this experiment (i.e. attending to an internal feature which provide less salient perceptual cues compared to the external contours).

6. General discussion

The purpose of the current study was to test whether holistic representations mediate the processing of impossible objects. The importance and centrality of holistic representations in human perception was emphasized in numerous studies (e.g. Farah et al., 1998; Oliva & Torralba, 2006). Yet, it has also been argued that impossible objects could not be represented holistically in *long-term memory* because they lack a 3D coherent structure (e.g. Schacter et al., 1991). Nevertheless, our theoretical framework that argues that similar perceptual processes mediate the representation of possible and impossible objects predicts that the *perception* of those objects would be represented in a holistic fashion similarly to possible objects. Particularly, based on the results of Freud, Ganel, and Avidan's (2013) functional imaging study, we assumed that the visual system utilizes valid object properties that are inherent to impossible objects to successfully represent them in a holistic fashion as typically found for possible objects.

The present results showed robust Garner interference for both object categories, suggesting that possible and impossible objects are represented in a similar fashion. Particularly, In Experiment 1, comparable Garner interference effects were found for possible and impossible objects when participants were asked to classify the cube's width while ignoring its height. Experiment 2 extended this finding and provided evidence for holistic processing of object shape when depth was explicitly processed. Experiment 3 provided converging evidence for these findings using non-familiar objects and reinforced the notion of holistic perception of both possible and impossible objects. Finally, Experiment 4 further extended our results and showed that the Garner interference can be found even when participants attended to the internal features of the stimuli, which contained essential information on object (im)possibility.

Taken together, the present results could pinpoint potential differences between perception and long term memory of impossible objects. Particularly, while previous studies (e.g. Schacter et al., 1991; Williams & Tarr, 1997) argued that the inherent ambiguity of impossible objects leads to impaired holistic representation of this object category in long term memory, here we provide evidence for intact holistic perception of these objects.

Studying the processes that mediate the perception of possible and impossible objects provides important insights about the visual properties that enable the creation of holistic representation. Particularly, possible and impossible objects share similar Gestalt attributes (e.g. object closure, defined surfaces, volume) which are known to be important for object recognition (Geisler et al., 2001; Koffka, 1935; Kovacs & Julesz, 1993; Wertheimer, 1923), but are different in their spatial organization. The current study suggests that the shared attributes overcome the odd spatial layout of impossible objects and support holistic processing of this object category, similarly to the way possible objects are processed.

Previous studies found that perceivers can easily distinguish between possible and impossible objects (e.g. Williams & Tarr, 1997). Additionally, developmental studies showed that the visual system is tuned to recognize impossibility early in-life (Regolin et al., 2011; Shuwairi, 2009; Shuwairi, Albert, & Johnson, 2007). The resemblance of the processing style of possible and impossible objects that was found in the current study does not contradict these findings. Particularly, and in line with Freud, Ganel, and Avidan (2013), we suggest that the visual system treats impossible objects similarly to possible objects at basic levels of visual processing, and that only in later stages of the processing hierarchy, a differentiation is made between the two object categories. These later processes may mediate the impaired memory representation typically found for impossible objects (e.g. Schacter et al., 1991).

One intriguing way for describing the nature of the basic-level representations that mediate the processing of possible and impossible objects relates to the well-known distinction between low and high spatial frequency content of the visual information (see Bar, 2004). It has been suggested that low-spatial frequencies of the image are processed faster and more efficiently by the visual cortex, which allows such information to facilitate normal processing of object shape (Bar, 2004; Bar et al., 2006). Note, that most information on object impossibility is likely to be carried by detailed, high-spatial frequencies of the image. Therefore, the low-spatial frequencies, that probably do not include informative details on object impossibility, could potentially subserve common representations of object shape for possible and impossible objects. It is therefore plausible that the holistic processing style that was evident in our results is not absolute, in the sense that it could be subserved mostly by low spatial frequency information, whereas more specific processing of the details could be acquired by different mechanisms.

Therefore, although the findings of the present study strongly suggest that impossible objects are treated in a Gestalt manner in term of processing their shape, as indicated by the presence of Garner interference, we cannot categorically conclude that the interference effect for impossible object was mediated by a completely intact processing mechanism of 3D depth information. After all, impossible objects do entail ambiguous interpretations of depth, which defines their impossibility. Still, given that the dimensions that constitute impossibility were explicitly referred to in some of our experiments (Experiments 2 and 4, yielding significant effects of Garner interference), and given that pictorial depth has been shown by previous studies to be processed in an automatic manner (Goldfarb & Tzelgov, 2005), our findings do suggest that depth information was at least partially processed and mediated the Garner interference effects found for impossible objects.

The seminal work of Hochberg (1968) suggests that possible and impossible objects are represented in a piecemeal process which rely on the interpretation of local depth cues. Nonetheless, Hochberg also states that perception is broken into different components which involve 'single glance representation' vs. a 'detailed representation that relies on schematic map'. We suggest that the initial perceptual representation of possible and impossible objects could rely on holistic representation, which in turn mediates the Garner interference effects obtained in the present study. Thus, in Hochberg's terms, the Garner interference effect for impossible objects could rely on the 'single glance representation'.

Finally, in the current study, as in other studies that used the Garner paradigm (e.g. Amishav & Kimchi, 2010; Ganel, 2011; Ganel & Goodale, 2003; Pansky & Algom, 1999), only four versions of the same exemplar were used in each experiment. This was done to reduce possible noise stemming from visual differences between different objects. The aim of Experiments 3 and 4 was to address this issue by using different sets of stimuli, in addition to the impossible cube that was used in Experiments 1 and 2.

To conclude, we provide novel evidence for a similar holistic representation mediating the perception of possible and impossible objects. Our results further emphasize the centrality of holistic processing in human perception and suggest that this processing style is applied even for atypical stimuli such as impossible objects.

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