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Global precedence changes by environment: A systematic review and meta-analysis on effect of perceptual field variables on global-local visual processing

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Abstract

Perceptual organization and, in particular, visual processing have been debated for many years. The global precedence effect in local–global visual processing, as introduced by David Navon, refers to the condition that global aspects of a scene are processed more rapidly than are local details. This perceptual dynamic is influenced by many factors that can be divided into two major categories: subjective or internal factors (e.g., age, disorder, culture) and the external factors called perceptual field variables (PFVs; e.g., stimulus size, eccentricity, sparsity). The aim of the current study was to identify the latter factors using a meta-analysis followed by a systematic literature review. In accordance of the standard framework suggested by PRISMA, 28 PFVs were observed through a literature search on articles published from 1982 to 2019, among which 10 factors have been qualified to be included in a meta-analysis. Subsequently, the random effects model proposed by Hedges and Olkin was used to estimate pooled effect sizes of PFVs. These effect sizes were used to compare and sort the PFVs on the basis of their intensity. According to Cohen's index, our analyses show that relevance, sparsity, and solidness type are categorized as small effects; visual field, level repetition, spatial frequency, and shape type are categorized as medium effects; and congruency, eccentricity, and size as large effect PFVs on global precedence.

Keywords Global precedence · Perceptual field variables · Visual perception · Navon task · Hierarchical stimuli · Local–global processing

Our surroundings are globally perceived as wholes that are made up of local parts. To find best solutions for real-world problems, both local and global levels are processed. This important aspect of visual processing is referred to as perceptual organization. The first debates about underlying mechanisms of perceptual organization started in 1977 (Miller, 1981; Navon, 1977) and are still going on. The global precedence effect is one of the most famous admissible phenomena in this area and was introduced about 4 decades ago by Navon (1977). Navon found that individuals more readily identify global aspects of their environment than its local details. The global precedence effect (GP) refers to the finding that global aspects of a scene are processed more rapidly than the local details in the scene.

Research has been conducted in recent decades to investigate aspects of GP. Querying the Web of Science website shows that the number of citations to the papers keyworded for 'global precedence' has increased twice as much during 2010–2018 compared with 2002–2010. After the first tasks invented by Navon, GP has been examined under tremendously diverging circumstances (e.g., unlimited exposure duration; Hoar & Linnell, 2013), three levels of hierarchy (Krakowski et al., 2016), exposed with distractor (Shedden, Marsman, Paul, & Nelson, 2003), and, during sadness (von Mühlenen, Bellaera, Singh, & Srinivasan, 2018). Also, various modalities have been considered in designing GP tasks—auditory (Schiavetto, Cortese, & Alain, 1999), tactile (Heller & Clyburn, 1993), and visual (Navon, 1977). Local–global processing was examined in different varieties of animals, such as insects (Avargues-Weber, Dyer, & Giurfa, 2012), pigeons (Cavoto & Cook,

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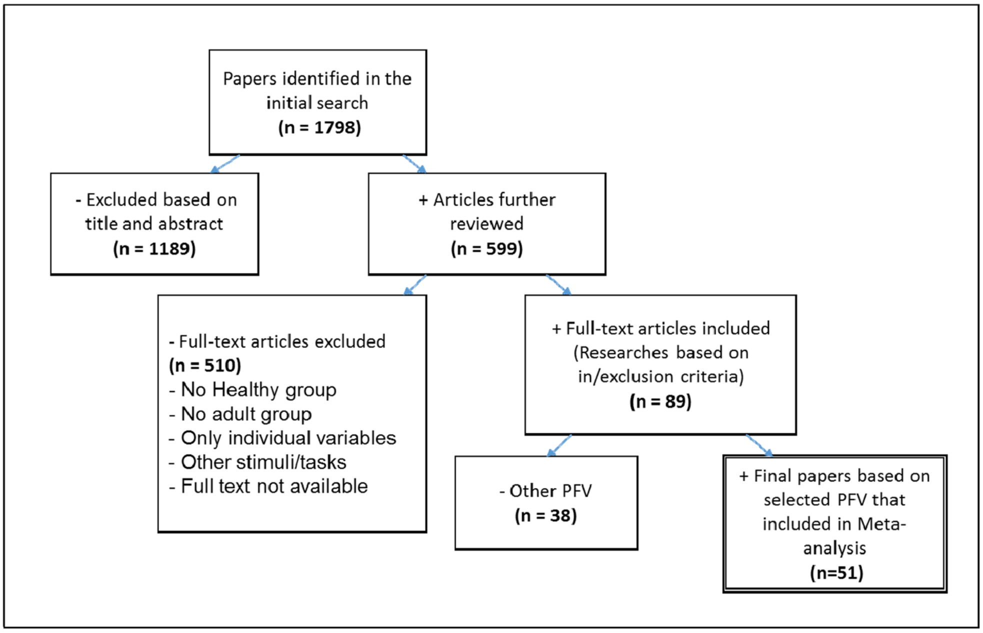


Fig. 1 Summary of selection process, displaying the inclusion and exclusion processes for the meta-analysis

2001), fish (Truppa, Sovrano, Spinozzi, & Bisazza, 2010), dogs (Pitteri, Mongillo, Carnier, & Marinelli, 2014), and monkeys (Tanaka & Fujita, 2000). The variables that affect local–global processing can be divided into two primary categories: (a) individual characteristics, including age (Bruyer & Scailquin, 2000), gender (Muller-Oehring, Schulte, Raassi, Pfefferbaum, & Sullivan, 2007), disorder (Yovel, Revelle, & Mineka, 2005), and culture (Wan, Yang, Liu, & Li, 2016); and (b) perceptual field variables, including stimulus size (Amirkhiabani & Lovegrove, 1996), eccentricity, sparsity (Blanca & Lopez-Montiel, 2009), visual field (Christie et al., 2012), and spatial frequency (Lamb & Yund, 1993).

Much of the literature studies the effect of individual characteristics, but this does not mean that the impact of environmental variables is negligible. Numerous papers have shown the importance of perceptual field variables (Kimchi, 1992), and many of them have studied the effect of these variables on local–global processing. However, a comprehensive review is still required to gain a wider perspective of the effect of multitude factors on local–global processing. The only published meta-analysis in this topic deals with the effect of individual variables on local–global visual processing in patients with autism (Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015).

Table 1 Terminology of perceptual field variables (PFVs)

	PFV	Definition
1	Visual field	The left–right position of stimuli accordance to fixation point. This variable sometimes called “laterality effect” in studies.
2	Eccentricity	Distance of stimuli from eye fixation point, in degrees
3	Congruency	Sameness of shape or letter in both global and local levels. Also known as “consistency effect” in some studies.
4	Sparsity	The ratio of free space between local shapes in global shape.
5	Shape type	Alphabet letters/geometrical shapes (square, circle, triangle, etc.).
6	Size	Scale of global shape in degrees, also called as “visual angel.”
7	Level repetition	Repetition of target level in consecutive trials of Navon-type tasks.
8	Spatial frequency	Abundance of noise versus monotony in stimulus image (e.g., sharpness/blurriness of edges).
9	Solidness type	Whether global shape is filled by local shapes or outlined.
10	Relevance	Conceptual heterogeneity between local and global level.

Table 2 Combined effect sizes for 10 variables (sorted based on effect size). Effect size values for large effect variables are highlighted in the table

	Factor	Total participants	I-square (in %)	Hedge' *g* Random model	95% CI	Cohen's interpretation
1	Congruency	420	32.9	**0.80**	0.65, 0.95	High
2	Eccentricity	82	67.7	**0.79**	−0.2, 1.76	High
3	Size	86	47.7	**0.79**	0.17, 1.41	High
4	Level repetition	351	37.6	0.67	0.46, 0.87	Med
5	Shape type (object vs. letter)	185	55.1	0.62	0.25, 0.98	Med
6	Spatial frequency	214	77.6	0.60	0.18, 1.01	Med
7	Left–right visual field	473	18.9	0.59	0.47, 0.70	Med
8	Solidness type (filled or outlined)	62	58.1	0.40	−0.47, 1.26	Low
9	Sparsity	72	0.0	0.39	0.15, 0.64	Low
10	Relevance	100	0.0	0.33	−1.17, 1.73	Low

In the present paper, we perform a meta-analysis by investigating quantitative results reported in the literature and address the gap in the knowledge about the environmental variables that have an effect on local–global perception. By meta-analysis, we could accurately estimate mean values of effect sizes for each variable across different theoretical approaches and contexts. Our primary objective is to rigorously synthesize, validate, and repeat those studies seeking the most effective perceptual field variable on visual local–global processing. We pursue to answer two questions: (1) Which features of visual stimuli have been literally distinguished by researchers in GP? and (2) Which of them have the most significant effect on GP?

Method

Literature search

The first step is the literature search. We would explore the studies that investigated the effect of variables on local–global processing. In accordance with the standard systematic review framework suggested by PRISMA (Moher, Liberati, Tetzlaff, & Altman, 2009), we conducted both computerized and manual literature searches. In the computerized literature search, we explored titles, abstracts, and keywords in the database of Web of Science (WOS) using a compound Boolean operation: ("global precedence" OR "local precedence" OR "local * global process*" OR "global advantage*" OR (Navon AND (Forest OR tree*)) OR "Wholistic * analytic" OR "global preference" OR "local preference" OR "local * interference" OR "global * interference" OR "hierarchical stimul*" OR "percep* bias").

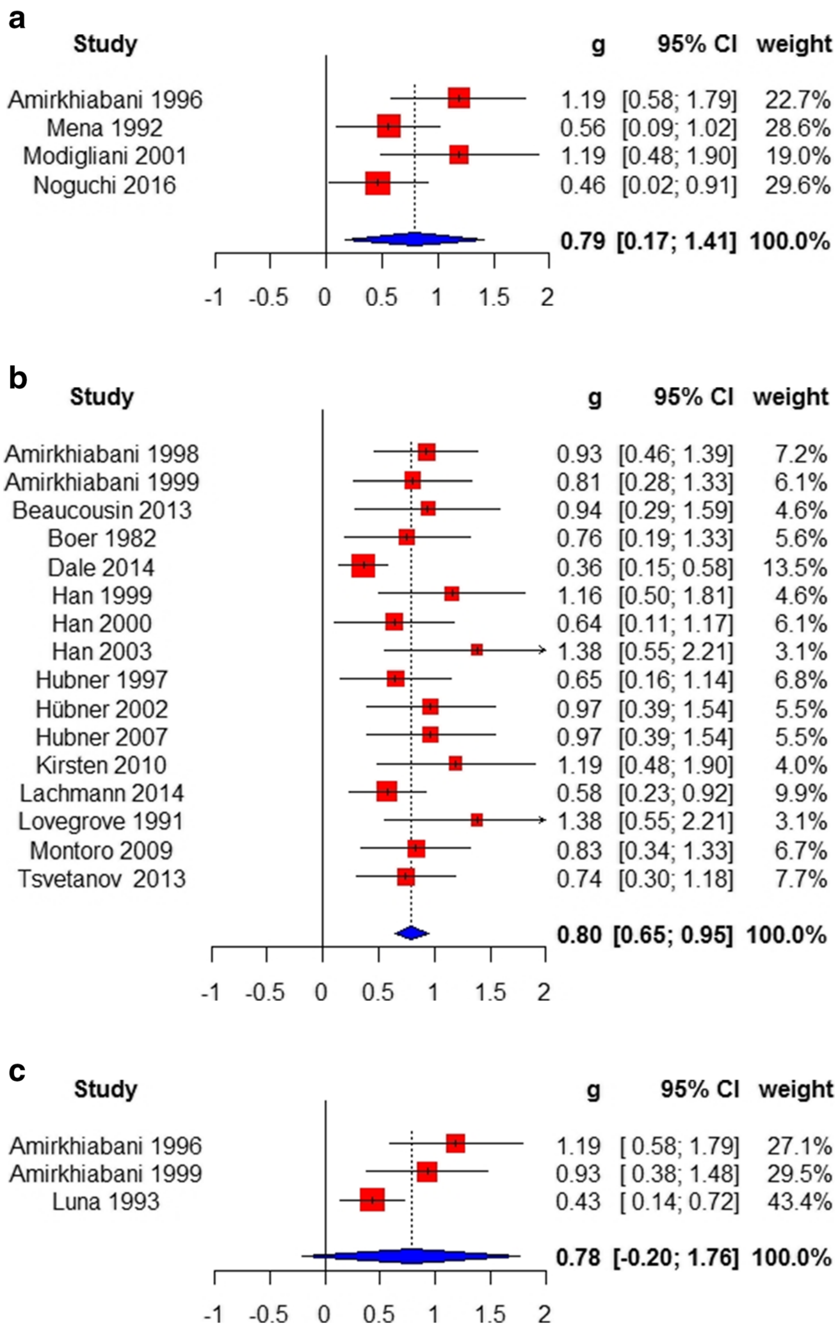
The computerized search covered a wide time span—from 1982 (the earliest available paper on our subject) to May 2019—that resulted in 1,798 hits. The broad set of keywords produced many false hits, but at the same time warranted the inclusion of most relevant research material. The manual literature search consisted of a search on references of review articles and the primary study articles and did not yield any additional research material that was missed in the computerized search. Before continuing to the next step, we were required to select a primary set of visual features, as follows.

Perceptual field variables

Within the screened literature, we could distinguish terms referring to the variables that were not related to individual differences but depended only on characteristics of environment and task features, so we called them perceptual field variables (PFVs). The primary set of distinguished PFVs is described in Appendix 1 Table 3.

Inclusion and exclusion criteria

Titles, abstracts, and, when necessary, full article texts were screened with strict inclusion criteria. We included only studies from published journal articles in English that investigated the effect of at least one PFV on at least one group of typically developing individuals. Master theses, doctoral theses, or conference presentations were not included. We limited the analysis to experimental studies that employed a behavioral task on local and/or global processing with static, nonface hierarchical stimuli in the visual modality; thus, the papers on motion perception and on face perception were excluded. Neuroimaging



a

Study	g	95% CI	weight
Amirkhiabani 1996	1.19	[0.58; 1.79]	22.7%
Mena 1992	0.56	[0.09; 1.02]	28.6%
Modigliani 2001	1.19	[0.48; 1.90]	19.0%
Noguchi 2016	0.46	[0.02; 0.91]	29.6%
	0.79	**[0.17; 1.41]**	**100.0%**

b

Study	g	95% CI	weight
Amirkhiabani 1998	0.93	[0.46; 1.39]	7.2%
Amirkhiabani 1999	0.81	[0.28; 1.33]	6.1%
Beaucousin 2013	0.94	[0.29; 1.59]	4.6%
Boer 1982	0.76	[0.19; 1.33]	5.6%
Dale 2014	0.36	[0.15; 0.58]	13.5%
Han 1999	1.16	[0.50; 1.81]	4.6%
Han 2000	0.64	[0.11; 1.17]	6.1%
Han 2003	1.38	[0.55; 2.21]	3.1%
Hubner 1997	0.65	[0.16; 1.14]	6.8%
Hübner 2002	0.97	[0.39; 1.54]	5.5%
Hubner 2007	0.97	[0.39; 1.54]	5.5%
Kirsten 2010	1.19	[0.48; 1.90]	4.0%
Lachmann 2014	0.58	[0.23; 0.92]	9.9%
Lovegrove 1991	1.38	[0.55; 2.21]	3.1%
Montoro 2009	0.83	[0.34; 1.33]	6.7%
Tsvetanov 2013	0.74	[0.30; 1.18]	7.7%
	0.80	**[0.65; 0.95]**	**100.0%**

c

Study	g	95% CI	weight
Amirkhiabani 1996	1.19	[0.58; 1.79]	27.1%
Amirkhiabani 1999	0.93	[0.38; 1.48]	29.5%
Luna 1993	0.43	[0.14; 0.72]	43.4%
	0.78	**[-0.20; 1.76]**	**100.0%**

Fig. 2 Forest plots for size (**a**), congruency (**b**), and eccentricity (**c**)

and electroencephalographic studies were included only if a behavioral task was employed. In addition, we excluded articles in which any measure of behavioral outcome—whether in terms of accuracy, error rates, or reaction times (RT)—was not summarized in the article body or in the appendices.

We recognized about 94.5% of the articles obtained by computer-assisted search as false-positive hits. Four criteria were most frequently cause for exclusion: (a) the article did not discuss local and/or global processing in visual modality, (b) the article did not administer the task to typically developed adults, (c) the article did not employ visual Navon tasks with hierarchical stimuli, and (d) the article did not report behavioral results except by graphs or figures. An overview of the inclusion and exclusion process is shown in Fig. 1.

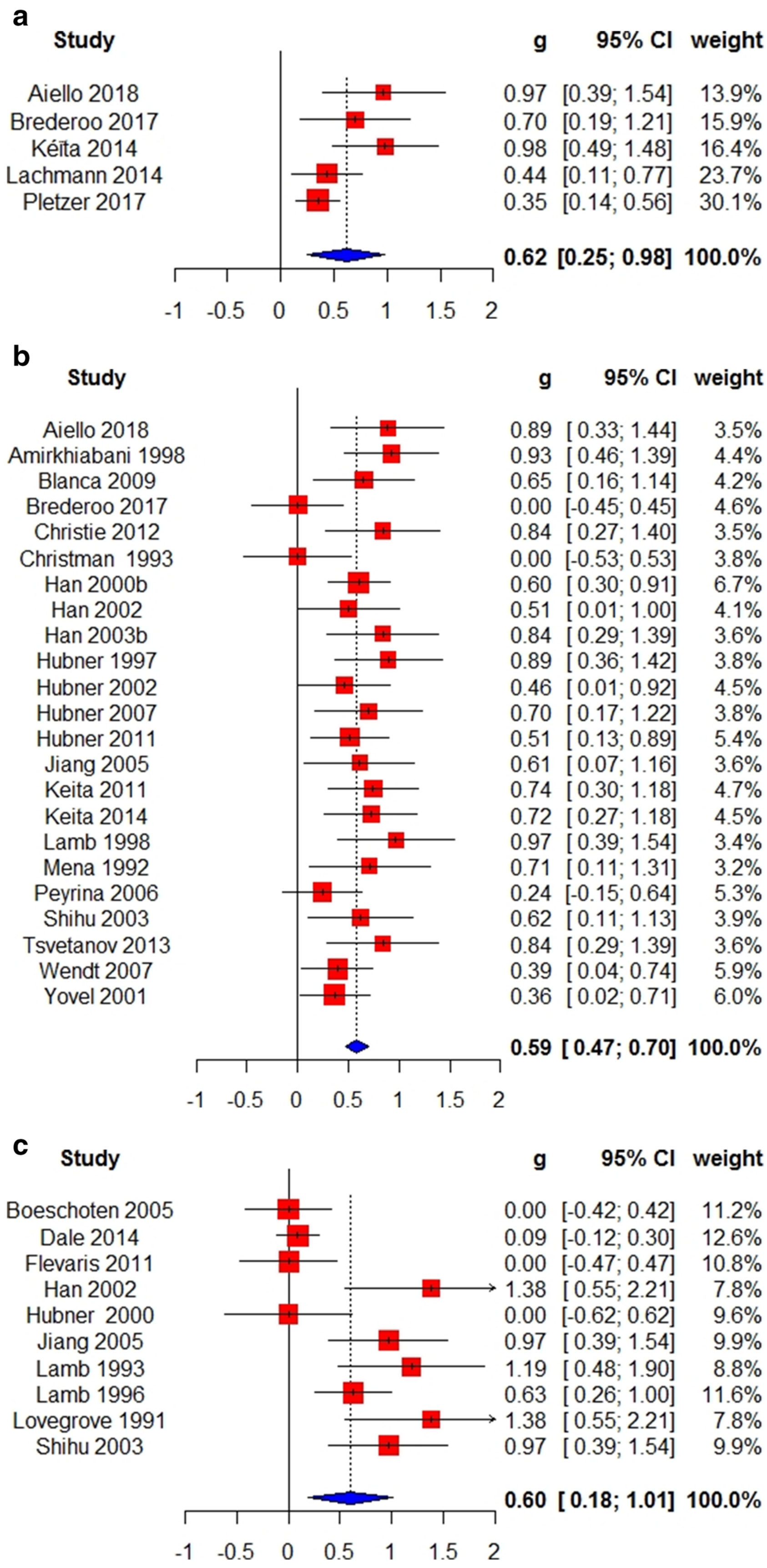


Fig. 3 Forest plots for shape type (**a**), visual field (**b**), spatial frequency (**c**), and level repetition (**d**)

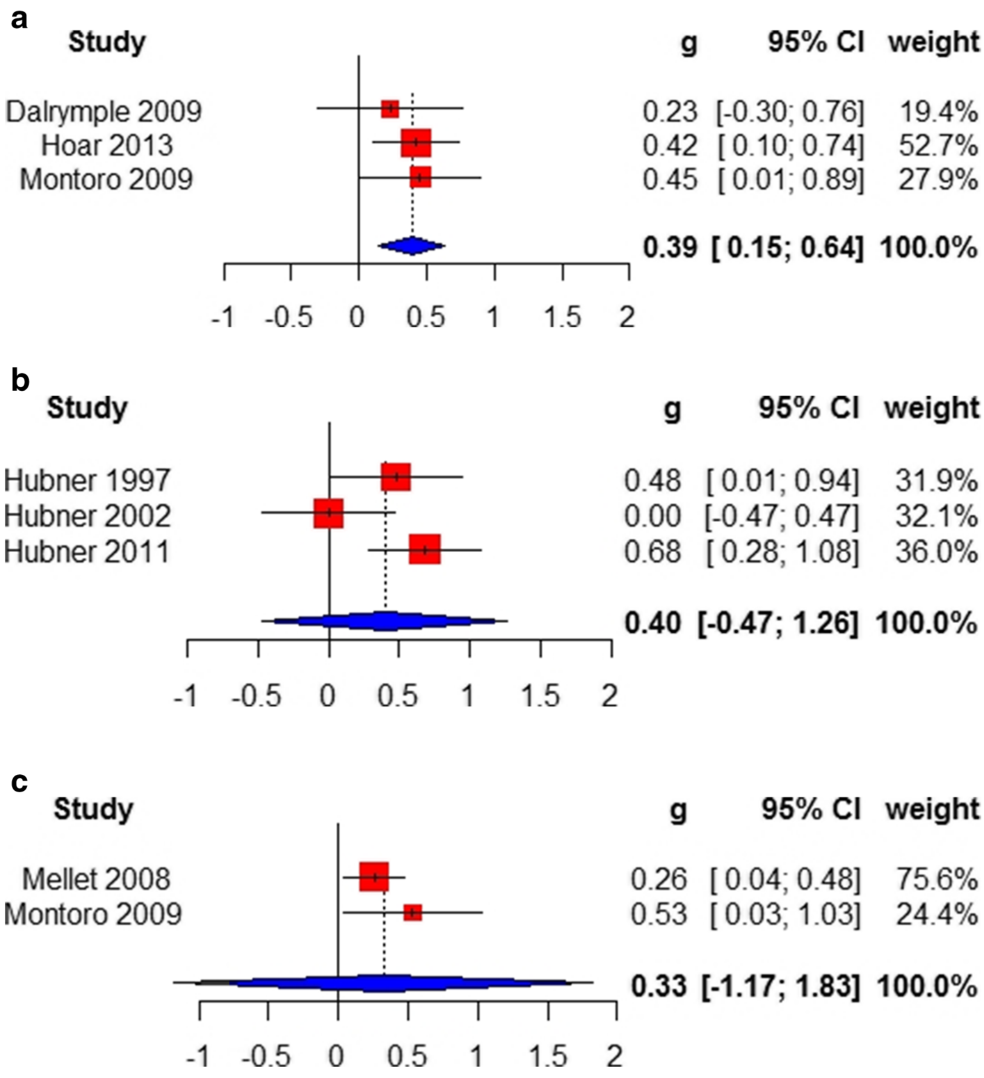


Fig. 4 Forest plots for sparsity (**a**), solidness type (**b**), and relevance (**c**)

Coding

The screened articles were coded by the first author by publication year. The selected 86 articles were coded according to the perceptual field variables for which the variations were considered during the hierarchical task. We call this coding PFV factor. We then grouped the studies based on the coding perceptual field variable. Note that each study may be included in more than one group.

For each study, the task performance was coded by sample sizes and a set of descriptive statistics on RTs. For each study and for each coding PFV, we obtained the effect size using Hedges's *g* statistic, which is calculated based on the sample size, mean, standard deviation, and *p* value (Hedges & Olkin, 2014). To accommodate the issue of missing *p* values for null reports, we assumed a *p* value equal to 1. We did not contact any of the authors to request missing data.

Data analysis

For each observation, using the descriptive statistics, we calculated Hedges's *g*, which is an estimation of the difference in population means divided by the common standard deviation, assuming a common variance under both conditions. A standard correction to Hedges's *g* was applied to account for a bias for small sample size (Hedges, 1981). In addition, we estimated the standard error of each observation to determine the weight of each effect size. All calculations and conversions were done using scripts in the R 'metafor' package (Viechtbauer, 2010). Significant tests were considered at a level of 0.05.

Essentially, meta-analytic calculations include at least two different models—namely, fixed and random effects. In principle, a fixed-effect model should be used when the studies share identical data collection conditions and a single value for the true effect is known. Thus, using a fixed effect generally produces less variance and tighter confidence intervals. On the other hand, a random-effect model should be used when the study conditions are expected to vary, and the distribution for the true effect is known. Our data clearly suggests dissimilar conditions with varying variable details and different cultures and demographics amongst the respondents; thus, it is reasonable to employ a random-effects meta-analysis. We used the approach of Hedges and Olkin (2014) on a random-effects model (Borenstein, Hedges, Higgins, & Rothstein, 2011; Larry & Ingram, 1985).

Results

Literature searches yielded 1,798 articles, which, when applying inclusion and exclusion criteria, were reduced to 89 articles. We reviewed full texts of the papers and labeled each one based on related PFVs. The systematic review revealed that only one study specifically discussed PFVs. In addition, we found PFVs that have been studied by numerous researches, but through different experimental designs; some remarkable paradigms were "priming." "multilevel stimulus," and "distractor" effects. We removed these PFVs for the rest of analysis, so that 10 PFVs (see Table 1) remained out of the 28 in our primary set. For only these 10 PFVs did we have studies satisfying the required conditions for a proper meta-analysis. Finally, 51 studies out of the 89 articles published in 1982–2019 were recognized to be eligible for the meta-analysis based on 10 PFVs. Figure 1 illustrates the selection process. Characteristics of studies included in our meta-analysis are depicted in Appendix 2 Table 4.

Meta-analysis

To explore and compare the effect of perceptual field variables on local–global processing, meta-analyses were performed in 10 categories: visual field (left or right), level repetition, relevance, sparsity, solidness type (filled or outlined), congruency, eccentricity, size (visual angle), spatial frequency, and shape type (object vs. letter). In Table 2, the I-square column summarizes the results of heterogeneity test for each category. Visual field, relevance, sparsity, and eccentricity have low heterogeneity; and level repetition, solidness type (filled or outlined), congruency, and size (visual angle) have moderate heterogeneity; and spatial frequency and shape type (object vs letter) have intense heterogeneity. The weighted effect sizes and corresponding forest plots are shown in Figs. 2, 3, 4, respectively, for the PFVs with low, moderate, and intense heterogeneity. The combined effect size for each PFV is shown in Table 2.

Discussion

Effect size (Hedges's *g*) for every variable indicates the intensity of the variable effect (see Table 2). Based on (Cohen, 1988), if Hedges's *g* is less than 0.5, intensity of the variable is recognized as a small effect; between 0.5 to 0.8 as a medium effect; and more than 0.8 as a large effect variable. According to this classification, relevance, sparsity, and solidness type are in the small effect variables group. Visual field, level repetition, spatial frequency, and shape type has a medium effect; and congruency, eccentricity, and size has a large effect. It should be noted that an estimation of combined effect size for the high heterogeneity variable spatial frequency would be considered unbiased due to usage of a random-effect model.

Meta-analysis is a statistical approach to obtain an aggregated result from multiple scientific studies in an effort to increase power and resolve conflicts among studies. In the present paper, we used PRIMSA framework to perform a systematic review and meta-analyses concerning the effect of perceptual field variables on global precedence. We determined 10 PFVs commonly used in the literature of GP and categorized them into three classes of effect sizes.

The effect sizes shown in Table 2 could be used as a reference for evaluation of effect sizes computed by future empirical studies. In fact, any plausible model for visual perception could explain the large effect of size, eccentricity, and congruency. These PFVs are not limited to GP, meaning that they would be interesting for any research that generally concerns visual perception. For example, in visual search, Carrasco and Yeshurun (1998) have shown that size and eccentricity are large effect variables. Moreover, emotion identification tasks are affected by global precedence, and thus large effect PFVs should be regulated in those experiments (e.g., it has shown that local perception facilitates identification of a sad face; Srinivasan & Hanif, 2010); thus, size of face stimuli should be controlled in these tasks.

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Appendix 1

Table 3 List of all 28 PFVs with short descriptions

	PFV	Task/stimulus design	Short description
1	Visual field	S	The left–right position of stimuli accordance to fixation point.
2	Eccentricity	S	Distance of stimuli from eye fixation point in degrees.
3	Congruency	S	Sameness of shape or letter in both global and local levels.
4	Sparsity	S	The ratio of free space between local shapes in global shape.
5	Shape type	S	Alphabet letters/geometrical shapes (square, circle, triangle, etc.)
6	Size	S	Scale of global shape in degrees, also called as “visual angel.”
7	Level repetition	T	Repetition of target level in consecutive trials of Navon-type tasks.
8	Spatial frequency	S	Abundance of noise versus monotony in stimulus image.
9	Solidness type	S	Whether global shape is filled by local shapes or outlined.
10	Relevance	S	Conceptual heterogeneity between local and global levels.
11	Exposure duration	T	Stimulus representing time length.
12	Form quality	S	Stimulus qualification appearance.
13	Component meaningfulness	S	Whether local–global level parts have meaning or not.
14	Saliency	S	Manipulating the stimulus aspect’s prominence to stand out from the rest.
15	Goodness of form	S	The quality of stimulus base on participant’s ratings.
16	Geometric shape	S	Type of basic geometric pattern (circle, square, etc.).
17	Color	S	Background or stimulus color (hue) in appearance.
18	3 levels of hierarchy	T	Hierarchical pattern that has two levels (global and local) in local parts.
19	Divided attention/selective attention task	T	Type of attention paradigm involved in task design of experiment.
20	Attend/nonattend stimulus	T	Whether participant attended to stimulus or not.
21	Priming	T	Using implicit memory effect in which exposure to a stimulus influences response to a later stimulus.
22	Masking/attentional window	T	Tasks involve presenting one visual stimulus (a “mask” or “masking stimulus”) immediately after another brief (usually 30 ms) “target” visual stimulus, resulting in a failure to consciously perceive the first stimulus. / Instructing observers to either diffuse their attention across the visual field.
23	Similarity/ nonsimilarity	S	Likeness rate between two local–global levels.
24	Motion	T	Tasks involve animated stimuli.
25	Cognitive load	T	Tuning the task complexity to control the used amount of working memory resources during the task.
26	Using distractor	T	Using external stimuli, diverting of the attention of an individual or group from the chosen object of attention onto the source of distraction.
27	Dual tasking	T	Doing two or more tasks at a certain time, simultaneously.
28	Cueing	T	Using external stimuli leading the brain to engage in a particular perceptual process.

Appendix 2

Table 4 Characteristics of the studies included in the analyses

	Research ID	# of subjects	Visual field	Spatial frequency	Solidness type	Relevance	Level repetition	Size	Sparsity	Congruency	Shape type	Eccentricity
1	Aiello et al. 2018	16	*								*	
2	Amirkhiabani and Lovegrove 1996	17						*				*
3	Amirkhiabani 1998	24	*							*		
4	Amirkhiabani and Lovegrove 1999	17								*		*
5	Beaucousin et al. 2013	12								*		
6	Blanca 2009	33	*									
7	Boer and Keuss 1982	14								*		
8	Boeschoten et al. 2005	20		*								
9	Brederoo et al. 2017	17	*								*	
10	Christie 2012	12	*									
11	Christman 1993	16	*									
12	Dale and Arnell 2014	86		*						*		
13	Dalrymple et al. 2009	12							*	*		
14	Flevaris et al. 2011	16		*								
15	Han et al. 1999	14								*		
16	Han et al. 2000a	14					*			*		
17	Han et al. 2000b	14	*									
18	Han et al. 2002		14*	10*								
19	Han and He 2003	10								*		
20	Han et al. 2003	16	*	*								
21	Hoar and Linnell 2013	40							*			
22	Hubner 1997	18	*		*					*		
23	Hubner 2000	8		*			*					
24	Hubner and Malinowski 2002	16	*		*					*		
25	Hubner et al. 2007	16	*							*		
26	Hubner and Kruse 2011	28	*		*		*					
27	Jiang and Han 2005		12*	16*								
28	Keita and Bedoin 2011	32	*									
29	Keita et al. 2014	22	*				*				*	
30	Lachmann et al. 2014	37								*	*	
31	Lagasse 1993	18						*				
32	Lamb and Robertson 1988	16	*									
33	Lamb 1993	12		*								
34	Lamb and Yund 1996	32		*			*					
35	List et al. 2013	91					*					
36	Lovegrove et al. 1991			10*						86*		
37	Luna 1993	48										*
38	Poirel et al. 2008	80				*	*					
39	Mena 1992	19	*					*				
40	Modigliani et al. 2001	12						*				
41	Montoro and Luna 2009	20				*			*	*		

Table 4 (continued)

	Research ID	# of subjects	Visual field	Spatial frequency	Solidness type	Relevance	Level repetition	Size	Sparsity	Congruency	Shape type	Eccentricity
42	Noguchi and Tomoike 2016	20						*				
43	Paquet 1994	40					*					
44	Peyrin et al. 2006	24	*									
45	Pletzer et al. 2017	93									*	
46	Robertson 1996	15					*					
47	Schatz and Erlandson 2003	21					*					
48	Tsvetanov et al. 2013	24	*							*		
49	Wendt e al. 2007	18	*									
50	Yovel et al. 2001	48	*									
	Sum	1398	473	214	62	100	351	86	72	420	185	82

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