Vision Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Local-global processing bias is not a unitary individual difference in visual processing

Rebecca Chamberlain [a,b,*], Ruth Van der Hallen [a], Hanne Huygelier [a], Sander Van de Cruys [a], Johan Wagemans [a]

[a] Laboratory of Experimental Psychology, KU Leuven, Tiensestraat 102, Box 3711, Leuven 3000, Belgium
[b] Department of Psychology, Goldsmiths University of London, 8 Lewisham Way, New Cross, London SE14 6NW, United Kingdom

ARTICLE INFO

Article history:
Received 14 July 2016
Received in revised form 19 December 2016
Accepted 25 January 2017
Available online xxxx

Keywords:
Local-global processing
Perceptual style
Individual differences

ABSTRACT

A large body of research reports individual differences in local and global visual processing in relation to expertise, culture and psychopathology. However, recent research has suggested that various different measures of local-global processing are not strongly associated with one another, calling its construct validity into question. The current study sought to further explore the validity of local-global processing biases in perception by developing three tasks based on two existing paradigms: the Embedded Figures Test (EFT) and the Navon hierarchical letters task. The newly developed tasks aimed to control for stimulus and response factors that may have impacted upon the reliability of previous research. They were administered to a large sample of undergraduate students (N > 100). The results of two new versions of the EFT indicated that disembedding performance is influenced by the structure of the embedding context. In addition, global precedence and interference in the Navon task remained present even when local attentional approaches to global hierarchical stimuli were restricted. Inter-task correlations within the EFT were high but low between the EFT and the Navon task, lending support to the notion that local-global processing is not a monolithic construct, but representative of a number of distinct perceptual abilities and biases. Future research may use these task distinctions to pinpoint more precisely which aspects of perceptual processing characterise specific (clinical) participant populations.

1. Introduction

The popular notion that we see the forest before the trees is an established and pervasive dogma in perceptual psychology. Sensitivity to global structure in an environment in which visual information must be parsed into scenes and objects is crucial and disruption of this process is often associated with psychopathology. Consequentially, **perceptual organization** is seen as a necessary aspect of healthy perception and a great amount of research is dedicated to understanding the universal perceptual organizational principles of the human visual system (for comprehensive reviews, see Wagemans, Elder, et al., 2012; Wagemans, Feldman, et al., 2012). A parallel stream of research explores the **differentiation of individuals** on the basis of the strength of perceptual organization at multiple stages of perceptual processing. This has led to the development of experimental paradigms that measure the degree to which individuals can construct global representations and can extract local detail from global form. An underlying assumption in this line of research is that individuals are characterized by a certain *perceptual profile or style*, with variable degrees of global and local bias. The investigation of perceptual style enables researchers to discover how perceptual organization varies as a function of experience, psychopathology, culture or genetics (Bellgrove, Vance, & Bradshaw, 2003; Caparos, Linnell, Bremner, de Fockert, & Davidoff, 2013; Davidoff, Fonteneau, & Fagot, 2008; de-Wit & Wagemans, 2015; Lewis & Dawkins, 2015; Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015). For example, it has been shown that individuals with autism spectrum disorder (ASD) show slower responses to global structure (Van der Hallen et al., 2015) or enhanced lower processing ability (Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Muth, Hönekopp, & Falter, 2014), that artists and musicians demonstrate enhanced local visual processing (Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013; Drake & Winner, 2011; Stoesz, Jakobson, Kilgour, & Lewycky, 2007) and that remote cultures

* Corresponding author at: Department of Psychology, Goldsmiths University of London, 8 Lewisham Way, New Cross, London SE14 6NW, United Kingdom.
E-mail address: r.chamberlain@gold.ac.uk (R. Chamberlain).

http://dx.doi.org/10.1016/j.visres.2017.01.008
0042-6989/© 2017 Elsevier Ltd. All rights reserved.

show a reduction in global bias associated with reduced exposure to urbanised environments (Caparos et al., 2012).

Witkin first coined the terms **field-dependence and field-independence** to refer to individuals with a stronger global and local bias, respectively (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). He argued that field dependence could be measured through tests such as the Rod-and-Frame Test (RFT; Witkin & Asch, 1948) and the Embedded Figures Test (EFT; Witkin, Oltman, Raskin, & Karp, 1971). Individuals who performed better on the RFT and EFT were argued to be more field-independent, as they could discount contextual information and focus on local elements of the visual field. Witkin et al. (1954) found that individual differences in performance for these tasks were stable across time and predicted individual differences in personality. The presence of a general bias for global relations between local parts, notwithstanding individual differences in that bias, was also probed in seminal studies by Navon (1977, 2003) using hierarchical letters (Fig. 1). These hierarchical letters could be congruent or incongruent, with the global level being the same or different, respectively, from the local elements that constitute it. In this way it was possible to assess the impact of incongruence on both local and global processing. This paradigm has revealed that participants respond faster and more accurately to global hierarchical structure (global precedence) and encounter interference from the global level when responding to the local elements (global interference; Navon, 1977, 2003).

Milne and Szczerbinski (2009) conducted a comprehensive review and investigation of the factorial structure of individual differences in local and global processing. When analysing inter-task correlations in a large battery of local-global tasks[1] taken by 90 participants, the authors found the pattern of correlations to be relatively diffuse. Only two meaningful factors were extracted from a factor analysis of the data: disembedding (upon which the Block Design Task and the EFT loaded significantly) and global bias (upon which slow performance on local trials and accurate performance on global trials in the Navon task loaded significantly). The authors argued that the construct of local and global visual processing is marred by conceptual and terminological inconsistencies. They identified a prevailing assumption in the literature that field-independence and the closely related construct of Weak Central Coherence, used to characterise the reduced global bias in ASD (Happé & Frith, 2006), are assumed to relate to reduced global processing in tasks like the Navon. However, given that the tasks in this study demonstrated little common variance, they concluded that this assumption is false and that the primary factor extracted from the data (disembedding) demonstrated the most conceptual overlap with field-independence and Weak Central Coherence. This factor was independent of the majority of the tasks included in the study ostensibly measuring either local or global processing.

In line with the field-dependence/-independence continuum, Dale and Arnell (2013) recently probed the validity of using one's bias for Navon figures as a proxy for global and local visual processing biases in general. They tested 60 participants on a classic Navon paradigm, a Navon matching paradigm and a face matching task in which spatial frequency was manipulated. Test-retest reliability was high for global bias in the face and Navon letter matching tasks, but was fairly weak for global bias in the standard Navon letter task. There were no significant inter-task correlations for global bias. The results of this study suggest that, although individual differences in performance on individual tasks intending to measure global bias are relatively stable, the convergent validity is questionable.

The research discussed here has called into question the convergent validity of local-global processing tasks as well as the stability of the concept itself. However, a prevailing issue with existing tasks measuring local-global processing is that they were developed some years ago and lack the control and specificity of many contemporary paradigms in vision research. For example, the Group-EFT or G-EFT used in Milne and Szczerbinski (2009) study was a pencil and paper task with only 18 trials that varied unsystematically in their complexity, meaningfulness and three-dimensionality. Therefore, in the current study, two paradigmatic local-global visual processing tasks were selected and modified: the EFT and the Navon task.

An alternative **Leuven Embedded Figures Test** (L-EFT) has already been developed to address lack of stimulus control in the G-EFT (de-Wit, Huygelier, Van der Hallen, Chamberlain & Wagemans, in press). The new version aims to measure individual differences in perceptual disembedding in isolation from other factors involved in task performance on the original EFT such as executive function and intelligence (Huygelier, Chamberlain, Van der Hallen, de-Wit, & Wagemans, 2015). In the current study two additional modified L-EFTs are presented which focus on the impact of meaningful and three dimensional complex contexts (M-EFT and D-EFT, respectively). These issues are particularly pertinent to two subdomains of individual differences in perceptual organization: ASD and artistic expertise and as such may be able to provide an explanation for why specific populations perform better on the EFT.

Individuals with ASD have previously been found to outperform controls on the G-EFT, a pencil and paper variant of the EFT that can be administered to groups of participants at one time (Brosnan, Gwilliam, & Walker, 2012; Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). It should be noted however that existing reviews and meta-analyses have produced a heterogeneous picture of the relation between ASD diagnosis and performance on the EFT as well as other tasks ostensibly measuring local visual processing (Dakin & Frith, 2005; Happé & Frith, 2006; Mottron et al., 2006; Muth et al., 2014; Van der Hallen et al., 2015). With respect to the EFT, this could be due to the different kinds of context used within the original G-EFT and subsequent versions of it, such as the children's EFT used in the first study showing a relation between ASD diagnosis and EFT performance (Shah & Frith, 1983). Embedding contexts within the original forms of the EFT include a mixture of meaningful and non-meaningful stimuli. Adjusting the meaningfulness of the context should alter disembedding performance in healthy controls because a unified meaningful stimulus is more difficult to interpret in terms of local parts (especially when these are not typical object parts). One potential reason for the advantage shown by individuals with ASD could be that they are less distracted by a semantically meaningful context, making it easier for them to locate an embedded target. A consequential prediction for individuals with ASD is that the meaningfulness of the complex context will not impact performance to as great an extent, in much the same way as segmentation of a Block Design does not provide as great an advantage to individuals with ASD in comparison with controls (Shah & Frith, 1993). However, it could also be the case that they do not cohere the objects in the embedding contexts whether meaningful or not. Under this interpretation, they could outperform healthy controls on both meaningful and non-meaningful context trials, but it is not possible to dissociate these two explanations using existing forms of the EFT.

In a somewhat similar way to the debate surrounding perceptual processing in ASD, it has also been shown that artists outperform non-artists on the G-EFT (Chamberlain et al., 2013; Drake &

[1] Tasks included in Milne and Szczerbinski (2009) were: the Group Embedded Figures Test (G-EFT), the Block Design Task, the Hidden Patterns Test, the Gestalt Completion Test, the Copying Test, VOSP silhouettes, Spot the Difference, the Rey Osterrieth Complex Figure, the Navon task, the Muller-Lyer illusion, Kanizsa illusory surfaces, visual search, impossible figures, the Good Form Test, global coherent form and motion, choice RT and verbal and performance IQ.

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

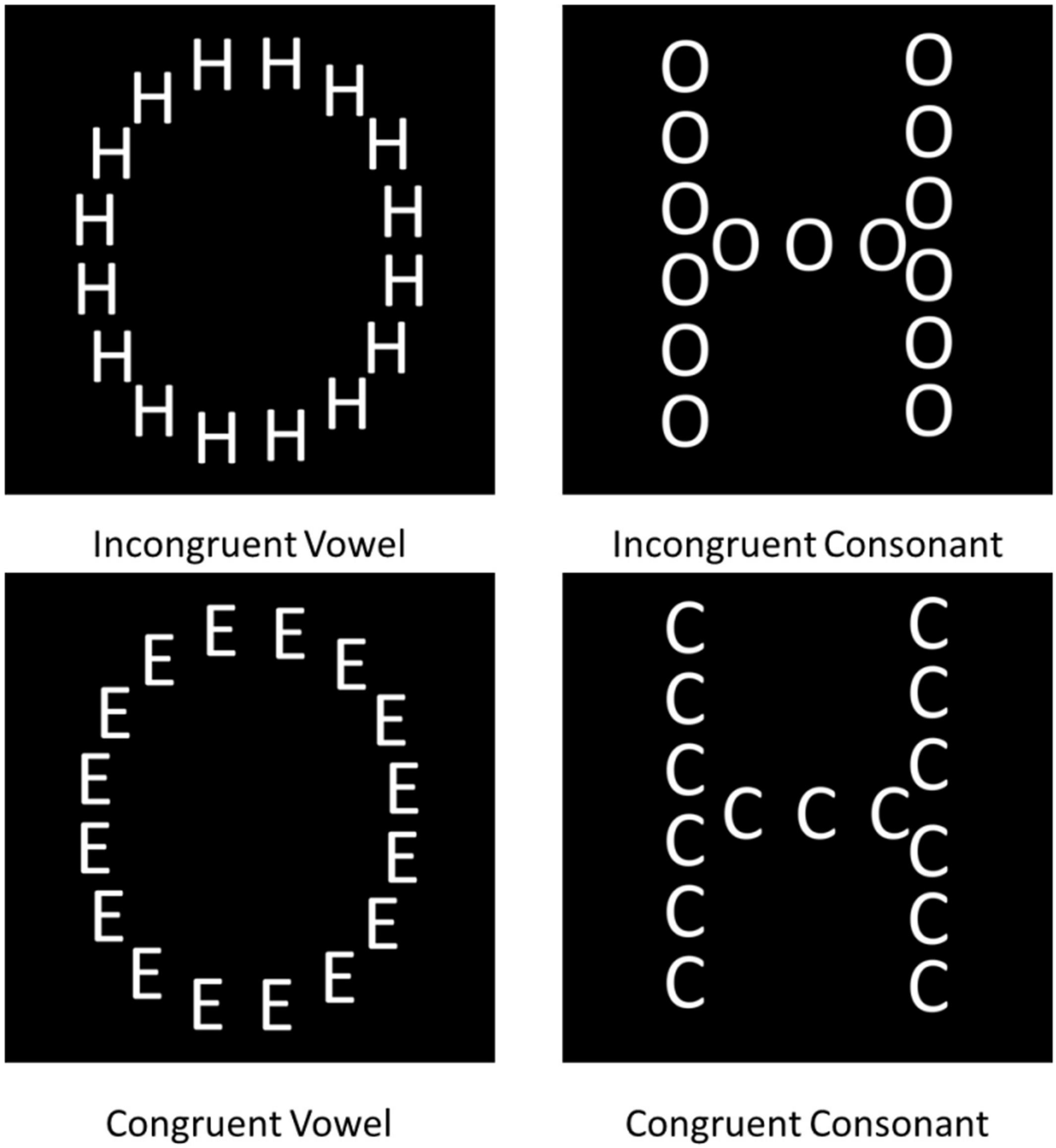

Fig. 1. Example stimuli from the global condition of the Navon selective attention task.

Winner, 2011; Pring, Ryder, Crane, & Hermelin, 2010). It was observed that some items from the G-EFT had 3D qualities to them, potentially making it more difficult to extract the embedded figure, especially if the target crossed depth boundaries within the complex context. As visual artists are accustomed to 'flattening out' a visual scene in order to create a 2D depiction of it, it can be predicted that artists show advantages in the EFT because they can see the 3D as a 2D representation and thus more easily locate the embedded figure. In this instance, it would be predicted that artists would show a smaller difference in performance between 2D context and 3D context trials in much the same way as individuals with ASD would show little difference between meaningful and non-meaningful trials. Again, existing forms of the EFT cannot address this issue in a systematic way due to the fact that they are comprised of low numbers of highly heterogeneous stimuli.

The **Navon task** was also modified in the current study. The Navon task used in previous paradigms with either letters typically only incorporates two or three different letters (Hills & Lewis, 2008; Plaisted, Swettenham, & Rees, 1999), making the task of identifying such letters very easy. In addition, the Navon stimuli are typically presented at a fixed position on the screen, enhancing the probability of participants using local rather than global cues to identify the letters[2]. These factors may have underestimated the precedence of global properties of the stimulus, as the degree of global bias is modulated by the degree of spatial certainty and central vs. peripheral fixation (see Kimchi, 2015 for a review of global precedence boundary conditions). This may be of particular concern when using this task in populations with ASD, where they may have a tendency to focus spontaneously on local rather than global stimulus features. Therefore, in the current study a Navon task was developed that restricted participants' ability to take a local attentional approach to the task in conditions in which a global attentional focus was required, by varying the location of the stimulus randomly around fixation and by asking participants to make a judgement based on higher-order stimulus properties other than letter identity.

[2] When the stimulus is always presented at the same position, it is easier to focus attention locally on the small-level letter at that position. When the stimulus position is jittered around fixation, the same local letter might not always be equally well visible at fixation. The perception of the global letter (based on the overall outline, perhaps based on the low spatial frequencies) will be much more stable for small position changes.

This ensured the use of global processing for successful task performance rather than different forms of local processing and as such represents a purer measure of perceptual processing in which both local and global levels are perceived and evaluated to the same extent. In turn, this is likely to reduce noise in the data owing to different participants using different attentional strategies to perform the task.

To summarize, **the aim of the current study** was to develop and test a series of tasks that measured the convergent validity of biases in local and global visual processing in order to shed light on individual differences in perceptual organization. It was hypothesized that the experimental manipulations in the M-EFT and the D-EFT would impact participants' accuracy rates and reaction times. More specifically, in the M-EFT it was predicted that meaningfulness of the embedding context would impair the ability to find the target, which would result in lower accuracy and slower reaction times. In the D-EFT it was predicted that three-dimensionality would impair the ability to find the target, resulting in lower accuracy and slower reaction times. For the Navon task it was hypothesized that participants would show a global precedence and global interference effect, manifest in faster and more accurate responses to global attention trials compared to local attention trials and in lower accuracy and slower reaction times for congruent vs. incongruent trials in a local attention condition. In terms of inter-task correlations, it was hypothesized that performance in the D-EFT and M-EFT would correlate with one another. On the basis of previous research (Dale & Arnell, 2013; Milne & Szczerbinski, 2009) it is likely that inter-task correlations between the EFTs and global precedence and interference in the Navon task will be weak. However, we predicted that they might be stronger than was revealed in previous research because the tasks we developed likely represent purer measures of local and global visual processing as they reduce executive processing demands and the use of strategies to enhance task performance.

2. Method

2.1. Participants

The sample consisted of first year undergraduate psychology students at KU Leuven. Participants were tested on a battery of tasks in groups of approximately 15 students in return for course credit. Table 1 provides an overview of the sample sizes and demographic characteristics of each group by task.

2.2. Procedure

All participants were tested within one hour in a quiet, dimly lit testing room. Computer tasks were performed on a set of identical Dell Inspiron desktop computers with a 23″ monitor. Participants completed the battery of tasks in a randomized order to reduce the influence of practice and/or order effects.

2.2.1. Navon selective attention task

The Navon task was a modified version of a hierarchical letter paradigm (Navon, 1977), designed to reduce the potential influence of factors confounding global processing such as spatial location and variation in shape characteristics. Participants were required to distinguish whether a global letter shape made up of local letters or the local letters themselves were vowels or consonants (Fig. 1). Vowel and consonant letter shapes were kept as comparable as possible. There were 5 consonant types (C, D, F, H, T) and 5 vowel types (A, E, I, O, U). Trial congruency was defined by the category type (vowel/consonant). In some congruent trials the exact letter identity matched between local and global stimulus levels, whilst in all other congruent trials only the category type matched. Presentation location of the test stimulus was randomized on a trial-by-trial basis, in order to eliminate the ability of participants to fixate on local spatial locations to determine global shape. The stimulus was presented in one of four corners of a 100×100-pixel square around central fixation. There were 10 practice trials followed by two blocks of 100 experimental trials. In alternate blocks whose order was randomized, participants were instructed to either focus on the global letter shape (global selective attention) or on the local letter shapes (local selective attention) and press the 'J' key if the letter was a vowel, and the 'F' key if the letter was a consonant. Each trial began with a fixation cross presented for 1000 ms. The fixation cross then disappeared and was followed by the experimental stimulus (a white letter shape on a black background). The stimuli were presented for 300 ms followed by a 4 s response window. Feedback was presented in the form of a coloured (red/green) fixation cross which also encouraged central fixation for the next trial. Both accuracy and reaction time(s) were recorded. Stimulus presentation and data collection were controlled using the Psychopy package (Peirce, 2007) and stimuli were created using the MATLAB toolbox GERT (v1.20) (Demeyer & Machilsen, 2012).

2.2.2. Meaningful Embedded Figures Test (M-EFT)

The M-EFT is an adaptation of the Leuven Embedded Figures Test (L-EFT; de-Wit & Wagemans, 2015; Van der Hallen et al., 2015), which was designed to provide a more controlled and reliable alternative to the commonly used Group Embedded Figures Test (G-EFT; Witkin et al., 1971). In this adaptation, the embedding contexts within which participants must locate a target shape are either meaningful (they represent real objects) or non-meaningful (they represent nonsense objects composed of the same parts as the meaningful objects; Fig. 2). Care was taken to match meaningful and non-meaningful trials for total number of lines used and for the number of lines crossing through and extending from the target shape. Trials were in a 3AFC format, with a match-to-sample paradigm, with three response alternatives presented below the reference stimulus. We have good experiences with this test format in large heterogeneous samples, based on the Leuven Perceptual Organization Screening Test (or L-POST; Torfs, Vancleef,

Table 1
Participant samples from two periods of data collection.

Task	Testing year	N	Age: Mean (SD)	Gender: Frequency female
D-EFT	2014	165	19.94 (4.06)	140
	2015	119	19.95 (3.16)	103
	Total	284		
M-EFT	2014	211	19.89 (3.62)	181
	2015	77	19.81 (2.87)	66
	Total	288		
Navon	2014	151	18.85 (1.34)	110
	2015	124	19.19 (3.16)	106
	Total	275		

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

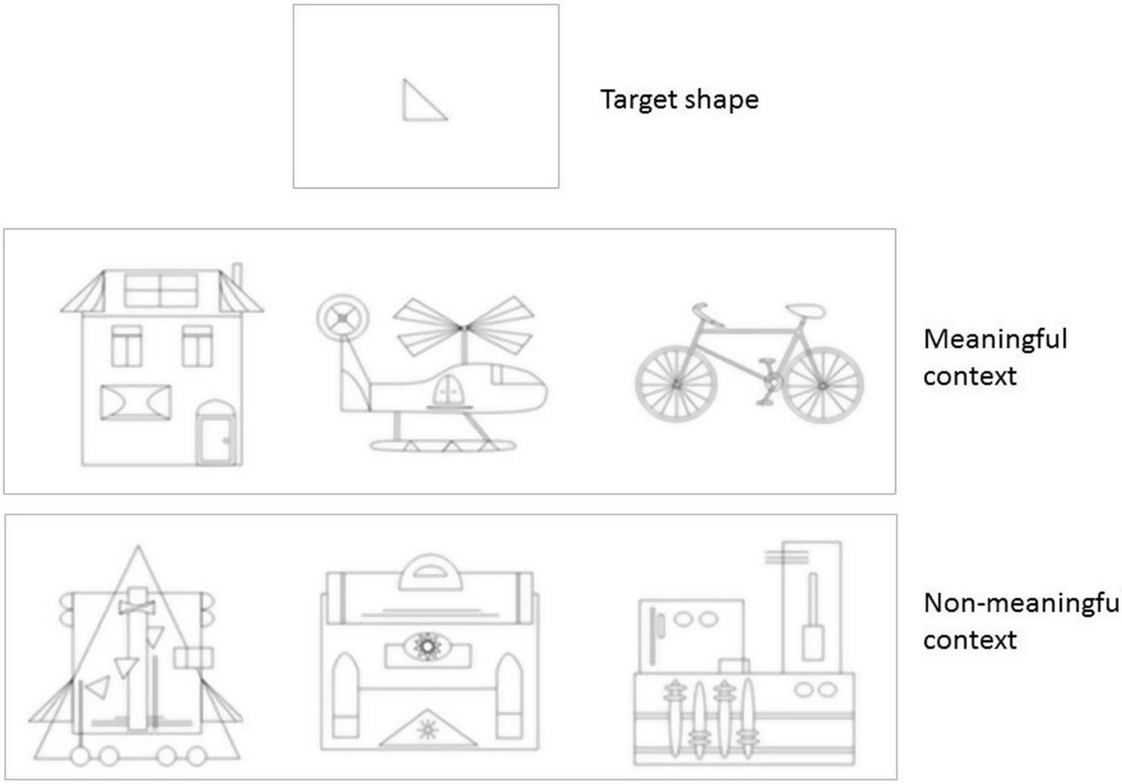

Fig. 2. Example trial of M-EFT with meaningful and non-meaningful contexts. The correct answer is the context presented on the left.

Lafosse, Wagemans, & de-Wit, 2014), because it is relatively easy for participants in terms of working memory load while having a lower guessing rate than Yes/No tasks or 2AFC tasks. There were 4 practice trials and 32 experimental trials. In each trial participants were presented with a target shape with three contexts presented beneath. The participant's task was to select the context that contained the target shape (left, middle, right) by clicking on it with the mouse cursor. The position of the correct response was varied randomly from trial-to-trial. There was no time limit and participants were given feedback as to whether their response was correct or not. Both accuracy and response time(s) were recorded. Stimulus presentation and data collection were controlled using C#.

2.2.3. Three-dimensional Embedded Figures Test (D-EFT)

The D-EFT is an adaptation of the L-EFT in which the embedding contexts within which participants must locate a target shape are either rendered in a 2D or 3D manner (Fig. 3). Care was taken to match 2D and 3D trials for total number of lines used and for the number of lines crossing through and extending from the target shape. The remaining D-EFT procedure was identical to that of the M-EFT.

2.3. Ethics

The study was approved by the Ethical Committee of the Laboratory of Experimental Psychology, KU Leuven. Belgium and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained through the laboratory course that the students were enrolled in.

3. Results

3.1. M-EFT

3.1.1. Outliers

Participants showed good accuracy (M = 0.79, SD = 0.11) on the M-EFT. Participants with accuracy rates more than 2.5 standard deviations below the sample mean (<0.52, n = 4) followed by participants with reaction times (M = 3.75 s, SD = 0.97) more than 2.5 standard deviations above the mean (>6.17 s, n = 7) were excluded from further analysis. In total 3.82% of the dataset was excluded from the final analysis (N = 277). Reaction times were log-transformed as there was evidence of positive skew.

3.1.2. Speed-accuracy trade-off

There was a moderate speed-accuracy trade-off, r (275)=0.43, $p < 0.001$, 95% CI [0.33, 0.53]. However, error rates were too high to use an inverse efficiency score (Bruyer & Brysbaert, 2011), so both accuracy and reaction time were submitted to further analysis.

3.1.3. Effect of meaningfulness on task performance

To assess the effect of meaningfulness of the embedding context on accuracy and reaction time, performance was compared between meaningful and non-meaningful trials. There was a statistical trend for accuracy to be higher in meaningful trials (M = 0.81, SD = 0.13) than non-meaningful trials (M = 0.79, SD = 0.12), t (276) = 1.79, p = 0.08, d = 0.11, 95% CI of mean difference [−0.001, 0.03]. Reaction time analyses were then conducted upon the log-transformed reaction times for correct trials only. Log reaction times were significantly longer for non-meaningful trials (M = 8.20 s, SD = 0.27) compared to meaningful trials (M = 8.15 s,

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

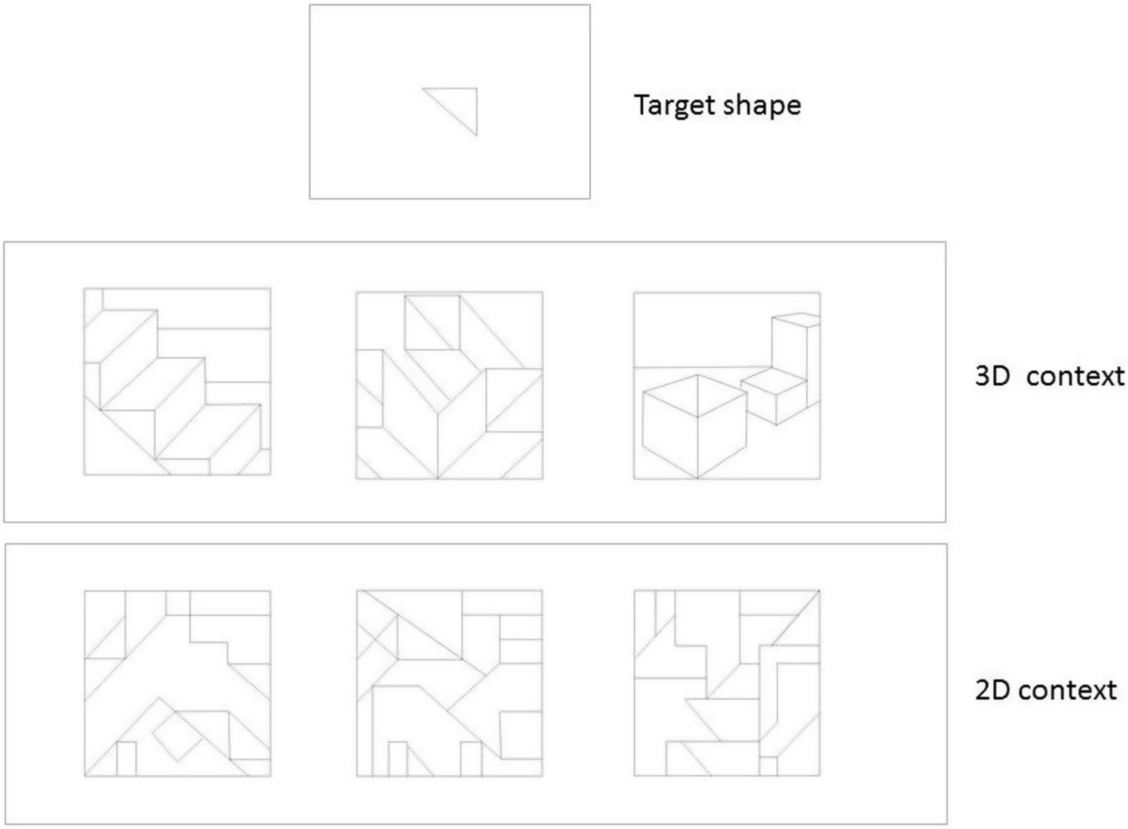

Fig. 3. Example trial of D-EFT with 3D and 2D contexts. The correct answer is the context presented on the left.

SD = 0.23), *t* (276) = 1.76, p = 0.002, *d* = 0.19, 95% CI of mean difference [0.02, 0.07].

3.2. D-EFT

3.2.1. Outliers

Participants showed accuracy just above chance on the D-EFT (M = 0.56, SD = 0.15). No participants were omitted from further analysis due to low accuracy rates relative to the entire sample. Participants with reaction times (M = 6.10 s, SD = 3.14) more than 2.5 standard deviations above the mean (>13.95 s, n = 8) were excluded from the final analysis (N = 276) constituting 2.82% of the dataset. Reaction times were log-transformed as there was evidence of positive skew.

3.2.2. Speed-accuracy trade-off

There was a strong speed-accuracy trade-off, *r* (274) = 0.68, p < 0.001, 95% CI [0.61, 0.74]. Because the high error rates preclude the use of the inverse efficiency score (Bruyer & Brysbaert, 2011), both accuracy and reaction time were submitted to further analysis.

3.2.3. Effect of three-dimensionality on performance

To assess the effect of three-dimensionality of the embedding context on accuracy and reaction time, performance was compared between 3D and 2D trials. There was a significant difference in accuracy between 3D trials (M = 0.61, SD = 0.15) and 2D trials (M = 0.50, SD = 18), *t* (275) = 10.43, p < 0.001, *d* = 0.63, 95% CI of mean difference [0.09, 0.13]. Reaction time analyses were then conducted upon the log-transformed reaction times for correct trials only. Log reaction times were no different for 2D trials (M = 8.54, SD = 0.46) compared to 3D trials (M = 8.57 s, SD = 0.51), *t*(275) = 1.50, p = 0.14, *d* = 0.09, 95% CI of mean difference [−0.009, 0.06].

3.3. Selective attention Navon task

3.3.1. Global attention

3.3.1.1. Outliers. Accuracy in the global attention condition was high (M = 0.91, SD = 0.07). Participants with accuracy rates more than 2.5 standard deviations below the sample mean (<0.74, n = 9) as well as participants with reaction times (M = 0.56 s, SD = 0.08) more than 2.5 standard deviations above the mean (>0.76 s, n = 6) were excluded from further analysis. In total 5.45% of the dataset was excluded from the final analysis (N = 260).

3.3.1.2. Speed accuracy trade-off. There was only a mild correlation between log-transformed reaction time and accuracy in the global attention condition, *r*(258) = 0.31, p < 0.001, 95% CI [0.19, 0.41] and therefore all analyses are performed on both accuracy rates and reaction time.

3.3.2. Local attention

3.3.2.1. Outliers. Accuracy in the local attention condition was high (M = 0.92, SD = 0.06). Participants with accuracy rates more than 2.5 standard deviations below the sample mean (<0.78, n = 5) were omitted from further analysis. In addition, participants with reaction times (M = 0.57 s, SD = 0.08) more than 2.5 standard deviations above the mean (>0.78 s, n = 6) were excluded from further analysis. In total 4% of the dataset was excluded from the final analysis (N = 264), with 8 of these participants also excluded from the global attention analysis on the basis of low accuracy or slow reaction time.

3.3.2.2. Speed accuracy trade-off. There was only a mild correlation between reaction time and accuracy in the local attention condition, $r(262) = 0.27$, $p < 0.001$, 95% CI [0.15, 0.37] and therefore all analyses are performed on both accuracy rates and reaction time.

3.3.2.3. Global precedence. To establish whether there was a global precedence effect in the current task, accuracy and reaction time for the global attention task as a whole were compared with the local attention task as a whole. Only those participants who were not excluded from either local or global attention conditions on the basis of slow reaction times or high error rates were submitted for analysis (N = 251). There was no effect of global precedence on accuracy, as accuracy was comparable in global attention (M = 0.92, SD = 0.05) and local attention (M = 0.92, SD = 0.05) trials $t(250) = 0.43$, $p = 0.66$, $d = 0.03$, 95% CI of mean difference [−0.007, 0.006]. However, participants were slightly but significantly faster in global attention (M = 0.55 s, SD = 0.07) compared to local attention (M = 0.57 s, SD = 0.08) trials, $t(250) = 5.08$, $p < 0.001$, $d = 0.32$, 95% CI of mean difference [0.01, 0.02]. This suggests that there is a small global precedence effect in the current Navon task, but only on reaction times.

3.3.2.4. Global interference. To establish global interference on local attention trials, accuracy and reaction time on congruent trials (v owel-vowel/consonant-consonant) were compared with accuracy and reaction time on incongruent trials (vowel-consonant/conso nant-vowel). Accuracy was significantly lower in incongruent trials (M = 0.90, SD = 0.07) compared to congruent trials (M = 0.94, SD = 0.05), $t(263) = 9.54$, $p < 0.001$, $d = 0.59$, 95% CI of mean difference [0.03, 0.05]. Reaction times were significantly longer in incongruent trials (M = 0.59 s, SD = 0.10) compared to congruent trials (M = 0.56 s, SD = 0.09), $t(263) = 9.33$, $p < 0.001$, $d = 0.57$, 95% CI of mean difference [0.02, 0.03].

3.3.2.5. Local interference. To establish local interference on global attention trials, accuracy and reaction time on congruent trials (v owel-vowel/consonant-consonant) were compared with accuracy and reaction time on incongruent trials (vowel-consonant/conso nant-vowel). Accuracy was significantly lower in incongruent trials (M = 0.91, SD = 0.06) compared to congruent trials (M = 0.93, SD = 0.05), $t(259) = 4.93$, $p < 0.001$, $d = 0.31$, 95% CI of mean difference [0.01, 0.02]. Reaction times were significantly longer in incongruent trials (M = 0.56 s, SD = 0.07) compared to congruent trials (M = 0.55 s, SD = 0.07), $t(259) = 6.83$, $p < 0.001$, $d = 0.42$, 95% CI of mean difference [0.01, 0.02]. The impact of local interference on reaction times was slightly less than the impact of global interference, $t\,(250) = 2.38$, $p < 0.05$, $d = 0.15$, 95% CI of difference between means [0.001, 0.01].

3.3.3. Difference between ID congruent and letter-type congruent trials

In some trials the local and global letter levels were congruent in terms of identity (i.e., the exact letter matched) while in others they were congruent in terms of letter-type (i.e., vowel-vowel or consonant-consonant). To investigate whether letter identity matching provided an extra benefit to participants in accuracy and reaction time over letter-type matching, a series of t-tests were conducted comparing ID congruent with letter-type congruent trials. In local attention trials, there was no significant difference in accuracy, $t(274) = 0.42$, $p = 0.68$, $d = 0.03$, 95% CI of mean difference [−0.01, 0.01] between ID congruent (M = 0.94, SD = 0.09) and letter-type congruent trials (M = 0.94, SD = 0.06). However, participants were significantly faster at responding to ID congruent (M = 0.55, SD = 0.11) than to letter-type congruent trials (M = 0.57, SD = 0.10), $t(274) = 3.62$, $p < 0.001$, $d = -0.22$, 95% CI of mean difference [0.01, 0.03]. In global attention trials, there was also no significant difference in accuracy, $t(274) < 0.01$, $p > 0.99$, $d < 0.01$, 95% CI of mean difference [-0.011, 0.011] between ID congruent (M = 0.92, SD = 0.11) and letter-type congruent trials (M = 0.92, SD = 0.07). Again, participants were significantly faster at responding to ID congruent (M = 0.55, SD = 0.09) than to letter-type congruent trials (M = 0.55, SD = 0.09), $t(274) = 2.41$, $p < 0.05$, $d = -0.15$, 95% CI of mean difference [0.002, 0.02].

3.4. Correlational analysis

3.4.1. Correlations between M-EFT and D-EFT

To assess the relationship between disembedding performance in the M-EFT and the D-EFT, correlations were conducted on overall accuracy and overall reaction time as well as accuracy and reaction time cost according to the relevant task dimension (meaningfulness/three-dimensionality) in both tasks (Table 2). The internal reliability of each task is reported in Table 4, where it can be seen that they are quite high in all tasks. The correlation matrix shows that there are strong inter-task correlations in reaction time and accuracy. Those participants who were faster and more accurate on the M-EFT were also faster and more accurate on the D-EFT. There is a weak, but consistent negative correlation between the effect of the dimensionality in the M-EFT and D-EFT and the overall accuracy and reaction time on the D-EFT and M-EFT. That is, individuals that performed well on the M-EFT and D-EFT showed less impact on reaction times when the embedding context was 2D compared to when it was 3D and when it was non-meaningful compared to when it was meaningful. Critically, the impact of condition (meaningfulness/dimensionality) on accuracy and reaction time was not correlated between the M-EFT and D-EFT. This suggests that individual differences in the degree to which complex contexts hamper (or facilitate) target localization are not consistent across different levels of context organization.

Table 2
Correlations between task performance on the M-EFT and D-EFT (N = 216). Cond = impact of the experimental manipulation on accuracy and RT; a larger difference indicates more impact of the manipulation on disembedding.

			M-EFT				D-EFT			
			Accuracy		RT		Accuracy		RT	
			Total	Cond	Total	Cond	Total	Cond	Total	Cond
M-EFT	Accuracy	Total	–	−0.03	**0.46****	**−0.27****	**0.62****	0.07	**0.57****	−0.21*
		Cond	–	–	−0.03	0.09	0.02	0.07	0.02	−0.20
	RT	Total	–	–	–	−0.22*	**0.43****	0.06	**0.67****	−0.20*
		Cond	–	–	–	–	**−0.30****	−0.06	**−0.27****	0.15
D-EFT	Accuracy	Total	–	–	–	–	–	0.17	**0.68****	−0.19*
		Cond	–	–	–	–	–	–	0.17	−0.09
	RT	Total	–	–	–	–	–	–	–	**−0.26****
		Cond	–	–	–	–	–	–	–	–

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

Table 3
Correlations between task performance on the M-EFT, D-EFT and Navon global and local selective attention tasks (N = 94).

		Navon global				Navon local			
		Accuracy		RT		Accuracy		RT	
		Total	Local Interference	Total	Local Interference	Total	Global Interference	Total	Global Interference
M-EFT	Accuracy	0.26*	−0.04	0.04	0.02	0.21*	−0.13	−0.11	−0.05
	RT	**0.37****	−0.19	0.31*	−0.09	0.28*	−0.10	0.26*	−0.06
D-EFT	Accuracy	0.26*	−0.01	0.06	−0.05	0.31*	−0.20*	0.01	−0.01
	RT	**0.36****	−0.07	0.16	0.01	**0.36****	−0.14	0.17	0.001

Notes: *p<0.05, **p<0.001.

Table 4
Spearman-brown corrected split-half estimates of individual task reliability.

Task	Variable	Reliability
DEFT	Accuracy	0.70
	RT	0.93
MEFT	Accuracy	0.63
	RT	0.87
Navon global	Accuracy	0.84
	RT	0.95
	Interference Accuracy	0.34
	Interference RT	0.09
Navon local	Accuracy	0.75
	RT	0.97
	Interference Accuracy	0.34
	Interference RT	−0.07

Note: Interference measures were calculated by subtracting RT or accuracy for congruent trials from incongruent trials in the local and global attention conditions to produce a difference score.

3.4.2. Correlations between M-EFT, D-EFT and both Navon selective attention tasks

Inter-task correlations were conducted within the sub-sample of participants that completed the D-EFT, M-EFT and Navon tasks (N = 94; Table 3). The internal reliability of each task is reported in Table 4. The prediction was that those participants who were better at disembedding the target from the context in the D-EFT and M-EFT would show reduced global interference in the Navon selective attention task. As can be seen from the correlation matrix, there was little to no overlap in task performance between the Navon task and the M-EFT and D-EFT. The only correlations surviving robust correction ($p < 0.001$) are those that associate reaction time in the M-EFT and D-EFT with accuracy in the global selective attention condition of the Navon task and moderately with accuracy on the local selective condition. This implies the presence of a more general performance related variable, likely to reflect individual differences in intelligence or motivation rather than local-global processing. Taken as a whole these results suggest that local and global processing as assessed by the Navon task are independent of local processing assessed by the two embedded figures tasks. The variability of the key dependent variables for each task (accuracy in the D-EFT and M-EFT and interference on RT in the local and global attention conditions of the Navon task) are displayed in Fig. 4.

4. Discussion

The current study aimed to investigate the convergent validity of tasks designed to study individual differences in local and global visual processing. Taken as a whole the results imply that disembedding performance (albeit not the contextual modulations that modulate it) is consistent across different forms of the EFT and represents an independent perceptual processing mechanism from the one underlying global precedence and interference in the Navon task. The results therefore indicate that enhanced disembedding performance does not come at the cost of reduced sensitivity to global stimulus configurations in Navon hierarchical letters. This supports the factor analysis result of Milne and Szczerbinski (2009), who also suggested that disembedding was a discrete perceptual factor.

The results of the **EFTs** ran contrary to our predictions. Accuracy was higher in the D-EFT for 3D trials compared with 2D trials. It was anticipated that 3D context trials would be more difficult for participants as they would struggle to reinterpret the complex context in order to find the embedded target shape. However, on re-inspection of the experimental stimuli (Fig. 2) an alternative explanation which aligns with the experimental data, can be put forward. Care was taken during the creation of the targets and contexts for this task to equate pairs of contexts (2D and 3D) according

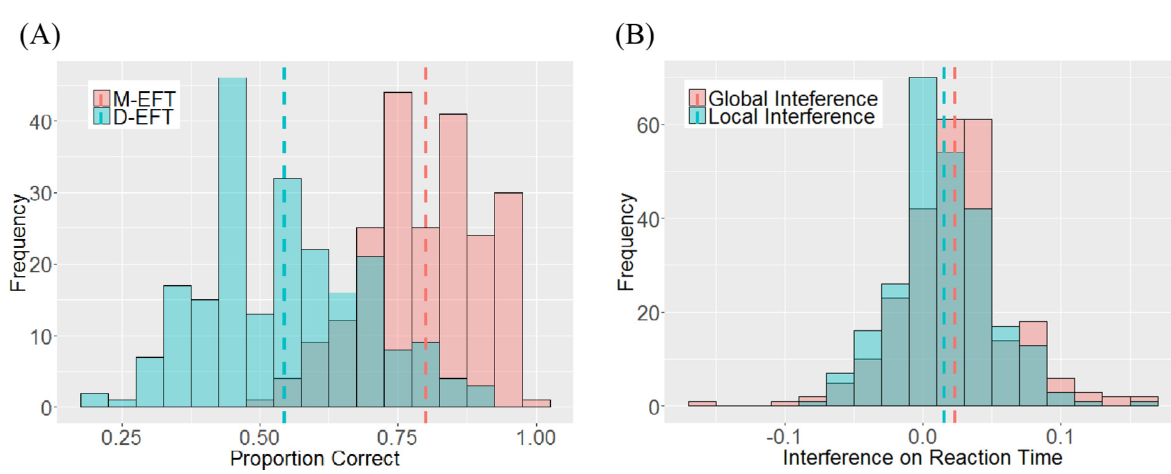

Fig. 4. Variability in task performance on M-EFT and D-EFT (A) and in local and global stimulus interference in the Navon letter task (B). Dotted lines represent the mean.

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

to the total number of lines used, the number of lines that cross one another and the number of lines that extended from the target into the complex context. However, notwithstanding this low-level control, it can be seen that 2D complex contexts *appear* far more complex than the 3D contexts. It can be suggested that task difficulty in the D-EFT relates to subjective complexity (due to the inability to group parts of the context based on object structure) rather than the objective complexity measures that were controlled for during stimulus creation. Due to the fact that the 2D contexts are perceived as more complex and (by their nature) more disorganized than their 3D counterparts, it can be suggested that they were more difficult to scan quickly. On the other hand, contexts that were 3D gave participants the opportunity to rapidly organize the visual scene and search more systematically for the target figure. It should also be noted that, while care was taken to try to mitigate the visual differences between the 2D and 3D contexts, features such as the distribution of shapes in the context and the number of distractor shapes may also have driven performance differences. Future research should attempt to control for some of these confounds to further determine the difference in performance between these two conditions.

In the M-EFT a significant difference in reaction times for meaningful and non-meaningful stimuli was found, echoed by a trend in the accuracy data, however the effects here were smaller than the effects found for the D-EFT. This could be because the context patterns in the M-EFT across the two conditions are more comparable in terms of how they are organized perceptually in terms of parts and spatial configurations. This could also explain why participants found the D-EFT more difficult overall than the M-EFT, as it can be predicted that they found the 2D contexts very hard to search due to their lack of organization, driving overall accuracy down.

As a whole, these data imply that the organization of the embedding context appears to be critical in the EFT. Note that this highlights the interaction between global (the organization of the context) and local (visual properties of the target) levels of hierarchical stimuli in perceptual processing. Organization at more abstract levels of visual processing can often facilitate local processing at lower levels of the visual hierarchy. Therefore, performance on the EFT does not appear to represent the mere ability to ignore the global context (as is more likely the case in the Navon task) but also represents the ability of an individual to identify clues or strategies within the global context that will enable them to quickly identify the local target. Hence, the results suggest that embedding occurs before disembedding. That is, organization of the context occurs before the individual constituents are processed and retrieved, which, in many ways, re-affirms the primacy of global perceptual processing. If it is the case that embedding and disembedding are directly opposed to one another and non-trivially separable through the discussed experimental parameters, this calls into question the validity of the EFT more generally.

A thorough understanding of how a task like the EFT functions will illuminate the nature of individual differences in perceptual processing in specific participant populations. Under the current framework, it appears that performance in the EFT is underpinned by an organized and flexible interpretation of the global context, as well as the ability to suppress that context in order to retrieve local elements. In this way, those populations who excel at the EFT may be those who have a more flexible approach to perceptual processing, rather than a bias toward the local or away from the global. A hint at this is provided by the fact that there are moderate correlations between performance on the global attention condition of the Navon task and accuracy and RT in the EFTs. This suggests a flexibility of visual attention which allows individuals to parse and search global configurations of local elements in both the Navon and the EFT. To test this proposal, it will be necessary to include more explicit measures of attentional switching and correlate them with EFT and Navon task performance. However, it should be noted that these correlations could also be a product of a task-general motivational or intelligence factor, that does not interact with attentional processing. Again, this can be tested by correlating EFT and Navon performance with more general measures of task motivation and intellectual functioning. In addition, studying the interplay of target embeddedness and embedding context structure in individuals with ASD will illuminate whether such perceptual flexibility is also a necessary task strategy for clinical populations.

In terms of the **Navon task** a global interference effect consistent with previous studies was found with a moderate effect size ($d = 0.57–0.59$). In addition, local interference effects were found in global attention trials, although the effect sizes were smaller than for global interference ($d = 0.31–0.42$). Participants were faster for trials in which the local and global letters were identical than when they belonged to the same letter-type category (vowel/-consonant), suggesting that both visual and semantic similarity drive the local and global interference effect. A global precedence effect was only seen for reaction times and elicited a small effect size ($d = 0.32$). These findings indicate that global visual structure is processed more quickly and disturbs the processing of local detail, even when implicit local processing in global attention trials is minimized. These effects fall in line with a great many studies on this issue but it should be emphasised that the global precedence effect found here is very small. It is difficult to determine whether the effect sizes reported here are commensurate with other research using the Navon task, as individual studies tend to use different conditions, numbers of trials and other task parameters such as number of local elements. It is also the case that global bias is subject to manipulation. For example, in studies by Austen and Enns (2000, 2003) it was found that expectation of the level that was to be the target of attention modulated global bias in a change detection task using hierarchical figures. In addition, stimulus differences like the degree of visual angle the hierarchical letter accommodates also impact on global and local precedence and interference effects (Kimchi, 1992). As a result, the effects found here are likely to be task and stimulus specific and therefore it is perhaps not surprising that they do not reliably correlate with other tasks.

In future studies it may be productive to directly contrast the current Navon task with a standard Navon letter task which uses a constant fixation location and a reduced stimulus set. The low split-half reliability found for local and global interference, particularly their impact on reaction times, calls into question whether this is a reliable measure of local or global bias, despite the putative task improvements. It also makes interpretation of the correlations in Table 3 difficult, because lack of correlation could be a product of the low reliability of the interference measures. Such low reliability is supported by Dale & Arnell (2013) conclusion that test-retest reliability of hierarchical letter tasks is low. It has been suggested by previous research that using shapes instead of letters produces more reliable interference and precedence measures (Dale & Arnell, 2013) and therefore it may be worth developing an equivalent shape stimuli paradigm for future research with the same kind of higher-order binary judgement (such as whether stimulus shapes are closed or open). In addition, different kinds of Navon-type tasks could also be tested against the current version, such as those that require participants to match a target figure to one of two types of hierarchical figures rather than respond to the properties of a single figure.

The results of the inter-task correlations suggest that disembedding performance measures share little variance with global interference and global precedence effects in the Navon tasks and calls into doubt the notion of a **unitary measure** of local or global visual processing bias. This implies that when discussing 'field-indepen

Please cite this article in press as: Chamberlain, R., et al. Local-global processing bias is not a unitary individual difference in visual processing. *Vision Research* (2017), http://dx.doi.org/10.1016/j.visres.2017.01.008

dence' or 'weak central coherence' in relation to perceptual bias, researchers must be cautious not to over-interpret the implications of such a bias to performance on other local-global tasks. There were robust within-task correlations in the EFT, suggesting that disembedding performance is to some extent independent of the type of complex context involved. However, the degree to which participants used the structure of the global context to guide local target search was not correlated between the D-EFT and the M-EFT, likely because there was a weak difference between the meaningful and non-meaningful conditions in the M-EFT. By contrast, the skill of disembedding in M-EFT and D-EFT did not drive performance in the Navon task. Indeed, when the EFT and Navon are considered together, it is difficult to pinpoint their conceptual overlap, echoing Milne and Szczerbinski (2009) claim that the local and global processing debate is beset by conceptual inconsistencies. Whilst the Navon task pitches discrete local and global levels against one another, it is hard to define the global and local level within the EFT, especially given that the target shape is often integrated within the global complex pattern. In addition, whilst in the Navon task participants must explicitly ignore the global or local forms, in the EFT perception of both the components and their configuration are key to successfully finding and identifying the target. Considering this, it is not surprising that performance in the two tasks does not align to a great extent. This may be just one example of the many different perceptual organization processes that can be at stake in complex tasks, including different kinds of 'local' and 'global' levels of processing and different kinds of 'part-whole' relationships. Finally, the discrepancy in these two tasks may also be due to their differential divergent validities in relation to aspects of intelligence and executive function, which is the subject of active research in this domain (Huygelier et al., 2015).

The findings of this study imply that one should rigorously analyse the specific global and local processing requirements for adequate performance in a given global-local task (rather than taking the local-global nature at face value), before using it to characterise participant populations. This is due to the fact that different tasks ostensibly measuring the same construct can actually lead to independent contributions to variance in a third dimension. For example, Chamberlain and Wagemans (2015) found that performance on the Block Design Task (BDT) and the EFT (both typical measures of local processing) contributed independent rather than shared variance to observational drawing skill, despite the fact that performance on the two tasks correlated moderately well. In this context it can be suggested that drawing skill is underpinned both by the ability to break a form down into its components (BDT) and the ability to reinterpret a global form in different ways in terms of local part relations (EFT). These two abilities may often, but do not necessarily, come together and may be enhanced by different training protocols. The same kind of analysis can be applied to clinical populations, and a recent meta-analysis (Van der Hallen et al., 2015) sheds light on where individuals with ASD do and do not show differences in task performance across a range of local and global processing tasks. The authors concluded that individuals with ASD showed slower global processing in a Navon task but equivalent performance to controls in the BDT and EFT. As outlined in the introduction, the lack of consensus on whether ASD diagnosis is commensurate with superior performance on the EFT could be due to heterogeneity with earlier forms of the EFT. The critical next step would be to employ these new forms of EFT (L-EFT; M-EFT; D-EFT) in a population of individuals with ASD. Hypotheses regarding the role of meaningfulness and organization of the embedding context in relation to perceptual processing in ASD can then be tested.

In **summary,** the current study adds to the consensus that local-global visual processing bias is not a unitary construct, but is represented by discrete perceptual processing abilities measured by different tasks. The ability to dis-embed a target from a complex context appears to be stable across tasks employing different organizations of contexts. In addition, global precedence and interference are robust independent effects in a highly controlled version of the Navon letters task. Researchers must be careful to understand the kind of perceptual processing scrutinized in these kinds of paradigms and make as much effort as possible to explicate the mechanisms of transfer from one local-global processing task to another (Dale & Arnell, 2014). In particular, this should be of consideration for those seeking to induce either a local or global processing attitude in order to influence higher-order cognitive functioning (Gao, Flevaris, Robertson, & Bentin, 2011). Future research should seek to further explore the commonalities and differences between local-global processing tasks so that performance on the tasks can be better understood in the context of individual differences in expertise, culture and psychopathology.

Acknowledgments

We would like to thank Lee de Wit for his help with the development of the tasks and testing. We would also like to thank our funding agencies: The Methusalem program of the Flemish Government (METH/14/02) and The Research Foundation of Flanders (FWO).

References

Austen, E., & Enns, J. T. (2000). Change detection: Paying attention to detail. *Psyche, 6*(11). Retrieved from http://cogprints.org/1055.

Austen, E. L., & Enns, J. T. (2003). Change detection in an attended face depends on the expectation of the observer. *Journal of Vision, 3*(1). 7–7.

Bellgrove, M. A., Vance, A., & Bradshaw, J. L. (2003). Local–global processing in early-onset schizophrenia: Evidence for an impairment in shifting the spatial scale of attention. *Brain and Cognition, 51*(1), 48–65. http://dx.doi.org/10.1016/S0278-2626(02)00509-2.

Brosnan, M. J., Gwilliam, L. R., & Walker, I. (2012). Brief report: The relationship between visual acuity, the embedded figures test and systemizing in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 42*(11), 2491–2497. http://dx.doi.org/10.1007/s10803-012-1505-0.

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive psychology: Is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)? *Psychologica Belgica, 51*(1), 5. http://dx.doi.org/10.5334/pb-51-1-5.

Caparos, S., Ahmed, L., Bremner, A. J., de Fockert, J. W., Linnell, K. J., & Davidoff, J. (2012). Exposure to an urban environment alters the local bias of a remote culture. *Cognition, 122*(1), 80–85. http://dx.doi.org/10.1016/j.cognition.2011.08.013.

Caparos Linnell, K. J., Bremner, A. J., de Fockert, J. W., & Davidoff, J. (2013). Do local and global perceptual biases tell us anything about local and global selective attention? *Psychological Science, 24*(2), 206–212. http://dx.doi.org/10.1177/0956797612452569.

Chamberlain, R., McManus, I. C., Riley, H., Rankin, Q., & Brunswick, N. (2013). Local processing enhancements associated with superior observational drawing are due to enhanced perceptual functioning, not weak central coherence. *The Quarterly Journal of Experimental Psychology, 66*(7), 1448–1466. http://dx.doi.org/10.1080/17470218.2012.750678.

Chamberlain, R., & Wagemans, J. (2015). Visual arts training is linked to flexible attention to local and global levels of visual stimuli. *Acta Psychologica, 161*, 185–197.

Dakin, S., & Frith, U. (2005). Vagaries of Visual Perception in Autism. *Neuron, 48*(3), 497–507. http://dx.doi.org/10.1016/j.neuron.2005.10.018.

Dale, G., & Arnell, K. M. (2013). Investigating the stability of and relationships among global/local processing measures. *Attention, Perception, & Psychophysics, 75*(3), 394–406. http://dx.doi.org/10.3758/s13414-012-0416-7.

Dale, G., & Arnell, K. M. (2014). Lost in the forest, stuck in the trees: dispositional global/local bias is resistant to exposure to high and low spatial frequencies. *PLoS One, 9*(7), e98625. http://dx.doi.org/10.1371/journal.pone.0098625.

Davidoff, J., Fonteneau, E., & Fagot, J. (2008). Local and global processing: Observations from a remote culture. *Cognition, 108*(3), 702–709. http://dx.doi.org/10.1016/j.cognition.2008.06.004.

Demeyer, M., & Machilsen, B. (2012). The construction of perceptual grouping displays using GERT. *Behavior Research Methods, 44*(2), 439–446. http://dx.doi.org/10.3758/s13428-011-0167-8.

de-Wit, L., & Wagemans, J. (2015). *Individual differences in local and global perceptual organization*. *Oxford Handbook of Perceptual Organization*. Oxford, UK: Oxford University Press. Retrieved: from ~u0064325/Publications/de-Wit%26Wagemans-Individual_differences_in_local_and_global_perceptual_organization.pdf" xlink:type="simple" id="ir010">https://perswww.kuleuven.be/~u0064325/Publications/de-Wit%26Wagemans-Individual_differences_in_local_and_global_perceptual_organization.pdf..

Drake & Winner, E. (2011). Realistic drawing talent in typical adults is associated with the same kind of local processing bias found in individuals with ASD. *Journal of Autism and Developmental Disorders, 41*(9), 1192–1201. http://dx.doi.org/10.1007/s10803-010-1143-3.

Gao, Z., Flevaris, A. V., Robertson, L. C., & Bentin, S. (2011). Priming global and local processing of composite faces: Revisiting the processing-bias effect on face perception. *Attention, Perception, & Psychophysics, 73*(5), 1477–1486. http://dx.doi.org/10.3758/s13414-011-0109-7.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*(1), 5–25. http://dx.doi.org/10.1007/s10803-005-0039-0.

Hills, P. J., & Lewis, M. B. (2008). Testing alternatives to Navon letters to induce a transfer-inappropriate processing shift in face recognition. *European Journal of Cognitive Psychology, 20*(3), 561–576. http://dx.doi.org/10.1080/09541440701728524.

Huygelier, H, Chamberlain, R, Van der Hallen, R, de-Wit, L, & Wagemans, J. (2015). The Leuven Embedded Figures Test (L-EFT): measuring perception or cognition? Presented at the European Conference on Visual Perception ECVP, Liverpool, UK.

Jarrold, C., Gilchrist, I. D., & Bender, A. (2005). Embedded figures detection in autism and typical development: Preliminary evidence of a double dissociation in relationships with visual search. *Developmental Science, 8*(4), 344–351.

Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology and Psychiatry, 38*(5), 527–534.

Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: a critical review. *Psychological Bulletin, 112*(1), 24–38.

Kimchi, R. (2015). The perception of hierarchical structure. In J. Wagemans (Ed.). *Oxford Handbook of Perceptual Organization*. Oxford: Oxford University Press. Retrieved from http://iipdm.haifa.ac.il/images/publications/Rutie_Kimchi/Kimchi_2015_in%20oxfordhb_Chapter%207.pdf.

Lewis, M. B., & Dawkins, G. (2015). Local Navon letter processing affects skilled behavior: A golf-putting experiment. *Psychonomic Bulletin & Review, 22*(2), 420–428. http://dx.doi.org/10.3758/s13423-014-0702-6.

Milne, E., & Szczerbinski, M. (2009). Global and local perceptual style, field-independence, and central coherence: An attempt at concept validation. *Advances in Cognitive Psychology, 5*(1), 1–26. http://dx.doi.org/10.2478/v10053-008-0062-8.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*(1), 27–43. http://dx.doi.org/10.1007/s10803-005-0040-7.

Muth, A., Hönekopp, J., & Falter, C. M. (2014). Visuo-spatial performance in autism: A meta-analysis. *Journal of Autism and Developmental Disorders, 44*(12), 3245–3263. http://dx.doi.org/10.1007/s10803-014-2188-5.

Navon, D. (1977). Forest before the trees: the precedence of global features in visual perception. *Cognitive Psychology, 9*, 353–383.

Navon, D. (2003). What does a compound letter tell the psychologist's mind? *Acta Psychologica, 114*(3), 273–309. http://dx.doi.org/10.1016/j.actpsy.2003.06.002.

Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods, 162*(1–2), 8–13. http://dx.doi.org/10.1016/j.jneumeth.2006.11.017.

Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, 40*(5), 733–742.

Pring, L., Ryder, N., Crane, L., & Hermelin, B. (2010). Local and global processing in savant artists with autism. *Perception, 39*(8), 1094–1103. http://dx.doi.org/10.1068/p6674.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: a research note. *Journal of Child Psychology and Psychiatry, 24*(4), 613–620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry, 34*, 1351–1364.

Stoesz, B. M., Jakobson, L. S., Kilgour, A. R., & Lewycky, S. T. (2007). Local processing advantage in musicians: Evidence from disembedding and constructional tasks. *Music Perception: An Interdisciplinary Journal, 25*(2), 153–165. http://dx.doi.org/10.1525/mp.2007.25.2.153.

Torfs, K., Vancleef, K., Lafosse, C., Wagemans, J., & de-Wit, L. (2014). The Leuven Perceptual Organization Screening Test (L-POST), an online test to assess mid-level visual perception. *Behavior Research Methods, 46*(2), 472–487. http://dx.doi.org/10.3758/s13428-013-0382-6.

Van der Hallen Evers, K., Brewaeys, K., Van den Noortgate, W., & Wagemans, J. (2015). Global processing takes time: A meta-analysis on local–global visual processing in ASD. *Psychological Bulletin, 141*(3), 549–573. http://dx.doi.org/10.1037/bul0000004.

Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M., & von der Heydt, R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure–ground organization. *Psychological Bulletin, 138*(6), 1172–1217. http://dx.doi.org/10.1037/a0029333.

Wagemans, J., Feldman, J., Gepshtein, S., Kimchi, R., Pomerantz, J. R., van der Helm, P. A., & van Leeuwen, C. (2012). A century of Gestalt psychology in visual perception: II. Conceptual and theoretical foundations. *Psychological Bulletin, 138*(6), 1218–1252. http://dx.doi.org/10.1037/a0029334.

Witkin, H., & Asch, S. E. (1948). Studies in space orientation. II. Perception of the upright with displaced visual fields and with body tilted. *Journal of Experimental Psychology, 38*(4), 455–477.

Witkin, H., Dyk, R. B., Faterson, H. F., Goodenough, D. R., & Karp, S. (1962). *Psychological differentiation: Studies of development*. New York: John Wiley & Sons Inc.

Witkin, H., Lewis, H. B., Hertzman, M., Machover, K., Meissner, P., Bretnall & Wapner, S. (1954). *Personality through perception: An experimental and clinical study*. Oxford: Harper.

Witkin, H., Oltman, P., Raskin, E., & Karp, S. (1971). *A manual for the embedd figures test*. Consulting Psychologists Press Inc.