Can performance in Navon Letters among people with autism be affected by saliency? Reexamination of the literature

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Abstract

Findings from Navon letters paradigm studies among individuals with autism spectrum disorder are inconsistent. The different results are often being interpreted in terms of 'local bias' and/or 'global weakness', according to the predictions of leading theories such as the 'Weak central coherence' or the 'Enhanced perceptual functioning'. We suggest that some of the inconsistencies may be a result of differences between these studies in the stimuli's physical characteristics and/or the task's attentional demands which are known to affect the relative saliency of the global and local levels. In this paper we systematically discuss the parameters that may affect global and local perception in autism and suggest future experimental designs and potential clinical implications of the paradigm.

The human perceptual system includes the ability to identify both wholes and their parts. For example, we perceive faces as a whole while identifying the eyes and nose as their parts, or perceive a square as a whole and the lines that construct it as its features. The common terminology in the literature refers to the overall shape as the "global level" of the stimulus and to the elements of which it is comprised, as the "local level". While previous studies have suggested that in typically developed (TD) adult individuals the perception of the global configuration precedes the perception of its parts (e.g., Navon, 1977), individuals with autism spectrum disorder (ASD) are commonly referred to as having locally biased processing style (Frith, 1989). This assumption is a sequel of accumulating clinical and empirical evidences. Hypersensitivity for small details was described in the very first description of autism by Kanner (1943) and also finds its expression in the diagnostic criteria of ASD according to DSM-IV and DSM-V with symptoms such as "persistent preoccupation with parts of objects" (APA, 2000) "extreme distress at small changes"; or "unusual interest in sensory aspects of environment" (APA, 2013). In the lab, several studies have demonstrated superior performances among ASD in comparison to TD participants, in tasks that emphasize processing of local elements, such as the Embedded Figure Test (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983), the Block Design task (Shah & Frith, 1993) and visual search tasks (Joseph, Keehn, Connolly, Wolfe & Horowitz, 2009; O'Riordan & Plaisted, 2001; Plaisted, O'Riordan & Baron-Cohen, 1998). Participants with ASD also tend to focus on details while drawing or copying a picture (Booth, Charlton, Hughes & Happe, 2003; Mottron, Belleville & Menard, 1999). In the auditory modality, individuals with ASD were found to show a better discrimination of pure tones in comparison with neuro-typical people (Bonnel et al., 2003; Bonnel et al., 2010).

Among the various theories of ASD in the literature there are two theoretical approaches that focus on the unique perceptual patterns which characterize individuals with ASD. The first approach is the "Weak Central Coherence Hypothesis" (Frith, 1989) according to which, individuals with ASD have a core deficit in their ability to extract overall (or: global) meaning from situations of everyday life (perceptual or conceptual).This, in turn, results in the communicative and cognitive characteristics of the disorder (but see also Happé & Frith, 2006). The increased attention to details **(**or: the local bias) is in fact, according to the theory, a side effect of the initial deficit. The second approach for autistic perception is the "Enhanced Perceptual Functioning" model (Mottron, Dawson, Soulieres, Hubert, & Burack, 2006) according to which, individuals with ASD have superior local perception and thus local perception becomes their perceptual default, while global processing is intact and can be used when necessary. Accelerated local perception explains, according to the theory, the increased sensory sensitivity and the superior performances in tasks that rely on local processing. At the same time, this accelerated low level perception, combined with atypical relations between low and high levels of processing, may interrupt the processing of complex materials (Minshew, Gldstein, & Siegel, 1997) and as a consequence, interferes with the development of other skills and behaviors.

Both approaches share the assumption of local perceptual bias among individuals with ASD (and its possible relation to autistic symptoms). The main controversy between the theories refers to the *origin* of the local bias, whether it is the result of weakness in global perception or the expression of superior local one (with an intact global processing). Hierarchical stimuli which contain relative discernable global shape and local elements are often used as an empirical framework for testing questions regarding the perceptual processing of the whole and its components. Thus, reexamining previous studies that have used hierarchical stimuli may shed light upon the controversy described above regarding the perception of individuals with autism. The present review will focus on the experimental literature that examined global and local perception among participants with ASD while using a well-known paradigm - the Navon letters. This paradigm is the focus of the current investigation not only due to its unique nature that allows testing global and local processing, but also because of the accumulating evidence it supplies which suggests that the relative saliency of the global and local levels may play an important role in hierarchical perception of individuals with ASD.

Navon letters: level effect and relative saliency effects

Navon letters are large letters representing the global level, built up of small letters which represent the local level. The letters composing the global and local levels can be either congruent or incongruent. Since both levels contain letters, they are not just semantically independent (one level cannot be predicted from the identity of the other), but also similarly coded. Therefore, Navon letters create hierarchical stimuli in which both letters at the two levels differ only in their level of globality according to their position in the hierarchy. Hence, differences and/or asymmetric interferences in reaction times and/or accuracy rates can be used to infer the precedence of one level on the other (Kimchi, 1992; Navon, 1977; Navon, 1981). Navon (1977) found that among TD participants, reaction times for the global level were faster than for the local level, and that in incongruent condition, the global level interferes with the perception of the local level but not vice-versa. Navon (1977) stated that among TD individuals, perception of global pattern precedes the perception of the local elements (the "Global precedence hypothesis") or in his famous words: "forest before trees". Although these findings were substantially replicated, the underlying mechanism remains questionable (see Kimchi, 1992; Navon, 2003). Furthermore, Navon's "global precedence hypothesis" (1977) has been challenged by a large body of studies which have demonstrated high sensitivity of the performances in Navon letters paradigm to a variety of changes in the stimuli's physical characteristics and/or in the task's attentional demands. In her seminal review, Kimchi (1992) summarized some of the variables which set boundary conditions of level precedence among TD participants. Experimental manipulations such as increasing the visual angle of the stimuli (e.g. Kinchla & Wolfe, 1979), increasing the distance between local elements (e.g. Martin, 1979), presenting the stimuli in the center of the visual field (e.g. Pomerantz,1983), filtering low spatial frequencies (e.g. Badock, Whitworth, Badock & Lovegrove, 1990; Hughes, Fendrich & Reuter-Lorenz, 1990) and prolonging exposure durations (e.g. Paquet & Merikle, 1984), all result in eliminating the global precedence and even reversing it (inducing local precedence). The mechanisms contributing to these effects are still debatable (see Kimchi, 1992 and Navon, 2003, for background and review), but the dependency on physical characteristics of the stimuli and task's demands suggests an important role for the relative saliency (that is, relative discernibility) of each level of processing in determining perceptual precedence, regardless of the initial perceptual bias that a person may have. In other words, alongside predisposition of the perceptual system, global advantage may be also mediated by sensory and/or attentional mechanisms (Kimchi, 1992). Relative saliency was also found to affect hierarchical perception of patients with brain damage, who have strong perceptual biases as a function of their brain lesion (Huberle & Karnath, 2010; Mevorach, Humphreys, & Shalev, 2006; Shalev, Mevorach, & Humphreys, 2007). In this paper we discuss how various manipulations that influence the relative saliency of the global/local levels may also affect hierarchical perception of individuals with ASD. Although the impact of these variables is well established in the perceptual literature, they were rarely taken into account in studies with people with autism. As previously mentioned, findings from Navon letters studies with ASD participants are inconsistent. Some of the studies reported local advantage among ASD participants while others found global advantage among them. These inconsistencies have been often explained in light of the two leading approaches described earlier. Findings indicating local advantage in individuals with ASD have been generally interpreted as supporting the prediction of both WCC and EPF theories, while findings indicating global advantage in ASD were mostly interpreted as supporting the EPF hypothesis. However, it should be taken into account that as will be detailed below, studies also substantially differ in the physical parameters of the stimuli and/or task demands which may have affected the relative saliency of the global/local levels of the stimuli that were presented to participants in these studies. Thus, it is possible that differences in the relative saliency of the global and local levels may account, at least partially, to the inconsistent effects reported in previous Navon letters studies with participants with ASD. We now turn to describe the main findings of these studies and then reexamine them according to specific parameters.

Search process

In order to identify the relevant studies for the current review, we scanned the databases of 'Pro-Quest- Central', 'Web of Science', 'PubMed', and 'Scopus' using the terms: 'autism' OR 'ASD' AND 'global-local visual' OR ' global-local processing' OR global-local visual perception' OR 'hierarchical stimuli', OR 'hierarchical perception' OR 'Navon letters' OR 'Navon'. We also added a manual search of references lists of the studies we found during the computerized search. Inclusion criteria were studies from published peer-review journal articles in English, which included ASD and non-autistic participants and compared their behavioral responses to 'Navon letters' (i.e. reaction times, accuracy rates), and which included an analysis of the differences between global and local processing. All of the included studies have used compound letters or Arabic numerals[1]. Finally, the included studies reported the physical characteristics of the stimuli, in particular visual angle of both the global and local levels. The above search process resulted in 22 papers; ten out of these 22 were excluded due to different reasons mentioned above [inadequate statistical analysis (3), and/or using Navon –like stimuli (e.g. hierarchical stimuli made up of arrows or geometrical figures (6), and/or incomplete information regarding the physical characteristics of the stimuli (4)].

Findings from Navon Letters Studies in People with ASD

The 12 remaining articles that are included in the current investigation contain 15 experiments and their main findings are briefly summarized in Table 1. Notably, this is a small number of papers, especially given the abundance of research that has been published on this topic with TD participants. Assuming people with ASD have a perceptual bias towards local information, one can expect that when performing the Navon letters task, this bias will be expressed in improved local processing: Faster reaction times to the local level than to the global level (i.e. local advantage) and/or slow reaction times to the global level in incongruent conditions (i.e. local to global interference). Regarding accuracy, one can expect fewer errors to local targets (local advantage) and/or increased error rates to the global level in incongruent conditions (i.e. local to global interference). Table 1 reveals that a certain local bias (in reaction times and/or in accuracy rates) among participants with ASD that *was not found* among their matched controls has been reported in ten out of fifteen experiments /insert Table 1 here/: Both local advantage and local to global interference among the ASD participants were reported by Plaisted, Swettenham, and Ress (1999; Exp. 1) and by Behrmann et al. (2006, in the incongruent condition). Wang et al. (2007) reported local advantage (Exps. 1 & 2) and local to global interference (Exp.3) among their ASD participants. Koldewyn, Jiang, Weigelt, and Kanwisher (2013; Exp. 1) found that when given a choice, children with ASD were less likely to report global information in comparison to TD children. Rinehart, Bradshaw, Moss, Brereton, and Tonge, (2000) reported both global and local interference among ASD participants (high functioning autism and Asperger Disorder[2]) but only global interference among controls. In a later study with the same participants, Rinehart, and her colleagues (2001), also reported that participants with high functioning autism but not those with Asperger Disorder were slower to shift from local to global targets under conditions of divided attention task, compared to the opposite direction. Increased interference in switching attention from the local level to the global level was also found by Katagiri, Kassi, Kamio, and Murohashi (2013) among participants with Asperger Disorder compared to TD controls. In a recent study, Guy, Mottron, Berthiaume, and Bertone (2016) found global advantage among TD participants while participants with ASD showed similar performances in global and local levels yet they exhibited larger local to global interference**.** On the other hand, five experiments found no evidence for local bias among participants with ASD in comparison to their matched controls. Mottron, Burack, Iarocci, Belleville, and Enns, (2003) found similar impact of manipulating the size of the visual angle in both groups. Scherf, Luna, Kimchi, Minshew, and Behrmann (2008) found no differences between children and adolescents with ASD and their matched controls. Children in both groups exhibited no level preference, while adolescences from both groups exhibited local bias. Ozonoff, Strayer, McMahon, and FIlloux (1994), and Plaisted et al. (1999; Exp. 2), demonstrated global advantage and global interference in both groups, while Mottron, Burack, Stauder, and Robaey (1999 a), demonstrated global interference in both groups and global advantage only in the ASD group (among control participants global advantage was marginally significant). From reviewing the above literature it emerges that notable inconsistencies were documented among ASD participants who perform the 'Navon letters' task, exhibiting both global and local precedence. However, a glimpse at Table 1 reveals that there are also substantial differences between studies in many of the stimuli's characteristics that were previously mentioned as known to influence global and local biases in Navon letters tasks (e.g. visual angle of the stimuli, distance between the local elements, exposure durations etc.). In addition, task's attentional demands (i.e. selective attention, divided attention, or free choice tasks) may also influence the perceptual bias of participants with and without autism (Kimchi, 1992; Muth, et al., 2014; Plaisted et al., 1999). There are also possible age dependent differences since sensitivity to global configuration of hierarchical stimuli may not be fully matured even in late childhood and adolescence (Scherf et al., 2008, Scherf, Behrmann, Kimchi, & Luna, 2009). Therefore, the inconsistency between findings of the studies summarized in Table 1may be explained, at least partially, by these differences, suggesting that similarly to TD individuals, hierarchical perception of ASD individuals can also be influenced by the relative saliency of each level. In other words, it is possible that under certain conditions, global or local bias can be induced amongst them. But what are these exact stimuli parameters? Clearly, we cannot directly infer from the literature regarding TD participants to people with ASD. Since people with ASD seem to exhibit alternate perceptual processing style, which is reflected in the group differences that were found, it is possible that the specific values of the parameters that facilitate global or local advantage among them may be different than those found in studies with TD participants. Evidence for that presumption can be found in some of the studies that were reviewed earlier. For instance, In Wang et al.'s study (2007) prolonging exposure durations improved global perception among ASD participants while the control group exhibited optimal global advantage at shorter durations. However, directly inferring from the data of previous Navon letters studies with ASD participants is also not an easy task. A close look at Table 1 reveals that most of the reviewed studies differ in at least one important parameter of the stimuli, and in most cases there are differences in several variables, each may differently influence the relative global and local saliency. This complexity is well-illustrated using the following example: Behrmann et al. (2006) found local advantage among participants with ASD while Mottron et al. (1999 a) found a global one. However, Mottron et al. examined adolescents (mean age 15) while Behrmann et al. examined young adults (mean age 34); Mottron et al. displayed the stimuli for 200 milliseconds while in the Behrmann et al's study, exposure duration was unlimited; Mottron et al. used a divided attention task while Bhermann et al. used a focused attention task and so on. Since all of these variables (age, exposure duration, and type of attentional demands) are known to influence global and local processing as measured by 'Navon letters', it is impossible to evaluate the relative impact of each of them. Furthermore, interaction effects between them are also possible so that each factor’s contribution may be mediated by the other. Although it is not very likely that their contribution reverses because of these potential interactions, systematic manipulations of one variable while the other variables are kept constant are required to examine this issue. However, as mentioned above not many studies examined the effect of such manipulations among participants with ASD. Mottron et al. (2003) and Wang et al. (2007; Exp.1) manipulated the size of the visual angle and their findings were inconsistent. Wang et al. (2007; Exp.2) examined the impact of different exposure durations of the stimuli. Plaisted et al. (1999) and Wang et al. (2007) manipulated task demands. Guy et al. (2016) and Scherf et al. (2008) examined different age groups. To summarize, the small number of studies using different stimuli and task properties does not enable us to *statistically* analyze the role of each parameter in isolation. Moreover, the very small sample sizes and the large age range further limit the ability to evaluate the effect of each of the above crucial parameters. Bearing in mind these complexities, this review aims to describe the main findings and form guiding directions. In what follows we systematically review the relevant studies according to the major factors that may affect global and local processing.

Visual angle of the stimuli

A well-documented finding is that among TD participants, increasing the visual angle of 'Navon letters' stimuli, improves the perception of the local level and can even turn the global precedence into a local precedence (Granholm, Cadenhead, Shafer, & Filoteo, 2002; Granholm, Perry, Filoteo, & Braff, 1999; Kinchala & Wolfe, 1979; Lamb & Robertson, 1989; 1990; Lamb, Robertson & Knight, 1990; Lawson et al., 2002). The visual angles that were used in the above studies ranged from 1.5° x 1° to 22.1° x 11.5° for the global level and from 0.2° x 0.13° to 4.6° x 3.68° for the local level. Interestingly, the specific visual angle in which the transition from global to local precedence occurs is not constant across studies but changes from one research to another. Lamb and Robertson (1990) suggested that the size at which the transition occurs depends on the specific range of sizes (i.e. stimulus set) presented to the participant, and may reflect an adjustment to a specific attentional processing area or a specific range of spatial frequencies. However, the differences in the sizes of the visual angle at which the transition from global to local precedence occurred may also stem, at least partially, from differences between studies in *other* parameters that are known to affect global and local perception, as mentioned earlier. Moreover, the effect of increased visual angle may also involve an interaction between several of these factors. For example, increasing the size of visual angle also expands the distance between the local elements, which is known to improve local perception (Martin, 1979). The distance between local elements was not kept constant in any of the studies that manipulated the size of the visual angle. Therefore, it is hard to tell to what extent each factor contributes to the general effect. Given the above complexities, we turn now to review the actual data that were reported in studies with ASD participants. The visual angles that were used in the ASD studies (see Table 1) ranged from 2.17° x 1.37° to 13° x 5° for the global level and from 0.45° x 0.28° to 1.6° x 1.03° for the local level. Inspection of Table 1 reveals that there is an overlap between the sizes of visual angles at which both global and local precedence occurred. Global advantage was obtained in the entire range: from 2.17° x 1.37° (the smallest) to 13° x 5° (the largest), and local advantage was obtained between 3.2° x 2.3° and 8.64°x5.46°. These findings cannot tell us much about the possible influence of the visual angle of the stimuli per se, mainly because, as already noticed, other parameters which define the relative saliency may have affected the results. Nevertheless, two studies (Mottron et al., 2003; Wang et al, 2007) examined the impact of visual angle by manipulating its size under constant conditions (though note that the distance between the local elements was changed accordingly). Mottron et al. (2003) examined 12 high functioning ASD participants aged 10-21 and their matched TD controls. They manipulated three sizes of visual angles (see Table 1) using neutral stimuli only (i.e. all hierarchical figures comprised of *different* local and global letters but the irrelevant letter was never a possible response) in a divided attention task. The visual angles ranged from 2.17° x 1.37° to 8.64° x 5.46° for the global level and between 0.45° x 0.28° and 1.6° x 1.03° for the local level. The results showed faster responses to global targets in the smallest visual angle and to local targets in the largest visual angle with no differences between groups. Wang et al (2007, Exp. 1) examined 15 ASD participants aged 8:3 to 21:6, recruited from schools for children with mental retardation, and their matched controls. They used incongruent stimuli only, which were presented in three sizes of visual angle ranging between 3.29° x 2.24° and 7.95° x 5.41° for the global level and from 0.55° x 0.34° to 1.51° x 1.1° for the local level. The task was a free naming task in which participants were asked to name the two numerals of the hierarchical stimuli. The order of naming was coded and reaction times for naming were measured. Participants with ASD exhibited a local advantage in naming latency at all visual angles while their control participants exhibited global advantage in the small and medium angles and local advantage in the large angle. In sum, Mottron et al. (2003) found the same effect for increasing the visual angle in both groups while Wang et al. (2007) found significant differences between autistic and non-autistic participants, with no effect of visual angle among participants with Autism. Comparing the findings of Mottron et al. (2003) with those of Wang et al. (2007) seems reasonable given that both studies share many characteristics: A similar sample size, a similar age range, identical matrix (i.e. the same number of local elements) and identical exposure durations. Yet, the instructions that were given to participants were different and may contribute to the different results. Note, however that the free naming task used in the Wang et al.'s study may be considered similar in its attentional demands to the divided attention task used in Mottron et al.'s study, since both tasks required the processing of both the global and the local levels of the hierarchical stimuli. In any case, the different results of these two studies can be attributed, at least to a certain extent, to differences in the sizes of visual angles that were used. Mottron et al. (2003) reported a global advantage among their ASD participants at the smallest visual angle (2.17° x 1.37°) which was smaller than the smallest angle used by Wang et al. (2007; 3.29° x 2.24°). In fact, the small angle used by Mottron et al. (2003) was the smallest angle used in all of the studies reviewed here. Thus, it is possible that global advantage among participants with ASD can be expected when using relatively small sizes of visual angles. But what size is small enough? Reexamining of Table 1 reveals five other studies that have used relatively small visual angles (Mottron et al., 1999 a; Behrmann et al., 2006; Scherf et al., 2008; Katagiri et al., 2013; Guy et al., 2016). The size of the global level in these studies ranged from 3.2° x 2.3° to 3.7° x 2.5°. Although findings in these studies are various regarding accuracy, in four of them (Guy et al., 2016; Katagiri et al., 2013; and Scherf et al., 2008 in the children group; Behrmann et al., 2006 in the congruent condition) there was no level differences among ASD participants in reaction times. Thus, it is also possible that (under the specific parameters used in these studies) this range of sizes may reflect a "borderline condition" in which global and local saliency are relatively similar among individuals with ASD. It is also possible that sizes that are smaller than this 'borderline condition' may produce global advantage among them (as in the smallest size in Mottron et al.'s study). However, future studies are needed in order to confirm these assumptions.

Density of the local elements

Kimchi and her colleagues (Kimchi & Palmer, 1982; Kimchi &Merhav,1991) have demonstrated that local elements are more salient in patterns composed of few and large elements, whereas in patterns composed of many small local elements (i.e. dense local elements), the local elements lose their function as individual parts of the global form and perceived as texture. Manipulating the density of the local elements of Navon letters by changing their number (i.e. the matrix), their size, and/or the distance between them were found to influence global and local perception of TD populations in the same manner (Blanca & Lopez, 2009; Dalrymple, Kingstone, & Handy, 2009; Martin, 1979). Similar effect was found in a patient with Balint's syndrome, who suffered from disturbed global perception (Huberle & Karnath, 2010). It has been suggested that the local bias among people with ASD that was reported in previous studies may reflect an impaired grouping by Gestalt principles (Scherf et al., 2008). Thus, increasing the density of local elements (i.e., decreasing the distance between local elements) may improve global perception. However, no published study directly manipulated the density of the local elements of Navon letters among people with ASD. In order to compute the density of local elements in the studies that are presented in Table 1 we looked for two parameters: *1*.The number of local elements (i.e. the matrix) which was mostly reported by the authors of each study. The matrices that were used in these studies ranged from 4 x 5 to 10 x 12 in a single or a double layer. *2*. The distance between the local elements (in degrees), as calculated by us. For each respective direction, vertical or horizontal, we subtracted the sum of the sizes of all of the local elements from the size of the global level. This left us with the sum of all of the 'empty spaces' between the local elements. Then we divided this sum by the number of local elements minus one in order to calculate the size of the distance between adjacent local elements. The calculation is described in the following formula:

$$\frac{Global\ angle - local\ angle\ x\ number\ of\ local\ elements}{number\ of\ localelements - 1}$$

For example, in the study by Behrmann et al. (2006), the visual angle of the vertical global and local letters were 3.2° and 0.44° respectively, and the matrix comprised of 5 x 4 items. Therefore, the vertical distance between local elements was calculated as: $\frac{3.2\circ-(0.44\circ)5}{4} = 0.25\ \circ$. The horizontal distance was: $\frac{2.3\circ-(0.53\circ)4}{3} = \ 0.06\ \circ$. Another glimpse at Table 1 shows that the density of the local elements may play an important role in global saliency among people with autism since four out of the five studies that have found global bias (i.e. global advantage and/or global to local interference) have used relatively small distances (of less than 0.1°) between local elements (Mottron et al., 1999 a; Rinehart et al., 2000) and/or relatively large matrix (Ozzonoff et al., 1994; Plaisted et al.,1999;

Rinehart et al., 2000). In the study by Ozzonof et al. (1994), the relatively large number of local elements (a 10 x 12 matrix, in comparison to 4 x 5 or 5 x 5 matrixes that were used in most of the other studies) may explain the global advantage that was found even though the researchers used large visual angles (13° x 5°) which are more likely to result in local precedence. Thus, these results may indicate that it is possible that people with ASD can improve their global perception as a result of increasing the density of local elements, either by increasing their number or by decreasing the distance between them.

Exposure durations of the stimuli

The exposure durations which were used in studies that examined the perception of 'Navon letters' ranged from 10 milliseconds (*ms*) (Paquet & Merikle, 1984) up to 4000 *ms* (Rinehart et al., 2000) and even to unlimited exposure duration (Behrmann et al., 2006). However, most studies, especially those that are not examining children or clinical populations, tend to use exposure durations of 100 to 200 *ms*. Limiting exposure durations is needed not only in order to separate the early perceptual processing from later attentional processing but also in order to avoid eye movements which is required in order to compare between processing of right vs. left hemisphere and/or to control the peripheral location of the stimuli in the visual field. The issue of eye-movements may have special importance regarding ASD studies. Recently, Song, Hakoda, Sanefuji, and Cheng (2015) found that the functional field of view is narrower in children and adolescents with ASD in comparison to TD controls. Thus, it is possible that eye movements might mask potential differences between groups in some cases. Moreover, children with ASD often perform lateral glances in which they are staring at an object with the pupil in the corner of the eyes. It is possible that these glances serve as a behavioral strategy that regulates the amount of local information in an image (Mottron et al., 2007). This notion is supported by the finding that among TD participants global and local perception can be affected by manipulation of retinal location of the stimuli, with local perception being faster at central presentation and global perception with peripheral presentation (Pomerantz, 1983; Lamb & Robertson, 1988, Robertson, 1996). Even though this assumption has not been directly tested, it raises the need for monitoring eye movements in perceptual studies of participants with ASD, especially when long exposure durations are involved. Studies that manipulated exposure duration among TD participants (while other conditions kept constant), reported that prolonging exposure durations affect the interference patterns between global and local levels, with unidirectional global to local interference at short exposure durations and both global to local and local to global interferences at longer exposure durations (Paquet & Merikle, 1984; Wang et al., 2007, Exp.2; Hibi, Takeda & Yagi, 2002, Exp.2, but see also Exp.1)[3]. Although these findings may be interpreted as supporting the global precedence hypothesis (Navon, 1977), one should note that shorter exposure durations also attenuate the relative availability of high spatial frequencies (Christman, 1989) and thus creates conditions of stimuli presented with global saliency. The only study which manipulated exposure durations among ASD participants was Wang et al.'s study (2007, Exp.2), in which stimuli were presented for 80 *ms*, 200 *ms*, and 500 *ms* in a free naming task (incongruent stimuli only). They found that global perception was optimal in the ASD group at the longest duration while the control group exhibited optimal global advantage at shorter durations. The other studies described in Table 1, exhibited substantial differences in exposure durations, as well as in other important parameters of the stimuli. However, in light of Wang et al.'s (2007, Exp.2) findings of optimal global advantage at longer exposure durations among participants with ASD, it is possible that long exposure durations can account, at least partially, for the global advantage in reaction times that was found in the studies by Plaisted et al. (1999, Exp. 2), and Rinehart et al. (2000).

Task's attentional demands

The perception of the global and local levels of 'Navon letters' is usually examined by using two different kinds of tasks: A focused attention task and a divided attention task (see Kimchi, 1992). In a focused attention task participants are required to identify the letter of the global *or* the local level while ignoring the other level. In a divided attention task participants are asked to locate specific target letters that may appear in either the global or the local levels while ignoring irrelevant letters. Notably, the two tasks have different attentional demands, which may differently interact with the unique characteristics of ASD. Directing attention towards a specific level, global or local in separate blocks, improves its perception as it enhances the perception of any stimulus we focus on. However, a focused attention task also contains a strong element of control of attention. Participants, while responding to the target level, need to suppress their reaction to the irrelevant level which may be less or more salient than the target level, and therefore less or more easy to ignore. A divided attention task, on the other hand, forces the participant to be flexible when searching in both levels for the target letters, which is a more demanding task. In normal populations it has been found that using a divided attention task may result in reduced global advantage (see Kimchi, 1992 for a review). In the case of people with ASD, difficulty in disengaging attention from one level of processing and shifting to another (Landry & Bryson, 2004), in particular when shifting from local to global information (White, O'Reilly & Frith, 2009) or when expanding the attentional window ('zooming out') is needed (Mann & Walker, 2003; Ronconi, Gori, Ruffino, Molteni & Facoetti, 2013) may result in a local capture (Shalev, 2007) that can be more pronounced in the absence of a specific instruction to attend to either of the levels (Happé & Frith, 2006). Consistent with this assumption, Rinehart et al. (2001) and Katagiri et al. (2013) found that under condition of divided attention, participants with ASD exhibited larger prolongation of reaction times when global targets were preceded by local targets. Moreover, Plaisted et al. (1999) examined the performances in a divided attention task (Exp.1) and in a focused attention task (Exp.2). The stimuli in both these experiments differed in their total number and in the letters identity composing them but shared the same physical characteristics (i.e. visual angle, number of local elements, and exposure duration of the stimuli). They found that children with ASD exhibited global bias in the focused attention task and local bias in the divided attention task. However, other studies exhibited no influence of manipulating task's demands among participants with autism. Wang et al. (2007) found local advantage in naming times among their ASD participants in both a free naming task, in which participants were asked to name freely the two numerals of the stimuli (Exp. 1) and in a forced naming task in which they were asked to name only one of the levels, the global or the local one (Exp.3). Furthermore, inspection of Table 1 reveals that task demands alone, cannot account for either global or local precedence among people with autism. Therefore, a divided attention task may contribute to local precedence but not necessarily more than other variables (e.g. Mottron et al., 2003). Happé and Frith (2006) suggested that a free choice task may be more beneficial for the purpose of exposing the spontaneous preference of autistic individuals. Free choice task can be performed as a free naming task in which the researcher examines the order in which the participant named the two levels of stimuli, global first or local first (Wang et al , 2007 Exp.1 & Exp. 2). Another possible task is a similarity judgment task in which participants are presented with incongruent stimuli and then with two other different stimuli, each of which shares only one level with the first stimulus, and participants are instructed to indicate which of the two is more similar to the first stimuli (Koldewyn et al. 2013, Exp. 1). However, the two studies included in the current review which have used a free choice task (Wang et al., 2007; Koldewyn et al., 2013) reported that participants with ASD exhibited random level preference, rather than local one. In the study by Wang et al. (2007, Exp. 1), random level choice was exhibited in the presence of local advantage in reaction times while among control participants reaction times as well as the preferred level were affected by saliency. In the study by Koldewyn et al. (2013), ASD participants exhibited no level preference while TD controls exhibited clear global preference.

Conclusions

In the present paper we reviewed the literature in order to examine possible influence of the physical characteristics and task's attentional demands on the performances in 'Navon letters' task among participants with ASD. The unique structure of Navon letters enables the examination and comparison of the perception of both global and local levels of the stimulus within a single task. As such, the Navon letters can shed light upon the course of hierarchical perception in autism, and in particular regarding the main controversy between the two leading approaches: the Weak Central Coherence (WCC) and the Enhanced Perceptual Functioning (EPF). However, reviewing the literature revealed inconsistent findings that do not fully support either of the theories. We claim that the inconsistent findings may depict the extensive differences between studies that have used Navon letters paradigm in many variables that are known to affect global and local saliency (e.g. visual angle, density of local elements, exposure duration, and task's demand). In other words, we suggest that a response for the relative saliency of each level in the hierarchy is an important key factor. We described earlier some of the difficulties in extracting specific values of physical parameters and task's demands used in previous studies that can predict global or local advantage among participants with ASD. Integrating the main trends which arise from the literature, we can hypothesize that *small stimuli which consist of large number of dense local elements presented at long exposure durations in a selective attention task* have the highest probability of inducing global advantage among individuals with autism. Importantly, this hypothesis will need to be empirically tested since no study among those included in the current review has systematically manipulated the combination of these factors at the same time. Moreover, most of the reviewed studies combined parameters that may contribute to both global and local saliency simultaneously. Therefore, it is also possible that some conditions may be more dominant than others in their influence on global saliency. For example, the density of local elements may be considered such a critical variable. As mentioned earlier, global precedence was found mostly in studies that have used the smallest distance between local elements and/or the largest matrix (Ozzonoff et al., 1994; Mottron et al., 1999 a; Plaisted et al., 1999; Rinehart et al., 2000). Either way, the best way to examine the role of saliency in hierarchical perception of individuals with ASD, unraveling the specific conditions that contribute to global and local advantage amongst them is to conduct further studies that manipulate a single variable (physical parameter or task demand) while other variables are kept constant. Furthermore, such systematic manipulations of factors that expected to influence the relative saliency of the global/local aspect of the figure would enable to disentangle effects reflecting the processing of local and global elements in displays, from effects indicating the ability to attend to the more or less salient aspects of a display. For example, when participants need to identify the global level of stimuli presented at local saliency or when they need to identify the local level under conditions of global saliency. Shifting the focus of research from fixed structural description of the process of hierarchical perception towards tracing the variables that may affect it can potentially have important clinical implications. If global perception of individuals with ASD may be facilitated by perceptual and /or attentional manipulations that improve the relative saliency of the global level, perception is malleable, it is reasonable that global perception of individuals with ASD can be trained and improved. If such improvement is obtained it may be used to ameliorate some of the autistic traits. For example, Macrae and Lewis (2002) followed by others (Gao, Flevaris, Robertson, &Bentin, 2011; Hills & Lewis, 2007; 2009; Lewis, Mills, Hills, & Weston, 2009; Perfect, 2003; Perfect, Dennis & Shell, 2007; Perfect, Weston, Dennis & Shell, 2008; Weston, Perfect, & Schooler, 2008; but see also Lawson, 2007) exhibited an improvement in face recognition after practicing global level judgments of Navon letters stimuli. Thus, there are basic theoretical and empirical grounds to predict that training global perception may lead to improved face recognition abilities of individuals with ASD. Such training may be carried out by developing computerized perceptual training programs for that purpose. The current review emphasizes that selecting the specific physical parameters of the stimuli could be crucial for this purpose.

In this paper we have established the idea that the inconsistent findings that were found in previous 'Navon letters' studies among participants with ASD can be explained in terms of stimuli and task's characteristics. The main suggestion rising from this review is that saliency may be a somewhat neglected yet a crucial factor in hierarchical perception of individuals with ASD.

Compliance with ethical standards:

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Ethical approval: this article does not contain any studies with human participants or animals performed by any of the authors.

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Table 1: *Navon letters studies with ASD participants*

References	*Participants*	*Visual angle* (Degrees)	*Matrix*	*Density* (Degrees)	*Exposure Time(ms)*	*Task & Stimuli type*	*Main Results* *Reaction time*	*Accuracy*	*Other*
Ozonoff et al. (1994)	14 HFA, CA 12 (8-16) 14 TD, CA 12 (S.D=1.73)	(G) 13.0 x 5.0 (L) 0.7 x 0.4	10x12 Double layer	(V) 0.666 (H) 0.02	1000	SAT Con + Incon +Neutral	GA+GI GA+GI	GI GI	
Mottron et al. (1999a)	11 HFA, CA 15 (7.8-19.7) 11 TD, CA 14 (10.7-20)	(G) 3.39x2.28 (L) 0.63x0.42	5 X 5	(V) 0.06 (H) 0.045	200	DAT Nutral	GA+GI GA+GI	No ME or Int No ME or Int	
Plaisted et al. (1999, Exp.1)	17 HFA, CA 10 (6.7-16.7) 17 TD, CA 10 (6.1-14.4)	(G) 4.6x3.0 (L) 0.3x0.2	10x12 Double layer	(V) 0.178 (H) 0.0545	1000	DAT Con + Neutral	No GA or LA GA +GI	LA+ LI GA+ GI	
Plaisted et al. (1999, Exp. 2)						SAT Con + Incon +Neutral	GA+GI GA+GI	GI GI	
Rinehart et al. (2000)	12 HFA, CA 10 (6.4-15.3) 12 AD, CA 12 (6.8-20.2) 12+12 matched TD	(G) 5.1x1.5~3.2 (L) 0.5x0.1~0.3	9x5~11	(V) 0.075 (H) 0.25~IC	Up to 4000	SAT Con + Incon +Neutral	GA+GI+LI GA+GI+LI GA+GI	LA in HFA (not AD)> than LA in TD	
Rinehart et al. (2001)	Same participants and same conditions as Rinehart et al. (2000)					DAT Incon	HAF (not AD) Slower to shift from L to G	No ME or Int	

Table 1 (continued)

References	*Participants*	*Visual angle* (Degrees)	*Matrix*	*Density* (Degrees)	*Exposure Time (ms)*	*Task & Stimuli type*	*Main Results*		
							Reaction time	*Accuracy*	*Other*
Mottron et al. (2003)	12 HFA, CA 16 (10-21)	(G) 8.64x5.46	5x5	(V) 0.16	200	DAT	LA	Accuracy not reported	
	12 TD, CA 15 (11-21)	(L) 1.60x1.03		(H) 0.077		Neutral	LA		
		(G) 4.34x2.74		(V) IC			not reported		
		(L) 0.91x0.51		(H) 0.0475			not reported		
		(G) 2.17x1.37		(V) IC			GA		
		(L) 0.45x0.28		(H) IC			GA		
Behrmann et al. (2006)	14 HFA, CA 34 (19-53)	(G) 3.20x2.30	5x4	(V) 0.25	Unlimited	SAT	Incon: LA + LI>GI	No ME or Int	
	27 TD (matched)	(L) 0.44x0.53		(H) 0.06		Con+Incon	GA + GI> LI	No ME or Int	
Wang et al. (2007, Exp.1)	15 ASD, CA 14 (8.3-21.6)	(G) 7.95x5.41	5x5	(V) 0.10	200	FNT	LA	ASD: No ME or Int. NA: Fewer mistakes in the large size (G&L).	ASD: random level choice, NA: choice affected by size
	15 NA, CA 14 (8.6-19.6)	(L) 1.51x1.10		(H) IC		Incon	LA		
	Results of Exp. 1 were based on data from 12 pairs of the above participants	(G) 4.66x3.17		(V) 0.14			LA		
		(L) 0.82x0.62		(H) 0.0175			GA		
		(G) 3.29x2.24		(V) 0.135			LA		
		(L) 0.55x0.34		(H) 0.135			GA		

Table 1 (continued)

References	*Participants*	*Visual angle* (Degrees)	*Matrix*	*Density* (Degrees)	*Exposure Time(ms)*	*Task & Stimuli type*	*Main Results* *Reaction time*	*Accuracy*	*Other*
Wang et al. (2007, Exp. 2)	Results of Exp. 2 were based on data from 11 pairs of participants	(G) 4.66x3.17 (L) 0.82x0.62	5x5	(V) 0.14 (H) 0.0175	80	FNT Incon	LA GA	ASD: No ME or Int. NA: LI in 500 ms	Random level choice in both groups
					200		LA GA		
					500		LA GA<GA in 80ms		
Wang et al. (2007, Exp. 3)	Results of Exp. 3 were based on data from 14 pairs of participants	(G) 4.66x3.17 (L) 0.82x0.62	5x5	(V) 0.14 (H) 0.0175	200	SAT Con+Incon	LI GI+LI <LI in ASD	LI No ME or Int. with level	
Scherf et al.[a] (2008)	15 HFA, CA 10 (SD=1) 15 TD, CA 11 (SD=1)	(G) 3.20x2.30 (L) 0.44x0.53	5x4	(V) 0.25 (H) 0.06	Unlimited	SAT Con+Incon	No LA/GA No LA/GA	No LA/GA No LA/GA	Effect for age in TD but not in ASD
	15 HFA, CA 15(SD=1) 15 TD, CA 15 (SD=1)						LA LA	LI LI	
	9 HFA, CA 28 (SD=7) 9 TD, CA 28 (SD=8)						See Behrmann et al.(2006), above		

Table 1 (continued)

References	*Participants*	*Visual angle* (Degrees)	*Matrix*	*Density* (Degrees)	*Exposre Time(ms)*	*Task& Stimuli type*	*Main Results* *Reaction time*	*Accuracy*	*Other*
Koldewyn et al. (2013)	45 HFA, CA 8.8 (5.9-12.08) 45 TD, CA 8.2 (5.07-11)	(G) 5.5x5.5 (L) 0.6x0.8	5x5	(V) 0.625 (H) 0.375	unlimited	Matching Incon	ASD: no clear preference for level TD: clear G preference		
Katagiri et al. (2013)	11 AD, CA 31.1 (SD=6.13) 11 TD, CA 28.3 (SD=5.35)	(G) 3.70 x2.50 (L) 0.40x0.30	Not reported	IC IC	100	DAT Neutral	GI =LI >LI (TD) GI>LI	GI>LI GI>LI	
Guy et al. (2016)	39 HFA, CA 11.3 (6-16) 40 TD, CA 10.9 (6-16)	(G) 3.20x2.30 (L) 0.44x0.53	5 X 4	(V) 0.25 (H) 0.06	Up to 1000	SAT Con+Incon	No LA/GA GA	LA, LI>LI(TD) No LA/GA	RT: Similar age effect in both groups

For each study, the ASD sample is described in the top row and controls below.

ASD= autism spectrum disorder; AD= Asperger disorder; CA= chronological age (years);Con= congruent stimuli; DAT= divided attention task; FNT= free naming task

G=global; GA= global advantage; GI= global-to-local interference; H= horizontal; HFA= high functioning autism; Incon= incongruent stimuli; IC[b]= imposable to calculate;

Int= interaction; L= local; LA= local advantage; LI= local-to-global interference; ME= main effect; NA= non-autistic; NT= naming time; RT= reaction time; SD=standard deviation; TD= topically developing; SAT=selective attention task; V= vertical

[a]The data of the TD children and adolescents were taken from (Scherf et al., 2009). Data of both TD and ASD adults were taken from Behrman et al. (2006).

[b]In some cases calculating the distance between the local elements was not possible based on the data reported in the articles.

Footnotes

1. Letters and numerals are well distinguished, familiar, and automatically identified by participants. However, distinguishing between certain geometrical shapes (e.g. circles and ellipses) or the direction of global vs. local arrows, may involve other perceptual and/or attentional processing. Thus, studies that used shapes were not included in the current investigation.

2. Several studies (Rinehart et al, 2000; 2001; Katagiri et al, 2013) distinguished between "high functioning autism" and "Asperger disorder" that existed in the former version of the DSM-IV (APA, 2000). We report these studies as is with no further discussion as we adopt the recent development that was introduced in the DSM-5 (APA, 2013).

3. Kimchi (1992) turns our attention to the fact that despite of these findings there are also studies that have used relatively long exposure durations and reported global advantage and global interference.