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Research report

Reduced multisensory facilitation in persons with autism

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ABSTRACT

Although the literature concerning auditory and visual perceptual capabilities in the autism spectrum is growing, our understanding of multisensory integration (MSI) is rather limited. In the present study, we assessed MSI in autism by measuring whether participants benefited from an auditory cue presented in synchrony with the color change of a target during a complex visual search task. The synchronous auditory *pip* typically increases search efficacy (*pip and pop effect*), indicative of the beneficial use of sensory input from both modalities. We found that for conditions without auditory information, autistic participants were better at visual search compared to neurotypical participants. Importantly, search efficiency was increased by the presence of auditory *pip* for neurotypical participants only. The simultaneous occurrence of superior unimodal performance with altered audio–visual integration in autism suggests autonomous sensory processing in this population.

1. Introduction

Our perceptual world is made up of events that usually stimulate more than one sense at a given time. The brain must therefore integrate sources of information originating from multiple sensory modalities in order to create a unified and coherent internal representation of our external environment (Stein and Meredith, 1993). This process, referred to as multisensory integration (MSI), ultimately allows us to interact with our surroundings and others in an adaptive manner. It has been previously suggested that atypical MSI may plausibly be the origin for certain characteristic behaviors in autism (Iarocci and McDonald, 2006; Marco et al., 2011), including the avoidance of overstimulating environments and the focus on repetitive sensory attributes (Lovaas et al., 1979). Major cognitive theories in autism such as the Weak Central Coherence (WCC) theory (Frith and Happe, 1994), the temporal binding deficit hypothesis (Brock et al., 2002) and the

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Enhanced Perceptual Functioning theory (Mottron et al., 2006) have evolved from the tenet that autistic (AUT) perception is best defined as being locally-oriented, often resulting in superior performance when a local or detailed processing strategy is advantageous, and a concurrent, inferior performance on tasks necessitating a global or integrative approach (Behrmann et al., 2006; Dakin and Frith, 2005). Such a perceptual approach is consistent with the premise of impaired MSI in autism (Iarocci and McDonald, 2006).

Despite the fact that sensory integration therapies are routinely proposed in rehabilitation (Dawson and Watling, 2000), experimental studies directly investigating MSI abilities in autism are relatively sparse and have yielded equivocal results (Foxe and Molholm, 2009). Most multisensory processing paradigms resulting in MSI deficits in autism have used socially-contingent type stimuli, such as human speech or faces (Magnee et al., 2007, 2008; Silverman et al., 2010; Smith and Bennetto, 2007); but see (Magnee et al., 2009). Importantly, some studies suggested that MSI deficits in autism might actually be limited for more complex "social" stimuli (e.g., speech), with intact integration of simple (non-linguistic, non-social) information (Bebko et al., 2006; Magnee et al., 2008; Mongillo et al., 2008). Therefore, the available literature suggests that MSI impairment in autism may be contingent on the type of information – social or non-social – being integrated across modalities.

In order to investigate if MSI deficit could be observed in autism using non-social stimuli, we assessed MSI within the context of the challenging pip and pop visual search paradigm (Van der Burg et al., 2008). In this task, the presence of an auditory cue (auditory tone or pip) presented in synchrony with the color change of a target during a complex visual search task typically results in more efficient search performance. The synchronous *pip* makes the target *pop*-out from its complex visual environment, suggesting the beneficial and spontaneous use of multiple sources of sensory information when available. This task is particularly relevant for investigating MSI in autism since this effect has proven to be purely multisensory (the visual cue alone cannot trigger the effect), is largely automatic (the effect is *stimulus-driven* and mainly independent of higher-level goals or expectations), and is believed to isolate integration occurring at lower-levels (non-social) within the sensory processing hierarchy (Van der Burg et al., 2008, 2011).

2. Methods

2.1. Subjects

Nineteen participants (16 M) diagnosed with AUT disorder (AUT – referred to as autism throughout) and 20 typically developing (TD) participants (19 M) were recruited from the database of the Rivière-des-Prairies Hospital (Montréal, Canada). The data of three participants with AUT disorder and one TD participant were not included in the analysis due to the impossibility of the subject to do the task adequately (less than 65% of correct responses when all the conditions were mixed). The resulting groups were closely matched in terms of gender (AUT: 15 M/1 F; TD: 19 M/0 F), age (AUT: mean age 24.5 years ± 5; range 14–31 years; TD: mean age 21 years ± 4; range 14–27 years), and Wechsler IQ [(full-scale = AUT: 102 ± 15; TD: 110 ± 9); (Performance = AUT: 101 ± 13; TD: 108 ± 10); (Verbal = AUT: 102 ± 17; TD: 111 ± 12)]. AUT Disorder was defined using stringent Diagnostic and Statistical Manual of Mental Disorders, 4th edition text revision diagnostic criteria, as operationalized by the combination of Autism Diagnostic Interview – Revised (ADI-R) (Lord et al., 1994) and the Autism Diagnostic Observation Schedule – Generic (ADOS-G) (Lord et al., 2000) algorithms. All AUT participants experienced language delay (acquisition of the first words or sentences ≥36 months) or atypical language during development (echolalia, stereotypic sentences, pronoun inversion, etc.), therefore representing a clinically homogenous group representative of prototypical autism. Control participants and their first-degree relatives were screened with a questionnaire for any history of neurological or psychiatric disorders. All participants had normal or corrected-to-normal vision as evaluated by a Snellen chart prior the beginning of the experiment. The ethics boards of both the Rivière-des-Prairies Hospital and the University of Montreal (where testing took place) approved the study. Written informed consent was obtained for all of the participants, who received financial compensation for their participation in the study.

2.2. Apparatus, stimuli and procedure

Stimulus presentation and data collection were controlled by an Hewlett–Packard DC5800 computer equipped with a built in ATI Radeon 3100 graphic card and a C-Media PCI CMI8738 sound card. Visual stimuli were presented on a 17-inch color CRT monitor refreshed at rate of 75 cycles/sec (Hz) with a screen resolution of 1024 × 768 pixels. Stimuli generation and animation were controlled with Matlab R2009b (Mathworks Inc., Sherborn, MA, USA). Participants sat in a silent and dimly lit room with their head positioned on a chinrest 59 cm away from the monitor. They were instructed to search for a horizontal or vertical line segment (target) among displays of 24, 36 or 48 oblique line segments (length .57° visual angle) of various orientations (distracters) (see Fig. 1A). The orientation of each distracter deviated randomly by either plus or minus 22.5° from horizontal or vertical; the target was always either horizontally- or vertically-oriented. At random intervals (on average once every 100 msec), a random number of items changed color between red and green with the constraint that the color of the target always changed alone, never coinciding with the color change of any distracter. The target and distracter line segments were presented on a black background. On average, target color changes occurred once every nine items color changes (on average once every 900 msec). Therefore, the more frequent distracter color changes around the target resulted in a complex and difficult visual search. A more extended description of the stimuli and procedure can be found in the methods of the Experiment 1 of the original paper of Van der Burg et al. (2008). A demonstration can be found on http://www.psy.vu.nl/pippop.

Two task conditions were presented: (1) a tone-present condition, in which the visual target change of color was accompanied by a short sound or *pip*, and (2) a tone-absent condition, in which no sound was presented during the task.

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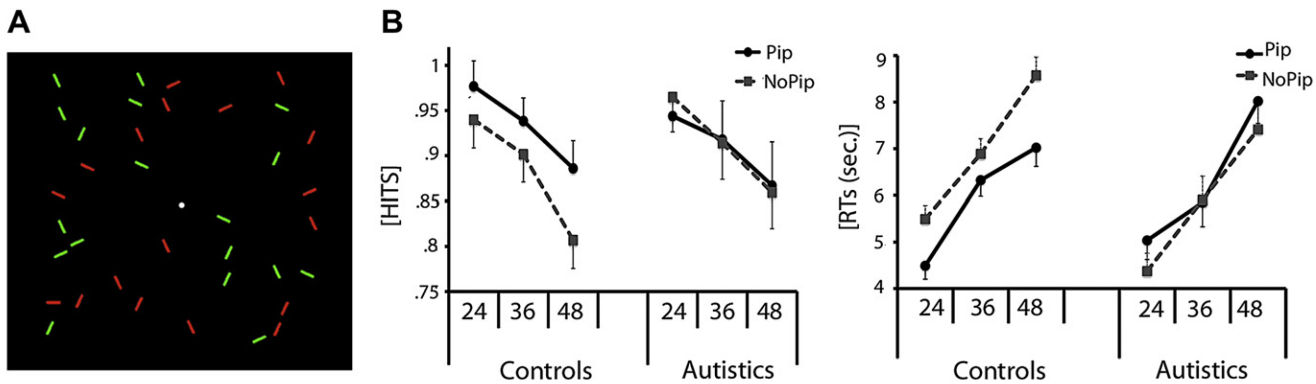

Fig. 1 – Panel A: example of the visual search displays used in the present study. Set size varied among 24, 36 & 48 items. Participants were instructed to respond as soon as they found a vertical or horizontal line segment. During the search, the distracters as well as the target continuously changed color between red and green. Panel B: the figure displays accuracy scores (HITs: proportion of correct responses) and mean RTs obtained in the "tone absent" (square-dashed line) and "tone present" (circle-straight line) conditions of stimulation in TD and AUT participants. Error bars denote standard error. A synchronous, non-spatial auditory event increased the number of hits and decreased search times for a visual target in the TD group, but not in the AUT group.

For both task conditions, participants were instructed to search for the target and to respond as quickly and accurately as possible by pressing one of two keys with the index and major fingers of their right hand when the target orientation was horizontal or vertical, respectively. The auditory stimulus consisted of a 500 Hz tone (90% normalized peak value, plateau time 50 msec, rise/fall time 5 msec) presented for 60 msec at 70 db-SPL via stereo speakers (Gigaworks T20, Creative Technology Ltd., USA) placed at the left and right side of the CRT screen used to display the visual stimuli. It is important to note that the tone did not provide information regarding the location, color, or orientation of the visual target; it was simply synchronized to the target color change.

Participants completed two tone-absent blocks and two tone-present blocks presented in counterbalanced orders. Each block consisted of 24 trials comprising eight trials for each set size (24, 36 or 48), with half of the trials containing a vertical target, and the other half a horizontal target. For all conditions, the color of the target could not change during the first 500 msec of each trial. The order of the trials was counterbalanced within each block. Each trial was displayed until participants responded, with a maximal duration of 18 sec. Participants were asked to keep fixation on a dot presented at the center of the screen. Breaks were encouraged between blocks to maintain a high concentration level and prevent fatigue. The participants' gaze was monitored throughout the experiment via a camera to ensure that they maintained central fixation. Participants practiced one block of six trials before the start of the experiment.

2.3. *Statistical analyses*

Task accuracy (HITs) was estimated by calculating the proportion of correct responses. The reaction times (RTs) reflected the time between search display onset and response to the target color change. Only latencies for correct responses were considered in the analysis. These two measures were submitted to a repeated measures analysis of variance (ANOVA) with set size (24, 36 & 48) and tone-presence (present *vs* absent) as within-subject variables, and experimental group (AUT and TD) as the between-subject variable. The reported values for p are those after a Greenhouse–Geisser correction for sphericity violations, with alpha set at .05. Based on significant F-values, Bonferroni post-hoc analyses were performed when appropriate. Proportions of correct responses, errors and omissions as well as RTs data are reported as supporting information.

3. Results

Fig. 1B illustrates the accuracy scores (proportion of correct responses) and mean RTs obtained in the "tone absent" and "tone present" conditions for TD and AUT participants.

3.1. *HITs*

No main effect of group was observed [$F(1,33) = .17$, $p = .9$]. As expected, a highly significant main effect of the set size was found [$F(2,66) = 35$, $p \leq 10E\text{-}3$], revealing that the increase of the number of distracters in the visual search display (24, 36 & 48) dramatically impaired the performance across groups. We also observed a significant main effect of tone-presence [$F(1,33) = 4.5$, $p = .04$] revealing higher accuracy in the ìtone presentî conditionî. Importantly, the ANOVA also revealed a significant group × tone-presence interaction [$F(1,33) = 5.8$, $p = .021$] which indicated that performance was significantly higher in the tone-present condition in the TD group ($p = .002$), whereas tone-presence did not affect performance (i.e., no bimodal enhancement) for the AUT group ($p = .847$).

3.2. *RTs*

No main effect of group was observed [$F(1,33) = .66$, $p = .42$]. As was found with the HIT performance, a highly significant main effect of the set size was found [$F(2,66) = 112$, $p \leq 10E\text{-}3$],

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revealing that the increase of the number of distracters in the visual search display (24, 36 & 48) dramatically slowed down response speed across groups (all $p \leq$ 10E-3 for the post-hoc comparisons) for both tone-present/absent conditions. We also observed a significant group × tone-presence interaction [$F(1,33) = 8.8$, $p = .006$] which indicated that RTs were significantly faster in the tone-present condition in the TD group ($p = .003$), whereas tone-presence did not affect RTs (i.e., no bimodal improvement) for the AUT group ($p = .269$). Finally, we also observed that the RTs of the AUT group were significantly faster compared to that of the TD group ($p = .036$) for the tone-absent condition only.

4. Discussion

The present study demonstrates that AUT individuals do not benefit from the presence of a typically facilitatory, temporally relevant tone during a demanding visual search task. The absence of this *pip* and *pop* effect in the autism group is suggestive of atypical integration of low-level, non-social perceptual cues originating from different sensory modalities. In contrast to what was previously suggested (Mongillo et al., 2008; van der Smagt et al., 2007), our research compellingly demonstrates that reduced MSI in autism is not selective to complex social stimuli, but can also be observed with low-level sensory information.

The demonstration of altered MSI in autism, defined in the present study by a lack of bimodal facilitation during visual search task, may be related to the reduced efficacy for integrating local information into complex perceptual information in autism, whether assessed within (intra-modal) or between sensory modalities (intermodal), as defined by the Bertone et al's (2003, 2005) complexity-specific hypothesis. Such a tendency for detail- or feature-based perception (also referred to as "local processing bias") instead of more holistic stimulus processing is also congruent with the WCC model (Frith, 1989), which in the present study, would represents a reduction in integrative processing between modalities, rather that within a single modality. This alteration of integration mechanisms has recently been established in the form of local neural alterations involved in intra-modal information processing (Bertone et al., 2010; Casanova, 2007; Keita et al., 2010) and reduced functional connectivity between specialized brain regions, as exemplified by altered anatomical and functional inter-regional connectivity (Anderson et al., 2011; Barttfeld et al., 2011; Belmonte et al., 2004; Brock et al., 2002; Horwitz et al., 1988; Just et al., 2007, 2004; Liu et al., 2011; Schipul et al., 2011; Thomas et al., 2011; Weinstein et al., 2011); but see (Leveille et al., 2010). Moreover, it has been recently suggested that some of the genes implicated in autism might play a role in the development of such atypical pattern of neural connectivity (Scott-Van Zeeland et al., 2010). Long-distance underconnectivity in autism implies that any facet of psychological function that is dependent on the coordination or integration of brain regions is susceptible to disruption (Brock et al., 2002; Just et al., 2004). Such atypical brain connectivity might therefore impair MSI processes since merging separate sensory inputs into a common percept necessarily requires inter-regional collaboration between separate sensory brain areas (Driver and Noesselt, 2008; Ghazanfar and Schroeder, 2006).

Consistent with this interpretation, Van der Burg et al. (2011) recently used electroencephalographic recordings to demonstrate that the multisensory facilitative effect observed with a task similar as the one used in the present study relies on early MSI (50–60 msec post-stimulus onset). Such early MSI processes putatively rely on long-range connections implicating primary sensory cortical areas (Falchier et al., 2002). It is therefore possible that it is the development of such connections that is particularly affected in autism (Courchesne et al., 2007). Supporting this hypothesis, a recent electroencephalographic study demonstrated that children with autism do not automatically combine sensory inputs early in the processing hierarchy to the same degree as TD individuals (Russo et al., 2010).

Aside from the underconnectivity hypothesis, the present results may be related to recent studies that have demonstrated that AUT children have a prolonged temporal window within which they integrate multisensory stimuli (Foss-Feig et al., 2010; Kwakye et al., 2011). A specific deficit in temporal processing of multisensory information will plausibly result in atypical MSI abilities, which intrinsically rely on the ability to temporally synchronize information originating across sensory systems (Stein and Meredith, 1993). A protracted temporal binding window in the autism group may therefore have impeded the time-locked association between the tone and the target's color change, ultimately resulting in the absence of the MS facilitation in the autism group.

Our results also demonstrated that atypical MSI in the AUT group is concomitant to more efficient unimodal visual search performance (e.g., shorter RTs in the AUT than in the TD group in the tone-absent condition). This result is consistent with previous demonstrations of superior visual search in autism (Joseph et al., 2009; O'Riordan et al., 2001), and an increased ability to detect visual targets embedded among distracters (Jolliffe and Baron-Cohen, 1997; Pellicano et al., 2005; Shah and Frith, 1983). This well replicated ability has been demonstrated to have a perceptual rather than attentional origin (Joseph et al., 2009), and has been associated with multiple other lower, and mid-level perceptual superiorities (Caron et al., 2006). Similar perceptual superiorities in autism have been also recently demonstrated in the auditory modality (Bonnel et al., 2010; Jones et al., 2009). The existence of multiple lower- (discrimination), mid- (visual search) and higher- (pattern manipulation) level perceptual superiorities in autism might therefore be an important determinant of cognition and behavior in this population (Mottron et al., 2006; Bertone et al., 2010).

The presence of such efficient, unisensory-based performance in the autism group is exemplary of autonomous sensory processing, where maximal performance on a visual task is not contingent on using multiple available sources of sensory information. Such autonomous processing has been postulated to be the collateral consequence of impaired large-scale, integrative connectivity (Belmonte et al., 2004) or be rooted in the altered development of local neural networks operating *within* each sensory modality (Bertone et al., 2010; Mottron et al., 2006). Accordingly, the concomitance of enhanced unimodal visuo-spatial performance and the lack of

MSI facilitation in the autism group may be related, to some extent, to the "inverse effectiveness" principle, which states that the result of MSI is inversely proportional to the effectiveness of the relevant stimuli (Stein and Meredith, 1993). This principle highlights the fact that MSI is usually more efficient when the reliability of one of the sensory channels is reduced (Ernst and Bülthoff, 2004). Enhanced visuo-spatial processing in autism may therefore reduce the tendency to take into account auditory information in order to resolve a visual search task. In a similar vein, a recent study using the rubber hand illusion demonstrated a reduction in sensitivity to visuotactile-proprioceptive discrepancy (reflecting atypical MSI) but more accurate proprioception in autism Spectrum disorders (Paton et al., in press). In order to explore if the reduced MSI observed in our autism group was directly related to their enhanced unimodal performance, we carried out additional analysis on a sub-sample of TD participants who had visual search performance comparable to that of the autism group in the tone-absent condition (see Supplementary Fig. 1). Results demonstrated that a facilitatory effect was still manifested for the tone-present condition in this TD subgroup, arguing against the idea that the reduced MSI observed in the autism group was solely due to difference of performance in the unimodal condition (e.g., enhanced visual search skills).

In the original study demonstrating the "pip and pop effect", Van der Burg et al. (2008) carried out control experiments, notably varying the probability of synchrony between target change and the auditory cue. They found that search benefited when the target color change was accompanied by a tone, even though this co-occurrence was relatively rare (occurring on only 20% of the trials; on 80% of the trials the tone accompanied a distractor event instead). The auditory event was therefore rather uninformative with regards to when to expect the target color change, and did not affect the overall pattern of results. Van der Burg et al. (2008) suggested that the integration of the synchronous auditory and visual signals is mostly automatic (because it still occurs when the pip is synchronized with distractors on the majority of trials). However, our observation of a strong effect of task difficulty (set size) on RTs in the "pip" (MSI) condition in TD does not support the presence of a real pop-out effect, which typifies automatic, bottom–up type processing. Therefore, it may be argued that, at least in part, the beneficial effect of sound synchrony is gated by a strategic, top–down control, and that it is such a process which may have been altered in the autism group. In fact, Van der Burg and colleagues already suggested that the effect diminishes if observers adopt a small, focused window of attention, suggesting that at least some distributed attention is necessary for observers to notice, and take advantage of the synchronized event (Van der Burg et al., 2008). This would be consistent with other evidence suggesting that attention plays a crucial role in audio–visual integration at multiple stages of information processing (Alsius et al., 2005; Talsma et al., 2007, 2010). This interaction between MSI and attention is of particular importance here, given that a recent electrophysiological study exploring face–voice interaction, demonstrated that MSI might be particularly impaired in autism under situations requiring high-level of attentional resources (e.g., divided attention) but not in situation where the attentional charge is lower (e.g., selective attention) (Magnee et al., 2011). Further works should therefore explore how the interplay between attention and MSI might explain the atypical MSI abilities observed in autism.

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Supplementary material

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