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Connection-based and object-based grouping in multiple-object tracking: A developmental study

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Developmental research on Gestalt laws has previously revealed that, even as young as infancy, we are bound to group visual elements into unitary structures in accordance with a variety of organizational principles. Here, we focus on the developmental trajectory of both connection-based and object-based grouping, and investigate their impact on object formation in participants, aged 9–21 years old ($N = 113$), using a multiple-object tracking paradigm. Results reveal a main effect of both age and grouping type, indicating that 9- to 21-year-olds are sensitive to both connection-based and object-based grouping interference, and tracking ability increases with age. In addition to its importance for typical development, these results provide an informative baseline to understand clinical aberrations in this regard.

Statement of contribution

What is already known on this subject?

- The origin of the Gestalt principles is still an ongoing debate: Are they innate, learned over time, or both?
- Developmental research has revealed how each Gestalt principle has its own trajectory and unique relationship to visual experience.
- Both connectedness and object-based grouping play an important role in object formation during childhood.

What does this study add?

- The study identifies how sensitivity to connectedness and object-based grouping evolves in individuals, aged 9–21 years old.
- Using multiple-object tracking, results reveal that the ability to track multiple objects increases with age.
- These results provide an informative baseline to understand clinical aberrations in different types of grouping.

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To perceive meaningful patterns in arrays of ever-changing information, our minds have to combine bursts of incoming input into organized units of perception. This ability is referred to as ‘perceptual organization’ (Wagemans, 2018). Early Gestalt theorists have formulated a number of principles that aim to capture the regularities according to which perceptual input is organized or grouped into meaningful units or *Gestalts* (see Wagemans, Elder, *et al.*, 2012; Wagemans, Feldman, *et al.*, 2012; for extensive reviews). Examples of these include the proximity principle, the similarity principle, or the connectedness principle. Note that, while these Gestalt principles mainly apply to visual perception, there are also analogous aspects in audition or somatosensory perception (Denham & Winkler, 2015).

Notwithstanding more than 100 years of research, the origin of the Gestalt principles is still an ongoing debate (for a more detailed discussion, see Spillmann, 2012; Wagemans, 2018). Initially, Gestalt psychologists emphasized the degree to which Gestalt laws are innate or intrinsic to the brain. In this view, Gestalt laws are fundamental properties of our perceptual system and provide the basis of our ability to make sense of sensory signals. Later on, Gestalt theorists stressed the extent to which Gestalt laws can be regarded as ‘heuristics’ that are derived from general features of the external world and developed on the basis of our perceptual experience with objects and their properties (Todorovic, 2008).

In support of the initial more nativist view, developmental research in infants has revealed that already during infancy we are bound to group visual elements into unitary structures in accordance with a variety of organizational principles (for an overview, see Quinn & Bhatt, 2015). For instance, studies on similarity (e.g., Quinn, Burke, & Rush, 1993), proximity (e.g., Quinn, Bhatt, & Hayden, 2008), common region (e.g., Bhatt, Hayden, & Quinn, 2007), or connectedness (e.g., Hayden, Bhatt, & Quinn, 2006) have indicated that these organizational principles are already present in 3-month-olds.

In addition to infant research, developmental research with regard to early and late childhood has revealed protracted developmental trajectories for certain perceptual organization abilities, even some that emerge already during infancy (e.g., Hadad & Kimchi, 2006; Kimchi, Hadad, Behrmann, & Palmer, 2005; Kovács, 2000). For instance, while 3- to 4-month-olds have proved sensitive to both local and global structures, sensitivity to global structure continues to develop into late childhood and the process of integration of local elements with regard to shape identification appears to develop only in full by late adolescence (for an overview, see Kimchi, 2015).

Step by step, developmental research has revealed how each Gestalt law or organizational principle has its own developmental trajectory and its own unique relationship to visual experience. While these principles seem characterized by unique developmental trajectories, they do not develop independently from each other, but sensitivity to one principle can affect sensitivity to other principles (e.g., Quinn & Bhatt, 2009).

In the current study, we will focus on the developmental trajectory of two stimulus-based principles, namely connectedness and object-based grouping, and investigate their impact on object formation using a multiple-object tracking (MOT) paradigm.

Multiple-object tracking was first developed by Pylyshyn and Storm (1988) as a means to investigate the nature of visual attention. In a standard MOT task, participants are asked to track a number of moving targets amongst a number of moving distracters. The task involves attention to multiple objects rather than focal attention to only a single object and is inherently active in nature, as passive vigilance does not suffice for good task performance (Scholl, 2009). According to criteria by Pashler (1998), MOT is ideal to study attentional aspects of vision as (1) the targets have to be selected while the distractors have to be ignored, (2) the participants have to sustain their attention over a period of time, and (3) the number of targets that can be tracked is inherently limited by the capacity of attention.

One of the first studies to employ MOT in relation to Gestalt principles was carried out by Scholl, Pylyshyn, and Feldman (2001). Specifically, Scholl *et al.* administered an intricate MOT task to typically developed (TD) adults to investigate the nature of a visual ‘object’ and the factors underlying object formation. Scholl *et al.* altered MOT displays by merging the targets and the distractors in various ways derived from the Gestalt principles of connectedness and object-based[1] grouping. In a baseline condition, referred to as the Boxes condition, participants tracked a number of squares that moved independently and randomly on a computer screen. In a number of experimental conditions, Scholl *et al.* then manipulated the grouping strength between the targets and distractors. Note, however, that all types of grouping are in fact irrelevant to the task at hand, as the way target and distractor items continued to move, remained just the same as in the baseline condition. In the Dumbbell condition, targets and distractors were paired through a single line, creating a dumbbell shape (2D shape). In the Necker Cube condition, targets and distractors were paired by connecting the pairs with four lines, creating a cuboid shape (3D shape). To control for the amount of visual clutter that was added to the design (in addition to the actual grouping effects), adequate control conditions were designed for each grouping condition. The results by Scholl *et al.* revealed that target and distractor groupings, although in principle irrelevant to the tracking task, made the task far more difficult (i.e., grouping interfered with target tracking), depending on the exact pairings of items and the strength of grouping induced in the design. Moreover, compared to the baseline condition where participants could easily track three of four targets, on average, tracking performance dropped to ±2.5 for the Dumbbell condition, and to ±1.5 for various types of object-based grouping, such as the Necker Cube condition. Such interference of grouping on performance provides strong evidence for an object-based nature of tracking and confirms the finding that attention can be drawn to objects rather than arbitrary collections of features or merely spatial locations. Most importantly for this study, however, these results reveal the way in which our visual system encodes a visual ‘object’ and which organizational principles underlie automatic object formation.

While MOT has since been employed to investigate the importance of other grouping principles (e.g., O’Hearn, Lakusta, Schroer, Minshew, & Luna, 2011), only a limited number of studies have further investigated the organizational principles that underlie object formation. Moreover, research on the developmental trajectory of both connectedness and object-based grouping post-infancy is rare and limited to two studies, both with a more clinical focus. A first study, by Evers *et al.* (2014), investigated sensitivity to connectedness in TD children and children with autism spectrum disorder (ASD; 6–10 years old). In line with the study by Scholl *et al.* (2001), Evers *et al.* administered an ungrouped baseline condition and a Dumbbell-like condition where targets and distractors were grouped by a single line. Their results revealed that, while performance of both groups suffered from connection-based grouping interference, performance of the ASD group showed significantly less signs of interference compared to performance of their TD peers. In addition to

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[1] *When discussing* object-based *grouping or attention, we are referring to the object-based component of visual attention in which discrete objects are directly attended, and attentional limitations are characterized in terms of the number of objects which can be simultaneously selected (for a review, see Scholl* et al., *2001). This is often contrasted with space-based attention, where locations in space are attended (and selected), regardless of the grouping or object formation processes at those locations.*

that, overall tracking ability was found to correlate with age, while no such correlation was revealed between age and grouping interference. A second study, by Van der Hallen, Evers, de-Wit, *et al.* (2015), investigated sensitivity to object-based grouping in TD children and children with ASD (8–14 years old). In line with the study by Scholl *et al.* (2001), Van der Hallen *et al.* administered an ungrouped baseline condition, a Necker Cube-like condition where targets and distractors were paired by connecting them with four lines, creating cuboid shapes (3D shape), and a Necker Control condition. Unlike Evers *et al.*, the results by Van der Hallen *et al.* revealed comparable interference of object-based grouping on performance for both groups, and while grouping interference was correlated with measures of intelligence, no such correlation was found with age, Social Responsiveness Scale (SRS) scores or Autism Diagnostic Observation Schedule (ADOS) scores.

Taken together, these two studies revealed interference for both connectedness and object-based grouping, suggesting that both principles play an important role in object formation during childhood. However, given that neither of these studies had a true developmental focus and these studies investigated only one type of pairing each, the developmental trajectory or extent to which sensitivity to both principles develop over time remains particularly unclear. Yet, insight into these developmental patterns is highly relevant: While we know that sensitivity to connectedness and object-based grouping first develops during infancy (see Quinn & Bhatt, 2015), it remains unclear to what extent both principles play a role in the way our perceptual system organizes information and, in particular, the when, how and what counts as an 'object' remains open questions, although they are obviously very important from a developmental perspective as well. In addition to its importance for typical development as such, gaining insight into these developments is also a critical precondition in order to understand the clinical aberrations in sensitivity to grouping, part-whole structures and object formation, such as those revealed in ASD (e.g., Evers, Van der Hallen, Noens, & Wagemans, 2018; Simmons *et al.*, 2009; Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015), schizophrenia (e.g., Silverstein, Kovács, Corry, & Valone, 2000) or Williams Syndrome (e.g., Kovács, Lukacs, Feher, Racsmany, & Pleh, 2010).

Therefore, the current study set out to investigate how sensitivity to both types of grouping evolves in children, aged 9–16 years old, and young adults, aged 18–21 years old, using an MOT paradigm inspired by Scholl *et al.* (2001). In terms of the developmental trajectory, based on previous research in infants, we predict that both children and adults will be sensitive to both connectedness and object-based grouping (Quinn & Bhatt, 2015). As sensitivity to global structure continues to develop into late childhood and the process of integration of local elements with regard to shape identification appears to develop only in full by late adolescence (Kimchi, 2015), we do expect connection-based grouping to impact performance at an earlier age than object-based grouping. However, based on the fact that Gestalt formation is stronger with object-based grouping compared to grouping by connection (3D vs. 2D shape, see Scholl *et al.*, 2001), and based on the results by Evers *et al.* (2014) and Van der Hallen, Evers, de-Wit, *et al.* (2015), we predict object-based grouping compared to grouping by connection to have a more detrimental effect on tracking performance. Last but not least, based on the results by Evers *et al.* (2014) and Van der Hallen, Evers, de-Wit, *et al.* (2015), we predict sensitivity to grouping to vary as a function of the number of autism-like traits (as evaluated using the SRS-2 and SRS-A) within our TD sample.

Method

Participants

The research protocol was administered to 113 TD, Dutch-speaking participants, 84 children and adolescents, aged 9–16 years old (*M* = 12.64, *SD* = 1.93; 63 girls and 21 boys), and 29 young adults, aged 18–21 years old (*M* = 18.63, *SD* = 0.78; 27 women and 2 men). Participant recruitment was set up through local mainstream schools as well as the university's recruitment facility. All participants were screened prior to participation, both with regard to learning disabilities and developmental pathology. Participants with a learning disability and/or known developmental disorder or a first-degree family member with a learning disability and/or known developmental disorder were excluded from the research protocol. ASD symptomatology was evaluated using the Dutch version of the SRS-2 or SRS-A (Roeyers, Thys, Druart, De Schryver, & Schittekatte, 2011). SRS-scores ranged from 37 to 87 (*M* = 51, *SD* = 9), with SRS data missing for three participants (two children, one adult participant).

Stimuli

The stimuli and research design (Figure 1) were based upon conditions from Scholl *et al.* (2001) with additional changes made to make the task more game-like for children. Displays were created and controlled by custom-made software.

In all conditions, irrespective of the grouping condition, each of the eight squares moved independently of one another. Movement trajectories were designed in such a way that, while the connecting lines would overlap during movement or would disappear in part and move 'behind' the target or distractor squares, the target or distractor squares themselves would never fully overlap with each other to ensure constant, good visibility of all squares. When squares reached the edge of the display, they bounced back from the edge and continued their movement.

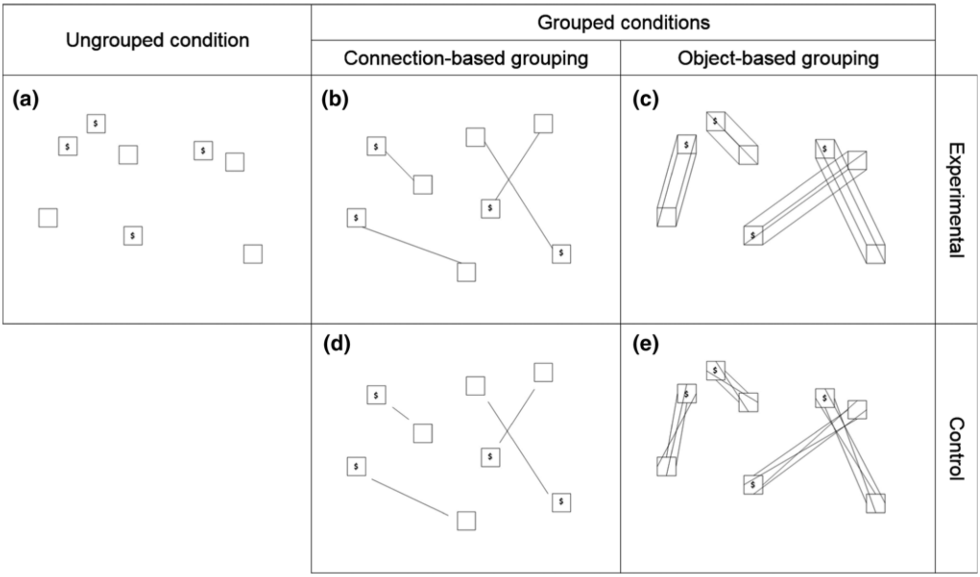

Figure 1. An overview of the five conditions (based on the study of Scholl *et al.*, 2001): (a) Boxes, (b) Dumbbell, (c) Dumbbell Control, (d) Necker Cube, and (e) Necker Control.

In the Boxes condition, which served as a baseline condition, all eight items were presented as individual squares (Figure 1a). In the Dumbbell condition, each target square was connected to a distracter square by a solid single line (Figure 1b). Each line was connected to a square at the middle point of the square. In the Dumbbell Control condition, a solid single line was displayed in between each target and distractor pair (Figure 1c). However, the solid line ended before it connected to either squares, leaving a gap on either end (gap size = 75% of the item size). This alteration maintained a similar amount of visual clutter but did not create a Dumbbell-like stimulus. In the Necker Cube condition, each target square was grouped with a distractor square by four solid lines (each vertex of a target square connected to a corresponding vertex of the distracter square). By connecting a target and a distracter square, each pair visually merged into a 3D Necker Cube (Figure 1d). In the Necker Control condition, each target square was grouped with a distracter square by four solid lines. However, rather than connecting the vertices of both squares, the lines were attached to the middle of each side of the squares and crossed mid-way connecting to the second square. This alteration maintained a similar amount of visual clutter but did not create a 3D Necker Cube-like stimulus (Figure 1e).

Except for the baseline, Boxes condition, the four main conditions can be considered as combinations of connection-based grouping versus object-based grouping on the one hand, and experimental (with fully connected line segments) versus control (with none or altered connecting line segments) conditions on the other hand, in a 2 × 2 design (see Figure 1). However, these conditions can also be organized according to the hierarchical level of grouping they seem to tap into. First, in all four of these conditions, the line segments create some kind of generic spatial grouping (based on proximity and good continuation) – a rather crude, basic type of grouping, which is probably established at a relatively low level in the visual hierarchy (Brooks, 2015). Second, in the two experimental conditions, the actual physical connections between the line segments and the square boxes create two connection-based grouping conditions, which can be distinguished from the control conditions (with none or altered connecting line segments) at a somewhat more fine-grained level of detail, given some type of actual connection is present. Third, at the highest level, the 3D nature of the resulting group of line segments can be represented, setting the 3D Necker Cube condition apart from all the others.

Procedure

All procedures performed in this study were in accordance with the ethical standards of the institutional ethical committee and approved by the ethical committee of the KU Leuven (SMEC) as well as in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Participant consents were obtained prior to testing, either directly from the participant or from both parent and child, depending on the age of the participant. Tests were administered in small groups in a quiet and slightly darkened room. All participants were seated in front of their own individual monitor with a viewing distance of approximately 57 cm.

At the start of each trial, a static display with eight squares was presented on screen. After 1-s, the outline of four target squares lit up and a dollar sign appeared within each of the outlined squares. After 4-s, the outlines turned back to their initial colour and the dollar sign disappeared. Thereafter, all eight squares began moving randomly across the screen at an average speed of 2.8° per second (using Bézier curves to create smooth movement trajectories). After 8-s, all squares stopped moving and the participants were asked to indicate the four previously indicated target squares out of the eight squares presented, using the computer mouse. Participants received immediate feedback: When they provided a correct answer, a golden dollar sign appeared and a sound ('ka-ching') was played; when their answer was incorrect, the indicated square turned grey. In each trial, four squares had to be selected, even if the participant had to guess in order to indicate four possible targets. Once the participants had selected four squares, they were asked to press the space bar to jump to the next trial.

All participants completed three practice trials and 20 test trials for each of the five stimulus conditions. The stimulus conditions were presented in a blocked manner, with the order of test blocks (and stimulus conditions) randomized across participants. Midway completing each test block of 20 test trials, participants were encouraged to take a self-paced break. At all times, participants were instructed to track the indicated squares, which would move amongst the distractors, irrespective of the grouping condition.

Data-analysis

In line with Evers *et al.* (2014) and Van der Hallen, Evers, de-Wit, *et al.* (2015), five average scores (one per condition) were computed for each participant. Each average score refers to the average number of correctly identified targets (range 0–4) across trials within a condition.

To allow for a more detailed evaluation of task performance, five interference scores were computed for each participant. Each grouping interference score refers to the strength of the grouping interference that was experienced and was calculated by subtracting the average score(s) of one or more conditions from the average score(s) of one or more of the other conditions per participant.

In line with Evers *et al.* (2014) and Van der Hallen, Evers, de-Wit, *et al.* (2015), we calculated:

1. a 'Dumbbell interference score': subtracting the average score on the Dumbbell condition from the average score of the ungrouped, Boxes condition for each participant, and
2. a 'Necker Cube interference score': subtracting the average score of the Necker Cube condition from the average score of the ungrouped, Boxes condition for each participant.

In addition to these two interference scores, we calculated three interferences scores in line with the grouping hierarchy that was introduced above (see Stimuli):

3. a 'Generic grouping interference score': subtracting the combined average score of the four grouped conditions from the average score of the ungrouped, Boxes condition for each participant;
4. a 'Connection-based grouping interference score': subtracting the combined average score of both experimental grouping conditions (Dumbbell and Necker Cube, two conditions where some type of *actual* connection between target and distractor squares did exist), from the combined average score of the three remaining conditions for each participant; and
5. a '3D-object-based grouping interference score': subtracting the average score of the Necker Cube condition from the combined average score of the four remaining conditions for each participant.

All analyses were conducted using the general statistical software package SAS, version 9.4, of the SAS System for Windows (SAS University Edition, 2013). Age (in months) was included as a continuous variable. Assumptions of normality and homogeneity were checked by means of a visual inspection of the histogram, quantile–quantile plot as well as a Shapiro–Wilk and Kolmogorov–Smirnov test. Significance tests were conducted with a significance level of .05. Correlations were conducted with a corrected significance level of .01 to account for multiple comparisons. Code and data are available upon request.

Results

To investigate the effects of grouping type and age, a repeated-measures mixed-model analysis was conducted with mean accuracy as the dependent variable, *Grouping Type* as a within-subject factor, *Age* (in months) as a between-subject factor, and a random intercept for each subject. This analysis revealed a main effect of *Grouping Type*, $F(4, 550) = 4.00$, $p = .003$, and *Age*, $F(1, 550) = 19.10$, $p < .0001$, but no *Grouping Type* × *Age* interaction effect, $F(4, 550) = 0.72$, $p = .576$ (see Figures 2 and 3). The main effect of *Grouping Type* revealed that participants performed best in the ungrouped baseline condition, followed by the Dumbbell Control, Dumbbell and Necker Control condition, and worst in the Necker Cube condition (all mentioned *post-hoc* comparisons $p < .05$, see Figure 2). More specifically, the participants performed significantly worse in the Dumbbell condition than in the Dumbbell Control condition, $t(550) = -3.03$, $p = .003$, *post-hoc* Tukey–Kramer corrected, $p = .021$, and significantly worse in the Necker Cube condition than in the Necker Control condition, $t(550) = -6.26, p < .0001$, *post-hoc* Tukey–Kramer corrected, $p < .0001$. Comparing both types of grouping, the participants performed better in the Dumbbell condition than in the Necker Cube condition, $t(550) = -9.27, p < .0001$, *post-hoc* Tukey–Kramer corrected, $p < .0001$. The main effect of *Age* revealed that across the five conditions, tracking performance increased with increasing age.

To investigate the presence of (grouping type specific) learning effects, a repeated-measures mixed-model analysis with mean accuracy as the dependent variable, and *Grouping Type* and *Trial Number* (per test block) as within-subject factors was

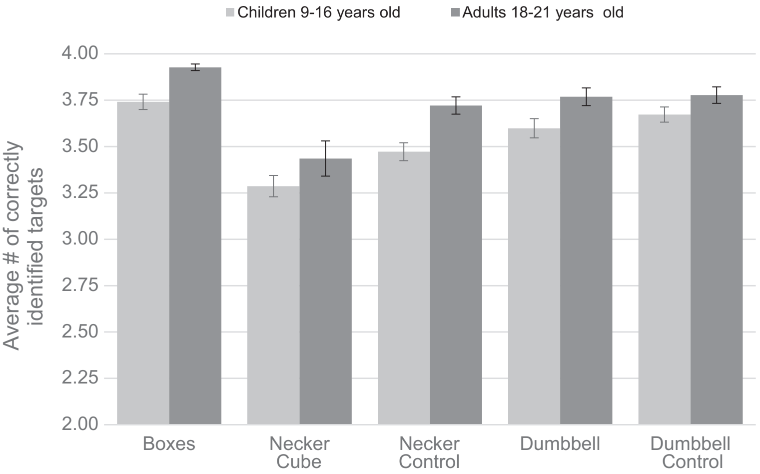

Figure 2. Mean accuracy scores per grouping condition. Error bars represent the standard error of the mean.

conducted. This analysis revealed a main effect of *Grouping Type,* $F(4, 90) = 40.06$, $p < .0001$, a significant main effect of *Trial Number,* $F(1, 90) = 11.32$, $p = .001$ but no *Grouping Type* × *Trial Number* interaction effect, $F(4, 90) = 2.16$, $p = .080$.

Looking at the five interference scores that were calculated per participant, the results show slightly different overall results for children versus adults (see Figure 4). For participants aged 9–16 years old, the highest level of grouping interference was revealed by the Necker Cube interference score ($M = 0.46$, $SD = 0.34$), followed by the 3D object-based grouping interference score ($M = 0.32$, $SD = 0.30$), the generic grouping interference score ($M = 0.24$, $SD = 0.26$), the connection-based grouping interference score ($M = 0.19$, $SD = 0.20$), and finally the Dumbbell interference score ($M = 0.16$, $SD = 0.37$). For young adults, the highest level of grouping interference was revealed by

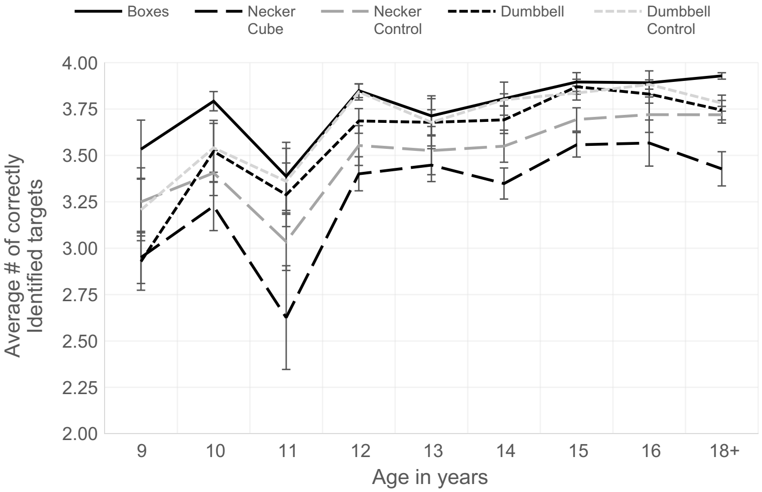

Figure 3. Overview of the effect of grouping on age per grouping condition. Error bars represent the standard error of the mean.

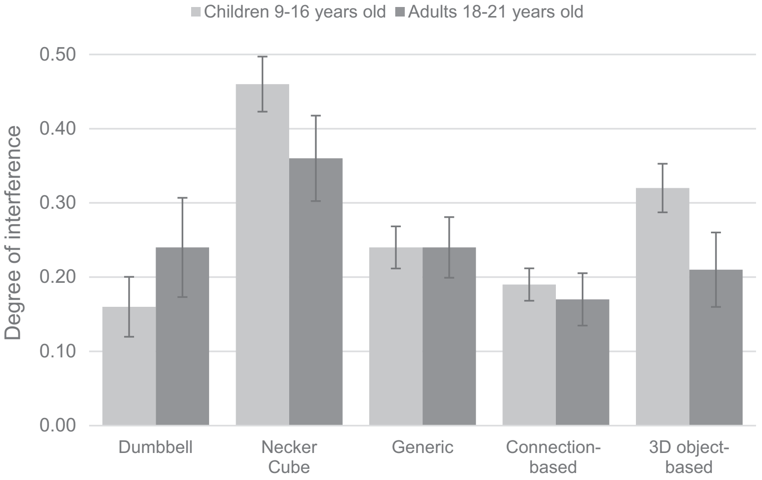

Figure 4. Mean interference scores per interference measure. Error bars represent the standard error of the mean.

the Necker Cube interference score (*M* = 0.36, *SD* = 0.31), followed by the generic grouping interference score (*M* = 0.24, *SD* = 0.22), the Dumbbell interference score (*M* = 0.24, *SD* = 0.36), the 3D object-based grouping interference score (*M* = 0.21, *SD* = 0.27), and finally the connection-based grouping interference score (*M* = 0.17, *SD* = 0.19).

Pearson product–moment correlations between the participants' age (in months) and the Dumbbell ($r = -.186$, $p = .054$), Necker Cube ($r = -.380$, $p < .0001$), generic grouping ($r = -.137$, $p = .165$), connection-based ($r = -.064$, $p = .520$), or 3D object-based ($r = -.427$, $p < .0001$) grouping interference scores were mixed, with some not significant and others highly significant, suggesting that grouping interference may somewhat reduce with increasing age.

Pearson product–moment correlations between the participants' SRS score and the Dumbbell ($r = -.042$, $p = .670$), Necker Cube ($r = -.072$, $p = .471$), generic grouping ($r = -.083$, $p = .412$), connection-based ($r = .120$, $p = .234$), or 3D object-based ($r = .152$, $p = .129$) grouping interference scores were all small and not significant.

Discussion

The current study set out to investigate how sensitivity to connection-based and object-based grouping developed in children and young adults, aged 9–21 years old, using an MOT paradigm.

First off, the results of the current study revealed an interesting pattern of results regarding grouping interference: Compared to the ungrouped baseline condition, tracking performance was significantly reduced in all four remaining conditions. Also, tracking was reduced more in the Necker Cube condition (3D object) compared to the Dumbbell condition (2D shape), and reduced more in both grouping conditions compared to their respective control conditions (i.e., Dumbbell vs. Dumbbell Control and Necker Cube vs. Necker Control).

In line with Scholl *et al.* (2001), participants' performance suffered from strong grouping interference in both grouping conditions, indicating that participants seemed to track the new 'wholes' or 'Gestalts' rather than the individual targets, even though this was detrimental to their performance and all grouping cues were irrelevant to the task. As interference was larger in the Necker Cube condition than the Dumbbell condition, 3D-shape formations appear more difficult to disentangle (to track subparts rather than wholes) than 2D-shape formations. Contrary to Scholl *et al.*, these results show a pattern of grouping hierarchy where grouping interference is experienced not just in both grouping conditions, but in all four non-baseline conditions, and both respective control conditions seem to behave as 'attenuated versions' of their respective experimental conditions, rather than actual baseline comparisons (see Figure 2). This pattern of results is especially pronounced for our youngest age group, children aged 9–16 years old, whereas looking at the adults only, the Necker Cube condition sets itself apart from the three remaining grouping conditions, amongst which the differences in the degree of interference are smaller. However, in their original study, Scholl *et al.* (2001) argued that none of the control conditions would elicit tracking behaviour which differs from what happens in the baseline condition, a view that was supported by the data in their study with adult participants.

Trying to understand the dissimilarities between these results, several key differences between Scholl *et al.*'s study and ours become apparent. For one, while Scholl *et al.* only tested TD adults, the current study administered the task to both TD children, aged 9–16 years old, and young adults, aged 18–21 years old. While differences are most apparent looking at data from our entire sample or children-only, comparing both sets of adult data still shows clear differences. While it is the case that, both for Scholl *et al.* and the current study, the Necker control and Dumbbell Control conditions no longer elicit strong grouping interference, the interference elicited in the Dumbbell condition for our sample is similar to that elicited in the Dumbbell Control condition, unlike what was found in Scholl *et al.* In other words, some of these differences seem to be due to differences in age and developmental characteristics of the sample, but not all differences can be ascribed to age.

A second, interesting difference between Scholl *et al.* and the current study, is the fact that Scholl *et al.* ran the different grouping conditions in a partial between-subjects design (and they included more conditions than the current study), while here grouping conditions were run as a within-subjects design. For Scholl *et al.*, a within-subjects design would have been practically impossible, given the large number of conditions they ran and compared to each other. As we included only five different conditions, the task length and number of trials per participant were easily within acceptable limits, even for our youngest participants. While one could wonder whether a within-subject design might have influenced the amount of interference in different conditions, we found no learning effect across conditions, suggesting this is actually not what is at play.

Most interestingly for the current study, our findings revealed a main effect of age, indicating that tracking ability (or attentional capacity) increased with age, regardless of the type of grouping that was introduced. This result is in line with previous findings (Brockhoff *et al.*, 2016; Koldewyn, Weigelt, Kanwisher, & Jiang, 2013; Trick, Jaspers-Fayer, & Sethi, 2005), which found tracking capacity in MOT to increase throughout childhood and adolescence. For instance, Trick *et al.* (2005) investigated the developmental pattern of visual attentional capacity in TD participants, aged 6–19 years old, asking them to track one, two, three or four items. Koldewyn *et al.* (2013) investigated the development pattern of attentional capacity (and dynamic attention) in participants, aged 5–12 years old, asking them to track up to three targets under different conditions of motion speed. Based on previous research (Evers *et al.*, 2014; Kimchi, 1990; Van der Hallen, Evers, de-Wit, *et al.*, 2015), we hypothesized age to impact our range of grouping conditions differently. However, no such differences were found – although the Necker Cube condition proved most stable across our age range, compared to the other three grouping conditions. Enns and Girgus (1985) investigated the developmental trajectory of proximity, similarity, closure, and continuation using Gestalt patterns. Prior to testing, they proposed two equally plausible, but opposing outcomes for their study: Either sensitivity to detect and use the global structural relation between elements in Gestalt patterns would increase with age (e.g., Boswell, 1976; Chipman & Mendelson, 1979), resulting in an age-related increase in grouping interference, or the ability to selectively attend task-relevant attributes of stimuli would increase with age (e.g., Shepp & Swartz, 1976; Strutt, Anderson, & Well, 1975), leading to an age-related decline in grouping interference. Their results revealed that participants, aged 6–24 years old, were sensitive to grouping, irrespective of their age, but young children were more sensitive and less able to selectively attend to certain information relevant to the task. The current study revealed a range of negative correlations between grouping interference and age, which is in line with Enns and Girgus' findings of reduced sensitivity to grouping interference at an older age. However, our results did not reveal anything to suggest that participants learned to selectively attend to relevant information, as no evidence was found to suggest that task learning was dependent on the grouping type at hand (and results only showed a marginally significant main effect of trial number).

Last but not least, the current study investigated to what extent the pattern in the data would correlate with ASD symptomatology. One way to investigate atypical visual processing in ASD is to evaluate performance on a local–global visual task within an ASD sample. By doing so, ASD symptomatology has been linked to (in)sensitivity to grouping in MOT in the past (e.g., Evers *et al.*, 2014; O'Hearn *et al.*, 2011; Van der Hallen, Evers, de-Wit, *et al.*, 2015). However, another possibility to investigate vision in ASD is to look for variation in visual processing (or sensitivity to grouping) in a typically developing population and see to what degree performance varies as a function of the number of autism-like traits. Looking at the degree of grouping interference experienced by our participants in relation to ASD symptomatology, however, revealed no relation between any of the grouping interference scores and ASD symptomatology. These findings are in line with the study by Van der Hallen, Evers, de-Wit, *et al.* (2015), but unlike the results by Evers *et al.* (2014), as Evers *et al.* did find a relation between grouping interference and ASD symptomatology: Participants with ASD (or high scores on the SRS) showed less grouping interference compared with TD participants (or low scores on the SRS), suggesting a greater ability to zoom in on local elements or attend beyond salient, global information. However, while the current study included a large sample of both children and young adults, none of the participants suffered from a known developmental or psychiatric condition (such as ASD). Therefore, the range in SRS-2 or SRS-A scores (and underlying ASD symptomatology) was substantially smaller compared with studies that included a clinical participant group, reducing our chance of finding a meaningful correlation.

In sum, the current study shows that 9- to 21-year-olds are sensitive to both connection-based and object-based grouping interference, while tracking ability increases with age. In addition to its importance for typical development, these results provide an informative baseline to understand clinical aberrations in different types of grouping.

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