Optotype and Grating Visual Acuity in Preschool Children

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PURPOSE. To investigate the contribution of stimulus and response differences to the different developmental courses of grating and optotype visual acuity at the preschool age range.

METHODS. Binocular visual acuity at 228 cm was assessed in 205 children in 7 age groups between 2.5 and 6 years and in 12 adults. Acuities were obtained in three tasks: detection of a grating in one of two positions, discrimination of the orientation of a single grating, and discrimination of the orientation of the gap in an uncrowded Landolt-C optotype. The three paradigms were as similar as possible in stimulus contrast, luminance, presentation mode, and psychophysical procedure.

RESULTS. Mean grating and optotype acuities were lower than adult acuities at all ages. Optotype acuity was overall higher and increased faster with age than grating acuities. Grating orientation acuity was slightly but not significantly lower than grating detection acuity in all but one age group. The grating detection task was successful at earlier ages (100% at 3.5 years) than both the optotype acuity task (100% at 4.5 years) and the grating orientation task (100% at 5.75 years).

CONCLUSIONS. Optotype and grating acuities follow a different developmental course in children between 3 and 6 years of age, with optotype acuity growing superior to grating acuity in that age range. The similarity of grating orientation to grating detection acuities and the difference between grating and optotype acuities suggest that superior optotype acuity is due to stimulus characteristics rather than to the complexity of the response required.

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rating acuity tests have made it possible to evaluate visual acuity from a very early age1–3 and in effect, shortly after birth.4–6 Because optotype acuity cannot be assessed reliably until the age of 3 or 4 years, this advantage of grating tests is, at least in part, responsible for their success and widespread use today. The different nature of grating and optotype acuity tests has triggered many studies on the validity of grating acuity estimates. These have shown fairly good agreement between the tests in normal populations7–8 (Warner A, et al. IOVS 1992; 33;ARVO Abstract I28), but often considerably discrepant acuity estimates in ophthalmic patients. Several patient studies have shown that, although impaired grating acuity is indicative of impaired optotype acuity, normal grating acuity is no guarantee for normal optotype visual acuity.9–11 Electrophysiological and behavioral grating paradigms tend to overestimate visual acuity established with optotype procedures in many patient populations,12–14 and the discrepancy increases with the severity of visual impairment.

The purpose of the present study was to establish the relationship between optotype and grating acuity in normally developing children at the preschool age, as a prelude to future studies of their relationship in clinical populations and to future application in the clinic. Such a study is justified, because normally developing children in 7 age groups show a relatively steady increase in visual acuity,15–20 whereas older patients show a gradual decrease in visual acuity with increasing age.21–24 Such differences arise probably because most studies used existing tests and standard procedures described for them. However, available behavioral grating and optotype acuity tests differ in several aspects that have been shown to affect acuity estimates—such as stimulus contrast,16 single or linear stimulus presentation,17,18 test distance,19,20 and the psychophysical criteria for establishing the threshold.20 To avoid such confounding variables in the present study, we abandoned traditional test and created stimuli and test procedures that were as similar as possible for the optotype and grating acuity assessments.

Apart from the differences mentioned, behavioral grating and optotype acuity tasks with E hooks or Landolt-Cs differ in two fundamental respects: (1) At the stimulus level, in the grating task, grating texture has to be detected, whereas in the optotype task a visuospatial feature—the position of the gap—has to be located; (2) at the response level, the grating merely has to be pointed out at one of two locations, whereas for E or C optotypes the orientation of the stimulus has to be indicated. To investigate the contribution of each of these factors, a third paradigm was included in which the orientation of grating had to be indicated. Comparing acuity estimates obtained with this grating orientation (GRO) task to estimates based on only the detection of the grating (GRD) would document the contribution of the more complicated visuospatial response. Conversely, comparing grating orientation acuity with Landolt-C orientation (LCO) acuity would reveal the role of the stimulus feature to be processed.

METHODS

Participants

Two hundred five children (105 boys and 100 girls) between the ages of 2.5 and 6.0 years participated in the study. They were recruited from three different kindergartens in the Leuven area and were tested at the school. Written informed consent was obtained from the parents. The research conformed to the tenets of the Declaration of Helsinki. The group was divided into seven age groups of 6 months each, starting with the age group 2 years 9 months (range, 2.50–3.00 years) and ending with the age group 5 years 9 months (range, 5.50–6.00 years).
In addition, 12 adult volunteers (nine women and three men) were tested with procedures identical with those used for the children. Their ages ranged from 20 to 29 years (mean, 23.39 ± 2.68 years).

Stimuli

All stimuli were presented by means of a presentation board consisting of two gray panels, 46 by 30 cm, mounted together orthogonally on their long side. One panel contained one round aperture of 9.2 cm diameter, behind which a single stimulus card could be mounted. This panel was used for presentation of the optotype stimuli and the gratings in the orientation task. The other panel contained two such apertures spaced apart horizontally 17 cm center to center, to present two stimulus cards simultaneously during the grating detection task. When one panel was used for presentation, the other served as a support, resting on the table.

Testing was conducted with overhead lights turned on, and if the room had a window the presentation panel was oriented to catch the daylight. Additional lighting directed toward the presentation panel was switched on if at the start of a session the luminance was below 20 cd/m². A preliminary study with the same stimulus material in 5 normal adults had shown that visual acuity remained constant for luminance of 20 cd/m² or more. During a test session, illumination of the panel remained constant.

The Landolt-C was used as the optotype stimulus instead of Snellen letters to avoid any influence of early developing reading skills on the test results. It was preferred over the E hook, because it was accepted as the standard optotype for visual acuity assessment by the Committee on Vision of the National Academy of Science National Research Council in 1980.22 The C sizes were chosen in accordance with the A units of the traditional Keeler C chart, and ranged from 30 to 0.63 cycles per cm in 18 steps of one-third octave, where an octave is a doubling or halving of the value (i.e., a base 2 logarithmic scale). The Cs were printed in black on 9.5 × 9.5-cm white plastic cards with a 90% luminance contrast. The cards were presented with the gap of the C optotype oriented at random in one of the four orthogonal directions, and the instruction was to indicate in which direction the gap was oriented.

Eighteen square-wave grating cards with similar dimensions matched the 18 Landolt-C stimulus cards in luminance contrast and spatial frequencies (30–0.63 cyc/cm in steps of one-third octave). In the GRO paradigm, the grating cards were presented one by one in horizontal or vertical orientation, and the instruction was to indicate the direction of the lines. In the GRD paradigm, a grating was presented simultaneously with a luminance-matched gray card that contained a 50% black-and-white subthreshold dot pattern on a similar card. The instruction was to indicate which of the two apertures in the gray panel contained the grating pattern. Three cards of slightly different overall luminance were available to compensate for small luminance differences between the grating cards. The gray cards were changed for each trial, regardless of the grating presented, to ensure that no systematic relationship could arise between luminance and grating position. Also, the orientation of the grating card was randomly changed between horizontal and vertical. This neutralized any orientation effects on acuity and made the visual stimulation during this task more similar to that in the GRO task.

Procedure

Threshold assessment was based on the forced-choice principle and proceeded in two steps. First, a quick staircase approach provided a rough localization of the threshold. Assessment started with the threshold and proceeded in blocks of two presentations per spatial frequency. Spatial frequency was lowered on subsequent blocks if both presentations yielded a correct response, until errors started to occur. That was the start of the second phase, in which responses around the threshold were sampled in blocks of four presentations with the same stimulus. The spatial frequency range over which the sampling took place depended on the responses obtained, and included one card with 100% correct responses, one card with chance level performance, and all cards in between. The cards included in the sampling were presented successively in an up-and-down order, so that in-between cards were presented more frequently, until at least 10 responses were available for each card. The acuity threshold was defined as the finest spatial frequency stimulus that could be detected correctly in 75% of the trials for the grating stimuli and in 54% for the Landolt-C optotype. The critical percentage was different for the grating and the LCO paradigms to account for the difference in sensitivity of forced-choice tasks with four instead of two choice options.23,24 The values chosen gave a sensitivity of d’ = 0.95 for the grating and the Landolt-C measurements.

The three paradigms were administered successively in a quasi-random order. At the start of each new paradigm, the task was explained. Participants were allowed to respond with a hand movement or a verbal description. A test failed if less than 100% correct responses were elicited on four consecutive presentations of the lowest spatial frequency stimulus available. If a particular task failed, the session was proceeded with the next paradigm.

Testing was binocular and participants wore their prescribed optical corrections. During assessment, participants sat on a chair and were instructed to sit up straight with the back against the back of the chair. Viewing distance was 228 cm and was measured from the test panel to the forehead. No chin rest was used. This position allowed some head movement, causing an uncertainty range of approximately ± 3 cm in viewing distance. For the youngest children, a second examiner attended to the child and the viewing distance. The unusual viewing distance was chosen for two reasons. First, increasing the viewing distance to the midrange of accommodation reduces the effect of small variations in spherical refraction quality of the eyes. Refractive errors may selectively affect optotype acuity, because it has been shown that optotype acuity is far more sensitive to optical blurring than is grating acuity.25–26 Second, a larger test distance ensured that the thresholds were readily within the spatial frequency range of the stimuli. At a distance of 228 cm the maximum assessable spatial frequency was 120 cyc/deg, which is well above the normal resolution abilities of the human eye. At this distance, the stimulus apertures in the presentation board constituted a visual angle of 2.31°.

Five examiners took part in the administration of the tasks. One of them (RV), a qualified neuropsychologist, is highly experienced with the procedures and materials. The other four examiners were carefully instructed and extensively trained before the study, and during the study the experienced examiner supervised their testing sessions.

Data Analysis

All acuity measures in cycles per degree of visual angle were transformed to base 10 logarithmic values before analysis. For readability of graphic presentations, data were transformed back to their corresponding values in cycles per degree, but were scaled in octave steps. For direct comparisons between acuity paradigms the cycles per degree data were transformed to octave difference—that is, base 2 logarithmic values. The relationship between base 10 and base 2 logarithmic scales is linear: \( \log_{10}(x) = \log_{2}(x) \log_{10}(2) \).

Appropriate parametric tests were used as specified in the text. When there was doubt about whether the underlying parametric assumptions had been met, nonparametric randomization tests27 were used instead, based on 10,000 redistributions of the data set. All statistical comparisons were evaluated at the 0.5 α level. Reported probability values are two tailed, unless specified otherwise.

RESULTS

Success rates of the three paradigms at different ages are presented in Table 1. The GRD paradigm was most successful, with a valid threshold in 91.3% of the children between the ages of 2.5 and 3.0 years and 100% success beyond 3.5 years of
TABLE 1. Overview of Success Rate and Visual Acuity Estimates of the Three Test Paradigms in Relation to Age

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Mean (y) Range</th>
<th>n</th>
<th>Success Rate M (cyc/deg)*</th>
<th>SD (octave)</th>
<th>Success Rate M (cyc/deg)*</th>
<th>SD (octave)</th>
<th>Success Rate M (cyc/deg)*</th>
<th>SD (octave)</th>
<th>All Three Success Rate n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2y9m</td>
<td>2.83-2.98</td>
<td>23</td>
<td>21</td>
<td>91.3</td>
<td>28.9</td>
<td>0.44</td>
<td>4</td>
<td>17.4</td>
<td>22.5</td>
</tr>
<tr>
<td>3y3m</td>
<td>3.29-3.48</td>
<td>35</td>
<td>33</td>
<td>94.9</td>
<td>32.5</td>
<td>0.41</td>
<td>10</td>
<td>28.6</td>
<td>29.2</td>
</tr>
<tr>
<td>3y9m†</td>
<td>3.50-3.97</td>
<td>35</td>
<td>35</td>
<td>100.0</td>
<td>31.2</td>
<td>0.39</td>
<td>22</td>
<td>62.8</td>
<td>28.6</td>
</tr>
<tr>
<td>4y3m</td>
<td>4.23-4.49</td>
<td>28</td>
<td>28</td>
<td>100.0</td>
<td>33.8</td>
<td>0.35</td>
<td>22</td>
<td>78.6</td>
<td>32.3</td>
</tr>
<tr>
<td>4y9m†</td>
<td>4.51-4.99</td>
<td>28</td>
<td>28</td>
<td>100.0</td>
<td>34.1</td>
<td>0.50</td>
<td>25</td>
<td>89.3</td>
<td>31.9</td>
</tr>
<tr>
<td>5y3m</td>
<td>5.30-5.88</td>
<td>29</td>
<td>29</td>
<td>100.0</td>
<td>36.9</td>
<td>0.30</td>
<td>28</td>
<td>96.5</td>
<td>32.3</td>
</tr>
<tr>
<td>5y9m</td>
<td>5.76-6.01</td>
<td>27</td>
<td>27</td>
<td>100.0</td>
<td>36.0</td>
<td>0.38</td>
<td>27</td>
<td>100.0</td>
<td>33.9</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>205</td>
<td>201</td>
<td>98.0</td>
<td>33.3</td>
<td>0.41</td>
<td>138</td>
<td>79.5</td>
<td>31.4</td>
</tr>
</tbody>
</table>

* Cycles per degree of visual angle. Calculations on log-transformed data were retransformed to cyc/deg for the mean values and to octave differences (i.e., log 2 values) for the standard deviations.

† One subject each in the age groups 3 y 9 m and 4 y 9 m who completed all three tasks were considered outliers and were omitted in calculating the mean and standard deviation.
acuity ($F_{(1,384)} = 7.54, P = 0.0063$) and GRO acuity ($F_{(1,384)} = 4.10, P = 0.0456$). The slopes for the two grating tasks did not differ significantly ($F_{(1,384)} = 0.52, P = 0.4714$).

In Table 2, adult data are statistically compared to those of the children in the oldest age group (5 years 9 months). The adult subjects obtained significantly higher acuity values than the oldest children on all three paradigms, indicating that the children had not yet reached adult acuity levels by the end of the fifth year of life. In contrast, the octave difference between LCO acuity and either of the grating acuities was not significantly different between the adults and the oldest children.

The necessity to exclude children who could not perform all three tasks introduced a selection bias toward developmentally more mature children, particularly in the younger age groups, in which the success rate of the GRO paradigm was very low. To appreciate the impact of this bias on the observed data from the 130 children. Several children were tested twice with some or all of the test paradigms. The retest took place within a week of the initial test session. Results of the first and second assessment are compared in Table 3. There was no significant difference between the test and retest thresholds for the LCO and GRO paradigms, but for the GRD paradigm the second measurement was significantly higher, the average threshold being 35.5 cyc/deg on the first and 36.4 cyc/deg on the second assessment. Visual acuity estimates with optotypes were more reliable than with gratings, as is indicated by the smaller SD and the narrower 90% confidence interval (i.e., the range around an observed threshold within which a new acuity assessment would be expected to fall in 90% of the cases). The reliability difference cannot be due to differences in age distribution, because these were similar in the three groups ($F_{(2,142)} = 0.415, P = 0.6624$). The percentage of retest thresholds that fell within 1 acuity card (≤ one-third octave) of the initial threshold was 89.71% for GRD, 81.40% for GRO, and 93.18% for LCO.

**DISCUSSION**

The results of this study show that acuity for single Landolt-C optotypes was superior to acuity for gratings in children with normal eyes, ages 2.5 to 6.0 years. In addition, optotype acuity improved faster with age than did grating acuities. Optotype and grating acuities at age 6 years remained significantly below acuities of adults. Grating detection and grating orientation acuities did not differ significantly except at one age. The disparity between optotype and both grating acuities and the similarity between the grating acuities suggest that the orientation discrimination aspect of the optotype task is not sufficient to explain differences in acuity. Rather, it is more likely that differences between optotype and grating stimuli explain the differences in acuities. Nevertheless, the different responses required probably resulted in completion of the GRD task at earlier ages than both the optotype task and the GRO task.

To establish the validity of our procedures, Figures 2 and 3 compare the average age-related acuity thresholds of the present study with those reported in other studies. Figure 2 presents the GRD acuity of all children who could complete the GRD task together with the results of other GRD procedures described in the literature. There is good agreement of our data with data in studies that used operant reinforcement of correct responses and with the results of Heersema and

### Table 3. Test-retest Differences for the Three Visual Acuity Paradigms

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>df</th>
<th>t</th>
<th>P</th>
<th>Pc 5</th>
<th>Pc 95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GRD</td>
<td>68</td>
<td>4.560</td>
<td>0.981</td>
<td>0.127</td>
<td>0.404</td>
<td>67</td>
<td>-2.60</td>
<td>0.0115</td>
<td>-0.415</td>
<td>0.700</td>
</tr>
<tr>
<td>GRO</td>
<td>43</td>
<td>4.721</td>
<td>0.844</td>
<td>0.069</td>
<td>0.455</td>
<td>42</td>
<td>-0.99</td>
<td>0.3278</td>
<td>-0.415</td>
<td>0.737</td>
</tr>
<tr>
<td>LCO</td>
<td>44</td>
<td>4.604</td>
<td>0.894</td>
<td>0.006</td>
<td>0.289</td>
<td>43</td>
<td>-0.03</td>
<td>0.9759</td>
<td>-0.379</td>
<td>0.379</td>
</tr>
</tbody>
</table>

Pc, percentile.

* Positive values indicate that the retest threshold was higher than the initial threshold.
van Hof-van Duin\textsuperscript{29} with the acuity card procedure. Two more recent studies with the acuity card procedure found lower acuities than in our study, particularly in the younger age groups.\textsuperscript{30,31} One of these tested monocular acuity,\textsuperscript{30} whereas, in our study and the other studies mentioned, binocular acuity was assessed. Monocular acuity is typically lower than binocular acuity in children.\textsuperscript{32,33} The study\textsuperscript{31} reporting lower binocular acuity may have underestimated acuity, because grating visibility was judged from the children’s looking behavior, as one would in infants, rather than using the child’s pointing to the grating or a verbal response. In addition, a conservative threshold criterion was used in this study.\textsuperscript{31}

There are only a few studies available on the normal development of single Landolt-C optotype acuity. In Figure 3 their results are compared with LCO acuities of all children from the present study who could perform the LCO task. In three studies, lower preschool optotype acuities were found than in the present study.\textsuperscript{17,54,55} All three assessed acuity as part of a screening in a clinical setting, and two assessed monocular instead of binocular acuity.\textsuperscript{17,54} In contrast, our data agree with the results described by Atkinson et al.\textsuperscript{56} and by Smorvik and Bosnes,\textsuperscript{57} who tested binocular acuity in a laboratory setting. Smorvik and Bosnes\textsuperscript{57} found ceiling scores at 6/60 acuity in a Landolt-C versus O detection paradigm from the age of 3 years onward, suggesting that optotype acuity is well above 30 cyc/deg during the preschool years. This suggestion receives confirmation by the study of Atkinson et al.,\textsuperscript{56} who found an average optotype acuity of 45 cyc/deg in 3.5-year-old children and 40 cyc/deg in 5.5-year-old children. The LCO acuity measured in our adult subjects was similar to that reported in other studies.\textsuperscript{17,58,59}

Several previous studies investigated the relationship between grating and optotype acuity in normal eyes. These studies differ in many aspects of stimulus, response, test paradigm, and subjects. Nonetheless, among the studies of normal preschool children, our binocular data agree well with the monocular findings obtained by Warner et al. (Warner, et al., IOVS 1992;33:ARVO Abstract 120) and by Dobson et al.\textsuperscript{7} Both studies compared the crowded Hooper Visual Organization Test (HVOT) test at 10 feet and the acuity card procedure at near distance. Warner et al. did not find a difference between grating and optotype acuity in 3-year-olds, whereas optotype acuities were higher on average in children aged 3.5 years,\textsuperscript{4} 4.0 years (Warner et al.), and 4.5 years,\textsuperscript{7} with the discrepancy increasing from 0.27 to 0.37 octave. The average octave difference between the tasks in our sample was 0.1948 (SD = 0.3801) in the 3-year-olds, 0.3799 (SD = 0.3595) in the 4-year-olds, and 0.4868 (SD = 0.3632) in the 5-year-olds. Two other studies covering the preschool age range reported the reverse relationship—lower optotype than grating acuity. This seems to be due to unusual acuities obtained with one or the other of the two measures. Rydberg et al.\textsuperscript{15} concluded that the acuity card procedure overestimated HVOT acuity in normal children aged 1.5 to 7.0 years. However, the reported binocular grating acuities were extremely high, with 95% of the values lying between 42 and 60 cyc/deg. This is much higher than the acuities that they measured in normal adults (27 to 36 cyc/deg), and disagrees with the acuities typically found in the preschool age range (see Fig. 2). Conversely, van Hof-van Duin and Pott (van Hof-van Duin, et al. IOVS 1990;31:ARVO Abstract 915) reported considerably lower acuity assessed with a crowded C chart than with the acuity card procedure in 5-year-old normal children, but their average C acuity of 19.0 cyc/deg was lower than is commonly found at that age\textsuperscript{20} (see Fig. 3).

Other studies have compared grating and optotype acuities in normal subjects beyond the preschool age range and reported superiority of optotype acuity over grating acuity.\textsuperscript{20,41,42} In 12 normal children of mean age 9.3 years, Thompson et al.\textsuperscript{20} found that letter recognition acuity was 0.475 octave higher than grating acuity tested using spatial frequency sweep visual evoked potentials. And, Volkers et al.\textsuperscript{41} found that letter acuity of 26 normally sighted adults exceeded grating acuity extrapolated from the spatial contrast sensitivity function by 0.183 octave. Thus, the evidence from our and others’ studies suggests that beyond age 3 years, optotype acuity is superior to grating acuity in individuals with normal eyes.

To make a direct comparison of optotype and grating acuity at different ages in the present study, we had to use a repeated measurement design. This necessitated the exclusion of children if they could not perform all three tasks. The question presents itself whether this age-related selection in some way biased the developmental pattern observed in our data. First, an underestimation of the superiority of optotype over grating acuity may have occurred in the younger age groups. This would be the case if children who could complete the GRO task overall had better grating acuity than children who could not perform this task, thereby minimizing the discrepancy with optotype acuity. This interpretation is not confirmed by our data, however. There was no statistically significant difference in the grating detection acuity of the children from the three youngest age groups (2 years 9 months to 3 years 9 months) who failed the GRO task ($n = 53$, mean = 30.4 cyc/deg, SD = 30.4 cyc/deg) and 40 cyc/deg in 5.5-year-old children. The LCO acuity measured in our adult subjects was similar to that reported in other studies.\textsuperscript{17,58,59}

![Figure 2](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932921/) Comparison of mean grating detection acuity and 95% confidence intervals in relation to age, with mean grating acuities reported in five other studies using the operant forced-choice preferential looking methods or the acuity card procedure.

![Figure 3](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932921/) Comparison of mean single optotype Landolt-C orientation acuity and 95% confidence intervals in relation to age, with mean single Landolt-C acuities reported in five other studies.
0.385 octave) compared with those who completed the GRD task (n = 35, mean = 32.2 cyc/deg, SD = 0.443 octave; fΔopt = 0.96, one-tailed P = 0.1705). Second, the age-related selection may have led to an overestimation of the superiority of optotype over grating acuity in the younger age groups if the selection favored visually more mature children. Our data show that optotype superiority was more apparent in the older children. Therefore, visually more mature children may show a larger discrepancy between optotype and grating acuity than their visually less mature age-mates who failed the GRO task. However, this interpretation is also not confirmed by our data. The optotype minus GRD acuity difference in the children from the age groups 3 years 3 months to 4 years 3 months who succeeded in the GRO task (n = 51, mean 0.288 octave, SD = 0.368) was actually lower (instead of higher) than in the children who failed the GRO task (and therefore were visually less mature; n = 20, mean = 0.474, SD 0.546 octave; fΔopt = 1.94, one-tailed P = 0.0280). This is also apparent from Figure 1. If a selection bias had resulted in an overestimation of the discrepancy between acuity measures, we would expect the discrepancy to decrease by adding children who completed the GRD and LCO task, but failed the GRO task. However, as Figure 1 shows, this was not the case. On the contrary, adding children who failed the GRO task merely confirmed the developmental pattern that was already apparent in the data from the children who completed all three tasks. Therefore, the inevitable selection bias imposed by our experimental design does not impair our conclusion that the discrepancy between optotype acuity and grating acuity decreases in the younger age group.

Although the gratings in the GRO and GRD paradigms were identical, the thresholds obtained with the GRO paradigm were lower in all age groups, but the difference was not statistically significant except in children who completed the task between 4.5 and 9.5 years of age. The average difference calculated over all age groups was 0.1441 (SD = 0.3449 octaves). The reason for this difference is not clear. One possibility is that meridional variations in acuity due to unnoticed astigmatism in our sample selectively affected visibility of gratings at particular orientations. This is not likely, however, because grating orientation was varied randomly in the detection paradigm, as in the orientation paradigm. Small luminance differences between gratings and distractor cards in the detection paradigm also is an unlikely explanation, because small luminance differences were dissociated from the grating position by randomly alternating between three distractor cards with slightly different luminances. Only one other study directly compared grating detection and grating orientation acuity in 36 children with amblyopia between 4.5 and 9.5 years of age, and found no difference. However, the maximum assessable acuity in their paradigm was 50 cyc/deg, which is just below the range of different grating acuities in our study.

The mechanisms underlying superior optotype acuity compared with grating acuity are unclear. As discussed, the orientation discrimination aspect of the tasks does not explain the acuity difference. Rather, differences between the stimuli must be invoked. An explanation based on stimulus features was proposed by Bondarko and Danilova, based on two-dimensional Fourier spectrum analysis of the Landolt-C optotype. They found differences in the amplitude spectrum along the direction of the gap and perpendicular to the gap at spatial frequencies lower than those corresponding to the gap. Through band pass spatial frequency filtering of the Landolt-C optotype, Hess, et al. showed that psychophysically trained subjects use these lower spatial frequency cues, whereas untrained subjects tend to respond to the visibility of the gap. Against a pure stimulus-dependent explanation, however, is the finding that gap detectability varies with orientation of the optotype. Schrauf and Stern showed that subjects made the least detection errors when the gap was directed to the right, so that the optotype resembled the letter C, whereas most errors occurred with the gap oriented downward. Such variations suggest the involvement of neural mechanisms and possibly top down influences from higher level visual processing. An example of such a top down influence that could account for the higher optotype than grating acuity is visual attentional modulation. Focusing visual attention to a particular object and location is known to increase neuronal sensitivity to the attended stimulus in all visual areas, whereas the representation of other features and locations is suppressed. Attentional selection of input is object and/or location driven and therefore is most effective with stimuli of limited spatial extent, such as optotypes. In gratings the spatial frequency information extends over a larger area, whereas in a Landolt-C optotype it is centered at the gap in the ring, which decreases in spatial extent as the optotype is made smaller.

A very different ordering of the three acuity paradigms emerges when the success rates are compared. The overall success rate of the GRO paradigm was 98.0%. This is in agreement with the success rates reported for the acuity card procedure in this age range. The orientation paradigms were more difficult to accomplish, particularly for the younger children. This indicates that the cognitive demands of these tasks are very different. The GRD task merely requires the processing of grating texture and the indication of its position in subject centered space. In contrast, the LCO and GRD tasks require a visuospatial feature to be processed. In the LCO task this feature is the relative position of a landmark (the gap) in the stimulus configuration. Our data show that this is cognitively more taxing than texture detection, but still easier than the categorization and representation in a response of the orientation paradigm. This indicates that different task requirements necessitate the recruitment of different neurocognitive mechanisms. That different brain regions are recruited in response to a particular stimulus depending on the task imposed is well documented by animal and human studies. For instance, posterior emission tomography (PET) has shown that although oriented gratings activate the ventral visual information stream up to the middle fusiform gyrus when passively looked at, the activation is confined to the early retinotopic visual areas when subjects respond by key press to the appearance of the gratings. Performing categorical orientation judgments on the same gratings (as in the GRO task) gives additional activation in the visual shape areas of the lingual and posterior fusiform gyrus. In addition, the latter task invokes increased activity in frontal areas and in parietal cortical areas that may be related to visuospatial attention. The later development of such higher parietal and frontal mechanisms may account for the age-related differences in the success rate observed in the three acuity tasks.

Some limitations of the present study have to be considered. We did not examine the refractive status of the children. Children wore their prescribed corrections during the acuity testing. Nonetheless, it is possible that a higher prevalence of small uncorrected refractive errors in the younger children lead to smaller discrepancies between optotype and grating acuities in the younger age groups. Optotype stimuli are degraded more by optical blur than gratings, and although children in Belgium annually undergo a standard medical checkup, including an evaluation of functional vision, it is possible that larger proportions of vision loss due to refractive error remain unnoticed in the younger age groups.

The different number of choice alternatives for the Landolt-C task and the grating tasks is another limitation of our study. We could have eliminated this difference by constrain-
ing the possible positions of the Landolt-C gap to left or right, or by asking the subjects to indicate whether the gap was aligned with the horizontal or vertical dimension. However, we refrained from doing so because that would have made the optotype paradigm more difficult in other respects. Left–right judgments are more difficult to perform for young children than discriminating the horizontal and vertical orientation of lines; and horizontal–vertical judgments are more complex for the Landolt-C optotype because two different gap positions (e.g., up or down) lead to the same response (vertical). An interesting alternative would have been to include a fourth paradigm requiring the detection of the Landolt-C optotype at one of two possible locations, with an O matched in size to the C at the alternative position. That would have balanced our manipulation of test stimulus and task–response difference, with both stimulus types occurring in both types of paradigm.

Another interesting point that we did not address in our study is the relation of superior optotype acuity to the phenomenon of crowding (i.e., the decrease in spatial resolution that results from placing contours or other optotypes near an acuity target). Because we used single Landolt-C optotypes, it is possible that the optotype superiority merely reflected the absence of crowding and that the observed optotype superiority would disappear if crowding was introduced. This outcome is not very likely, though, because several studies reporting higher optotype than grating acuity in children used this paradigm and showed no such effects. If the absence of crowding and that the observed optotype superiority would disappear if crowding was introduced.

Despite these limitations, our conclusion remains that grating acuity and single optotype acuity follow a different developmental time course, with the superiority of optotype acuity emerging during the preschool age. These results extend previous findings because we used closely matching test paradigms for gratings and optotypes. This confines possible explanations to the critical aspects of grating detection and optotype recognition. By also including a grating orientation paradigm we were further able to show that the higher optotype acuity is not dependent on the visuospatial component of the optotype task, but on the nature of the stimulus. In addition, these findings provide a crucial background for the interpretation of data obtained in pediatric patients. Although the sample size in the present study is small to derive normative values, our data provide a valid estimate of the absolute acuity values that can be expected with each paradigm. Furthermore, the described distribution of optotype to grating acuity discrepancies is sufficient to establish cutoff criteria for risk populations.

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