Infantile Nystagmus Syndrome Is Associated With Inefficiency of Goal-Directed Hand Movements

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PURPOSE. The effect of infantile nystagmus syndrome (INS) on the efficiency of goal-directed hand movements was examined.

METHODS. We recruited 37 children with INS and 65 control subjects with normal vision, aged 4 to 8 years. Participants performed horizontally-oriented, goal-directed cylinder displacements as if they displaced a low-vision aid. The first 10 movements of 20 back-and-forth displacements in a trial were performed between two visually presented target areas, and the second 10 between remembered target locations (not visible). Motor performance was examined in terms of movement time, endpoint accuracy, and a harmonicity index reflecting energetic efficiency.

RESULTS. Compared to the control group, the children with INS performed the cylinder displacements more slowly (using more time), less accurately (specifically in small-amplitude movements), and with less harmonic acceleration profiles. Their poor visual acuity proved to correlate with slower and less accurate movements, but did not correlate with harmonicity. When moving between remembered target locations, the performance of children with INS was less accurate than that of the children with normal vision. In both groups, movement speed and harmonicity increased with age to a similar extent.

CONCLUSIONS. Collectively, the findings suggest that, in addition to the visuospatial homing-in problems associated with the syndrome, INS is associated with inefficiency of goal-directed hand movements. (http://www.trialregister.nl number, NTR2380.)

Keywords: infantile nystagmus syndrome, children, sensorimotor development, goal-directed hand movements

To be able to participate properly in daily school activities, visually impaired children, like all children, need well-developed motor skills that allow them to handle devices, such as low-vision aids,1 smartphones, pencils, and laptops. In young visually impaired children who are not yet using a visual aid, the visual feedback of their movements is structurally different from their normally sighted peers: fine details are not seen and, therefore, their interaction with surrounding objects has not the same stimulating effect. When visual acuity is low, motor development can be influenced or even delayed.2–9 Earlier studies have shown that fine and gross motor skills as well as control of balance are underdeveloped in children with a visual impairment.2–9 Furthermore, children with mild-to-severe visual acuity loss and amblyopia are known to generate grasping movements of lower quality than children with normal sight.10,11 Reimer et al.,12 who studied the effect of visual impairment on goal-directed aiming in a small group of children with albinism, demonstrated that 8-year-old children with albinism were less accurate than the control group. In present-day society, in which the use of technical devices has increased dramatically, children indeed strongly rely on fine motor skills. In that context, it is useful to investigate the motor skills of visually impaired children. A precise description of the effects of visual impairment on the efficiency of goal-directed hand movements still is lacking.

In the present study, we investigated goal-directed hand movements of children with infantile nystagmus syndrome (INS). This syndrome is the third cause of low vision in the Netherlands,13 and is characterized by involuntary oscillations of the eyes that typically are conjugate and horizontal in direction, and by infantile onset.14,15 As a direct result of the inability to maintain stable foveal vision, INS is associated with reduced visual acuity.16,17 The INS occurs in an isolated (idiopathic) form, or is accompanied by congenital or acquired defects in the visual system, such as albinism, bilateral optic nerve hypoplasia, infantile cataract, aniridia, or various inherited types of retinal degeneration.15,18–20 If INS is accompanied by another sensory disorder, a patient has two disorders (e.g., albinism and INS).19 Idiopathic and accompanied INS forms are included in this study, which makes the study group a realistic reflection of the prevalence of INS children in the Netherlands. The INS population is a very heterogeneous group. Evidence for a relation between stereopsis and fine motor skills in children with amblyopia (mean...
Infantile Nystagmus Syndrome

The clinical details of the children with INS are shown in Table 1. Distance visual acuity was measured monocularly and binocularly with correction with the Landolt C-test at 5 m and the illiterate E-chart at 6 m under controlled lighting conditions in an ophthalmological setting. Near-visual acuity was determined binocularly with the angular LH version of the C-test at 40 cm. Stereopsis was assessed with the Titmus Fly Test, and, if possible, with the TNO-test (a red-green system). Data regarding stereopsis scores of two normally sighted children are missing. Orthoptic examination was performed by orthoptists: they performed alternate cover test, cover-uncover test and, if necessary, the 4 dioptr (D) base out prism test. A gross estimation of the visual field was obtained by confrontational techniques, to secure full view at the digitizer tablet. After cycloplegia, slit-lamp examination, and funduscopy and objective refraction were obtained, and, if necessary, the spectacle correction was prescribed or changed before the experiment started. All children with glasses wore them during the entire experiment.

**Apparatus and Procedure**

The participants were asked to perform goal-directed hand movements by displacing a cylinder-shaped object by means of a horizontal sliding movement across the surface of a digitizer tablet (type 21ux; Wacom, Saitama, Japan). The digitizer was positioned in front of the child's body midline and displayed two circles (diameter 25 mm) that acted as the start and end location of each movement. Children were asked to perform accurate and fast hand movements between the start and end target, as in a Fitts paradigm, with both eyes open. The size of the cylinder matched that of a 6 D stand magnifier (diameter 56 mm, height 49 mm). An electronic sensor was placed in the center of the cylinder, allowing its X and Y positions to be digitally recorded at a sampling rate of 144 Hz. Children performed movements across two distances of either 10 or 20 cm horizontal distance between the center of the start and end target. Each participant received a random sequence of experimental conditions, each condition containing 20 movements. In the first 10 movements, target locations were visually presented, but in the second 10 movements they were not. Before the start of each trial, the child was asked to position the object in the starting circle on the digitizer, after which the experiment was started. A period of approximately 0.5 seconds later, the go signal was given and the target circle appeared on the digitizer. This was the indication for the child to slide the cylinder as fast and as accurately as possible toward the target location. When the target was reached, the former starting circle disappeared. The child had to wait for a random period of approximately 0.5 to 1.5 seconds before the next go signal was given and the target circle appeared (at the location of the former starting circle). The child then moved the object back to the start circle and the next trial started. A total of 40 different trials were performed for each condition. The order of the trials was randomized to avoid any learning effects. Participants were asked to perform the task as accurately and as fast as possible, without looking away from the target.
Infantile Nystagmus Syndrome captures the adaptability of error-correction mechanisms. In goal-directed aiming tasks and condition, an endpoint variability (EV) measure reflecting movement efficiency with which kinetic energy is being recycled during the deceleration phases of the strokes, respectively, which are larger in nonharmonic movements, reduce the statistical fit of the regression line, resulting in lower Rsq. In this sense, Rsq is a measure of the linearity of the Hooke's portrait, and is directly related to the harmonicity of the movement. A higher Rsq (i.e., closer to 1), associated with a more linear Hooke's portrait, indicates a simple harmonic motion, corresponding to a more (kinetically) efficient motor performance.

For the three dependent variables (MT, EV, and Rsq), the data were averaged across the 10 repetitions of each task condition and entered into SPSS (SPSS, Inc., Chicago, IL, USA). General linear model procedures were carried out, with INS group as between-subjects factor, age (in months) as covariate, and target visibility as within-subject factor, for the 10 and 20 cm condition, separately. Only 2-way interaction effects including group (INS versus control group) and target visibility (visible and invisible) are reported, in accordance with our research hypotheses. Preliminary analyses revealed no significant difference regarding stereopsis and performance scores between children with INS and albinism and children with INS without albinism, and were reason to leave albinism out of the General Linear Model procedures. To investigate the effect of visual impairment on the performance of children with INS, Pearson correlations were calculated between their visual acuity scores and mean performance scores (MT, EV, Rsq). If correlations were significant, step-down correlation analyses were conducted for the different conditions. Floor and ceiling effects resulted in not normally distributed stereopsis scores. Consequently children were clustered according to their stereopsis level; “nil” if “no” stereoscopic response could be generated, “reduced” if response indicated stereopsis between 800 and 60 sec arc, and “normal” if response indicated stereopsis better than or equal to 40 sec arc. The $\chi^2$ analyses were performed to compare the level of stereopsis between children with INS and children with normal sight. We performed t-tests to compare performance scores (MT, EV, Rsq) of the subgroup with INS and reduced stereopsis with performance scores of the subgroup with INS and no stereopsis. To test the second hypothesis, first, Pearson correlations between age and visual acuity were calculated, because in typically developing children and children with INS, visual acuity increases with age. Second, Pearson correlations were calculated between MT, EV, Rsq, and age (in months) controlling for visual acuity, per vision group, and target visibility condition, separately for movements with an amplitude of 10 and 20 cm.

### RESULTS

Figure 3 shows the mean MT, EV, and Rsq for each group (normally sighted versus INS) as a function of target visibility (visible versus invisible) and amplitude (10 and 20 cm).
### TABLE 1. Clinical Characteristics of Children With INS

<table>
<thead>
<tr>
<th>Age, y</th>
<th>OD*</th>
<th>OS†</th>
<th>Diagnosis</th>
<th>Deviation</th>
<th>Stereopsis, sec arc</th>
<th>Refractive Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>0.2</td>
<td>0.2 0.16 0.2</td>
<td>Idiopathic INS</td>
<td>L esotropia</td>
<td>Nil</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.12</td>
<td>0.08 0.08 0.08</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>Nil</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0.06</td>
<td>0.04 0.25 0.1</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>R S: –3.5 C: −2.75 A: 180°</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.08</td>
<td>0.1 0.08 0.08</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>N S: +4.5 C: −2.00 A: 14°</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.1</td>
<td>0.06 0.06 0.08</td>
<td>Achromatopsia, INS</td>
<td>Orthophoria</td>
<td>R S: +3.25 C: −3.25 A: 178°</td>
</tr>
<tr>
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<td>5</td>
<td>0.06</td>
<td>0.06 0.05 0.08</td>
<td>Achromatopsia, INS</td>
<td>Orthophoria</td>
<td>R S: +4.50 C: −1.00 A: 3°</td>
</tr>
<tr>
<td>7</td>
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<td>0.24</td>
<td>0.2 0.25 0.25</td>
<td>Retinoschisis (X linked), INS</td>
<td>Orthophoria</td>
<td>480 No correction</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>0.2</td>
<td>0.2 0.16 0.16</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>R S: –0.25 C: −1.00 A: 69°</td>
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<tr>
<td>9</td>
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<td>0.2 0.25 0.25</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>R S: –1.75 A:100°</td>
</tr>
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<td>10</td>
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<td>0.16 0.3 0.2</td>
<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>R S: +1.00 C: −2.00 A: 1°</td>
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<tr>
<td>11</td>
<td>5</td>
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<td>0.2 0.25 0.2</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
<td>R S: +3.25 C: −1.25 A: 10°</td>
</tr>
<tr>
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<td>0.16 0.2 0.32</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
<td>R S: +2.50 C: −2.25 A: 172°</td>
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<tr>
<td>13</td>
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<td>0.36</td>
<td>0.7 0.6 0.63</td>
<td>Hypermetropia (&gt;4D), INS</td>
<td>Orthophoria</td>
<td>R S: +4.50 C: −1.75 A: 170°</td>
</tr>
<tr>
<td>14</td>
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<td>0.125 0.16 0.16</td>
<td>Albinism, INS</td>
<td>R esotropia</td>
<td>L esotropia</td>
</tr>
<tr>
<td>15</td>
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<td>0.1 0.1 0.1</td>
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<td>Orthophoria</td>
<td>R S: −4.75 C: −2.5 A: 7°</td>
</tr>
<tr>
<td>16</td>
<td>6</td>
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<td>0.2 0.25 0.32</td>
<td>Albinism, myopia &gt;6D, INS</td>
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<td>R S: −5.50 C: −1.00 A: 180°</td>
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<tr>
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<td>0.16 0.16 0.16</td>
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<td>R S: −8.25 C: −1.75 A: 7°</td>
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<tr>
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<td>0.36</td>
<td>0.3 0.4 0.5</td>
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<td>Orthophoria</td>
<td>R S: −4.75 C: −0.50 A: 170°</td>
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<tr>
<td>19</td>
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<td>0.2 0.125 0.32</td>
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<td>Orthophoria</td>
<td>R S: +16.25 C: −2.00 A: 152°</td>
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<tr>
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<td>0.25 0.32 0.32</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
<td>R S: −1.25 C: plan A: 180°</td>
</tr>
<tr>
<td>21</td>
<td>6</td>
<td>0.12</td>
<td>0.2 0.32 0.23</td>
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<td>Orthophoria</td>
<td>R S: −0.75 C: −2.00 A: 167°</td>
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<tr>
<td>22</td>
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<td>0.12</td>
<td>0.2 0.2 0.25</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
<td>R S: −0.75 C: −3.00 A: 163°</td>
</tr>
<tr>
<td>23</td>
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<td>0.24</td>
<td>0.2 0.25 0.32</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
<td>R S: −2.25 C: −0.25 A: 7°</td>
</tr>
<tr>
<td>24</td>
<td>7</td>
<td>0.36</td>
<td>0.25 0.25 0.32</td>
<td>Albinism, INS</td>
<td>R esotropia</td>
<td>R S: −2.25 C: −1.25 A: 8°</td>
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<tr>
<td>25</td>
<td>7</td>
<td>0.36</td>
<td>0.32 0.25 0.25</td>
<td>Idiopathic INS</td>
<td>L esotropia</td>
<td>R S: −0.75 C: −0.75 A: 110°</td>
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<td>0.12 0.2 0.2</td>
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<td>Orthophoria</td>
<td>R S: −4.25 C: −3.00 A: 5°</td>
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<td>8</td>
<td>0.18</td>
<td>0.25 0.16 0.25</td>
<td>Congenital cataract (aphakia), INS</td>
<td>L esotropia</td>
<td>R S: +12.00 C: −3.75 A: 14°</td>
</tr>
<tr>
<td>28</td>
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<td>Nightblindness (CSNB), INS</td>
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<td>R S: −10.00 C: −3.00 A: 104°</td>
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<td>31</td>
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<td>0.3</td>
<td>0.125 0.4 0.4</td>
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<td>R S: −3.75 C: plan A: 180°</td>
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<tr>
<td>32</td>
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<td>0.2</td>
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<td>Albinism, INS</td>
<td>Orthophoria</td>
<td>R S: −4.50 C: −3.25 A: 10°</td>
</tr>
<tr>
<td>33</td>
<td>8</td>
<td>0.24</td>
<td>0.04 0.25 0.25</td>
<td>Retinoschisis (X linked), INS</td>
<td>R esotropia</td>
<td>480 No correction</td>
</tr>
</tbody>
</table>

*OD*: Ocular Distance
*OS*: Ocular Shift
*Ang*: Angle of Deviation
*DS*: Dioptric Strength
*O/D*: O/S: O/D: O/S: O/D:
*LS*: Line System
*C*: Cylindrical
*计划*: Plan
Children With INS Versus Children With Normal Vision

A longer MT was found in the INS group in the 10 cm condition, \( F(1, 99) = 13.59, P < 0.001 \), and 20 cm condition, \( F(1, 99) = 11.50, P = 0.001 \), indicating slower hand movements in children with INS than in children with normal vision (Fig. 3A). A larger EV was found in the INS group in the 10 cm condition, \( F(1, 99) = 6.61, P = 0.012 \), indicating a less accurate performance in children with INS than children with normal vision (Fig. 3). In the 20 cm condition, the group effect on EV approached statistical significance, \( F(1, 99) = \)

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**Table 1.**

<table>
<thead>
<tr>
<th>Age, y</th>
<th>DVA ODS ODS</th>
<th>NVA ODS</th>
<th>Diagnosis</th>
<th>Deviation Stereopsis,</th>
<th>Refractive Correction</th>
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<td></td>
<td>right eye</td>
<td>left eye</td>
<td></td>
<td>sec arc</td>
<td></td>
</tr>
<tr>
<td>34</td>
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<td>0.4</td>
<td>0.25</td>
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<td>Orthophoria</td>
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<tr>
<td>35</td>
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<td>0.08</td>
<td>0.16</td>
<td>CSNB, INS</td>
<td>Orthophoria</td>
</tr>
<tr>
<td>36</td>
<td>0.36</td>
<td>0.32</td>
<td>0.4</td>
<td>Idiopathic INS</td>
<td>Orthophoria</td>
</tr>
<tr>
<td>37</td>
<td>0.4</td>
<td>0.2</td>
<td>0.32</td>
<td>Aniridia, INS</td>
<td>Orthophoria</td>
</tr>
</tbody>
</table>

DVA, distance visual acuity; ODS, binocular; OD, right eye; OS, left eye; NVA, near visual acuity; ang, angular; CSNB, congenital stationary night blindness.

* Distance visual acuity binocularly at 6 m in decimals as measured with E-gratings.
† Distance visual acuity monocularly at 5 m in decimals as measured with C-test angular.
‡ Near visual acuity binocularly at 40 cm in decimals as measured with LH line version of the C-test.

**Figure 1.** Depicts the 10 horizontal strokes produced in the 10-cm amplitude condition by a representative child with normal vision (A) and a child with INS (B), and Hooke’s portraits (acceleration versus horizontal displacement graphs) produced by a representative child with normal vision (C) and a representative participant with INS (D). A linear regression line (red line) was fitted through all the points constituting the Hooke’s portraits (in C, D). The Rsq value is an index ranging from 0 to 1, quantifying how well the curve approximates this straight line (in C), mean Rsq is 0.67; in D, mean Rsq is 0.71). The arc-like endings at each side of a Hooke’s portrait, which are larger in nonharmonic movements, reduce the fit of the regression line, resulting in lower Rsq. This corresponds to a less (kinetically) efficient motor performance.
3.55, \( P = 0.062 \) (Fig. 3B). A larger RSq was found in the INS group in the 10 cm condition, \( F(1, 99) = 9.90, P = 0.002 \), and the 20 cm condition, \( F(1, 99) = 11.44, P = 0.001 \), indicating a less harmonic performance in children with INS than in children with normal vision (Fig. 3C).

In summary, the INS group made slower (10 and 20 cm condition), less accurate (10 cm condition), and less harmonic (10 and 20 cm condition) goal-directed hand movements than the normally sighted group.

**Target Visibility**

Target visibility had a main effect on MT in the INS and normally sighted group in the 10 cm condition, \( F(1, 99) = 10.20, P = 0.002 \), and 20 cm condition, \( F(1, 99) = 15.97, P < 0.001 \), indicating a slower performance in the invisible target condition (Fig. 3A). Target visibility had a main effect on EV in the INS and normally sighted group in the 10 cm condition, \( F(1, 99) = 14.86, P < 0.001 \), and 20 cm condition, \( F(1, 99) = 9.37, P = 0.003 \), indicating a less accurate performance in the invisible target condition (Fig. 3B). An interaction effect between target visibility and vision group in the 10 cm condition, \( F(1, 99) = 6.66, P = 0.011 \), indicates that target visibility affected the EV more in the INS group than in the normally sighted group. Target visibility had no significant main effect on RSq in the INS and normally sighted group in the 10 cm condition, \( F(1, 99) = 3.67, P = 0.058 \), and the 20 cm condition, \( F(1, 99) = 2.44, P = 0.122 \) (Fig. 3C).

In summary, INS and normally sighted children made slower and less accurate movements when moving toward previously visible target locations. Furthermore, target visibility affected the EV more in the INS group than in the normally sighted group in the 10 cm condition.

**Visual Acuity**

On average, the Pearson correlations between visual acuity and mean MT, visual acuity and mean EV, and visual acuity and
mean RSq were Pearson’s $r = -0.39, P = 0.030$, Pearson’s $r = -0.38, P = 0.020$, and Pearson’s $r = 0.21, P = 0.217$, respectively. The results clearly show that visual acuity correlates negatively with the speed and accuracy of the goal-directed hand movements as expected. Table 2 shows, for the INS and normally sighted groups for each condition, the Pearson correlations between visual acuity scores on the one hand and mean MT, EV, and RSq scores on the other.

Of the children with normal vision 84.1% had “normal stereopsis,” 15.9% had “reduced stereopsis,” and none had “no stereopsis.” None of the children with INS had “normal stereopsis,” 51.4% had “reduced stereopsis,” and 48.6% had “no stereopsis.” The variation in level of stereopsis was significant between the normally sighted and INS groups, $\chi^2(2) = 71.89; P < 0.001$.

Performance of children with INS with reduced stereopsis was compared to the performance of children with INS and no stereopsis. In the 10 cm condition, we found no significant differences in performance speed, $t(35) = -0.64, P = 0.525$, accuracy, $t(35) = -0.139, P = 0.183$, and efficiency, $t(35) = -0.32, P = 0.749$. We found no significant differences in performance speed, $t(35) = -0.32, P = 0.750$, accuracy, $t(35) = -0.98, P = 0.354$, and efficiency, $t(35) = -0.09, P = 0.932$, in the 20 cm condition either.

In conclusion, normally sighted children had a significant better stereopsis than children with INS. In the INS group, no significant differences in performance were found between children with reduced stereopsis and no stereopsis.

### Age Effects

Figure 4 shows MT, EV, and RSq plotted as a function of age with regression lines representing the linear relation between variables and age, in movements with an amplitude of 10 cm. The results for the 20 cm amplitude condition were comparable. While controlling for visual acuity, correlation analyses were conducted per vision group and target-visibility condition, in movements with an amplitude of 10 and 20 cm (Table 3). We controlled for visual acuity because, as expected, positive correlations between age (months) and visual acuity (decimals) were found in the INS and normally sighted group, Pearson’s $r = 0.518$, $P = 0.001$, and Pearson’s $r = 0.555$, $P = 0.004$, respectively.

In summary, as a function of age, the similar movement-efficiency changes were observed in the children with INS and in the control group.

### Performance of Goal-Directed Hand Movements in Children With INS

With regard to the first hypothesis, we found that children with INS performed goal-directed hand movements more slowly, less accurately (particularly in small amplitude movements; i.e., 10 cm), and less harmonically than children with normal vision. This seems in contradiction with the study of Reimer et

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**Table 2.** The INS Group’s Pearson’s $r$ and $P$ Values Between Visual Acuity* and MT, Visual Acuity and EV, and Visual Acuity and RSQ

<table>
<thead>
<tr>
<th>Group</th>
<th>Conditions</th>
<th>MT</th>
<th>EV</th>
<th>RSq</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MT</td>
<td>$r$</td>
<td>$P$</td>
<td>$r$</td>
</tr>
<tr>
<td>INS</td>
<td>10 Visible target</td>
<td>-0.45</td>
<td>0.005</td>
<td>-0.33</td>
</tr>
<tr>
<td></td>
<td>Invisible target</td>
<td>-0.34</td>
<td>0.040</td>
<td>-0.33</td>
</tr>
<tr>
<td></td>
<td>20 Visible target</td>
<td>-0.35</td>
<td>0.045</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>Invisible target</td>
<td>-0.24</td>
<td>0.156</td>
<td>-0.18</td>
</tr>
<tr>
<td>Normally Sighted</td>
<td>10 Visible target</td>
<td>-0.21</td>
<td>0.087</td>
<td>-0.23</td>
</tr>
<tr>
<td></td>
<td>Invisible target</td>
<td>-0.15</td>
<td>0.298</td>
<td>-0.40</td>
</tr>
<tr>
<td></td>
<td>20 Visible target</td>
<td>-0.38</td>
<td>0.002</td>
<td>-0.21</td>
</tr>
<tr>
<td></td>
<td>Invisible target</td>
<td>-0.12</td>
<td>0.351</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

MT, movement time; EV, endpoint variability; RSQ, Hooke’s portrait linearity.

* Visual acuity at 6 m in decimals as measured with E-gratings.

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**Figure 4.** Mean MT in seconds (A), EV in cm$^2$ (B), and Hooke’s portrait linearity (RSq, C) separately for vision group (normally sighted versus INS) and target visibility condition (visible versus not visible) plotted as a function of age, for movements with an amplitude of 10 cm. The regression lines represent the linear relation between MT, EV, and RSq on the one hand and age on the other. The legend shows regression equation $(r)$, and corresponding $R^2$ values per vision group and target visibility condition.
al., who investigated goal-directed aiming in visually impaired children with albinism. They reported a less accurate performance for the INS group compared to the normally sighted group, but found no significant differences between the two groups in speed. The population in that study, however, was older (eight years), smaller ($N = 11$), and included only children with albinism. One might argue that the slower movements for the INS group found in the present study resulted from longer movement trajectories as consequence of less accurate movements. We found evidence against this argument, because there were no significant differences in trajectory length between INS and normally sighted children. The origin of the slower and less accurate goal-directed movements in children with INS should, therefore, be found by slower or suboptimal sensorimotor processes, which were partly captured by our analyses of harmonicity and its variations as a function of visual acuity and target visibility.

**Efficiency of Goal-Directed Hand Movements in Children With INS**

The analysis of harmonicity provided additional insights in goal-directed aiming at the level of sensorimotor coordination. The Hooke’s portraits of children with normal vision (Fig. 1C) as well as children with INS (Fig. 1D) revealed relatively nonharmonic movements, resembling those observed in adults performing under high precision constraints. Moreover, children with INS demonstrated less harmonic movements than children with normal vision. To elaborate, in rhythmical aiming movements, under low-precision constraints a moving arm acts as a linear oscillator displaying simple harmonic motion. Kinetic energy built up during one movement is stored as potential (elastic) energy in the tendons and muscles, and released at the reversal point, that is, the start of the next movement. In this way, only little kinetic energy is lost. Under high-precision constraints, however, it is likely that high levels of cocontraction occur to arrive precisely and with low speed within the designated target area. Such conditions have a negative effect on the harmonicity of the movement and the dissipation of kinetic energy. One way to express the results regarding harmony in the present study is that children performing aiming movements in a Fitts task seem to experience a task difficulty that is “subjectively” higher than adults with the same set of task constraints. These less harmonic movements might be interpreted as reflecting less optimal sensorimotor coordination or cocontraction regulation in children than in adults, which is accompanied by more dissipation of energy in each stroke. For children with INS, the less harmonic movements reflect their suboptimal motor efficiency, which is inferior compared to children with normal vision. In other words, the poorer goal-directed hand movements in the INS group may result from inefficient perception–action couplings or cocontraction strategies probably because the satisfaction of multiple constraints underlying task performance (i.e., fast as well as accurate aiming) is more difficult.

**TABLE 3. Pearson’s $r$ and $P$ Values Between MT, EV, and RSq on the One Hand and Age in Months on the Other, for Children With Normal Vision and INS, in Movements With an Amplitude of 10 and 20 cm With Visible and Invisible Targets**

<table>
<thead>
<tr>
<th>Group</th>
<th>VT</th>
<th>IVT</th>
<th>VT</th>
<th>IVT</th>
<th>VT</th>
<th>IVT</th>
<th>VT</th>
<th>IVT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal sighted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r$</td>
<td>-0.57</td>
<td>-0.52</td>
<td>-0.61</td>
<td>-0.51</td>
<td>-0.31</td>
<td>-0.45</td>
<td>-0.35</td>
<td>-0.34</td>
</tr>
<tr>
<td>$P$</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.015</td>
<td>0.003</td>
<td>0.012</td>
<td>&lt;0.001</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>INS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r$</td>
<td>-0.50</td>
<td>-0.35</td>
<td>-0.27</td>
<td>-0.51</td>
<td>-0.35</td>
<td>-0.35</td>
<td>-0.19</td>
<td>-0.52</td>
</tr>
<tr>
<td>$P$</td>
<td>0.002</td>
<td>0.039</td>
<td>0.27</td>
<td>0.002</td>
<td>0.036</td>
<td>0.037</td>
<td>0.270</td>
<td>0.764</td>
</tr>
</tbody>
</table>

VT, Visible target; IVT, Invisible target.

The analysis of visual acuity and target visibility effects on the motor efficiency parameters under scrutiny provided additional insights into the direct and indirect influence of vision on goal-directed aiming. All children with INS were visually impaired with a visual acuity between 0.4 and 0.05. The degree of visual impairment in the INS group was related to movement speed and accuracy, especially in the condition with a lower level of difficulty (10 cm amplitude movements; see Table 2). A lower visual acuity was associated with a slower and less accurate performance. A poorer visual acuity provided less optimal feedback (even in the conditions with invisible targets, because children still had global information of the task setting and their arm) that probably directly affected the ability to guide the movement and homing-in to the target. The degree of visual impairment was not related to harmonicity (except for the 10 cm condition with visible targets), which provided additional evidence that this is more a sensorimotor coordination problem rather than being only a visual perceptual problem.

To analyze the direct influence of vision on goal-directed aiming, target visibility was manipulated. As expected, invisible targets caused slower and less accurate movements in children with INS and in children with normal vision. With respect to the effect of target visibility, one might expect that the reduced visual information would make the INS children’s movements rely more on the other sensory systems. However, performance of children with INS was even less accurate than that of the children with normal vision when targets were invisible, in the 10 cm condition. We interpret the poorer performance of children with INS in the invisible target condition from a perception-action perspective (see also the report of Schurink et al.1). In this context motor control including goal-directed hand movements merges from the ongoing interaction between the child and the environment. Within this context, action control, like action development generally is approached as a dynamic system in which organismic, environmental and task constraints interact to establish optimal patterns of coordination. With development, the different action and perception subsystems become more
developed efficiency of goal-directed hand movements is compared to children with normal vision. According to Fitts’ amplitude, children with INS show less (extreme) problems target visibility was not duplicated in the 20 cm condition. Inefficient coupling between perception and action. These problems remain or even exacerbate when visual information was reduced (invisible targets). We advocate that these motor control problems are a result from the inefficient perception-action integration earlier in life, suggesting a developmental problem. In conclusion, we interpret the poorer performance of children with INS not as caused by poorer vision directly, because the influence of vision was excluded in this condition, but as resulting from an inefficient coupling between perception and action.

This interaction effect for accuracy between group and target visibility was not duplicated in the 20 cm condition. Accordingly, the problems with the integration of perception and action seem task-specific. In arm movements with a larger amplitude, children with INS show less (extreme) problems compared to children with normal vision. According to Fitts law, with target width being kept constant, movements with an amplitude of 10 cm are relatively easier than movements with an amplitude of 20 cm, the Index of Difficulty being 3 and 4, respectively. So, INS children indeed experience a subjective task difficulty that is related not only to the task, but also to the inefficiency of their sensorimotor coordination.

Age-Specific Differences in Goal-Directed Hand Movements

Regarding the second hypothesis, as expected, in both groups movements of older children were more accurate, faster and more harmonic than that of younger children. In line with previous research, also visual acuity improved with age in children with INS and normal vision. One might hypothesize that improvement of goal-directed behavior results from a better visual acuity for the older children. We present two arguments against this hypothesis. First, in the correlation analyses, we controlled for visual acuity. Second, age effects in children with INS and normal vision also were present when influence of vision was excluded (invisible targets), so poorer performance in the INS group was not caused (solely) by poorer vision. Enhancement of goal-directed behavior in older INS children results probably from the improving integration of the action and perception subsystems, due to development and experience.

Although the problems in calibration and integration of perception-action subsystems in children with INS seem to be smaller in older children, under certain conditions these children still perform less accurately, slower and less harmonically than children with normal vision. So, in children with INS, inefficiency of sensorimotor control is not fully recovered at the age of eight years. This finding has important clinical implications. For rehabilitation purposes, it is important to instigate interventions at a young age. A properly developed efficiency of goal-directed hand movements is essential for handling objects (for instance a computer mouse or pen), visual aids, and other (fine) hand and arm activities. This emphasizes the importance of these results for everyday life.

One of the possible causes of inefficiency of the perception-action system is that children with INS are less stimulated to interact with their environment, because it appears less visually detailed and alluring to them and, as a result, provides fewer (obvious) opportunities for action. For example, they do not easily detect small objects and details on surfaces in their environment and, therefore, are not challenged as much to interact with them, or in a less proficient way at least. This, in turn, leads to less detailed visual inspection, less object manipulation, underpractice of fine-motor skills and so on; in other words, they experience a substantial lack of valuable sensory-motor experiences. As a result, in INS children, perception and action subsystems are, arguably, less integrated and attuned to each other, resulting in less differentiated, effective, and adaptive goal-directed behavior. The key contribution of the analyses presented here is that we should not treat this as a problem of poorer vision alone, but instead we should focus on the interaction between perception and action, for diagnostic purposes as well as in intervention.

In our study, visually impaired children with INS, including idiopathic INS (N = 10) and INS with associated visual deficit (N = 27), were investigated. A study weakness is that we could not analyze the direct effect of INS on goal-directed behavior, because we could not perform nystagmography. A quantification of nystagmus (amplitude and frequency) would have been necessary, as well as a separation of the idiopathic INS group from the group with INS with associated visual deficit group. Nystagmus waveforms can be changed by individuals’ strategies and visual demand. So, ideally the role of nystagmus could be analyzed by eye-movement recordings during the task. However, eye-movement recording with a high sample frequency and with the possibility of free head movements is not yet available. The young age of the children, the experimental set up (with a horizontally positioned digitizer) and the load on the children during the whole experiment (including ophthalmologic assessment and experimental task) all together were reasons to leave out eye-movement recordings. The relatively small size of the separate groups was reason to combine them.

Conclusions

This study clearly shows age- and task-specific differences in goal-directed aiming between children with INS and children with normal vision. The lower speed and harmonicity of the movements generated by children with INS alongside their homing-in problems as reflected by a larger endpoint scatter, specifically for small-amplitude movements, suggest these behavioral differences should be attributed to a perception-action based association between INS and the efficiency of goal-directed aiming movements rather than to visual impairment as such. The educational or clinical implication of the analyses presented here is that rehabilitation of children with INS should focus on the interaction between perception and action, which preferably should be initiated at a young age.

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References


Infantile Nystagmus Syndrome


