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What the Eyes Already 'Know': Using Eye Movement Measurement to Tap into Children's Implicit Numerical Magnitude Representations

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To date, a number of studies have demonstrated the existence of mismatches between children's *implicit* and *explicit* knowledge at certain points in development that become manifest by their gestures and gaze orientation in different problem solving contexts. Stimulated by this research, we used eye movement measurement to investigate the development of basic knowledge about numerical magnitude in primary school children. Sixty-six children from grades one to three (i.e. 6–9 years) were presented with two parallel versions of a number line estimation task of which one was restricted to behavioural measures, whereas the other included the recording of eye movement data. The results of the eye movement experiment indicate a quantitative increase as well as a qualitative change in children's implicit knowledge about numerical magnitudes in this age group that precedes the overt, that is, behavioural, demonstration of explicit numerical knowledge. The finding that children's eye movements reveal substantially more about the presence of implicit precursors of later explicit knowledge in the numerical domain than classical approaches suggests further exploration of eye movement

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measurement as a potential early assessment tool of individual achievement levels in numerical processing.

Key words: cognitive development; eye movements; implicit knowledge; number line estimation

INTRODUCTION

Ever since Vygotsky's (1978) essay *'Interaction between learning and development'* was made available to a wider audience in the late 1970s, his developmental theory was readily taken up by scientists and practitioners interested in the question of how to further children's cognitive growth (cf. Wertsch, 1985). Vygotsky's concept of what he called a child's *zone of proximal development* emphasizes the need to also consider children's learning potential instead of merely focussing on what a child has *explicitly* mastered at any given point in his or her development. An important question is therefore how to assess children's learning potential, that is, how to determine their level of knowledge that is not yet explicitly expressed (Brown & Ferrara, 1985).

Karmiloff-Smith's (1992) notion of representational re-description as a process by which '*implicit* information *in* the mind subsequently becomes explicit knowledge *to* the mind' (p. 18) provides a theoretical approach to this question. The idea that cognitive growth can be characterized as a transition from implicit forms of knowledge to more explicit knowledge provides developmental researchers with a fascinating yet challenging starting point for translating the Vygotskyan ideas into the domain of knowledge acquisition.

However, before discussing the various ways in which the idea of a transition from implicit to explicit knowledge in the course of development was investigated in the developmental sciences, it is important to briefly clarify how to distinguish between explicit and implicit contents of knowledge, and how to describe the latter. In this context, the model proposed by Dienes and Perner (1999) offers an intuitively understandable way of approaching the implicit–explicit distinction. The authors propose that fully explicit knowledge entails that a person is aware of that knowledge, that is, that the person is conscious of that knowledge and is in a position to entertain second-order thoughts about it.

Furthermore, what is essential from a *methodological* point of view is finding appropriate measures of children's respective implicit cognitive capacities. Identifying knowledge that is not yet explicitly available to the child but only *implicitly existent*, that is, identifying what constitutes the child's zone of proximal development, requires sophisticated approaches.

A number of influential developmental studies that aim at identifying children's implicit or 'budding knowledge' (Vygotsky, 1978) were published by Susan Goldin-Meadow *et al*. Focussing on the gestures that accompany children's problem solving processes, Goldin-Meadow *et al*. were able to demonstrate subtle mismatches between children's verbal and nonverbal behaviours (Alibali & Goldin-Meadow, 1993; Goldin-Meadow, Alibali, & Church, 1993). According to the authors, gesture–speech mismatches can be indicative of a child's specific readiness-to-learn by revealing forms of knowledge that are there at an implicit level, but not yet explicitly available to the child (Goldin-Meadow, 2000; Goldin-Meadow & Sandhofer, 1999). Although most of these studies were carried out with

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preschoolers presented with classical conservation tasks, the authors also transferred their approach to mathematical problem solving contexts, that is, algebraic word problems (Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999) and numerical equations (Alibali, Flevares, & Goldin-Meadow, 1997; Garber, Alibali, & Goldin-Meadow, 1998; Perry, Church, & Goldin-Meadow, 1988).

More recently, a second strand of research was implemented by Clements and Perner on implicit forms of knowledge that could be interpreted as immature precursors of more mature explicit forms of knowledge (1994; see also Garnham & Perner, 2001). The authors investigated children's implicit understanding in the context of so-called false belief tasks by measuring their anticipatory gaze responses. Similar to the research on gestures, these studies demonstrated systematic mismatches between children's finger pointing and verbal answers on the one hand, and their gaze behaviour on the other. The authors further reported that implicit knowledge as revealed by eye movements substantially preceded the development of explicit knowledge in the false belief tasks. Other studies confirmed Clements and Perner's conclusion that it is possible to use eye movement as a means to tap into children's implicit knowledge and to identify the transition from implicit to explicit knowledge in the course of development (Clements, Rustin, & McCallum, 2000; Garnham & Ruffman, 2001; see also Perner & Dienes, 1999).

The starting point for the present study was a question put forward by Ruffman, Garnham, Import, and Conolly (2001), who wondered whether dissociations between children's eye movements and their explicit behaviour can be found in domains other than false belief contexts. One area of research that lends itself to the use eye movement measures in order to add new insights to the already extensive data available in the context of behavioural research paradigms is the development of children's knowledge of numerical magnitude or the changes in the underlying representations thereof.

In a number of behavioural studies, Siegler *et al*. were able to demonstrate that during the first years of schooling children's knowledge about numerical magnitudes undergoes fundamental changes (Booth & Siegler, 2006; Laski & Siegler, 2007; Siegler & Booth, 2004; Siegler & Opfer, 2003). The assumption that children's numerical knowledge during those years does not just grow quantitatively, but, above all, that the underlying patterns of numerical representations undergo a qualitative change was investigated using a number of different forms of estimation tasks. Thus, apart from the finding that children's numerical estimates become more accurate with time, Siegler *et al*. were also able to empirically substantiate the idea that primary schoolers' representational patterns change from a logarithmic to a more adequate linear model of numerical magnitude. This change is assumed to take place between the first and the second grade, and is considered a crucial step that enables children to improve their achievement in a wide range of mathematical task domains. Tying the line of research into basic numerical processing to the above-mentioned assumption that there are early implicit precursors of later explicit forms of knowledge during childhood development suggests the use of eye movement measurement in order to find out more about the developmental changes in children's knowledge about numerical magnitude. The question is whether the behaviourally established quantitative and qualitative changes can also be demonstrated using eye movement parameters, and, more importantly, whether eye movement measures that we assume to be able to tap into implicit knowledge add to what we already know about the development of numerical magnitude representation in children. If eye movement measurement proves to be a complement to the standard behavioural settings, providing earlier or different insights into children's numerical magnitude representations, it may

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be used as a tool for the early assessment of individual differences in the domain of numerical processing.

In the present study, we measured children's eye movements while they carried out a number line estimation task (Siegler & Opfer, 2003). The use of a parallel behavioural version of this task as a control condition enabled us to reliably separate the implicit understanding children revealed through their gaze behaviour from their explicit, overtly established numerical knowledge. Furthermore, a cross-sectional design allowed us to trace the quantitative and qualitative changes in children's knowledge across three grade levels.

METHODS

Participants

Sixty-six children from two public primary schools in Berlin participated in the present study after parents had given their written informed consent. Twenty children were first graders (9 females; mean age 6.6 years, S.D. = 0.63), 22 second graders (12 females; mean age 8.1 years, S.D. = 0.43), and 24 were third graders (12 females, mean age 8.9 years, S.D. = 0.57). Children who were considered by their teachers as either having specific learning deficits (i.e. children with poor grades in mathematics) or suffering from behavioural difficulties (i.e. children who exhibited attentional or other behavioural problems in class) were not included in this sample.

Materials and Procedure

All children were tested with two versions of a number line estimation task (Siegler & Opfer, 2003), each consisting of 30 numerical stimuli presented in randomized order. For both tasks, a horizontal number line (length: 16 cm) was shown in the middle of a computer screen, with a one or two-digit number appearing above it (vertical distance to the middle of the number line: 7 cm). Start and end points of the number line were labelled with 0 and 100, respectively. The stimuli varied numerically between 3 and 98, and were distributed evenly across the entire range of numbers (i.e. numbers/markers were 3/33; 6/26; 7/57; 11/11; 15/15; 18/70; 20/60; 24/24; 28/8; 31/61; 32/32; 36/36; 44/84; 45/15; 49/49; 51/11; 53/53; 59/59; 64/24; 65/35; 67/67; 75/75; 76/46; 78/78; 80/99; 86/46; 87/87; 94/74; 96/96; 98/98).

In the behavioural version of the task, children had to move a marker to the appropriate position on the number line for each displayed item using a computer mouse as the input device. Marker movement was restricted to horizontal movements on the number line. Upon mouse click, marker positions were recorded automatically. No time constraints were imposed on children's responses.

In the eye-tracking version, the same number line and the same stimuli were used. Children were instructed to actively search for and focus their gaze on the correct number line position for each number. A marker (i.e. pointing arrow) appeared after 4000 ms. Children had to decide as fast as possible whether the marker indicated the correct position on the number line or not, and give their answer by button click (i.e. correct position or incorrect position). Incorrect markers were positioned at least 20 numerical steps below or above the respective correct position on the number line. Half of the incorrect markers indicated numerical positions that were smaller than the displayed numbers (i.e. e.g. 64/24), the other incorrect markers were positioned on larger numerical values (i.e. e.g. 3/33). The children's responses were recorded automatically.

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In both settings, participants were seated in front of a computer within 60 cm from the screen (1024 × 768 px). The children were familiarized with the task environments during 10 practice trials. The practice trials covered numbers in the range between 1 and 100, with all experimental items being excluded (numbers/markers consisted of correct items, large differences between displayed number and indicated number line position, as well as small differences, i.e. 2/2; 9/99; 50/50; 2/99; 99/2; 40/20; 50/30; etc.). During the practice trials, children were asked to comment on their response behaviour in order to make sure they understood the tasks correctly. Errors in the execution of the tasks were corrected by the experimenter, that is, in the behavioural version of the task some younger children did have initial problems using the mouse as a device for moving the arrow along the number line without pressing the button that confirmed a certain positional choice, and some older children tended to try to speed up the sequence of events in the eye-tracking setting by repeatedly pressing the mouse button before answer execution was allowed. During the experimental trials, no further feedback was given to the children. The order of the two number line estimation tasks (i.e. behavioural and eye-tracking) was changed for each grade level after half of the children.

Eye-movement data were collected using a stationary eye-tracking system with a temporal resolution of 1000 Hz and a spatial resolution of 0.01° (Eyelink 1000®, SR Research Ltd., Mississauga/Ontario, Canada). The eye-data were analyzed using customized software scripts written in Perl (open source, http://www.perl.com/). Duration and average x, y position of single fixations were computed for all experimental trials.

Data Analysis

Behavioural data

For a first analysis, children's responses in the behavioural task were scored as correct if the marker was set within the margins of 10 numerical steps around the correct position on the number line (i.e. the correct position on the number line ± 5 numerical steps). Percentages of correct responses were determined and subjected to a one-way analysis of variance (ANOVA) with grade level as a between-subject variable. Post-hoc tests corrected for multiple comparisons using the Bonferroni procedure were applied to further assess differences between the groups of children.

Second, in a more fine-grained analysis of the data each child's percent absolute error was computed for each trial by first taking the absolute of the numerical distance between the position of the marker and the numerical magnitude of the stimulus and then dividing it by the scale, that is, by 100 (Siegler & Booth, 2004). A one-way ANOVA with grade level as between-subject factor was performed on children's mean absolute error. Bonferroni corrected post-hoc tests were applied to further assess differences between groups of children.

Finally,[1] comparisons of the fits of linear and logarithmic functions to the median estimates of children, grouped by grade level, were conducted. In order to determine differences in the fits of both models, residuals were tested using paired-samples t tests for each grade level separately.

Eye-tracking data

Only fixations within the first 4000 ms of each trial (i.e. before the marker appeared) were entered in the analyses. Fixations that fell outside the number line and fixations with durations of less than 50 ms were dismissed. Trials with only one fixation or more than three blinks during the first 4000 ms and trials with more than

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one button click were excluded. After the removal of the invalid trials, an average of 94.4% (S.D. = 7.2) of the data entered the statistical analyses for each participant.

In a first step, the distance between the x position of each single fixation and the correct position for the respective stimulus on the number line was determined. Similar to the response classification in the behavioural task, a fixation was labelled as correct if it fell within a margin of 10 numerical steps around the correct position on the number line, that is, within the correct area of interest (AoI) for the respective stimulus.

Second, in a next step of analysis, mean absolute distances of all the fixations from the respective correct positions on the number line and mean gaze durations on the correct AoI were computed. Grand mean x distances were computed separately for all the correct and error trials. Gaze durations on the correct AoIs (i.e. the correct position on the number line ± 5 numerical steps) as well as on all other positions were determined by adding the durations of all single fixations falling on the particular areas per trial (correct AoI versus other), and by calculating the grand mean gaze durations separately for all correct and all error trials. One-way ANOVAs were performed on the aggregated gaze distances and durations with grade level as a between-subject factor. Bonferroni corrected post-hoc tests were conducted as follow-ups.

In parallel to the curve-fitting procedure for the behavioural data, median values for the numerical equivalents of the positions of number line fixations were determined for all correct trials. However, first fixations were excluded from these analyses, because chi-square tests revealed that in what we assume to be an initial orientation on the number line, with their first eye movement children significantly more often targeted one of three points of reference on the number line (i.e. the beginning, the end and the midpoint) than could be predicted from the set of stimuli (χ^2 (1) = 42.18, $p < 0.001$). For all later fixations, the observed frequencies of eye movements to these three landmarks did not differ significantly from what could be expected (all p's > 0.208).

Comparisons of the fits of the best-fitting linear and logarithmic models determined by the behavioural data for each grade level to the median numerical positions of all remaining fixations were conducted. In order to determine differences in the fits of both models, residuals were tested using paired-samples t tests for each grade level.

Additionally, the behavioural data from the eye-tracking experiment were divided into categories that combined the correctness of the marker positions (correct or false) with the correctness of children's responses to these markers (correct or false). This way we were able to determine for each child a set of numerical items for which their explicit representations, as discernible from children's overt behaviour, were still imprecise. Percentages of correct responses were determined and subjected to a one-way analysis of variance (ANOVA) with grade level as a between-subject factor. Bonferroni corrected post-hoc tests were applied to further assess differences between the grade levels.

RESULTS

Behavioural Performance Data

The dichotomous accuracy data computed for both number line estimation tasks indicate a systematic growth of explicit numerical knowledge across the three grade levels. Percentages of correct responses differed significantly between the

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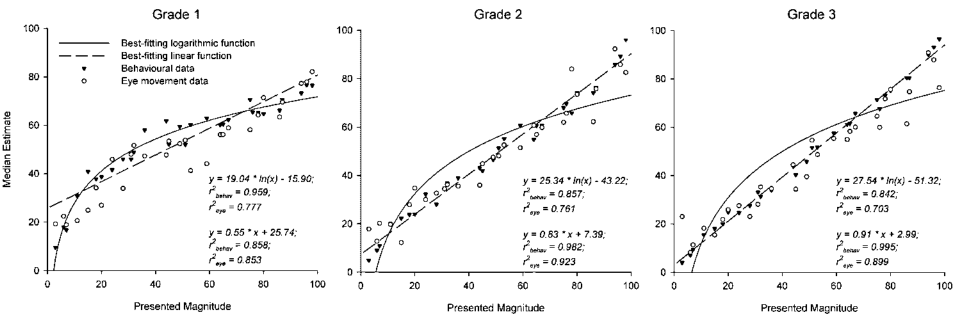

Figure 1. Fits of logarithmic and linear models to children's behavioural estimates and to their fixations in the eye-tracking experiment, separated into the three grade levels.

groups of children, that is, for the behavioural task: first graders $M = 20.19$, S.D. = 13.93; second graders $M = 39.70$, S.D. = 12.61; third graders $M = 55.17$, S.D. = 14.77, $F(2, 63) = 22.70$, $p < 0.001$; for the eye-tracking task: first graders $M = 58.96$, S.D. = 11.99; second graders $M = 69.66$, S.D. = 11.21; third graders $M = 82.91$, S.D. = 7.65, $F(2, 63) = 29.73$, $p < 0.001$. Post-hoc analyses for both sets of data revealed significant increases in accuracy for second compared with first graders (ps < 0.001), and for third compared with second graders (ps < 0.001).

The in-depth analyses on the relation of grade level and percent absolute error in the behavioural task showed a systematic increase in accuracy of estimates with grade level. Mean percent absolute error differed significantly between the groups of children, that is, first graders $M = 17.80$, S.D. = 7.24; second graders $M = 9.23$, S.D. = 4.51; third graders $M = 5.22$, S.D. = 1.78, $F(2, 63) = 37.20$, $p < 0.001$. Post-hoc analyses showed significant decreases of mean percent absolute error between first and second graders as well as between second and third graders (ps < 0.021).

Comparisons of the fits of logarithmic and linear functions to children's median estimates in the behavioural task indicate a fundamental difference in children's numerical representations that distinguishes grade 1 from grades 2 and 3 (Figure 1). Although first graders' estimates were fitted substantially better by the logarithmic model than by the linear one, this picture is reversed in both older groups.

Testing the residuals between both models and children's estimates revealed that while the first graders' data were fit significantly better by a logarithmic function ($t(29) = 2.58$, $p < 0.015$), in second and third graders the linear functions provide significantly better models (second graders: $t(29) = 4.65$, $p < 0.001$; third graders: $t(29) = 6.69$, $p < 0.001$).

Eye Movement Data

Because our study is interested in identifying manifestations of *implicit* numerical knowledge in children's eye movements, in a first step we only analyzed the eye-tracking data for those stimuli where no evidence of explicit knowledge was identifiable from children's *behavioural* responses, that is, we focussed on stimuli that elicited overt incorrect behavioural responses in both settings. For this first analysis, we further excluded incorrect trials where the execution of a correct answer would have forced children to *reject* a solution presented by the computer in the eye-tracking task because we assumed that the younger children in

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particular may have been less prepared to decide *against* a proposed answer. This means that in this first step, we restricted our search for evidence of implicit knowledge in children's eye movements to trials where children's explicit answers were incorrect in the sense of accepting false marker positions. After the exclusion of children with less than two trials satisfying these restrictions, the data from 36 children were entered into the analyses.

The inspection of the distributions of single fixations relative to the respective correct positions on the number line reveals a striking effect of grade level on children's eye movements during those specific incorrect trials (Figure 2). While in first graders, the eyes seem to roam a wide range of numerical positions on the number line, in third graders, approximately two-thirds of all fixations fall within the immediate vicinity of the respective correct positions. The distributional pattern of second graders' fixations lies somewhere between the two extremes.

As could be expected from the distributions of single fixations, a highly significant effect of grade level on mean distances from the correct positions was found, $F(2, 33) = 12.25$, $p < 0.001$. The numerical distance between mean x positions of fixations and the respective correct positions on the number line decreases from $M = 28.17$ (S.D. = 4.74) in first graders to almost half the numerical distance in third graders ($M = 15.73$, S.D. = 4.12), with second graders lying in between ($M = 22.81$, S.D. = 7.08). Post-hoc analyses yielded significant differences between first and second graders on the one hand, and second and third graders on the other (ps < 0.050).

Mean gaze duration for the correct AoIs increased significantly across the three grade levels (first graders: $M = 741$ ms, S.D. = 315 ms, second graders: $M = 1073$ ms, S.D. = 443 ms, third graders: $M = 1684$ ms, S.D. = 739 ms; $F(2, 33) = 10.05$, $p < 0.001$), while mean gaze duration for all other positions did not change significantly ($F(2, 33) = 1.67$, $p = 0.206$). Post-hoc tests on mean gaze durations on correct AoIs revealed significant differences between first and third

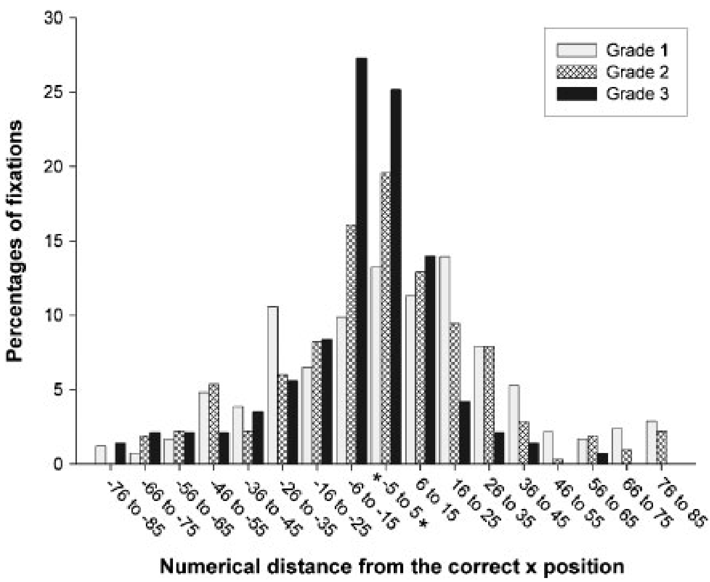

Figure 2. Proportions of single fixations for trials with stimuli that elicited only incorrect overt behavioural responses in both settings separated into the different numerical distance intervals around the correct positions: distributions for the three grade levels.

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graders, and between second and third graders (p's < 0.025), but not between first and second graders ($p = 0.194$).

In contrast to the results for the incorrect trials, children's eye movement data for the correct trials did not reveal any significant effects of grade level. Mean distances of fixations from the respective correct positions remain more or less stable across the three groups ($F(2, 33) = 1.12$, $p = 0.336$), and mean gaze duration on the correct AoIs did not differ significantly between the grade levels ($F(2, 33) = 1.40$, $p = 0.260$).

In-depth analyses of the fits of number line fixations to the logarithmic and linear models determined in the behavioural setting revealed a somewhat different picture for the eye movement data compared with the behavioural data (Figure 1). Although first graders' estimates were fitted substantially better by the logarithmic model than by the linear model in the *behavioural* task, this does not hold true for their eye movements. Comparable to the second and third graders, for the eye-tracking data the linear model provides a better fit in first graders as well. However, tests of the residuals between the models and the gaze data revealed that in first graders the differences in the fit of the linear compared the logarithmic functions are not significant ($t(29) = 1.80$, $p = 0.082$). In second and third graders the linear functions provide the significantly better models (second graders: $t(29) = 3.68$, $p = 0.001$; third graders: $t(29) = 3.06$, $p = 0.005$).

DISCUSSION

The present study was aimed to investigate whether eye movement measures can be used to gain deeper insights into specific patterns of children's numerical magnitude representations at certain points in the course of their development than overt behavioural tasks alone. We presented children with two number line estimation experiments (Siegler & Opfer, 2003) of which one was a behavioural and the other an eye-tracking setting. The behavioural version of the task allowed us to, first, identify trials in the eye-tracking setting for which the overtly displayed knowledge was still imprecise. Second, children's specific patterns of estimates in the behavioural task provided the baseline for comparing their eye movement behaviour.

Overall, the results of our cross-sectional study demonstrate that children's *explicit* understanding of numerical magnitude develops substantially during their first three years in primary school. This improvement can be gathered not only from the quantitative analyses of the data, but also from the more qualitative in-depth analyses. First of all, accuracy measures for both tasks show that children's responses improve consistently in the course of their first years in school. The percentages of errors decrease, and the precision of their estimates increases. At the same time, the behavioural data give rise to the assumption that somewhere along the transition from grade one to grade two, children's numerical magnitude representations change from a more immature logarithmic pattern of representation to the more appropriate linear model. These findings are well in line with the literature on numeric estimation skills in primary school children (Booth & Siegler, 2006; Siegler & Booth, 2004; Siegler & Opfer, 2003).

But apart from these results that confirm previously documented changes in children's explicit numerical knowledge, that is, knowledge that is overtly accessible by behavioural measures, our eye movement data demonstrate that even when, on first sight, children still appear to be stuck on a more immature level their implicit knowledge might already have undergone some subtle yet

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detectable changes. The eye movement data demonstrate that even in cases where no evidence of appropriate insight into a certain numerical magnitude can be found in children's overt behavioural responses, their eye movements might still show manifestations of knowledge at work on a more implicit level. Thus, for instance, our analyses of children's eye movements in error trials indicate that third graders seem to understand more about certain numerical magnitudes than first or second graders even when they do not actually appear to be more knowledgeable than their younger peers on the level of overt behaviour. The eye movement data reveal that compared with children from lower grade levels, older children shift their gaze significantly more often and also for a significantly longer time to the respective correct positions on the number line in trials where their *explicit* responses are consistently false.

And, more importantly, while on the level of explicit behaviour the reflections of children's numerical representations indicate an irreconcilable discrepancy between the underlying logarithmic representations in first graders, and the linear patterns in second and third graders, the eye movement data might bridge this gap by revealing implicit forms of knowledge that are present before a certain knowledge becomes explicit. The intriguing finding that the linear model actually provides a better fit to the eye movement data than the logarithmic one at a point in time when children's strictly behavioural estimates argue for logarithmic patterns of numerical representations (cf. Figure 1) might be interpreted in the sense of Clements and Perner (1994). The authors argue for the idea that periods of merely implicit knowledge precede explicit understanding. Thus, while first graders' overt behaviour suggests that their representation of numerical magnitude still follows an immature logarithmic model, a change towards more mature representational patterns might already be on the way, as revealed by measures that are capable to tap this emerging knowledge. There might, thus, be a transitional phase where both representational patterns exist in parallel. Such an idea is well in line with Siegler's (1996) Overlapping the Wave model of change that proposes that during development 'multiple ways of thinking coexist for prolonged periods' (p. 89).

Children's specific eye movement patterns might thus be interpreted as first indicators of children's changing numerical knowledge, that is, knowledge that has 'not yet matured but [is] in the process of maturation' (Vygotsky, 1978, p. 86). As proposed by researchers, eye movement data might be used to gain evidence in implicit forms of understanding that are precursors of explicit forms of understanding (Clements & Perner, 1994; Goldin-Meadow, Alibali, & Church, 1993).

In summary, our data consolidate the results from two strands of research on children's cognitive development. First, we are adding yet another piece of evidence to the substantial body of research on nonverbal manifestations of mismatches between children's explicit knowledge and their—at any given time—still implicit understanding of certain facts in the world (Goldin-Meadow, 2000). And second, we corroborate the view expressed by Perner and Dienes (1999) that eye movements can be used as sensitive indicators of implicit knowledge that precede more explicit forms of knowledge.

Starting from the present results, the next logical step would be the implementation of a longitudinal study that would allow for insights into the specific ways in which children's numerical magnitude representations change with respect to implicit and explicit forms of understanding, bearing in mind that certain parts of knowledge about numerical quantities will always remain implicit (e.g. abstract representations of numerical quantity in the sense of a 'mental number line', c.f. Dehaene, Bossini, & Giraux, 1993), and will never become fully explicit.

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Furthermore, at this point we can only speculate about the question whether individual differences in the implicit precursors of the yet to develop explicit forms of knowledge about numerical magnitudes might be used as predictors of children's later achievement in the domain of mathematics in general. But as children's estimation skills have been demonstrated to be highly correlated with their math achievement scores, it might be a useful undertaking to evaluate eye movement measurement as a diagnostic tool that can be employed at an earlier point in development than behavioural estimation tasks (Booth & Siegler, 2006; Laski & Siegler, 2007; Siegler & Booth, 2004).

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Note

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