Research Report

A DEVELOPMENTAL DEFICIT IN LOCALIZING OBJECTS FROM VISION

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Abstract—*We describe a college student, A.H., with a developmental deficit in determining the location of objects from vision. The deficit is selective in that (a) localization from auditory or tactile information is intact; (b) A.H. reports the identity of mislocalized objects accurately; (c) visual localization errors preserve certain parameters of the target location; and (d) visual localization is severely impaired under certain stimulus conditions, but nearly intact under other conditions. These results bear on the representation and processing of location information in the visual system, and also have implications for understanding developmental dyslexia.*

In this article, we report a single-case study of subject A.H., a college student with a remarkable developmental deficit in localizing objects from vision. After presenting a brief case history, we describe her severely impaired performance on two types of visual-spatial tasks. We then report experiments aimed at characterizing the underlying cognitive deficit, and finally we discuss the implications of our findings for issues concerning the normal visual system and developmental reading disorders.

CASE HISTORY

A.H., a 20-year-old right-handed woman, is an undergraduate student at a major university, where her grade-point average is 3.54 (0–4 scale). During her elementary school years, it was recognized that A.H. had difficulty with spelling and arithmetic. However, her academic performance was otherwise very good, and she was not placed in classes for students with learning disabilities. Samples of her elementary and secondary schoolwork show frequent spelling and arithmetic errors, and also provide evidence that the visual deficit we report was present in childhood and adolescence.

On the Wechsler Adult Intelligence Scale-Revised, A.H.'s scaled scores for individual subtests ranged from very high (e.g., 16 for Comprehension) to very low (e.g., 6 for Digit Symbol), resulting in a full-scale IQ of 111 (Verbal 119, Performance 103). Reading assessment revealed that A.H.'s comprehension of connected text was generally good. However, in reading isolated words and sentences, she made frequent letter transpositions (e.g., *snail* read as "nails"), word transpositions (e.g., *John gave Mary* read as "Mary gave John"), and confusions among letters differing in orientation (e.g., *pen* read as "den"). Frequent errors were also observed in spelling (e.g., *merge* spelled as "mrege") and number processing (e.g., *39* read aloud as "ninety-three").

A.H.'s medical history is unremarkable, and neurological exam, electroencephalogram, and magnetic resonance imaging performed during this study revealed no clinically apparent abnormalities. Tests of visual acuity, visual fields, and contrast sensitivity were normal. An audiogram was also normal, but A.H. was substantially impaired on a test of phoneme discrimination (Wepman, 1973).

In the study of cognitive deficits, a rough distinction is drawn between developmental deficits (those that are present from the time a cognitive function begins to develop and are not associated with obvious neurological damage) and acquired deficits (those resulting from clear neural insult). Given A.H.'s lack of obvious neurological damage, and the evidence of cognitive impairment in childhood, her deficit may be considered developmental.

IMPAIRED PROCESSING OF VISUAL LOCATION

Direct Copying

A.H. exhibited severe yet selective impairment on several nonspeeded *direct-copying* tasks, in which she copied visual stimuli that remained continuously in view. Figure 1 presents the Rey-Osterrieth complex figure (Osterrieth, 1944; Rey, 1941) and A.H.'s direct copy. A.H. reproduced the shapes of the figure's various component parts correctly, but made numerous errors involving location and orientation of the parts.

Similar errors were observed on the Benton Visual Retention Test (Sivan, 1992), which involves reproducing simple visual figures by direct copy or from memory. On the direct-copying subtest, A.H. reproduced only 4 of 10 figures correctly. Across the 10 figures, she made a total of 9 errors in copying figure elements, all involving mislocation or misorientation (e.g., reversing the positions of an adjacent diamond and semicircle). This performance level falls into the "grossly defective" range, the lowest of five categories defined on the basis of results from 200 control subjects (Sivan, 1992). Interestingly, A.H.'s performance in reproducing figures from memory was not substantially worse than her copying performance. On both immediate and 15-s-delayed recall of figures presented for 10 s each, she was correct on 2 of 10 figures and made 12 total errors on figure elements. Given that the recall subtests are more difficult than the copying subtest for normal subjects (Sivan, 1992), these results suggest that A.H. is not significantly impaired in short-term

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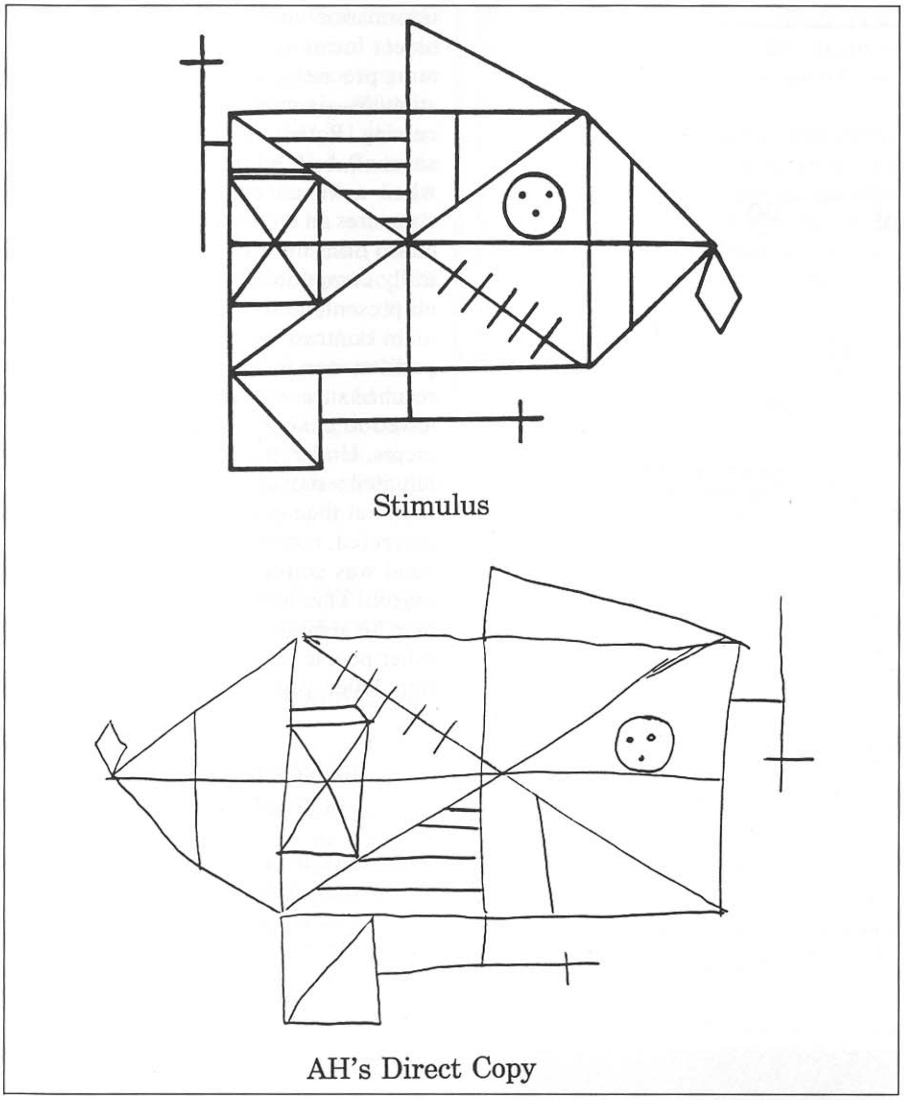

Fig. 1. The Rey-Osterrieth complex figure and A.H.'s direct copy.

retention of location and orientation information.

Dramatically impaired direct copying was also apparent in samples of A.H.'s high school work. As part of an art-class assignment, A.H. visited galleries in Washington, D.C., and made direct-copy sketches from five paintings. Four of the five sketches show clear mislocations and misorientations of objects. For example, in sketching Renoir's *The Luncheon of the Boating Party,* A.H. limited her efforts to the straw hats worn by six members of the party. Although she correctly placed a hat appearing near the center of the painting, she mislocated the other five hats. Hats appearing on the left side of the painting were drawn at the corresponding positions on the right, and vice versa.[1]

Responding to Location With Directed Movements

Although A.H. made both localization and orientation errors in direct copying, we focus in this article on her processing of object location. The results we discuss may also have relevance for understanding A.H.'s orientation errors, given that such errors can usually be described as errors in localizing parts of an object relative to one another.

In a nonspeeded test of visual localization, A.H. moved a computer mouse to indicate the location of an *X* presented for 250 ms on a video monitor. For stimuli at locations 6.7° left, right, up, and down from the screen's center, her error rates were 57%, 47%, 35%, and 36%, respectively (72 trials per location). All errors were confusions between left and right or between up and down (e.g., moving the mouse downward for a stimulus at the top of the screen). The mean overall error rate for 3 control subjects was 0.6%, and all of the subjects had error rates below 3% for each location.

In a reaching task, A.H. closed her eyes while a 3-cm wooden cube or cylinder was placed on a table in front of her at one of 10 locations (Fig. 2). She then opened her eyes and reached for the object with a ballistic movement (i.e., without changing direction in midmovement). For objects directly in front of her, A.H. made no errors in 24 trials. For objects on her left or right, however, she reached to the wrong side of the midline on 63 of 96 trials (66%). The composite video image in Figure 3 shows A.H. reaching to the right for an object on her left.

Performance did not differ between stimuli on the left (33/46 incorrect) and stimuli on the right (30/50 incorrect), $\chi^2(1, N = 96) = 1.29, p > .25$. (Indeed, no differences between left and right stimuli were observed in any of the studies we present; accordingly, we henceforth report results collapsed over left and right locations.)

1. The errors in A.H.'s art-class sketches (as well as other errors apparent in her elementary and secondary schoolwork) argue against the possibility that her performance in the present study represents malingering. In particular, the presence of errors in work predating this study indicates that A.H. did not invent her deficit around the time of the study in order to gain attention as an interesting research subject. Of course, one might entertain the possibility that she has been simulating a deficit for many years. However, until our review of her schoolwork, A.H.'s localization and orientation errors either went unrecognized (as in the case of the art-class sketches) or were attributed to carelessness. An interpretation of long-term malingering would therefore require the assumption that A.H. persisted for years in a simulation that did not succeed in attracting the notice of parents or teachers, and that offered no other apparent gains.

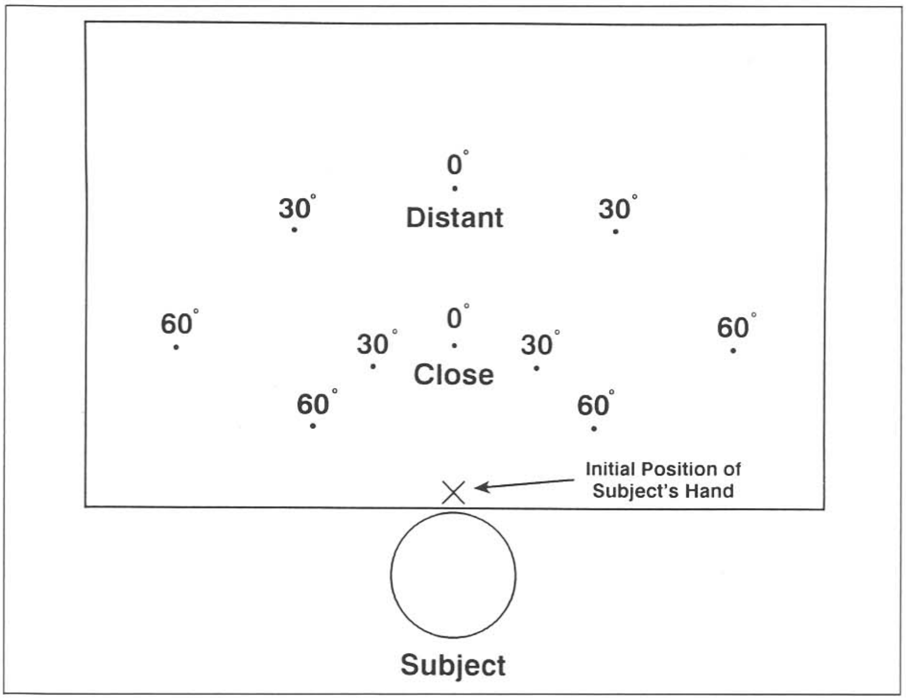

Fig. 2. Stimulus locations for the reaching task. Close and distant locations were 18 and 36 cm from the subject, respectively, on a flat surface in front of her. Eccentricity of stimulus locations was defined relative to an imaginary midline. Locations were marked with a dot, but were not labeled.

A.H.'s 66% error rate in reaching to the left or right is reliably worse than chance, $\chi^2(1, N = 96) = 26.04, p < .001$, and we have also observed below-chance performance in other tasks (see, e.g., the 70% error rate reported later for the experiment manipulating stimulus contrast). This phenomenon suggests that A.H.'s deficit is not properly conceived as one in which visual stimulus information cannot be used to compute object location, and a random choice—more precisely, a choice unrelated to the stimulus—is made at some level of processing. Rather, it appears that (at least some of) A.H.'s localization errors occur when a visual process systematically computes an incorrect location representation from the stimulus (e.g., systematically computing a left location for stimuli presented on the right).

In contrast to her severely impaired performance in ballistic reaching, A.H. reached successfully for objects when allowed to change direction during movements. Under these conditions, she often initiated a movement in the wrong direction, but then quickly and smoothly self-corrected, reporting that she realized her hand was getting farther away from the object. This ability to self-correct may help to explain why neither A.H. nor other people were aware of her localization deficit prior to this study.

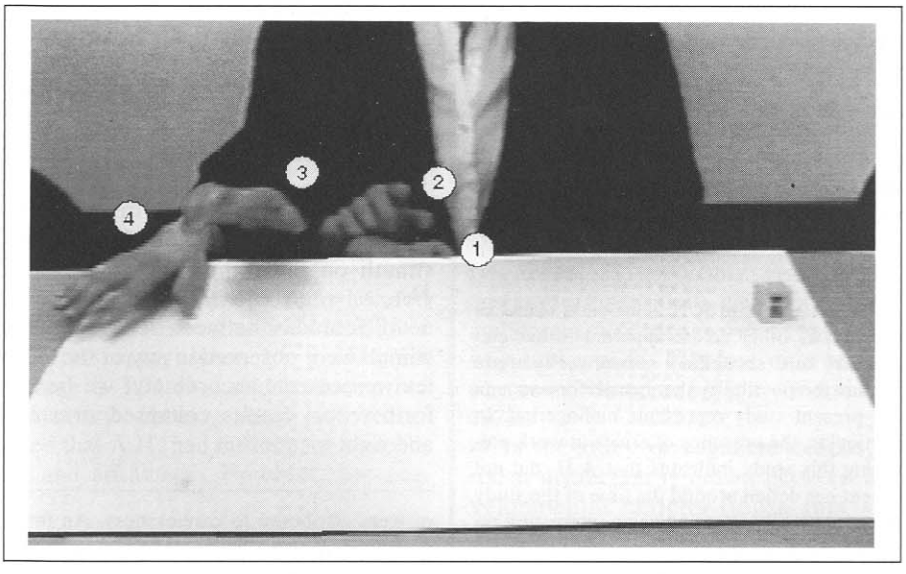

Fig. 3. Composite video image illustrating an incorrect ballistic reaching movement to the distant 60° right position for a target at the distant 60° left position. Labels 1 through 4 indicate successive positions of A.H.'s hand as she reached in the wrong direction.

FUNCTIONAL LOCUS OF IMPAIRMENT

Results from several tasks demonstrate that A.H.'s localization errors reflect a deficit specific to vision. In contrast to her severely impaired performance with visual stimuli, A.H. showed intact localization from auditory, kinesthetic, and tactile information.

Listening with eyes closed to a click or sustained tone presented on her left or right at 30° or 60° eccentricity, A.H. was 100% correct in reaching or pointing to the side of the midline from which the sound originated (136/136 for clicks, 50/50 for tones). She was also 100% correct (60/60) on a kinesthetic localization task in which she felt for an object with one hand, then withdrew the hand and reached for the object with her other hand (with eyes closed throughout the trial).

In a task comparing visual and tactile localization, A.H. closed her eyes while a stimulus card was placed in front of her. Attached to the card were a short (3.1-cm) plastic bar and a tall (6.2-cm) plastic bar, arranged side by side with the tall bar on the left on half of the trials and the short bar on the left in the other half. In the visual condition, A.H. looked at the bars and pointed left or right to indicate the position of the tall bar relative to the short bar. In the tactile condition, A.H.'s eyes remained closed as the palm of one hand was placed in contact with the stimulus bars. Without moving her hand, A.H. judged the arrangement of the bars and then made the pointing response with her other hand. In the visual condition, A.H. was only 71% correct (64/90); in the tactile condition, however, she was 98% correct (88/90), $\chi^2(1, N = 180) = 33.8$, $p < .001$.

These results indicate that A.H.'s errors in localizing visual stimuli reflect a disorder of visual perception, and not a general spatial deficit affecting localization from all sensory modalities, or an apraxia or ataxia affecting the ability to carry out intended movements.

NATURE AND IMPLICATIONS OF THE VISUAL DEFICIT

Localization Versus Identification

A.H.'s visual impairment affects localization but not identification of objects. On 60 trials in the reaching task, she was asked to identify the stimulus object as a cube or cylinder before reaching for it. Her identification responses were uniformly accurate for both correctly and incorrectly localized objects. Performance was also intact on other tests of visual object identification. This dissociation between localization and identification adds to the substantial body of evidence suggesting that location and identity are processed separately in the visual system (e.g., Atkinson & Braddick, 1989; Haxby et al., 1991; Maunsell & Newsome, 1987; Mishkin, Ungerleider, & Macko, 1983; Sagi & Julesz, 1985; Ungerleider & Mishkin, 1982).

Components of Location Representations

In mislocating visual stimuli, A.H. did not specify locations entirely unrelated to the correct locations. Rather, her localization errors consistently preserved certain parameters of target location. For example, in 59 of her 63 errors in the reaching task (94%), A.H. reached to the location having the correct distance and eccentricity but the wrong direction relative to the midline (e.g., target at the distant 60° left location, reaching response to the distant 60° right location).

This dissociation suggests that mental location representations have an internal structure involving multiple independent components. More specifically, direction of displacement from a reference axis (e.g., left or right of a vertical midline, above or below a horizontal midline) may be represented separately from other location parameters, such as eccentricity.

Visual Subsystems

A.H.'s visual localization performance varies dramatically with certain stimulus factors, including stimulus duration, motion, and contrast. In one task, a white disk with a diameter of 1.61° and luminance of 19.4 cd/m^2 was displayed on a black background at a location 8.44° to the left or right of a central fixation point. Stimulus duration was varied from 17 to 1,000 ms, with 72 trials at each of 10 durations randomly intermixed within trial blocks. A.H. responded by pressing a left button for stimuli on the left and a right button for stimuli on the right. Remarkably, her error rate was low for very brief stimuli, but rose sharply with increasing exposure duration (Fig. 4). Three normal control subjects each had error rates less than 3% at each stimulus duration.

Many researchers have assumed that brief stimuli and moving stimuli are processed by the same visual mechanisms (see, e.g., Lennie, Trevarthen, Van Essen, & Wässle, 1990). Hence, given the results for exposure duration, one might expect that A.H. would show better localization performance for long-duration, moving stimuli than for long-duration, stationary stimuli. This expectation was confirmed in several experiments with rotating and translating visual stimuli. For example, for an *X* that remained in view on a computer monitor until a response was made, A.H. was 59% correct (118/200) in the left-right localization when the stimulus was stationary, but 99.5% correct (199/200) when the *X* rotated about its center, $\chi^2(1, N = 400) = 99.8$, $p < .001$.

Effects of stimulus contrast were observed in a task on which A.H. indicated the location of a 1.61° disk presented for 1 s at a location 8.44° left or right of center on a computer monitor with background luminance of 0.03 cd/m^2. For low-contrast (0.19 cd/m^2), medium-contrast (1.22 cd/m^2), and high-contrast (19.4 cd/m^2) stimuli, her error rates were

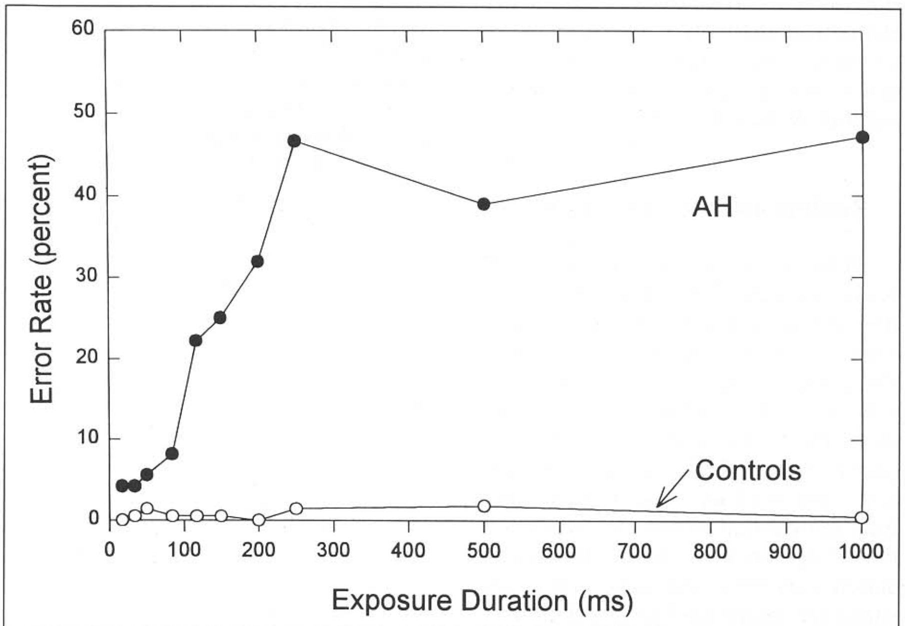

Fig. 4. Localization error rate as a function of exposure duration for A.H. and 3 normal control subjects.

11%, 55%, and 70%, respectively, $\chi^2(2, N = 192) = 48.93, p < .001$.

The duration, motion, and contrast effects invite the speculation that computation of location is intact within a visual subsystem sensitive to brief, moving, low-contrast stimuli, but impaired within a subsystem sensitive to high-contrast, stationary stimuli of longer duration. On this interpretation, A.H.'s error rates are low when stimulus conditions favor the former subsystem, and high when conditions favor the latter.

Psychophysical data from normal subjects have led some researchers to propose a distinction between sustained and transient visual subsystems that differ in their sensitivity to stimuli as a function of duration, motion, contrast, and other factors (e.g., Breitmeyer & Ganz, 1976). Conceivably, then, computation of location is intact within A.H.'s transient subsystem and impaired within her sustained subsystem. Should this interpretation prove viable, further study of A.H. may provide grounds for probing the functional characteristics of the subsystems (e.g., What stimulus properties is each subsystem sensitive to, and what outputs does each compute?). Results of such work should in turn be useful for assessing whether, as several researchers have suggested, the functional distinction between sustained and transient subsystems corresponds to the neuroanatomical distinction between parvocellular and magnocellular visual pathways (e.g., Lennie et al., 1990; Livingstone & Hubel, 1988).

Reading and the Visual Deficit

Although a detailed discussion of A.H.'s reading is beyond the scope of this article, we note that her reading errors may stem from the visual localization deficit. Letter and word transpositions may reflect mislocalization of letters within words, and words within text. Similarly, letter orientation confusions (e.g., *dog* read as "bog") might result from mislocation of parts of letters relative to one another. A.H.'s localization deficit may therefore have some relevance for understanding developmental dyslexias.

We do not suggest that visual localization deficits underlie all developmental dyslexias. Individuals categorized as dyslexic probably vary considerably at the level of underlying cognitive dysfunctions, and efforts to identify a single cause of dyslexia seem unlikely to prove fruitful. A more productive approach may be to probe the underlying cognitive deficits in many individuals with developmental reading disorders, in order to assess the extent and nature of the individual variation. This approach might, for instance, help to resolve the apparent contrast between our hypothesis that A.H. has a deficit affecting the sustained visual subsystem and the prominent current hypothesis that developmental dyslexia results from a transient-system deficit (e.g., Galaburda & Livingstone, 1993; Lovegrove, 1993).

CONCLUDING REMARKS

In ongoing studies with A.H., we are examining her visual deficit at cognitive, neurological, and genetic levels (e.g., Dagnelie & McCloskey, 1994). We are also studying the phonological deficit suggested by A.H.'s impaired phoneme discrimination performance, asking how (if at all) this deficit is related to the visual impairment.

In related work, we are attempting to determine whether developmental or acquired impairments similar to A.H.'s can be found in other individuals. Although impaired performance bearing some resemblance to that of A.H. has been observed in a few brain-damaged patients (e.g., Feinberg & Jones, 1985; Halligan, Marshall, & Wade, 1992; Jacobs, 1980), we have found no studies in which the patient's performance suggested an underlying cognitive deficit similar to A.H.'s. This does not necessarily mean, however, that A.H.'s impairment is unique or even extraordinarily rare. Although her visual deficit creates significant problems for her, she has functioned sufficiently well that the deficit went unrecognized for many years. Thus, similar deficits in other individuals may also go undetected.[2]

Regardless of the outcome of our ongoing work, the results presented in this article suggest that extensive single-subject analyses of developmental learning disabilities may prove fruitful for advancing not only knowledge of the disabilities, but also understanding of normal cognition.

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2. A.H.'s ability to function reasonably well probably reflects a number of factors, including her intact localization under many conditions (e.g., moving visual stimuli, auditory or tactile stimuli), her exceptional intelligence, and her long experience (presumably since birth) in coping with and compensating for her deficit. The problems A.H. did experience were usually attributed (by A.H. and other people) to lack of talent in specific areas (e.g., spelling, foreign languages) or to carelessness, absentmindedness, and clumsiness (e.g., misreading clocks, pouring water onto the floor when trying to water a plant).

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