Representation of Objects and Events: Why Do Infants Look So Smart and Toddlers Look So Dumb?

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Abstract

Research has demonstrated that very young infants can discriminate between visual events that are physically impossible versus possible. These findings suggest that infants have knowledge of physical laws concerning solidity and continuity. However, research with 2-year-olds has shown that they cannot solve simple problems involving search for a hidden object, even though these problems require the same knowledge. These apparently inconsistent findings raise questions about the interpretation of both data sets. This discrepancy may be resolved by examining differences in task demands.

Keywords

infant cognition; development; search tasks

A paradox has emerged in the developmental literature. On the one hand, a wealth of research from more than a decade of exciting studies shows that very young infants have knowledge of physical laws concerning continuity and solidity (Baillargeon, Graber, DeVos, & Black, 1990; Spelke, Breinlinger, Macomber, & Jacobson, 1992). On the other hand, recent work has revealed a surprising lack of such knowledge in children between 2 and 3 years of age (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prasada, 2000). The question is raised: Are there true discontinuities, even regressions, in children's concepts of the physical world? Or can the discrepancies between the infant and the toddler data sets be resolved by pointing to differences in task requirements? Or perhaps the explanation lies in differences in methodology. For example, in the infant studies the dependent measure is looking, and in the toddler studies it is active search. Whatever the explanation, this paradox must be resolved before a comprehensive theory of early cognitive development can be constructed.

Beginning with the seminal article by Baillargeon, Spelke, and Wasserman (1985), the emerging picture of infants has been that 3- to 4-month-olds show a stunning sophistication in their perception of the physical world. The typical paradigm in this line of research entails the presentation of an event (e.g., a rotating screen in Baillargeon et al., 1985; a rolling ball in Spelke et al., 1992) during repeated trials (referred to as *habituation* trials). Test trials consist of equal numbers of "possible" (*consistent*) events, which accord with the natural laws of physics, and "impossible" (*inconsistent*) events, which break those laws. The assumption is that if infants look longer at inconsistent than at consistent events, they have detected an incongruence with the physical law.

INFANT STUDIES ABOUT OBJECT AND EVENT REPRESENTATION

The procedure in the infancy studies can be clarified by considering an example from Experiment 3 in Spelke et al. (1992). During habituation trials, 3-month-old infants saw a ball roll from the left and disappear behind a screen. A bright blue wall protruded above the screen. When the screen was lifted, the ball could be seen resting against the wall on the right side of the display. Following these trials, an obstacle was placed on the track to the left of the wall, with the topmost part of the obstacle, as well as the blue wall, showing above the screen. On test trials, the ball was again rolled from left to right. For the inconsistent event, when the screen was raised the ball was resting in the old place by the wall, so that it seemed to have violated rules of solidity (i.e., two solid objects cannot occupy the same space at the same time) and continuity (objects exist continuously and move on connected paths over space and time). By appearing at the far wall, the ball seemed to have moved through the solid obstacle or discontinuously jumped over it. For the consistent event, when the screen was raised the ball was resting against the obstacle, a novel position but one that conformed to physical laws. The infants looked significantly longer at the inconsistent event than at the consistent event. A control group saw the ball in the same positions when the screen was raised, but the ball's movement had not violated any physical laws. This group looked at the ball equally in the old and novel locations, thus indicating that they had no intrinsic preference for either display and no preference for the original position.

From this and other experiments, investigators have drawn the conclusion that very young infants reason about objects and events by drawing on some form of knowledge about solidity and continuity (Baillargeon, 1993; Spelke et al., 1992).

SURPRISING RESULTS FROM TODDLERS

The discordant results from toddlers come from experiments presenting the same type of physical event—a rolling ball that goes behind a screen and stops—but in this case the child's task is to actually find the ball (Berthier et al., 2000). The apparatus (see Fig. 1) features a wooden screen with four doors that hides the progress of the ball down the track. The ball is always stopped by a barrier, which can be positioned at any of the four doors. The cue to the ball's location is the top of the barrier protruding several centimeters above the screen. If the child understands physical laws of solidity and continuity, he or she should open the door by the barrier. Test trials consist of the experimenter placing the barrier on the track and lowering the screen to conceal the track. Then the experimenter draws the child's attention to the ball and releases it at the top of the track. Finally, the child is invited to open a door to find the ball.

In Figure 2, the columns labeled "opaque" show individual performance on this task in the study by Berthier et al. (2000). Children under 3 years old performed no better than would be expected if they were simply guessing at the ball's location. Of 16 children in each age group, no 2-year-old and only three 2.5-year-olds performed above chance levels; 13 of the 3-year-olds did so, however. (Note: Data for 3-year-olds are not displayed in Fig. 2.) The almost total lack of success for children under 3 years of age was quite surprising, and in a series of studies my colleagues and I have sought to understand why their performance is so poor.

Fig. 1. View of the apparatus used for the toddler task. The child is opening the third door, and the ball, resting against the wall, is visible through the door. From "Where's the Ball? Two- and Three-Year-Olds Reason About Unseen Events," by N.E. Berthier, S. DeBlois, C.R. Poirier, J.A. Novak, and R.K. Clifton, 2000, *Developmental Psychology*, *36*, p. 395. Copyright by the American Psychological Association. Reprinted with permission of the author.

Offering more visual information about the ball's trajectory seemed like a reasonable way to help the toddlers (Butler, Berthier, & Clifton, 2002). We replaced the opaque wooden screen with a transparent one of tinted Plexiglas, leaving four opaque doors to hide the bottom of the wall and the ball's final resting position. Otherwise we kept the procedure and the rest of the apparatus the same. Now children had a view of the ball as it passed between doors, with the additional cue of no emergence beyond the wall. Despite this substantial increase in visual information about the ball's whereabouts, 2-year-old children still had great difficulty in searching accurately: Only 6 out of 20 children performed above chance. Of the 12 children tested at 2.5 years of age, 10 were above chance, so this age group benefited notably from the additional information (see data in Fig. 2 labeled "clear").

We also recorded eye gaze, monitored from a digital video camera trained on the child's face. Children at both ages were highly attentive as the ball was released, and they tracked its movement down the ramp on 84% of trials. Two aspects of their tracking behavior predicted their response: the point where they stopped tracking the ball and whether they broke their gaze before choosing a door. For older children, tracking the ball to its disappearance was the most typical pattern, and this virtually guaranteed they would open the correct door. A different story emerged for the 2-year-olds. Like 2.5-year-olds, they typically tracked the ball to its final location, but this did not ensure success. If they looked away after correctly tracking the ball, they made errors, although this was not the case for 2.5-year-olds (Butler et al., 2002).

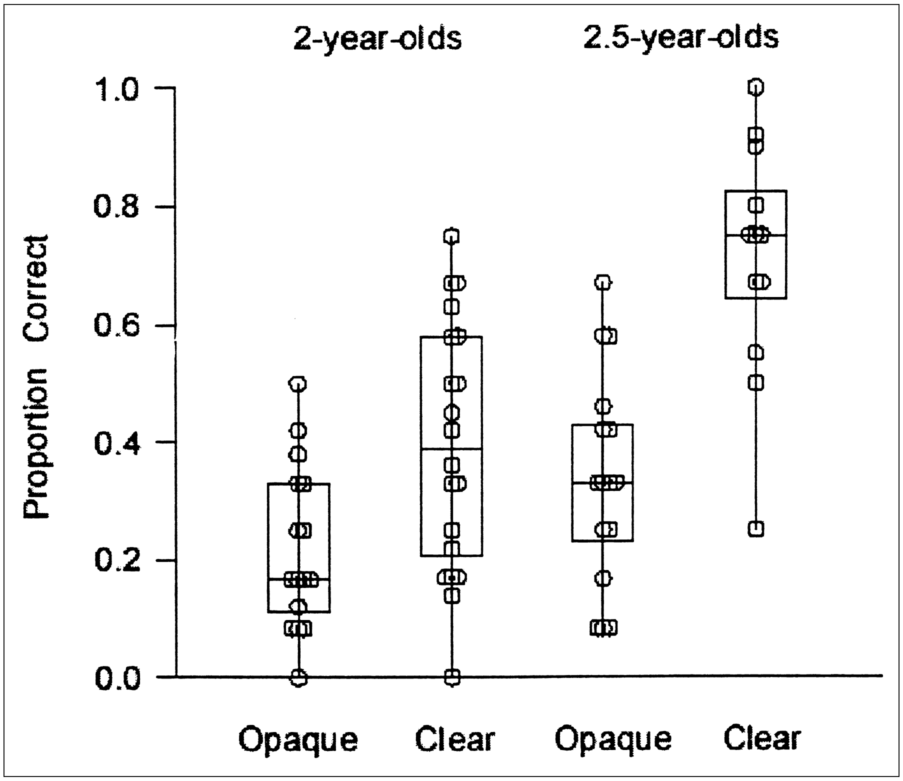

Fig. 2. Proportion of trials correct on the first reach for 2- and 2.5-year olds. Results are shown separately for trials with an opaque screen and a transparent screen. Each circle represents one child's performance. The boxes enclose the second and third quartiles of the distributions, and the horizontal lines in the boxes are the medians. From "Two-Year-Olds' Search Strategies and Visual Tracking in a Hidden Displacement Task," by S.C. Butler, N.E. Berthier, and R.K. Clifton, 2002, *Developmental Psychology*, *38*, p. 588. Copyright by the American Psychological Association. Reprinted with permission of the author.

IS THE PROBLEM KEEPING TRACK OF HIDDEN MOVEMENT?

A second visual manipulation was tried (Mash, Keen, & Berthier, in press). We hypothesized that if the children were given a full view of the ball's trajectory until it came to rest against a wall, they would be able to search correctly. In effect, we reversed the sequence of events that concealed the ball: In our previous studies (Berthier et al., 2000; Butler et al., 2002), the screen was first positioned in front of the ramp, hiding most of it from view, and then the ball was released at the top of the ramp, going out of sight while still moving. In this new study, the ball rolled down the ramp and came to a stop by a wall, then the screen was lowered to conceal both the ramp and the ball. At that point, the child's task was the same as in previous studies—open a door to find the ball. Note, however, that in this case the child did not have to reason about solidity and continuity in order to find the ball. Keeping track of its position behind the screen was all that was required.

Allowing complete access to the ball's movements benefited the older children somewhat, but the great majority of 2-year-olds still had enormous problems. Only two out of eighteen 2-year-olds tested performed above chance, whereas seven out of eighteen 2.5-year-olds did. As when we used the clear screen, gaze offered clues as to why children failed. If children looked at the ball as the screen was lowered and maintained this orientation until opening a door, they were correct about 90% of the time. Most children, however, broke their gaze, which resulted in errors. Merely watching as the screen was lowered over the ramp and ball did not aid search; only a continuous fixation up to the point of choosing the door led to success.

WHAT ABOUT TASK DIFFERENCES?

In the infant task, 3- to 4-month-old infants looked longer at physically impossible events than at possible events (Baillargeon et al., 1990; Spelke et al., 1992). No prediction was required on the infants' part, as they simply reacted to a visual array of an object in the wrong place or the right place. In contrast, the search task used with toddlers involved prediction and planning within a more complex apparatus. In order to make the infant and toddler tasks more comparable, we designed a looking-time task in which the same door apparatus was used, but the children never opened a door (Mash, Clifton, & Berthier, 2002). Instead, they observed the same events as before, but a puppet, Ricky the raccoon, opened the door.

Most of the time, Ricky opened the correct door and removed the ball. But on test trials, Ricky opened an incorrect door (no ball found, a physically possible, or consistent, event) or opened the correct door but found no ball (a physically impossible, or inconsistent, event). After the door was opened and no ball was found, the experimenter raised the screen to reveal the ball resting against the wall (consistent event) or beyond the wall (inconsistent event). This visual array is highly similar to what infants saw on the test trials of Experiment 3 in Spelke et al. (1992), described earlier. Like the infants, the toddlers looked longer at the inconsistent placement of the ball than at the consistent placement. This result was independently corroborated by a looking-time study with toddlers that used a similar apparatus but a different procedure in which the experimenter opened the doors while the child watched (Hood, Cole-Davies, & Dias, 2003).

CONCLUSIONS

To interpret the results of these studies, first consider what can be ruled out as an explanation of toddlers' poor performance in this search task. The results from the original study using an opaque screen (Berthier et al., 2000; and from Hood et al., 2000, as well) suggested that toddlers have no knowledge of continuity or solidity. In the clear-screen study (Butler et al., 2002), 2-year-olds again failed to recognize the barrier's role in stopping the ball. Maintaining gaze on the spot where the ball disappeared was the behavior most predictive of correct door choice—more evidence that toddlers did not reason about this physical event. But unexpectedly, taking away the reasoning requirement did not lead to success. Observing the disappearance of a stationary ball should have enabled the children to select the correct door if the problem were either hidden movement or the necessity to reason about the barrier's role (Mash et al., in press). The fact that performance remained poor in this condition rules out these explanations of toddlers' poor search performance. The puppet study, which used looking as the response rather than reaching, found that 2-year-olds, like infants, looked longer at the inconsistent event (Mash et al., 2002). This study rules out the disconcerting possibility that infants are endowed with knowledge about physical events that gets lost during development, and is regained around 3 years of age. Finally, although infants and toddlers both fail in search tasks that require a reaching response, previous work not discussed here demonstrated that 6-month-olds will reach for objects hidden by darkness (Clifton, Rochat, Litovsky, & Perris, 1991). Thus, it is not the response of reaching, in contrast to looking, that is the cause of infants' and toddlers' failure, but rather a problem of knowing where to search.

What could be the toddlers' problem in the search task? A distinct possibility, already mentioned, is the requirement of prediction. In order to plan and execute a successful search, toddlers had to know the ball's location in advance. Moreover, they had to coordinate this knowledge with appropriate action. Further research is needed to determine if either or both of these aspects are critical. One means of exploring this possibility is to devise new tasks that require location prediction but have fewer spatial elements to be integrated than the ball-barrier-door task and require simpler action plans.

A second prime issue needing further investigation is the relation between gaze behavior and search. Choice of the correct door was associated with continuous gaze at the hiding event; gaze breaks before searching were fatal to success. These data imply that children did not use sight of the barrier's top as a cue for the correct door. Likewise, adults faced with an array of 20 identical doors with no further marker might well use unbroken gaze at the point of disappearance as a strategy. If confusion among identical doors is the children's problem, then making the doors distinct should help. This manipulation coupled with careful analysis of gaze could determine whether the toddlers' problem is simply spatial confusion among identical doors. If so, the interesting question remains as to why the barrier's top does not cue location.

Finally, a theoretical issue is unresolved. The results for the looking-time task indicate that toddlers, and even infants, have some knowledge about the ball's expected location, but the contents of their knowledge is unclear. According to Spelke (Spelke et al., 1992), the principles of continuity and solidity are part of a constant core of physical knowledge that infants are endowed with. Infants of 3 to 4 months in age mentally represent hidden objects and can reason about an object's motion being constrained by continuity and solidity. Spelke et al. (1992) did not claim, however, that the infants in their study could predict the ball's location, and the toddler data suggest that infants' and even 2-year-olds' reasoning may be limited to recognizing after-the-fact incongruent events. If so, perceptual recognition of implausible event outcomes seems like a valuable building block on which to construct further knowledge, and eventually prediction, about the physical world.

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Note

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Why People Fail to Recognize Their Own Incompetence

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Abstract

Successful negotiation of everyday life would seem to require people to possess insight about deficiencies in their intellectual and social skills. However, people tend to be blissfully unaware of their incompetence. This lack of awareness arises because poor performers are doubly cursed: Their lack of skill deprives them not only of the ability to produce correct responses, but also of the expertise necessary to surmise that they are not producing them. People base their perceptions of performance, in part, on their preconceived notions about their skills. Because these notions often do not correlate with objective performance, they can lead people to make judgments about their performance that have little to do with actual accomplishment.

Keywords

self-evaluation; metacognition; self-concept; overconfidence; performance evaluation

Real knowledge is to know the extent of one's ignorance.

—Confucius

Confucius' observation rings just as true today as it did 26 centuries ago. To achieve and maintain an adequate measure of the good life, people must have some insight into their limitations. To ace an exam, a college student must know when he needs to crack open his notebook one more time. To provide adequate care, a physician must know where her expertise ends and the need to call in a specialist begins.

Recent research we have conducted, however, suggests that people are not adept at spotting the limits of their knowledge and expertise. Indeed, in many social and intellectual domains, people are unaware of their incompetence, innocent of their ignorance. Where they lack skill or knowledge, they greatly overestimate their expertise and talent, thinking they are doing just fine when, in fact, they are doing quite poorly.

IGNORANCE OF INCOMPETENCE: AN EXAMPLE

Consider the following example. In a sophomore-level psychology

Math Anxiety: Personal, Educational, and Cognitive Consequences

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Abstract

Highly math-anxious individuals are characterized by a strong tendency to avoid math, which ultimately undercuts their math competence and forecloses important career paths. But timed, on-line tests reveal math-anxiety effects on whole-number arithmetic problems (e.g., 46 + 27), whereas achievement tests show no competence differences. Math anxiety disrupts cognitive processing by compromising ongoing activity in working memory. Although the causes of math anxiety are undetermined, some teaching styles are implicated as risk factors. We need research on the origins of math anxiety and on its "signature" in brain activity, to examine both its emotional and its cognitive components.

Keywords

anxiety; mental arithmetic; math competence; working memory; problem solving

My graduate assistant recently told me about a participant he had tested in the lab. She exhibited increasing discomfort and nervousness as the testing session progressed, eventually becoming so distraught that she burst into tears. My assistant remarked that many of our participants show some unease or apprehension during testing—trembling hands, nervous laughter, and so forth. Many ask, defensively, if their performance says anything about their overall intelligence. These occasionally extreme emotional reactions are not triggered by deliberately provocative procedures—there are no personally sensitive questions or intentional manipulations of stress. Instead, we merely ask college adults to solve elementary-school arithmetic problems, such as 46 + 18 = ? and 34 − 19 = ?

The reactions are obvious symptoms of anxiety, in this case math anxiety induced by ordinary arithmetic problems presented in timed tasks. On the one hand, it is almost unbelievable that tests on such fundamental topics can be so upsetting; knowing that 15 − 8 = 7 ought to be as basic as knowing how to spell "cat." On the other hand, U.S. culture abounds with attitudes that foster math anxiety: Math is thought to be inherently difficult (as Barbie dolls used to say, "Math class is hard"), aptitude is considered far more important than effort (Geary, 1994, chap. 7), and being good at math is considered relatively unimportant, or even optional.

In this article, I discuss what has been learned about math anxiety across the past 30 years or so, and suggest some pressing issues to be pursued in this area. An important backdrop for this discussion is the fact that modern society is increasingly data and technology oriented, but the formal educational system seems increasingly unsuccessful at educating students to an adequate level of "numeracy," the mathematical equivalent of literacy (Paulos, 1988).

MATH ANXIETY DEFINED AND MEASURED

Math anxiety is commonly defined as a feeling of tension, apprehension, or fear that interferes with math performance. The first systematic instrument for assessing math anxiety was the Mathematics Anxiety Rating Scale (MARS), published by Richardson and Suinn (1972). In this test, participants rate themselves on the level of anxiety they would feel in various everyday situations, such as trying to refigure a restaurant bill when they think they have been overcharged or taking a math test. My co-workers and I use a shortened version of the test, which yields scores that correlate well with scores obtained using the original test and also has very acceptable test-retest reliability (i.e., an individual who takes the test on different occasions generally receives similar scores). We have also found that for a quick determination, one can merely ask, "On a scale from 1 to 10, how math anxious are you?" Across at least a half-dozen samples, responses to this one question have correlated anywhere from .49 to .85 with scores on the shortened MARS.

There is a rather extensive literature on the personal and educational consequences of math anxiety, summarized thoroughly in Hembree (1990). Perhaps the most pervasive—and unfortunate—tendency is avoidance. Highly math-anxious individuals avoid math. They take fewer elective math courses, both in high school and in college, than people with low math anxiety. And when they take math, they receive lower grades. Highly math-anxious people also espouse negative attitudes toward math, and hold negative self-perceptions about their math abilities. The correlations between math anxiety and variables such as motivation and self-confidence in math are strongly negative, ranging between −.47 and −.82. It is therefore no surprise that people with math anxiety tend to avoid college majors and career paths that depend heavily on math or quantitative skills, with obvious and unfortunate consequences.

Interestingly, math anxiety is only weakly related to overall intelligence. Moreover, the small correlation of −.17 between math anxiety and intelligence is probably inflated because IQ tests include quantitative items, on which individuals with math anxiety perform more poorly than those without math anxiety. The small correlation (−.06) between math anxiety and verbal aptitude supports this interpretation. However, math anxiety is related to several other important characteristics. As conventional wisdom suggests, it is somewhat higher among women than men. The gender difference is rather small, may be particularly apparent in highly selected groups (e.g., college students), and may be partly attributable to a greater willingness on the part of women to disclose personal attitudes. Nonetheless, when we recruited participants for research on math anxiety, we found fewer men than women at high anxiety levels, but just the reverse at low levels (Ashcraft & Faust, 1994).

Individuals who are high in math anxiety also tend to score high on other anxiety tests. The strongest interrelationship is with test anxiety, a .52 correlation. Despite the overlap among kinds of anxiety, however, the evidence is convincing that math anxiety is a separate phenomenon. For instance, intercorrelations between alternative assessments of math anxiety range from .50 to .70, but intercorrelations of math anxiety with other forms of anxiety range from .30 to .50. In a particularly clear display of the specificity of math anxiety, Faust (1992) found physiological evidence of increasing reactivity (e.g., changes in heart rate) when a highly math-anxious group performed math tasks of increasing difficulty. When the same participants performed an increasingly difficult verbal task, there was hardly any increase in their reactivity (e.g., Ashcraft, 1995, Fig. 6), and participants with low math anxiety showed virtually no increase in either task.

MATH ANXIETY AND MATH COMPETENCE

An obvious but unfortunate consequence of the avoidance tendency is that compared with people who do not have math anxiety, highly math-anxious individuals end up with lower math competence and achievement. They are exposed to less math in school and apparently learn less of what they are exposed to; as a result, they show lower achievement as measured by standardized tests (e.g., Fennema, 1989). The empirical relationship is of moderate strength (a correlation of −.31 for college students), but sufficient to pose a dilemma for empirical work. That is, when highly math-anxious individuals perform poorly on a test, their poor performance could in fact be due to low competence and achievement rather than heightened math anxiety. If the relationship between anxiety and competence holds for all levels of math difficulty, then variations in competence will contaminate any attempt to examine math performance at different levels of math anxiety.

Fortunately, there are ways out of this dilemma. One is to test additional samples of participants on untimed, pencil-and-paper versions of the math problems studied in the lab. For example, we (Faust, Ashcraft, & Fleck, 1996) found no anxiety effects on whole-number arithmetic problems when participants were tested using a pencil-and-paper format. But when participants were tested on-line (i.e., when they were timed as they solved the problems mentally under time pressure in the lab), there were substantial anxiety effects on the same problems.

We have also taken a second approach (see Ashcraft, Kirk, & Hopko, 1998). In brief, we administered a standard math achievement test to individuals with low, medium, or high math anxiety, and replicated the overall result reported by Hembree (1990; i.e., math achievement scores decrease as math anxiety increases). But we then scored the achievement test to take advantage of the line-by-line increases in difficulty. With this scoring method, we found that there were no math-anxiety effects whatsoever on the first half of the test, which measured performance on whole-number arithmetic problems. Anxiety effects were apparent only on the second half of the test, which introduced mixed fractions (e.g., 10 1/4 − 7 2/3), percentages, equations with unknowns, and factoring. For these problems, there was a strong negative relationship between accuracy and math anxiety. Thus, individuals with high levels of math anxiety do not have a global deficit in math competence, and they can perform as well as their peers on whole-number arithmetic problems. Investigations of higher-level arithmetic and math, though, do need to take the competence-anxiety relationship into account.

There is still reason to be somewhat suspicious of this relationship between anxiety and competence, however. Effective treatments for math anxiety (see Hembree, 1990,

Table 8) have resulted in a significant improvement in students' math achievement scores, bringing them nearly to the level shown by students with low math anxiety. Because the treatments did not involve teaching or practicing math, the improvement could not be due to a genuine increase in math competence. We suspect instead that these students' original (i.e., pretreatment) math competence scores were artificially low, depressed by their math anxiety. When the anxiety was relieved, a truer picture of their competence emerged.

COGNITIVE CONSEQUENCES OF MATH ANXIETY

Our original studies were apparently the first to investigate whether math anxiety has a measurable, on-line effect on cognitive processing, that is, whether it actually influences mental processing during problem solving. In our early studies (Ashcraft & Faust, 1994; Faust et al., 1996), we found that math anxiety has only minimal effects on performance with single-digit addition and multiplication problems. One anxiety effect we did find, however, was in a decision-making process sensitive to "number sense" (Dehaene, 1997)—when making true/false judgments, highly math-anxious individuals made more errors as the problems became increasingly implausible (e.g., 9 + 7 = 39), whereas low-anxiety participants made fewer errors on such problems.

Arithmetic problems with larger numbers (e.g., two-column addition or multiplication problems), however, showed two substantial math-anxiety effects. First, participants at high levels of anxiety routinely responded rapidly to these problems, sometimes as rapidly as participants with low anxiety, but only by sacrificing considerable accuracy. This behavior resembles the global avoidance tendency characteristic of highly math-anxious individuals, but at an immediate, local level: By speeding through problems, highly anxious individuals minimized their time and involvement in the lab task, much as they probably did in math class. Such avoidance came at a price, however—a sharp increase in errors.

Second, the results showed that addition problems with carrying were especially difficult for highly math-anxious individuals. In particular, the time disadvantage for carry versus no-carry problems was three times larger for participants with high anxiety (753 ms) than for those with low anxiety (253 ms), even aside from the difference in accuracy between the two groups. Our interpretation was that carrying, or any procedural aspect of arithmetic, might place a heavy demand on working memory, the system for conscious, effortful mental processing. In other words, we proposed that the effects of math anxiety are tied to those cognitive operations that rely on the resources of working memory.

In an investigation of this possibility, Kirk and I (Ashcraft & Kirk, 2001) tested one- and two-column addition problems, half requiring a carry. We embedded this test within a dual-task procedure, asking our participants to do mental math, the primary task, while simultaneously remembering random letters, a secondary task that taxes working memory. Two or six letters were presented before each addition problem, and after participants gave the answer to the problem, they were asked to recall the letters in order. We reasoned that as the secondary task became more difficult (i.e., when more letters had to be held in working memory), performance on the primary task might begin to degrade, in either speed or accuracy. If that happened, we could infer that the primary task indeed depended on working memory, and that the combination of tasks began to exceed the limited capacity of working memory.

When the addition problem involved carrying, errors increased substantially more for participants with high math anxiety than for those with low anxiety (Ashcraft & Kirk, 2001, Experiment 2). Moreover, as we predicted, this was especially the case when the secondary task became more difficult, that is, with a six-letter memory load. On carry problems (e.g., 6 + 9, 27 + 15), highly anxious individuals made 40% errors in the heavy-load condition, compared with only 20% errors for individuals with low anxiety in the high-load condition and 12% errors for both groups in the light-load condition. In the control conditions, with each task performed separately, the comparable error rates were only 16% and 8%. These results could not be attributed to overall differences in working memory. That is, we examined the participants' working memory spans (the amount of information they were able to remember for a brief amount of time) and found no differences between the groups when spans were assessed with a verbal task. But span scores did vary with math anxiety when they were assessed with an arithmetic-based task.

These results are consistent with Eysenck and Calvo's (1992) model of general anxiety effects, called processing efficiency theory. In this theory, general anxiety is hypothesized to disrupt ongoing working memory processes because anxious individuals devote attention to their intrusive thoughts and worries, rather than the task at hand. In the case of math anxiety, such thoughts probably involve preoccupation with one's dislike or fear of math, one's low self-confidence, and the like. Math anxiety lowers math performance because paying attention to these intrusive thoughts acts like a secondary task, distracting attention from the math task. It follows that cognitive performance is disrupted to the degree that the math task depends on working memory.

In our view, routine arithmetic processes like retrieval of simple facts require little in the way of working memory processing, and therefore show only minimal effects of math anxiety. But problems involving carrying, borrowing, and keeping track in a sequence of operations (e.g., long division) do rely on working memory, and so should show considerable math-anxiety effects. Higher-level math (e.g., algebra) probably relies even more heavily on working memory, so may show a far greater impact of math anxiety; note how difficult it will be, when investigating high-level math topics, to distinguish clearly between the effects of high math anxiety and low math competence.

GAPS IN THE EVIDENCE

Math anxiety is a bona fide anxiety reaction, a phobia (Faust, 1992), with both immediate cognitive and long-term educational implications. Unfortunately, there has been no thorough empirical work on the origins or causes of math anxiety, although there are some strong hints. For instance, Turner et al. (2002) documented the patterns of student avoidance (e.g., not being involved or seeking help) that result from teachers who convey a high demand for correctness but provide little cognitive or motivational support during lessons (e.g., the teacher "typically did not respond to mistakes and misunderstandings with explanations," p. 101; "he often showed annoyance when students gave wrong answers . . . . He held them responsible for their lack of understanding," p. 102). Turner et al. speculated that students with such teachers may feel "vulnerable to public displays of incompetence" (p. 101), a hypothesis consistent with our participants' anecdotal reports that public embarrassment in math class contributed to their math anxiety. Thus, it is entirely plausible, but as yet undocumented, that such classroom methods are risk factors for math anxiety.

Other gaps in the evidence involve the cognitive consequences of math anxiety, including those that interfere with an accurate assessment of math achievement and competence. My co-workers and I have shown that the transient, on-line math-anxiety reaction compromises the activities of working memory, and hence should disrupt performance on any math task that relies on working memory. The mechanisms for this interference are not yet clear, however. It may be that intrusive thoughts and worry per se are not the problem, but instead that math-anxious individuals fail to inhibit their attention to those distractions (Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998).

Finally, as research on mathematical cognition turns increasingly toward the methods of cognitive neuroscience, it will be interesting to see what "signature" math anxiety has in brain activity. The neural activity that characterizes math anxiety should bear strong similarities to the activity associated with other negative affective or phobic states. And our work suggests that the effects of math anxiety should also be evident in neural pathways and regions known to reflect working memory activity.

Recommended Reading

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Note

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