

Crawling-Onset Age Predicts Visual Cliff Avoidance in Infants

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Two experiments are reported that tested the effects of crawling-onset age, the amount of crawling experience, and testing age on avoidance of the deep side of a visual cliff apparatus by human infants. In Experiment 1, 49 infants ranging in age from 7 to 13 mo. were tested on the visual cliff after 1 or 2 mo. of crawling experience. Discriminant analysis revealed that crawling-onset age, and not crawling experience, discriminated between those infants who crossed and those infants who avoided the apparent drop-off. Infants who crossed the deep side were infants with an early crawling-onset age. In Experiment 2, 40 infants were tested on a visual cliff apparatus, half at 9 and half at 12 mo. of age. Discriminant analysis again found that crawling-onset age discriminated between infants who crossed and infants who would not cross the deep side, whereas testing age alone did not. These results call into question the idea that experience crawling is critical in inducing visually guided avoidance behavior in infants. It is argued that the crawling-onset age effect occurs because crawling during the tactile phase of infancy interferes with later visual control of locomotion.

Early research on the visual cliff avoidance response has generally been interpreted as providing evidence for instinctual or innate depth perception. Gibson and Walk (1960; Walk & Gibson, 1961) found that the young of many species choose to locomote toward the "visual ground" or shallow side of a visual cliff apparatus, avoiding the "visual cliff" or deep side. Perhaps the most convincing evidence from their work for the innate argument is the fact that baby goats, tested within a few hours after birth, avoided the visual cliff 100% of the time.

Human infants were tested by having their mothers call them across the deep and shallow sides of the visual cliff apparatus. Gibson and Walk (1960) found that most of the infants refused to cross the deep side. However, 10% of the infants did cross. Other researchers have found that as many as 66% of the infants tested were willing to cross the deep side (e.g., Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). To account for

the behavior of these crossing infants, some psychologists have proposed that humans require locomotor experience before being able to perceive the spatial layout of the environment.

Campos et al. (1978) have argued, for example, that locomotor experience is a critical factor in the development of the avoidance response. These researchers appear to favor a reafference theory (cf. Held & Hein, 1963; Von Holst, 1954) to explain the development of "space" perception. The reafferent theory holds that efferent signals to the muscles involved in locomotion are stored together with the visual stimulation produced by the subsequent locomotor movements (the reafferent stimulation) to provide a basis for evaluating future visual input. Campos et al. (1978) interpret the results of a number of visual cliff studies as providing support for their argument. However, it is not clear that the results of these studies can be cited as unequivocal support of an experience based theory.

The three main sources of data are studies by Walk (1966), Scarr and Salapatek (1970), and Campos and his associates (Campos & Langer, 1971; Campos, Langer, & Kowitz, 1970; Schwartz, Campos, & Baisel,

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1973). Walk analyzed age and experience factors, combining data from a number of experiments. He found that infants over 10 months of age showed more avoidance than infants under 10 mo. of age. He also reported a positive relationship between the amount of crawling experience and cliff avoidance for infants 10 mo. or older. However, the relationship between experience and avoidance was negative for the group of infants tested under 10 mo. of age. Furthermore, the interpretation of the data is made difficult because it was collected over a number of experimental conditions, many of which did not provide normal information for depth.

Scarr and Salapatek (1970) reported the results of a study on the development of fear of the visual cliff. Their measure of fear was subjective and included avoidance of the visual cliff as well as retreat behavior, facial expressions, and crying. Scarr and Salapatek found a positive relationship between age and fear of the visual cliff but found a negative relationship between experience and fear when age effects were controlled for in their analysis. Thus, their results seem to suggest a maturational, rather than experiential, effect.

Campos and his associates (Campos & Langer, 1971; Campos et al., 1970; Schwartz et al., 1973) also examined changes in fear of the visual cliff with age but used heart rate as the dependent variable. They found heart rate deceleration in infants 2, 3½, and 5 mo. old when the infants were lowered toward the deep side, but found acceleration of heart rate in a 9-mo.-old group. They interpreted heart rate deceleration as indicating interest and heart rate acceleration as indicating fear. Since Campos and his co-workers did not investigate the relationship between crawling experience and heart rate, this age-related shift from interest to fear could be interpreted in terms of maturation rather than experience.

Almost universally, researchers have assumed in the past that fear or an understanding of the consequences of a cliff mediate avoidance behavior. However, this need not be the case. A reasonable alternative is that the avoidance response reflects the operations of a visual-motor program; that is, visual input specifying a surface of

support controls directions to the motor system to move forward. No emotional or conceptual mediating response is necessary. This alternative position derives, in part, from a consideration of a baby goat's behavior. Baby goats do not avoid *approaching* cliffs and will often stand on the edge of one, not behavior one would expect if fear were a factor. Also, an experiment by Rader, Bausano, and Richards (1980) suggests that the avoidance response in young human infants is controlled by a response specific visual-motor program. Radar et al. found that those infants who avoided the cliff when crawling failed to avoid it when locomoting in a walker. In other words, the avoidance response was found to be specific to the act of crawling. If fear or a concept was mediating avoidance when the infant was crawling, one would expect avoidance to generalize to locomotion in a walker.

In examining age and experience factors as predictors of avoidance behavior during crawling, Rader et al. (1980) found that the age at which an infant first begins to crawl is the best and only independent predictor of avoidance behavior. Regardless of either the amount of crawling experience or the age at testing, infants who were early crawlers crossed the visual cliff, and infants who were late crawlers avoided the cliff. This finding of Rader et al. suggests that earlier-than-average crawling interferes with expression of the avoidance response. The failure of experience to independently predict behavior strongly argues against an experience-based explanation of nonavoidance behavior.

However, in the Rader et al. (1980) study, the amount of crawling experience and testing age were not experimentally manipulated and were confounded with crawling onset age. Also, the small number of subjects ($N = 22$) in that study might have caused the effect of experience and testing age to be obscured. The two experiments reported here were designed to correct these deficiencies. First, the number of subjects was increased substantially. Second, we directly manipulated the amount of crawling experience in one experiment and testing age in the second study while randomly sampling crawling onset age. In Experiment 1, infants were tested after either 1 or 2 mo. of crawl-

ing experience. These values were chosen as most likely to reveal an effect of experience. In Experiment 2, infants were tested at either 9 or 12 mo. of age. A value of 9 mo. was chosen as the lower level, since this was the lowest value that would not preclude many late crawlers. It was predicted that only crawling onset age would discriminate between avoiding and nonavoiding infants.

Experiment 1

Method

Subjects. Parents of 53 infants were contacted through newspaper birth announcements before their infants had begun to crawl. Monthly telephone calls were made to keep in touch with the infants' locomotor development. When the phone calls revealed that an infant had been creeping for 2 wk. or was just able to crawl, that age was taken as the crawling onset age, and the infant was randomly assigned to either the 30- or 60-days crawling-experience condition. Two weeks of creeping was included as a criterion for crawling onset age because some infants never go through a true crawling stage prior to walking.

Four subjects were excluded from the study because they failed to complete the testing. A total of 49 infants was tested with a mean testing age of 281 days ($SD = 44.01$). There were 22 subjects in the 30-day crawling-experience condition; the mean crawling experience was 32 days ($SD = 5.2$), and the mean crawling onset age was 231.9 days ($SD = 28.4$). There were 27 subjects in the 60-days crawling-experience condition; the mean crawling experience was 62 days ($SD = 6.38$), and the mean crawling onset age was 232.5 days ($SD = 48.9$).

Apparatus. The visual cliff apparatus was the same apparatus used by Rader et al. (1980). Its dimensions were 4 ft. (1.22 m) \times 12 ft. (3.66 m) with a center platform 2 ft. (.61 m) wide. The center platform was flush with the glass. Red and white gingham material with 1-in. (2.5-cm) checks was used for the floor of the shallow side, the cliff and floor of the deep side, and covered the platform separating the two sides. The distance from the platform to the floor of the deep side was 42.5 in. (108 cm). To control reflections by providing illumination from below, there was a distance of $\frac{3}{4}$ in. (1.9 cm) from the platform to the floor of the shallow side. Fluorescent tubes were placed along the perimeter of the visual cliff apparatus just under the glass on both sides; 2-in. (5.1-cm) wide masking tape on the glass above the lights prevented direct viewing of the tubes.

Video cameras were positioned at each end of the visual cliff, and the experimental sessions were recorded on a videotape recorder.

Procedure. The experiment's design was a comparison of two groups having different amounts of crawling experience (30 or 60 days), in which infants with varying crawling onset ages were randomly assigned to either group.

Subjects were tested once on each side of the visual

cliff apparatus; the order of testing site (deep or shallow) was randomly assigned to each subject. Infants were placed on the center platform headed toward the testing site. One experimenter remained in the room for safety reasons, standing in the corner of the room near the mother. The mother stood at the end of the visual cliff apparatus on the side selected for the testing site and called the infant to cross. The infant was first tested for 2 min. without a toy presented. After the initial 2 min., the mother was allowed to use a toy to coax the infant to cross. This second phase of the 4-min. testing period matches the procedure usually used. The mothers were instructed not to place the toy on the glass nor to tap the glass. Testing on one side of the cliff apparatus ended when the infant reached the mother or when 4 min. elapsed without the infant's leaving the platform in the direction of the mother.

Results

All infants crossed the shallow side of the visual cliff apparatus. Twenty-six infants avoided the deep side, and 23 infants crossed the deep side. A discriminant analysis was used to investigate the effect of crawling onset age and days of crawling experience on avoidance behavior on the deep side. The criterion for the two groups to be discriminated was whether or not the infant crossed the deep side within the 4-min. testing period. The predictor variables used were crawling onset age and the number of days of crawling experience.

The standardized discriminant function was found to be $(.9309) CA + (-.47396) CE$, where CA represents crawling onset age and CE represents days of crawling experience. The linear combination based on this function is significant, $F(2, 46) = 5.305$, $p = .0085$. This discriminant function indicates that crawling onset age is a significant predictor of avoidance behavior, univariate test, $F(1, 47) = 8.431$, $p = .0056$. Crawling experience does not add significantly to discrimination of the two groups, univariate test, $F(1, 47) = 1.546$, $p = .2198$.

For those infants who crossed the deep side of the visual cliff apparatus, the mean number of days of crawling experience was 52.08 ($SD = 15.99$) and the mean crawling onset age was 215.7 days ($SD = 32.1$). For those infants who avoided the deep side, the mean number of days of crawling experience was 46.23 ($SD = 16.83$) and the mean crawling onset age was 247.3 days ($SD = 42.5$). There was a progressive increase in the per-

centage of infants avoiding the deep side as crawling onset age increased. For those infants with a crawling onset age of 150–200 days ($N = 10$), 20% avoided the deep side; with a crawling onset age of 201–250 days ($N = 22$), 50% avoided the deep side; and for those infants with a crawling onset age of 251–300 days or more ($N = 17$), 76.5% avoided the deep side.

An examination of the behavior exhibited by those infants who crossed the visual cliff found that 12 of the 23 infants who crossed did not cross until after the initial 2 min. of testing; they crossed during the time when the toy was shown. Those infants tended to fixate on the toy or mother while crossing.

Discussion

The results clearly show the strong relationship of crawling onset age to avoidance behavior and the insignificance of the number of days of crawling experience in determining cliff avoidance. Those infants who learned to crawl early tended to cross the visual cliff, and those who learned to crawl later tended to avoid it, independent of having had 1 or 2 mo. of crawling experience. These results replicate the findings of Rader et al. (1980). However, the early crawlers in this experiment were also younger when tested than the late crawlers, so testing age could have accounted for the difference in behavior. Experiment 2 was designed to look at the effect of testing age on avoidance behavior by testing infants randomly assigned to two age groups—9 and 12 mo.

Experiment 2

Method

Subjects. Parents of 43 infants were contacted through newspaper announcements when the infants were 9 or 12 mo. of age. Crawling onset age was determined by questioning parents at the time of contact. Three infants did not complete the testing procedure and were excluded from the study. There were 20 subjects in the 9-mo. testing age condition with a mean testing age of 277 days ($SD = 13.96$) and a mean crawling onset age of 211 days ($SD = 24.98$). There were 20 subjects in the 12-mo. testing age condition with a mean testing age of 366 days ($SD = 13.15$) and a mean crawling onset age of 225 days ($SD = 57.06$).

Apparatus and procedure. The apparatus and testing procedure were identical to those used in Experiment

1. The design was a comparison of two testing age groups (9 or 12 mo.) in which subjects, having varying crawling onset ages, were assigned to either group according to age at contact.

Results

All of the infants tested crossed the shallow side of the visual cliff apparatus. Seventeen infants avoided the deep side, and 23 crossed within the 4-min. testing period. A discriminant analysis was performed using crossing and noncrossing subjects as groups to be discriminated. The predictor variables used were crawling onset age and testing age. The standardized discriminant function was found to be $(.8312) CA + (.52457) TA$, where CA and TA are crawling onset age and testing age, respectively. The linear combination based on this function is significant, $F(2, 37) = 3.826, p = .0309$. Crawling onset age alone is a significant discriminator, univariate test, $F(1, 38) = 5.791, p = .0211$, whereas testing age alone is not, univariate test, $F(1, 38) = 2.476, p = .1239$.

For the infants who crossed the deep side of the visual cliff apparatus, the mean testing age was 312 days ($SD = 47$), and the mean crawling onset age was 204.78 days ($SD = 32.82$). For those infants who avoided the deep side, the mean testing age was 335.11 days ($SD = 46.79$), and the mean crawling onset age was 236.76 days ($SD = 51.17$). There is, as in Experiment 1, a progressive increase in the percentage of infants avoiding the deep side as crawling onset age increases. For those infants with a crawling onset age of 150–200 days ($N = 16$), 18.75% avoided the deep side; with a crawling onset age of 201–250 days ($N = 14$), 42.9% avoided it; and for those infants with a crawling onset age of 251–300 days or more ($N = 10$), 80% avoided it.

The behavioral observations were similar to those in Experiment 1. Twelve of the 23 infants who crossed did so only after the first 2 min. of testing; they crossed during the period when the toy was shown.

Discussion

The results of Experiment 2 clearly show the strength of crawling onset age as a predictor of visual cliff avoidance behavior.

Crawling onset age has greater weight than testing age in the discriminant function and is a significant predictor on its own of avoidance behavior. Although testing age receives a substantial weighting in the discriminant function, it is not a significant predictor on its own. The weighting factor of testing age may be inflated as the assignment procedure produced more infants with crawling onset ages over 250 days in the 12-mo. old group. Thus, even though it is clear from these results that crawling onset age is a significant predictor and testing age is not, the actual contribution of testing age may be overestimated in the discriminant function of this experiment.

The behavioral observation that the infants who crossed tended to do so in the period of testing when the toy was presented suggests that they are more likely than later crawlers to initiate crawling when not attending to the visual information specifying a solid surface of support.

General Discussion

Both Experiments 1 and 2 found that crawling onset age is the best and only significant discriminator of avoidance and non-avoidance groups. Infants who begin crawling at earlier ages are more likely to cross the visual cliff, regardless of testing age or the amount of crawling experience, than those who learn to crawl later. The power of either days of crawling experience or testing age alone to predict avoidance behavior is nonsignificant.

The percentage of infants tested who crossed the deep side was 51.7% across the two experiments. Since this percentage of nonavoiders is substantial, it is unlikely that we simply missed the relevant levels of experience or testing age. If the effect of experience were within the 1st month only, we should have found a low percentage of crossers, since all of the infants tested would have had the benefit of a month's experience. Similarly, if an age shift occurs prior to 9 mo. of age, we should have found few crossers, since all infants would have already passed through the shift.

Given a cursory examination, these results

appear at odds with the studies cited in the introduction of this article that report an age effect. However, two points should be kept in mind in making such comparisons. First, it is impossible to know to what extent testing age was confounded with crawling onset age. To be tested for the avoidance response at a young age, an infant must be an early crawler. If one examined the results of Experiment 1 of this article without considering crawling onset age of Experiment 2, the likely conclusion would be that testing age accounts for the difference between avoiders and nonavoiders. The second point is that the early avoidance response may have a developmental history that is independent of the development of the fear response. It may well be that experience or maturation contributes to the development of fear or a concept of a cliff at a later stage. Once developed, fear or conceptual responses could then direct locomotor response. Future research should investigate possible modulating effects of age or experience and should seek to determine the mechanisms underlying their effect.

Our finding that crawling onset age alone discriminates between avoiding and non-avoiding infants replicates the Rader et al. (1980) finding. The Rader et al. data, however, strongly suggested an all-or-nothing effect of crawling onset age. All infants who learned to crawl prior to 6.5 mo. crossed the visual cliff, whereas all infants who learned to crawl after 6.5 mo. avoided the visual cliff. Of the three infants who learned to crawl just at 6.5 mo. two avoided the cliff and one did not. The data in the two experiments reported here, however, suggest a more continuous effect of crawling onset age. In both Experiments 1 and 2, there was an increasing proportion of infants avoiding the visual cliff with increasing crawling onset age. If both Experiments 1 and 2 are combined, the proportion of infants avoiding the cliff with crawling onset ages of 150–200 days was 19.2%; with crawling onset ages of 201–250 days, the proportion was 47.2%; and with crawling onset ages of 251–300 or more days, it was 77.8%. There is a difference between the experiments reported here and the Rader et al. study in the measurement

of crawling onset age. In the Rader et al. study, crawling onset age was the age at which an infant could first locomote over a distance of 4 ft. to its mother when she called—regardless of how that locomotion was achieved. In the experiments reported here, *crawling onset age* was the age when an infant could locomote by crawling, that is, move about on his or her hands and knees or the age at which he or she had been creeping for 2 wks. However, this difference in definition of *crawling onset age* should do no more than to shift the effect of crawling onset age ahead 2 or 3 wk. Thus, it is most likely that the difference between the two studies in finding a discontinuity of effect results from sampling differences.

In formulating a hypothesis concerning the mechanism underlying the effect of crawling onset age, Rader et al. suggested the development of a perceptual-motor program that is maturationally controlled. This program was seen as operating to direct crawling movements in response to visual information specifying a solid surface of support. Rader et al. suggested that if crawling onset occurs prior to the emergence of this program, then crawling will be directed more by tactile input and that this dominance of tactile over visual input will continue, at least through the crawling stage. The continuous effect of crawling onset age found in the two experiments reported here indicates that should this hypothesis prove correct, the maturational onset of such a program is not perfectly correlated with crawling onset age.

The effort of crawling onset age is particularly interesting because it suggests that there exists a critical period for the linking of visual input and crawling behavior. If crawling begins earlier than this period, the type of crawling behavior seen later is qualitatively different in that it appears to be less

dependent on the visual input specifying a surface of support. This notion fits the behavioral observations of the early crawlers' willingness to crawl while looking elsewhere than at the surface ahead of them. The tactile input appears more important to these infants than to the later crawlers in controlling locomotion forward.

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