

## Children's and adults' size estimates at near and far distances: A test of the perceptual learning theory of size constancy development

Michael Kavšek\*

Department of Developmental and Educational Psychology, Institute of Psychology, University of Bonn, Kaiser-Karl Ring 9, 53111 Bonn, Germany; e-mail: [kavsek@uni-bonn.de](mailto:kavsek@uni-bonn.de)

Carl E. Granrud

School of Psychological Sciences, University of Northern Colorado, Campus Box 94, Greeley, CO, 80639, USA; e-mail: [Carl.Granrud@unco.edu](mailto:Carl.Granrud@unco.edu)

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**Abstract.** This study tested the perceptual learning theory of size constancy development, which proposes that children younger than 9 years are relatively insensitive to monocular cues for distance and size, and that developmental changes in far-distance size estimation result from increasing sensitivity to these cues. This theory predicts that before 10 years, children will make less accurate size judgments at far distances under monocular than under binocular viewing conditions. Five age groups were tested: 5–6, 7–8, 9–10, 19–28, and 50+ years. Participants judged the size of a standard disc, from viewing distances of 6.1 and 61 m, by pointing at 1 of 9 nearby comparison discs. Testing was conducted under both monocular and binocular viewing conditions. Five- to 6-year-olds underestimated object size at the far distance, 7- to 8-, 9- to 10-year-olds, and older adults made size estimates that were close to accurate, and the young adults significantly overestimated size. At the near distance, all age groups underestimated size and no age differences were found. Contrary to predictions from the perceptual learning theory, viewing condition had no significant effect on size estimates.

**Keywords:** size constancy; size perception; space perception; object perception; perceptual learning theory of size constancy; perceptual development.

### 1 Introduction

Before about 9 years of age, children tend to underestimate the size of a distant object. From 9 years on, they generally estimate accurately or overestimate a distant object's size (Brislin & Leibowitz, 1970; Granrud, 2009; Granrud & Schmechel, 2006; Leibowitz, Pollard, & Dickson, 1967; Merriman, Moore, & Granrud, 2010; Zeigler & Leibowitz, 1957). Two main theories have been proposed to explain this developmental change: the metacognitive and perceptual learning theories of size constancy development (e.g., Granrud, 2009, 2012).

The metacognitive theory (Granrud, 2009, 2012; Rapoport, 1967) proposes that children and adults perceive distant objects as smaller than their actual sizes, and that young children respond to perceived size in size-matching tasks. As a result, they underestimate object size (i.e., exhibit underconstancy) at far viewing distances. Older children and adults, however, are aware of their underconstant perceptions at far distances and they supplement perception with deliberate size-matching strategies. When estimating a distant object's size, they make nearly accurate size estimates (exhibit size constancy), and sometimes overestimate size (exhibit overconstancy), by using explicit strategies such as the distance compensation strategy, which involves deliberately inflating estimated size to compensate for the effects of distance on perceived size. According to this theory, developmental changes in size estimation during childhood are caused by increasing metacognitive awareness of the effects of distance on perceived size and the development of strategy use.

\*Corresponding author.

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According to the perceptual learning theory (e.g., Jenkin & Feallock, 1960; Leibowitz, 1974), young children are less sensitive than older children and adults to monocular cues that specify size and distance, such as linear perspective and texture gradients. These cues are especially important for size perception at far distances because binocular cues become less effective as viewing distance increases. Sensitivity to monocular depth cues increases gradually during childhood, according to this theory, and accurate size constancy can be achieved at far distances by about 10 years of age.

Recent research has supported the metacognitive theory. Granrud (2009) and Merriman et al. (2010) found evidence that age-related increases in use of the distance compensation strategy account for age-related changes in far-distance size estimation performance between 5 and 11 years of age. It has remained possible, however, that developmental changes in far-distance size estimation result from concurrent increases in strategy use *and* sensitivity to monocular depth cues. The present study investigated this possibility by asking whether increased sensitivity to monocular cues contributes to the development of far-distance size constancy.

Three main findings have been cited as indicating that sensitivity to visual cues for size and distance increases during childhood: an early report that intelligence is unrelated to size estimation accuracy (Jenkin & Feallock, 1960), a report that young children are unresponsive to the Ponzo illusion (Leibowitz & Judisch, 1967), and the finding of a monocular–binocular difference in young children’s size judgments for distant objects (Leibowitz et al., 1967). Each of these findings is discussed below.

Jenkin and Feallock (1960) asked children and adolescents to judge the size of a standard object from a distance of about 8 m and found that size estimation accuracy was not related to intelligence. Size estimates made by adolescents, whose mental ages were reported as 8 years, did not differ from those made by adolescents with average intelligence, but they were more accurate than size estimates made by 8-year-olds with average intelligence. Jenkin and Feallock (1960) concluded from their results that developmental changes in size estimation accuracy could not result from developments in cognition and must, therefore, be caused by increased sensitivity to visual cues for distance and size, although their study did not include measures of sensitivity to these cues. In a more recent study of 6- to 8-year-old children, Merriman et al. (2010) found that reasoning ability (measured by two subscales of the WISC-III) is not related to size estimation accuracy at a viewing distance of 6.1 m. However, they obtained very different results when a longer viewing distance was used: reasoning ability is significantly correlated with size estimation accuracy at a distance of 61 m. The Merriman et al. (2010) results further suggested that a high level of reasoning ability is associated with more accurate far-distance size judgments because it promotes use of the distance compensation strategy. Children who score high in reasoning ability tend to report using this strategy when judging a distant object’s size, and they make larger far-distance size estimates than comparably aged children with lower levels of reasoning ability who tend to report no strategy use. In light of the Merriman et al. (2010) findings, the existing evidence on reasoning ability and size constancy supports the metacognitive theory, not the perceptual learning theory.

Leibowitz and Judisch (1967) reported that 5-year-old children are not susceptible to the Ponzo illusion, an illusion in which two equal-length lines appear to differ in length when flanked by diagonal lines. Following the misapplied constancy-scaling theory of the Ponzo illusion, which proposes that this size illusion results from illusory depth produced by linear perspective, Leibowitz and Judisch (1967) concluded that young children are insensitive to the depth information provided by linear perspective and argued that their results supported the perceptual learning theory. However, more recent studies have demonstrated that 4- and 5-year-old children respond to several versions of the Ponzo illusion and that children’s responses to this illusion are as strong as, and perhaps stronger than, the responses exhibited by adults (Granrud & Granrud, 2004; Predebon, 1985; Pressey, 1974). Furthermore, infants respond to object size across changes in distance, which are specified by linear perspective and texture cues, in Ponzo-like displays as early as 4 months of age (Frichtel & Lécuyer, 2007; Yonas, Granrud, Le, & Forsyth, 2007). Developmental studies of the Ponzo illusion therefore provide no support for the perceptual learning theory.

The monocular–binocular difference in far-distance size estimation found by Leibowitz et al. (1967) may be the only result supporting the perceptual learning theory that has remained unchallenged. Leibowitz et al. (1967) reported that 5- to 9-year-old children made smaller, less accurate size judgments when viewing objects at distances of 30.5 and 61 m with one eye than when viewing the objects with two eyes. In contrast, 11-year-old children and young adults made nearly accurate size estimates at these distances and were equally accurate under monocular and binocular viewing conditions.

At shorter distances, 3.8 to 15.2 m, no effects of monocular versus binocular viewing were found in any of the age groups. Leibowitz et al. (1967) concluded that older children and adults are sufficiently sensitive to monocular cues that binocular cues are unnecessary for achieving size constancy at far distances, whereas 5- to 9-year-olds are less sensitive to monocular cues for distance and size, and that this relative insensitivity accounts for these children's underconstant size judgments at far distances.

The Leibowitz et al. (1967) results are surprising given the nature of binocular depth information. Although binocular cues can aid depth discriminations at distances of 40 m and greater, when separations in depth are very large (Palmisano, Gillam, Govan, Allison, & Harris, 2010), binocular cues are most effective at near distances, up to about 6 m (e.g., Cutting & Vishton, 1995; Gregory, 1966). If binocular vision provides an advantage for size perception, it seems likely that the advantage would be greater at nearer than at farther distances. The Leibowitz et al. (1967) results are also difficult to evaluate because the published article does not report whether the size estimates made under monocular and binocular conditions differed significantly within individual age groups at specific distances. Additional research on the effects of monocular versus binocular viewing on children's size estimates therefore seems warranted.

In the present study, children and adults estimated the sizes of objects at near and far distances, 6.1 and 61 m, by choosing a size match from a set of nearby comparison objects. The objects were viewed under monocular (one eye patched) and binocular conditions. A pretest, in which participants estimated the sizes of standard objects from a distance of 4 m, was also conducted to ensure that the children understood and could perform the size-matching task.

Five age groups were tested: 5–6, 7–8, 9–10, 19–28, and 50+ years. The first four age groups were included to test the perceptual learning theory. If a monocular–binocular difference in far-distance size estimation accuracy was observed in the two younger age groups but not in the older groups, it would support the Leibowitz et al. (1967) findings and would indicate that increasing sensitivity to monocular cues contributes to age-related increases in far-distance size estimation accuracy. The older adults were included in the study to follow up on recent findings by Bian and Anderson (2009) that middle-aged adults make more accurate distance judgments than college-age adults at viewing distances of 4 to 12 m. Given the close relationship between size and distance perception, we hypothesized that older adults would make more accurate size estimates as well.

## 2 Method

### 2.1 Participants

Five groups of participants were tested: 5- to 6-year-old children ( $n = 17$ , 8 males and 9 females, mean age = 78.5 months, age range = 70–83 months), 7- to 8-year-old children ( $n = 13$ , 7 males and 6 females, mean age = 96.8 months, age range = 86–105 months), 9- to 10-year-old children ( $n = 12$ , 6 males and 6 females, mean age = 120.6, age range = 114–132 months), 19- to 28-year-old adults ( $n = 20$ , 9 males and 11 females, mean age = 22.8 years, age range = 19–28 years), and adults 50 years of age and older ( $n = 18$ , 9 males and 9 females, mean age = 59.8 years, age range = 50–84 years). The children were recruited from a primary school, the young adult participants were university students, and the older participants were acquaintances of the experimenters' research assistants. The children's parents and the adult participants were given a written description of the study and they gave written informed consent. The study was approved by the ethics committee of the Institute of Psychology at the University of Bonn (Bonn, Germany).

### 2.2 Materials

In each pretest and test trial, participants viewed one standard object and nine comparison objects. They judged the size of the standard object by pointing to the comparison object that matched the standard object in size. All of the objects were white circular discs made from 1-cm-thick, foam-core board.

The comparison objects were similar to those used by Merriman et al. (2010). They were arranged in an arc in front of the participant, with each comparison object 2 m from the participant. Each disc was positioned on the ground with its front surface at a 45° angle relative to the ground plane. The comparison objects were arranged in order of size, with the smallest object on the left and the largest on the right from the participant's viewpoint. The smallest disc had a diameter of 15.24 cm and the largest had a diameter of 76.2 cm. The diameter of each successive disc increased from left to right in 7.62 cm increments.

There were nine standard objects for the pretest, which were identical to the comparison objects in size. In each pretest trial, one standard object was presented directly in front of the participant at a distance of 4 m. There were three standard objects for the test trials: 68.58, 60.96, and 53.34 cm in diameter. These objects were identical to the second, third, and fourth largest comparison objects. In each test trial, one standard object was positioned in front of the participant at a distance of either 6.1 m, the near distance, or 61 m, the far distance. In each pretest and test trial, the standard object stood on the ground with its front surface perpendicular to the ground plane.

All testing was done on a large, unmarked, grass-covered field. The standard objects were positioned such that all other objects on the field (e.g., trees and fences) were at least 20 m from the standard object in the far-distance trials. No objects were this close to the standard object in the near-distance trials either, with the exception of the comparison-object array.

### 2.3 Procedure

The experiment included four pretest trials and four test trials. In each trial, the participant was asked to point to the comparison object that matched the standard object in size. The pretest consisted of two monocular and two binocular trials. Before testing began, one experimenter asked the participant to look into a kaleidoscope to establish the dominant eye. In the monocular trials, participants wore an eye patch, which covered the nondominant eye. The eye patch could be worn below eyeglasses. Half of the participants received the monocular trials first and half received the binocular trials first. One standard object was viewed at a distance of 4 m in each pretest trial. The standard objects for the four pretest trials were chosen randomly from four sets of objects: the 15.24 cm and 22.8 cm objects, the 30.48 cm and 38.1 cm objects, the 45.72, 53.34 cm and 60.96 cm objects, and the 68.58 cm and 76 cm objects. One object from each set was used as a standard object in the pretest.

The pretest was conducted to ensure that children understood the task and could respond accurately when the standard objects were nearby. Participants were included in the sample if they chose the correct size match in all four pretest trials or, if any incorrect choices were made, the selected object was immediately adjacent to the correct object in the comparison-object array in at least three out of the four trials. All of the participants who were tested passed the pretest. Therefore, no participants were excluded from the sample.

In the test trials, half of the participants received the two monocular trials first and half received the two binocular trials first. One near-distance trial and one far distance trial was given in each viewing condition. Order of the near-distance and far-distance trials was counterbalanced. For the first three test trials, the standard object was chosen randomly, without replacement, from the three possible sizes: 68.58, 60.96, and 53.34 cm. After all three sizes had been used, the standard object for the fourth test trial was chosen randomly from the three possible sizes.

Before each pretest and test trial, the participant faced in the opposite direction of the standard object while it was put into place. When the standard object was in place, the participant was instructed to turn around, inspect the standard object, and point to the comparison object that was the same size as the standard object. No time limit was placed on the participant. The participant's choice was recorded by two experimenters. If either experimenter could not determine which comparison object was selected, the participant was asked to walk to and touch the object.

Three experimenters conducted the testing session. Two interacted with the participants and recorded their responses. After each trial, they compared their results and clarified inconsistencies. A third experimenter put the standard objects in place.

## 3 Results

[Table 1](#) shows mean percent error values for the five age groups in each viewing condition at each distance. These values represent the percentage by which participants in each group under- or overestimated the standard objects' sizes. Negative error values indicate underconstancy, positive error values indicate overconstancy, and a value of zero would indicate accurate size estimation.

The error values were compared in a mixed-design analysis of variance (ANOVA) with distance (near and far) and viewing condition (monocular and binocular) as within-subjects factors and age (5–6, 7–8, 9–10, 19–28, and  $\geq 50$ ) as a between-subject factor. The main effect of viewing condition was not significant,  $F(1, 75) = .26, p = .61$ , and viewing condition did not interact significantly with age,  $F(4, 75) = .30, p = .88$ , or distance,  $F(4, 75) \leq .01, p = .93$ . In addition, there was no interaction between

**Table 1.** Mean percent error values for each age group under monocular and binocular viewing conditions at the near (6.1 m) and far (61 m) distances

Age	Near distance		Far distance	
	Monocular <i>M</i> ( <i>SD</i> )	Binocular <i>M</i> ( <i>SD</i> )	Monocular <i>M</i> ( <i>SD</i> )	Binocular <i>M</i> ( <i>SD</i> )
5–6 years	–9.74 (9.99)	–11.81 (10.32)	–17.89 (12.00)	–18.23 (16.80)
7–8 years	–10.03 (9.40)	–10.66 (13.22)	–5.33 (11.39)	–5.75 (15.56)
9–10 years	–4.34 (7.98)	–6.63 (10.39)	4.36 (12.50)	3.09 (15.87)
19–28 years	–6.79 (9.59)	–2.47 (9.38)	10.70 (14.55)	10.00 (12.15)
≥50 years	–3.32 (13.38)	–6.06 (7.34)	3.95 (20.20)	3.61 (11.21)

viewing condition, age, and distance,  $F(4, 75) = .43, p = .79$ . These results indicate that monocular versus binocular viewing had no effect on the participants' size judgments. Across all age groups, the participants made similar size estimates under monocular and binocular viewing conditions.

The main effect of distance was significant,  $F(1, 75) = 16.08, p < .001, \eta_p^2 = .18$ , as was the main effect of age,  $F(4, 75) = 16.43, p < .001, \eta_p^2 = .47$ . The interaction between age and distance was also significant,  $F(4, 75) = 8.45, p < .001, \eta_p^2 = .31$ . To explore this interaction further, one-way ANOVAs were conducted to compare mean error values (collapsed across viewing conditions) between age groups at each distance. Error values varied significantly between age groups at the far distance,  $F(4, 75) = 19.19, p < .001, \eta_p^2 = .51$  but did not vary significantly between age groups at the near distance,  $F(4, 75) = 2.43, p < .05$ . These analyses indicate that the different age groups made different size estimates at the far distance but made similar size estimates at the near distance.

Tukey post hoc comparisons ( $\alpha = .05$ ) found that the 5- to 6-year-olds' far-distance size estimates differed significantly from those of the other four groups. The 7- to 8-year-olds' far-distance size estimates differed significantly from those of the 19- to 28-year-olds but not from those of the 9- to 10-year-olds or ≥50-year-olds. Finally, no significant differences were found between the far-distance size estimates made by the 9- and 10-year-olds, 19- to 28-year-olds, and ≥50-year-olds.

Planned exploratory one-sample *t* tests were conducted to compare mean error values (collapsed across viewing condition) to zero for each age group at each distance. All five age groups significantly underestimated size at the near distance ( $p < .05$  for all comparisons). At the far distance, the 5- to 6-year-olds significantly underestimated size,  $t(16) = -6.25, p < .001$ , two-tailed, while the 7- to 8-year-olds', 9- to 10-year-olds', and older adults' mean size estimates did not differ significantly from zero ( $p < .05$  for all comparisons). The 19- to 28-year-olds significantly overestimated size at the far distance,  $t(19) = 4.15, p < .001$ , two-tailed.

#### 4 Discussion

Viewing condition had no measurable effect on children's or adults' size estimates. Size estimates were approximately equal in the monocular and binocular conditions at both the near (6.1 m) and far (61 m) distances. These results conflict with the Leibowitz et al. (1967) report that children's far-distance size estimates are less accurate under monocular than under binocular viewing conditions. However, the results are consistent with findings that adults' size judgments are equivalent under monocular and binocular viewing conditions across a wide range of distances (Holway & Boring, 1941). In contrast, the Leibowitz et al. (1967) results appear to be anomalous in light of the existing research on size perception and binocular vision. The monocular–binocular difference reported by Leibowitz et al. (1967) was, to our knowledge, the only finding in the literature indicating that children's underconstant far-distance size estimates result from insensitivity to monocular depth cues. Given the results of the present study, the perceptual learning theory no longer appears to have any empirical support.

Consistent with previous studies, this study found age-related changes in far-distance size estimates. The 5- to 6-year-old children significantly underestimated size at 61 m. The 7- to 8-year-olds exhibited a trend toward underconstancy, although their mean error value did not differ significantly from zero. The 9- to 10-year-olds and ≥50-year-olds displayed nonsignificant trends toward overconstancy, and the 19- to 28-year-olds exhibited significant overconstancy. Far-distance size estimation does not appear to follow a developmental trend from inaccurate size estimation in early



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childhood to accurate size estimation in adulthood. Instead, it develops from underconstancy in early childhood to overconstancy in early adulthood. The young adults made inaccurate far-distance size estimates, overestimating size by about 10% on average. This result is consistent with several previous studies of adults' size judgments at far distances (e.g., Carlson, 1960, 1962; Epstein, 1963; Gilinsky, 1955). Granrud (2012) suggested that perceived size is underconstant for adults and children at far distances, but that adults strategically inflate their size estimates. They do not know precisely how much to inflate their estimates, however, so they make heuristic-based guesses which often overshoot the accurate size, resulting in overconstancy. Other authors have given similar explanations for overconstancy (Teghtsoonian, 1974; Wohlwill, 1963).

On the basis of the Bian and Anderson (2009) finding that middle-aged adults make more accurate distance estimates than college-age adults, we hypothesized that the older adults in our study would make more accurate far-distance size estimates than the younger adults. The results neither confirmed nor clearly disconfirmed this hypothesis. The older adults' size estimates were slightly more accurate than those made by the younger adults; their estimates were in the direction of overconstancy, but their mean error did not differ from zero. However, the two adult groups' size estimates did not differ significantly. Given the Bian and Anderson (2009) findings and the nonsignificant trend observed in the present study, additional research comparing far-distance size estimates in younger and older adults seems warranted.

No age differences were found at the near distance. Granrud (2009) and Merriman et al. (2010) also found no age differences in size estimates made at 5 and 6.1 m. The near-distance results provide further evidence against the perceptual learning theory. If older children and adults were more sensitive than younger children to visual cues for size and distance, older participants should make more accurate size estimates at 6.1 m. Greater sensitivity to visual cues should provide an advantage at 6.1 m as well as at 61 m. Differences between the age groups at the near distance approached significance, and studies using more sensitive methods or larger samples may reveal that adults can make more accurate size estimates than young children at 6.1 m. However, the nonsignificant results found at the near distance in this study suggest that differences in sensitivity to visual cues did not contribute significantly to the age differences observed at the far distance.

The lack of an age difference at the near distance also indicates that the age difference found at the far distance cannot be attributed to lower motivation or task proficiency in the younger than in the older participants. A difference in either of these variables would be expected to cause different performances at the near as well as the far distance. The pretest results provide additional evidence for these conclusions. To pass the pretest, participants had to make accurate or nearly accurate size matches at a distance of 4 m. Every participant in the study passed the pretest, indicating that even the youngest children understood the task, could follow the instructions, and had sufficient motivation to make accurate size judgments. Furthermore, to pass the pretest, participants had to choose objects from all parts of the comparison object array. They had to choose small comparison objects to match small standard objects and large comparison objects to match large standard objects. A child could not pass the pretest if he or she had a consistent response bias, such as choosing a comparison object from the center of the array. The age difference observed at the far distance, therefore, cannot be attributed to a response bias in the younger groups.

The near-distance results indicate that perceived size is underconstant at 6.1 m for children and adults. Even adults appear to be unaware of their underconstant perceptions at this distance. Granrud, Granrud, and Arnall (2003) found that varying instructions had no effect on size estimates made by children and college-age adults at 6.1 m. Both groups made equivalent size estimates at this distance when asked to judge the sizes that objects looked, without regard to their actual sizes, and the sizes that objects were, without regard to how they looked. These results indicate that neither adults nor children distinguish between perceived and objective size at 6.1 m. Furthermore, Merriman et al. (2010) found that most children who strategically inflate their size estimates at 61 m report no strategy use at 6.1 m. The Granrud et al. (2003) and Merriman et al. (2010) findings suggest that children and adults respond to perceived size at near distances and use size estimation strategies only at farther distances. Because strategy use mediates the correlations between reasoning ability and size estimation and between age and size estimation, the absence of strategy use at near distances accounts for the lack of correlations between these variables at near distances (Merriman et al., 2010).

The existing research on development of size estimation supports the metacognitive theory. At 5 to 6 years of age, children consistently underestimate object size at distances of 5 m and farther, they

report no strategy use, and they generally make no distinction between perceived and objective size (Granrud, 2009; Granrud & Schmechel, 2006). Between 7 and 11 years, children become increasingly aware of the effects of distance on perceived size, they distinguish between a distant object's perceived and objective size, they begin to use the distance compensation strategy as their reasoning abilities increase, their far-distance size estimates become more accurate, and overconstancy is often exhibited (Granrud, 2009; Merriman et al., 2010). Eventually, in early adulthood, overconstancy is the norm. The metacognitive theory accounts for all of these findings. Age-related changes in far-distance size judgments appear to depend on increases in metacognitive awareness, reasoning ability, and strategy use. Contrary to the perceptual learning theory, we have found no evidence that increasing sensitivity to monocular depth cues contributes to the development of far-distance size estimation performance.

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