

DEVELOPMENTAL TRENDS IN THE ADHERENCE OF PERCEPTION TO WEBER'S LAW

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Abstract

Weber's law, a basic psychophysical principle by which sensitivity to changes along a given physical dimension decreases when stimulus intensity increases, characterizes human adults' perception for virtually all sensory dimensions. Nevertheless, the developmental trajectory of its validity in perception has not yet been tested. Here we investigated how early in childhood perception becomes adherent to Weber's law (i.e. minimum detectable increment in stimulus magnitude increases proportionally with stimulus magnitude). Children aged 5-10 and adults were asked to perceptually estimate the size of discs varying in radius. The just noticeable difference (JND) for a given size was determined in the method of adjustment by the variance of the estimations. JND increased with object size in accord with Weber's law at all ages tested. However, while for adults JND increased linearly with stimulus magnitudes, young children exhibited a quadratic trend in the increment in JND with stimulus magnitude. The results thus document a fundamental difference in the way visual information is encoded by the developing perceptual system compared to the matured one, even at a very basic level of processing. We also showed that, similar to adults, visually-guided action in children violated Weber's law, providing the first clear evidence for an early emergence of the dissociation between vision for perception and vision for action in children.

Weber was the first to mathematically describe how a continuum of sensation is represented psychologically. According to his basic psychophysical law, 'just noticeable' changes in a stimulus increase with the magnitude of the original stimulus, indicating that the sensitivity to changes in any physical continuum is relative rather than absolute. Fechner later defined a logarithmic relationship between physics and perception, postulating that the external stimulus is scaled into a logarithmic internal representation of sensation. This logarithmic relationship probably reflects the need of the perceptual system to compress a large range of physical information to a restricted range of subjective perception (Baird & Noma, 1978). The adherence of perception to Weber's law therefore demonstrates the reliance of perception on relational invariants that mediate perceptual constancy and a veridical interpretation of the outside world.

Weber's law has been shown to characterize human perception for practically all sensory dimensions. Nevertheless, the developmental trajectory of its validity in perception has not yet been tested. Here we investigated how early in childhood perception becomes adherent to Weber's law (i.e. minimum detectable increment in stimulus magnitude increases proportionally with stimulus magnitude). Children aged 5-10 and adults were asked to adjust a comparison disc, presented on the computer display, to match the size of a real disc presented in front of them. We used 3 diameter sizes for the real disc (25, 35, and 45 mm), each repeated 16 times. The just noticeable difference (JND) for a given size was computed as a function of within-participant standard deviations of the perceptual estimates. This variance reflects the 'area of uncertainty' for which the observer is insensitive to the difference between the size of the comparison and the target object, which, according to Weber's law, should increase linearly with object size (Ganel et al., 2008).

Results revealed that although perceptual estimations scaled with object size at all ages, more veridical estimations were obtained in adulthood (Figure 1a). Variability of these perceptual estimations (JNDs scores; Figure 1b) also decreased with age demonstrating, as expected, higher variability in perceptual estimates during early childhood. Most importantly, JNDs increased linearly with object size, in accord with Weber's law, at all ages tested, demonstrating an early emergence of the adherence of perception to Weber's law. However, while adults demonstrate a linear increment in JNDs with object size, the changes in JNDs for both the 5- to 6- and 7- to 8-year-olds is best described by a quadratic fit, implying subtle developmental changes in sensitivity to changes in object size. Adult-like pattern of linear increment in JNDs as a function of object size was observed only at about 10 years of age.

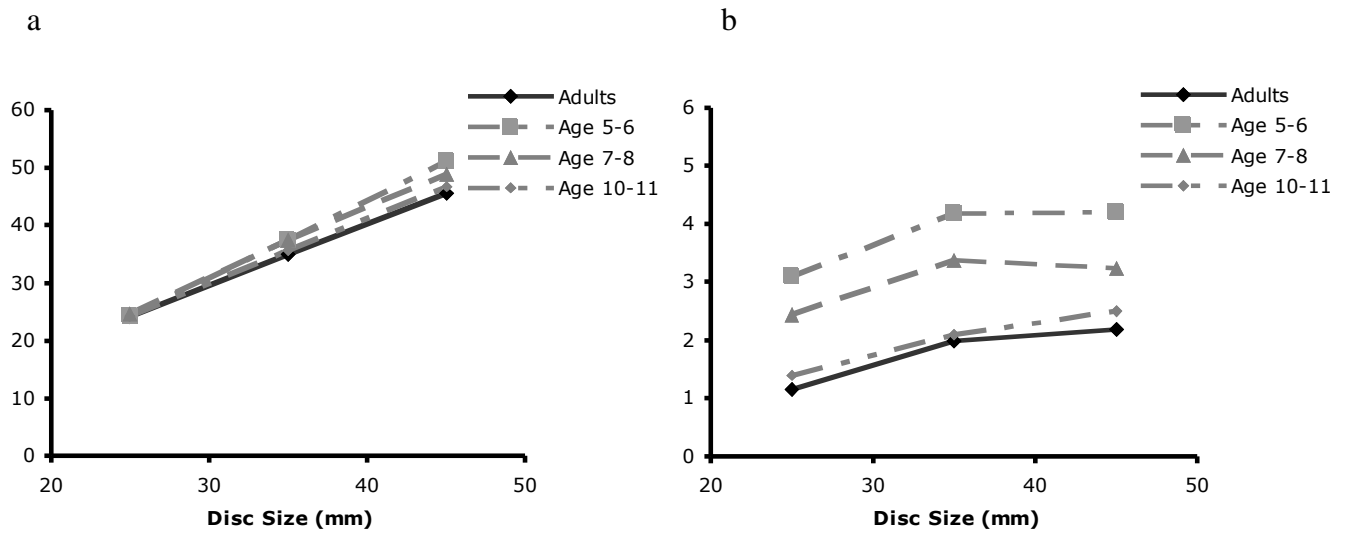


Figure 1. The estimated diameters (a) and their variability (b) (i.e., JNDs scores) as a function of object size, for each age group. Variability of the estimated diameters measured as a function of disc size indicated adherence to Weber's law.

These results demonstrate an early emergence of the adherence of visual perception to a basic psychophysical law, pointing to the critical role of these fundamental computations in achieving an efficient perception of the outside world. At the same time, a quadratic rather than a linear increment in JND as a function of object size during early childhood indicates developmental changes in visual sensitivity to changes in object size that may reflect the refinement of the perceptual system in its sensitivity to relative metrics of the visual world. It is only by 10 years of age that an adult-like pattern of linear increment is observed. The results thus document a fundamental difference in the way visual information is encoded by the developing perceptual system compared to the matured one, even at a very basic level of processing. This finding, of perceptual coding becoming more sensitive to relative metrics with age, can account for a large body of findings demonstrating a protracted development of perceptual abilities. It has been recently shown, for example, that in adults, but not in young children, highly supported contours (in which relative short length of contours are interpolated, compared to the total length of the contours) are more easily interpolated than low-support contours. It is only by middle childhood that interpolation becomes tied to this cue of relative length of the interpolated contours (Hadad, Maurer, & Lewis, 2010).

Vision for perception and vision for action

This basic psychophysical principle of Weber has been shown to have dissociable effects on the visual coding for perception and for action in adults (Ganel et al., 2008). The findings of perception following Weber's fundamental law of psychophysics while action violates this law, suggests that action and perception are mediated by qualitatively different computations;

with the first relying on absolute while the latter on relative metrics of visual information. This dissociation provides direct evidence for the functional distinction between vision for perception and vision for action in adults (Goodale & Milner, 1992).

Despite the extensive evidence for the two neural and functionally distinct systems in the mature brain, only a handful of studies have tracked the developmental trajectory of the two visual streams, providing inconsistent results. We tracked the development of this functional dissociation, asking whether the qualitatively different pattern observed in adults of adherence of perception but not of action to Weber's law would also be evident early in life.

Children aged 5-8 and adults were asked to grasp discs varying in diameter. Participants sat in front of a black tabletop on which the objects were placed at a viewing distance of approximately 30 cm. The anticipatory opening between the thumb and index finger (maximum grip aperture, MGA) was recorded by an Optotrak Certus device (Northern Digital, Waterloo, ON), which tracked the 3-D position of three infra-red light emitting diodes attached separately to the participant's index finger, thumb, and wrist. JNDs for a given size were computed as a function of within-participant standard deviations of grip aperture.

Results indicated, as expected, a scaling of MGA with object size. Participants at all ages opened their hands wider than the actual size when grasping the objects, as typically observed in adults (e.g., Pettypiece et al., 2010). However, as can be seen in Figure 2a, the slope defining the increment in grip as a function of object size was steeper in adults compared to children. JNDs decreased with age, indicating, again, an expected higher variability in children compared to adults. Most importantly, however, the results show that in contrast to perception, JNDs remained invariant across object size for grasping, regardless of age (Figure 2b).

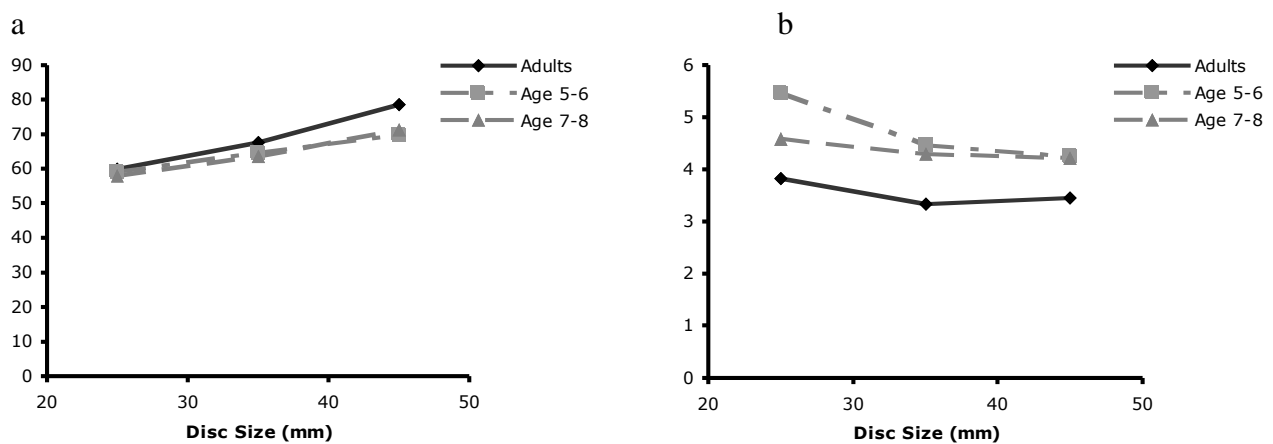


Figure 2. The MGAs (a) and their variability (b) (i.e., JND scores) as a function of object size, for each age group.

Conclusions

The qualitative differences in computations carried out for perception and action were observed in children as young as 5 years of age. The children's pattern of results resembled that of adults, showing that while variability of perceptual estimates increased as a function of object size, variability of grasping did not scale with object size. This provides the first clear evidence for an early emergence of the dissociation between vision for perception and vision for action in children.

The adherence of perception to Weber's law demonstrates the reliance of perception on relational invariants that mediate object constancy under changes of the viewpoint (Goodale & Ganel, 2009). For action, in contrast, spatial maps must emphasize relationships between an observer's body and external objects rather than relationships between external

objects alone (e.g., Bruno, 2001). The evidence provided here for an early specialization of two visual systems points to the critical value of these qualitatively different computations carried out by the two systems in achieving adaptive perception and behavior in the outside visual environment.

This behavioral evidence for relatively early action-perception dissociation is not surprising given that the perception-action division of labor maps onto different neural pathways that are all developing within the first year of life (Johnson, 1990).

This is not to say, however, that the specialization of the two visual systems is fully mature during early childhood. Indeed, although perception in children generally follows Weber's law, it is not specialized to the adult-like level in terms of the quantitative analysis of the JND. It has been suggested that the neural pathways mediating perception and visually guided action gradually specialize to the adult-like state by reweighting or selective pruning over the course of development (Dobkins, 2005). It is possible then, that a longer developmental trajectory would be observed for the specialization of perception and action when a higher visual coding is required.

Acknowledgments

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