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A CORRELATIONAL EVALUATION OF THE MISAPPLIED CONSTANCY THEORY OF GEOMETRIC OPTICAL ILLUSIONS

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "A Correlational Evaluation of the Misapplied Constancy Theory of Geometric Optical Illusions", submitted by A. George Alder in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

The present study evaluated Gregory's (1963; 1968) misapplied constancy theory of geometric optical illusions using the individual differences approach. It was hypothesized that there would be significant covariation between subjects' degrees of size constancy and their degrees of illusion for illusions with perspective cues. Size constancy estimates were obtained, under both monocular and binocular viewing conditions, from 67 female university students. Subjects' magnitudes of illusion, for four figures with identifiable perspective cues and four figures lacking, or with ambiguous, perspective cues, were also estimated. Results indicated that there was no common factor underlying those illusions with perspective cues. Further, there were no significant correlations between the estimates of subjects' size constancy and illusion magnitudes, regardless of illusion type or condition under which size constancy estimates were obtained. The present results are consistent with those from previous investigations, and, as such, they provide no support for Gregory's theory. Several possible directions for future research with illusions are presented.

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CONTENTS

List of Tables

List of Figures

List of Appendices

Introduction

Psychologists have long believed that an understanding of the stimulus arrays and the situations that consistently produce deviations from veridical perception (i.e., illusions) is an essential requisite for a comprehensive theory of perception. Helmholtz (1881) has argued that:

> The study of what are called illusions of the senses is, however, a very prominent part of the psychology of the senses; for just those cases which are not in accordance with reality are particularly instructive for discovering the laws of the means and processes by which normal perception originates (cited in Coren & Girgus, 1978a, p. 9).

Woodworth (1938) viewed the study of illusions as crucial to the study of psychology, in that illusions may provide important clues to the functioning of basic perceptual processes. Further, Gregory (1968) has stated that the explanation of illusions is a challenge which any truly viable theory of perception must meet.

An illusion may be defined as a sensory impression or perception that is at variance with the objective situation that can be determined by some other reliable means (e.g., physical measurement) (Rock, 1975). Geometric optical illusions comprise a special type of illusion that is perceived in a two-dimensional (or flat) line drawing (Robinson, 1972). Almost all geometric optical illusions can be sub-divided into two parts; the test line(s) and the inducing line(s). The test lines are those components of the line drawings in which the distorted perceptions occur and the inducing lines are the remaining lines in the figures (Rock, 1975). The magnitude of a geometric optical illusion can be established by having observers indicate the apparent location or size of the test lines and comparing their judgements with the real or veridical values. Such techniques have been widely employed in perceptual research.

The emphasis on the importance of the study of illusions can be seen to be reflected in the relatively large number of articles that are devoted to illusions in the psychological literature. Oppel, in 1885, provided what can probably be said to be the first serious psychological discussion of a simple two-dimensional stimulus which produced subjective perceptions at variance with physical reality (Coren & Girgus, 1977; 1978a; Robinson, 1972). In this paper, Oppel demonstrated that an interrupted linear extent was perceived as being longer than an uninterrupted extent of exactly the same physical length. He used the term "geometrisch-optishe Tauschung" (generally translated as "geometrical optical illusion") for such figures (Coren & Girgus, 1977; 1978a; Robinson, 1972). Since 1885, several hundred different illusion-producing two-dimensional configurations have been presented in the psychological literature and over 1000 articles have involved the study of visual illusions (Coren & Girgus, 1978a). Although at times authors have suggested a diminishment of psychology's interest in visual illusions (e.g., Tolansky, 1964), when the literature was reviewed on one such occasion (Zusne, 1968), it was found that the number of articles dealing with visual illusions had kept pace in relation to the total number of psychology related papers published. And although illusions have been shown to exist in other sensory modalities (e.g., haptic, auditory), the visual illusions have received the majority of attention in the literature. Many of these articles have attempted to provide theoretical explanations of visual illusions; to date, however, not one of the diverse explanations for illusions has been generally accepted and incorporated into an overall theory of visual perception.

Thus, although they have been extensively studied for over a century, geometric visual illusions have remained virtually unexplained (C. R. Carlson, Moeller, & Anderson, 1984; Coren & Porac, 1984).

Several different theoretical approaches to the study of visual perception exist (cf., Gregory, 1974), some of which minimize the importance of studying visual illusions. One such theory is that proposed by Gibson (1950; 1966) who believes that perception is a direct experience and not an interpretation based on sensation. For Gibson (1966), geometric optical illusions are not subjective phenomena as they have always been taken to be and therefore, their study plays little part in his theory of perception. However, the study of visual illusions is perhaps most appropriate if the act of perception is seen as being a decision about the "real" nature of the stimulus display (Robinson, 1972). This view is similar to Helmholtz's conceptualization of the act of perception as being one of "unconscious inference", wherein perception is seen as an inductive process based on the observer's interpretation of the stimulus array (Boring, 1942). The observer is attempting to discover meaning in the stimulus array. As Coren and Girgus (1978a) suggest then, visual illusions demonstrate in this theoretical context that perception is an active process which takes place beyond the eye and is not directly predictable from only the physical stimuli. From this perspective, visual illusions are not seen as resulting from the breakdown of normal perception, but rather, they are seen as being the result of the normal functioning of perceptual mechanisms that, in the presence of unusual stimulus arrays and/or situations, lead to the perceived distortion. Thus, the crucial question now becomes one of identifying the specific, usually adaptive, mechanism that is involved in both the normal and the illusory perceptions.

In attempting to isolate an underlying perceptual mechanism potentially responsible for the non-veridical perceptions observed in geometric optical illusions, one should first consider the nature of the stimuli that give rise to such distorted percepts. The geometric optical illusions are simple two-dimensional stimuli almost invariably consisting of lines presented on paper (Coren & Girgus, 1977). If perception is considered to involve the search for meaning in a stimulus array, then one is left to determine what meaning an observer could possibly derive from the geometric optical illusions. As visual perception normally occurs within a context of three-dimensional viewing, it may be that, when presented with a two-dimensional stimulus, the observer attempts to relate a three-dimensional analogue to the two-dimensional array (Coren & Girgus, 1977). Support for this suggestion is provided by Gibson (1951), who has shown that random line drawings presented on paper tend to be perceived in terms of objects, and by Woodworth (1938), who stated that it is an "undoubted fact" that line drawings suggest objects in three dimensions. This tendency has been proposed by various researchers to influence observers' perceptions of the geometric optical illusions. As Gregory (1963) suggests, "The illusion figures may be thought of as flat projections of typical objects lying in three-dimensional space" (p. 678).

Such conceptualization is by no means novel. Helmholtz (1873) held that "The simple rule for all illusions of sight is this: we always believe that we see such objects as would, under conditions of normal vision, produce the retinal image of which we are actually conscious" (cited in Warren & Warren, 1968, p. 130). Thiery, (1889, cited in Boring, 1942) also noted that some illusions may be seen to resemble two-dimensional projections of common scenes or objects. Sanford (1903, cited in Over, 1968) suggested that, in terms of retinal stimulation, many of the two-dimensional geometric optical illusions convey the same depth information as do certain three-dimensional objects. This line of reasoning laid the foundation for the development of perspective theories of geometric optical illusions.

Perspective is the projection of a three-dimensional scene on a two-dimensional surface and can be the representation of the size, relative position, or distance of an object. For example, lines that converge or slant tend to be regarded as depicting variations in distance. As such, perspective has been called a pictorial cue to depth (Rock, 1975). Perspective theories postulate that certain features in the illusion figures convey depth and that when observers view these illusions they interpret the figure as if it were three-dimensional. Investigators who have advocated perspective explanations of geometric optical illusions (e.g., Tausch, 1954, cited in Robinson, 1972) have suggested that in order to perceive real objects more accurately, observers have learned to correct for depth in three-dimensional displays. More distant objects are perceptually enlarged in relation to proximal objects. It has been proposed that pictorial depth cues (e.g., perspective) implicit in some of the geometric optical illusions may inappropriately trigger this correction mechanism, thereby producing a distortion. Woodworth

(1938) stated that according to the perspective theory, the perspective read into the illusion configuration results in the distorted percept.

Robinson (1972) has suggested that perspective explanations comprise what is perhaps the most consistent trend in theorizing about geometric optical illusions. As such, perspective-type interpretations have been applied to many of the illusions. Perhaps the most obvious application of the basic idea is to the Ponzo illusion (e.g., Fisher, 1968; Leibowitz, 1965) where two horizontal lines of equal physical length are enclosed in a pair of converging oblique lines (see Figure A-3). The common distortion is that the upper horizontal line appears to be noticeably longer than the lower horizontal line. An explanation of this illusion from the perspective theory would be that the converging oblique lines convey increasing distance and, therefore, the upper horizontal line appears farther away than the lower. Because the top line is seen as being farther away it is judged to be longer than the lower line.

Similarly, a perspective theory explanation has been proffered for the two forms of the Mueller-Lyer illusion, with Thiery (1896; cited in Robinson, 1972) being the first explicitly to suggest a perspective interpretation. He proposed that the Mueller-Lyer figures could be seen to resemble a two-dimensional projection of a trestle (or a saw horse) viewed either from directly below (in the case of the featherhead figure in Figure A-2) or directly above (as in the arrowhead figure in Figure A-1). It was claimed that the shaft in the Mueller-Lyer figure with featherheads was perceived as being farther away and therefore longer than the shaft of equal physical size in the Mueller-Lyer with arrowheads.

The horizontal-vertical illusion (see Figure A-4) has also been subjected to a perspective interpretation. Woodworth (1938) noted that in drawings, a short vertical line may represent a comparatively longer horizontal line extending or receding along the observer's line of sight. In the horizontal-vertical illusion, it is suggested that the vertical segment represents such a foreshortened line. As such, the apparently receding line (i.e., the vertical) is seen to be longer than the physically equivalent horizontal line. Other geometric optical illusions (e.g., the Poggendorf - Figure A-10; Sander's Parallelogram - Figure A-11) have been subjected to a similar type of analysis and the claim has been made that they contain at least implicit perspective cues (Gillam, 1971; Green & Stacey, 1966).

Although investigators have provided perspective explanations of visual illusions, a critical shortcoming existed in the early conceptualizations of the perspective theory (e.g., Thiery, 1896;, cited in Robinson, 1972; Woodworth, 1938). Specifically there was no detailed discussion of how or why the perspective cues contained in the various illusion figures were used by the observer so that the apparent size distortions were seen in the two-dimensional figures. The early theories did not specify an underlying mechanism that the perspective cues triggered to produce the apparent distortion. Thus, although the early theories noted that many of the illusion figures had perspective cues in common, they did not develop an explanation as to how these cues could produce the observed distortions.

Kristof (1961; cited in Robinson, 1972) may be said to be the first investigator to attempt to remedy the inadequacy in the early theories by explicitly proposing that the perspective cues in the illusory figures activated perceptual mechanisms responsible for constancy. The illusion is noticed because of the contradiction between the obvious flatness of the stimulus display and the compensation made by constancy scaling for the perspective depth in the flat display. Gregory (1963; 1968) further developed Kristof's version of the perspective theory and it is Gregory's theory that has become the focus of the large volume of discussion surrounding the perspective theories (Robinson, 1972). Gregory (1963) suggested that the perceptual mechanisms responsible for maintaining size constancy in normal conditions are also responsible for the relationship between implicit perspective cues and apparent size in the geometric optical illusions.

Size constancy is the tendency for the perceived size of objects to remain more or less stable (constant) despite changes in the size of the retinal image of the object that occur with changes in distance (Rock, 1975). One possible implication is that the perceptual system somehow takes into account the apparent distance of the object in interpreting the size of the retinal image (Epstein, 1973; Oyama, 1977). Further, neither the process of taking distance into account nor the information about the distance of the object need to be noted consciously by the observer (Rock, 1975).

In incorporating the mechanisms responsible for size constancy into his perspective theory of geometric optical illusions Gregory (1963) modified the traditional view that constancy scaling depends solely on apparent distance. Gregory (1963; 1968) attributes size constancy to two different kinds of scaling mechanisms: primary and secondary. Secondary scaling is supposedly triggered purely by apparent distance with errors in the perception of distance resulting in corresponding size errors. Gregory (1963) suggests that the moon illusion may be an example of the misapplication of secondary constancy scaling. In contrast, perspective and other cues normally associated with distance (e.g., interposition, relative height) are said by Gregory to set primary constancy scaling. Further, the cues which set primary constancy scaling may be at variance with apparent depth, and under these circumstances illusions may result. The illusion figures contain some features typically associated with distance (e.g., perspective) but an impression of depth does not result because the figures are presented on an obviously flat background. Regardless, the distance cues result in corresponding size distortions in the figure, with the parts of the figure for which perspective indicates increased distance undergoing expansion and the "near" parts being reduced. An important aspect of Gregory's theory is that the size distortions occur in spite of the obvious flatness of the display; that is, the illusions arise due to the misapplication of primary size constancy scaling. Further, primary and secondary scaling mechanisms are assumed to function independently, with either one, the other, or both, functioning at any given point (Gregory, 1968).

The essential difference between previously proposed perspective theories of illusions and Gregory's theory is the view that size constancy can not only be set by apparent distance (i.e., by means of secondary scaling) but also, it can be set directly by depth cues, especially perspective, in the stimulus display (i.e., by means of primary scaling). Gregory (1967) conceives of these two scaling mechanisms as being very different both in terms of development and functioning. Secondary scaling is, according to Gregory (1968), "...evidently linked to the interpretation of the retinal image in terms of what object it represents" (p. 289). Secondary scaling is not necessarily directly tied to the available retinal information and is seen to be susceptible to modification by the observer's perceptual set or presupposition (Gregory, 1967). On the other hand, primary scaling is, as previously mentioned, triggered by pictorial depth cues normally associated with distance. It is called "primary" as it seems to be mediated by neural systems located early in the perceptual system and is seen to be relatively primitive (i.e., characteristic of early stages of development) (Gregory, 1963).

Gregory (1963) provides some evidence suggesting the existence of the two scaling mechanisms. Evidence for secondary scaling is supposedly provided by the following demonstration. When a Necker Cube (see Figure A-12) is drawn on paper, there is no appreciable change in the apparent size of the "near" and "far" faces of the two possible depth interpretations (although it should be noted that this point has been challenged by Hotopf (1966) and Robinson (1972)). However, if a luminous Necker Cube is viewed monocularly in the dark, thereby removing all cues to the flatness of the figure, Gregory (1965a; 1968) reports firstly, that the depth interpretation of the cube continues to reverse (as when presented on paper), and secondly, that the face of the cube that is seen as being more distant is also seen as being larger than the apparently "near" face (although the two cast the same size retinal image). Gregory interprets the apparent difference in size between the two faces of the cube as one stemming from an awareness of the apparent difference that results when the figure is seen to reverse, and he postulates that it is secondary constancy scaling which operates to enlarge the "far" face of the cube. As Gregory has not presented any of the above findings in a formal experimental report one should view his evidence for the existence of a separate secondary constancy scaling mechanism as being somewhat less than conclusive.

While recognizing the importance of demonstrating the independent existence of primary constancy scaling, Gregory (1963) has noted difficulty in providing direct evidence of primary constancy scaling. He calls the evidence that he does present as being at least however, "suggestive" (Gregory, 1968).

Gregory notes that a straight line drawn across a corner of a Necker cube (see Figure A-13) appears to be bent, with the direction of the bend remaining consistent despite any reversals in the depth interpretation of the cube. Supposedly, the angle against which the line lies suggests a typical perspective interpretation which sets primary constancy scaling, and this triggers the apparent bending of the line. This demonstration is used to convince the reader that primary and secondary constancy scaling can occur both simultaneously and independently. Gregory's evidence here seems highly suspect, based as it is on merely anecdotal reports without any confirmation from controlled experimental results. Further, Gregory does not clearly define exactly what constitutes a typical perspective interpretation so it is difficult to imagine exactly how, or in what way, primary constancy scaling would operate to result in the apparent bend in the line.

As additional support for the existence of primary constancy scaling, Gregory (1963) mentions the findings from cross-cultural studies of geometric optical illusions. These findings show that people who live in primitive cultures where the houses (buildings) do not have straight edges and corners (i.e., "uncarpentered" environments), show reductions in the magnitudes of certain illusion figures relative to people who live in more "carpentered" environments (cf., Deregowski, 1980; Segall, Campbell, & Herskovits, 1966). Due to the fact that the ability to react to perspective cues requires some degree of learning, Gregory (1963) proposes that people who live in environments where certain perspective cues are not typically associated with changes in distance in normal three-dimensional viewing, do not learn these perspective cues. Thus, if an illusion figure contains perspective cues not typically occurring in the observer's natural environment (e.g., converging lines), Gregory would suggest that primary constancy scaling would not be triggered in this individual.

This source of evidence for the existence of primary constancy scaling must also be questioned. As Robinson

(1972) and Coren and Girgus (1977; 1978a) have noted, an environmental explanation of the data from the cross-cultural studies may not be justified. Subsequent research (e.g., Leibowitz, 1971) suggests that factors other than environment (e.g., education) may contribute to the reduced susceptibility to the illusion figures. Thus, cross-cultural differences can not be seen as providing compelling evidence in support of Gregory's conception of primary constancy scaling.

Additional evidence cited by Gregory in support of the existence of primary constancy scaling is the finding by Gregory and Wallace (1963) that a man, blind from a few months after birth until the age of 52 (when he regained his eyesight through a corneal graft), demonstrated little if any susceptibility to the usual distortions in geometric optical illusions. Further, the man upon regaining his sight demonstrated little constancy. While it is clear that Gregory cites this example in order to emphasize the importance of learning (or experience) with regard to the achievement of constancy, it is not clear why or how this evidence would lend credence to the distinction that Gregory makes between the two constancy scaling mechanisms. Thus, while Gregory consistently emphasizes the importance of the distinction between primary and secondary constancy scaling for his theory of geometric optical illusions (cf., Gregory 1963; 1966; 1967; Gregory & Harris, 1975) he has yet to demonstrate convincingly the independent existence and functioning of the two scaling mechanisms.

Gregory has, however, provided a rather compelling demonstration (again using luminous figures) that, once all of the cues to the flatness of certain two-dimensional illusion configurations have been removed, observers tend to perceive them in three dimensions. The illusion figures are made into photographic transparencies that are illuminated from behind by a luminescent panel and are viewed monocularly in the dark. Gregory (1965a; 1968) reports that, when an observer views such a display, the arrow/feather-heads in the Mueller-Lyer illusion usually resemble actual corners. The figure with featherheads resembles an inside corner (i.e., a floor-to-ceiling corner of a room viewed from within the room) and the central shaft appears elongated, whereas the figure with the arrowheads resembles an outside corner (i.e., a ground-to-roof corner of a cube-shaped building viewed from a high vantage point) and the central shaft appears to be shortened.

Once the flatness of the display is removed Gregory is able to measure the apparent distances of various parts of the figure by using a device in which the rear-illuminated photographic transparencies of the illusion figures are placed behind a polarized sheet. Monocular viewing of the figure is achieved by using a cross polarizing filter to block vision to one eye. A mirror is used to introduce optically into the visual field one or more moveable reference lights which can be viewed binocularly. The distance of these reference lights is thus determined using binocular vision. Placement of the lights at the perceived distances of various parts of the figure allows for the measurement of the apparent distance of those parts of the monocularly viewed figure (cf., Gregory (1968) for a more detailed description of the apparatus which he calls "Pandora's Box").

Gregory (1968) reports the results of an experiment in which 20 subjects assessed both the apparent depth of various Mueller-Lyer figures (with fin angles ranging from 40° to 170°) and the magnitude of illusion for the same figures. Apparent depth was assessed using the Pandora's Box apparatus, with depth being defined as the difference between subjects' assessments of the distances of both the central shaft and the ends of the arrow/feather-heads. The magnitudes of the various illusions were measured by presenting the different Mueller-Lyer figures on normal (textured) backgrounds to the subjects who set an adjustable comparison line to apparent equality (with respect to the central shaft). The results of the study show that fitted curves for the apparent depths of the figures, and for the magnitudes of the illusions as plotted against the various fin angles, are quite similar. The correlation between the apparent depths and the magnitudes of the illusions was greater than 0.90 (Gregory, 1968).

While it seems apparent from the above that Gregory has been able to demonstrate quite clearly that certain illusion figures, when viewed without cues to their flatness, are perceived by viewers as three-dimensional objects, other researchers have found less compelling results. Using the reduced cue condition described by Gregory (1963), Green and Hoyle (1963) presented a self-luminous Poggendorf display to 21 subjects. Their assumption was that if the Poggendorf illusion arises as a result of the observers' attempts to make a three-dimensional interpretation of the two-dimensional display, then removing the cues to flatness should facilitate such an interpretation. However, when presented with the luminous figure, all 21 subjects reported that the display appeared two-dimensional. While most subjects were able to arrive at a three-dimensional interpretation when explicitly asked to do so, considerable variation existed in their interpretations.

In a similar experiment Hotopf (1966) presented luminous models of the arrowhead and featherhead Mueller-Lyer illusion to 25 subjects who viewed the figures monocularly in the dark. The results showed that none of the 25 subjects perceived the figures exactly as Gregory's theory would predict and 16 of the subjects saw both figures as being two-dimensional. Similar results have been reported by Pike and Stacey (1968) who had 30 subjects monocularly view both featherhead and arrowhead luminous versions of the Mueller-Lyer figure in a dark room. Seventeen of the 30 subjects provided a two-dimensional description of the arrowhead figure while 14 of the 30 subjects provided a two-dimensional interpretation for the featherhead figure. Taken as a whole, the results from these three studies certainly diminish Gregory's claim that all illusions can be conceived of as flat projections of three-dimensional objects with "typical" perspective interpretations.

While the studies undertaken to assess the frequency of observers' depth interpretations of illusion stimuli using luminous displays have provided equivocal results, similar studies have been performed using stimuli presented on normal textured backgrounds. Worral & Firth (1971) presented 75 subjects with a pair of obliquely converging (but not touching) lines drawn in black on a white card (these lines resembled the inducing lines in a Ponzo configuration). When asked what the drawing most looked like, 62% of the subjects gave responses that specified or implied extended depth (e.g., a road going into the distance). However, when the subjects were presented with a similar figure, except that the converging lines met to form an apex, only 7% of the response implied or specified extended depth.

Similar results can be found in a study by Ward, Porac, Coren, and Girgus (1977) who presented 120 subjects with 13 different stimulus configurations (six of which were standard illusion figures with the remaining seven being modifications of illusion figures). Subjects were presented with the 13 stimuli drawn on white paper and they were told that the figures could be viewed as primitive pictures drawn by a child attempting to depict an object or a scene. Subjects were then asked to write down what object or scene they thought the stimulus array might represent. Written reports were independently rated by three judges and responses not receiving unanimous ratings were excluded from the data analysis. Overall, 41% of the responses to the 13 stimuli were judged to be depth interpretations. Specifically, for the Mueller-Lyer illusion, 34% and 46% of the responses, for the featherhead and arrowhead versions respectively, implied depth. The bisected version of the horizontal-vertical illusion elicited depth responses from only 21% of the subjects. Results from the inducing lines for the Ponzo configuration are remarkably similar to those obtained by Worral and Firth (1971). Using the inducing lines which converge to form an apex, Ward et al., (1977) report that only 3% of the subjects gave depth responses. Generally, the experimental evidence would suggest that, as when they are presented as luminous figures, illusion configurations presented on normal backgrounds do not overwhelmingly elicit phenomenal depth interpretations.

While these results would appear to be inconsistent with Gregory's misapplied constancy theory, it may be that the results represent an instance of a registered versus perceived depth problem (Coren & Girgus, 1977; 1978a). Rock (1975) has suggested that a distinction may be made between registered and perceived events in the visual system. Thus, information that is not necessarily consciously noted by the observer may be registered at some level by the visual system and this information may interact with retinal input to determine the final perceptual output (Epstein, 1973). Epstein (1973) further suggests that "...the registered input may have no phenomenal counterpart or occasionally it may be accompanied by phenomenal reports that seem inconsistent with the registered input" (p. 276). Thus, with regard to the studies that have attempted to assess the frequency of depth interpretations of various illusion figures, it may be that the stimulus arrays used, while not consistently eliciting phenomenal reports of depth, nevertheless do, at some subconscious level of registration, trigger constancy scaling.

In order to evaluate the misapplied constancy theory of illusions several investigators have taken a different approach to assess the role of depth cues in illusion formation. The premise of these investigations is that if depth cues that conflict with the "typical" depth interpretation (as derived from a perspective interpretation) are incorporated into the illusion figure, the magnitude of the illusion should decrease. Fisher created five versions of the Ponzo illusion in which sketched (two-dimensional line-drawing) projections of solid square rods were substituted for the usual converging inducing lines (see Figure A-14). The resulting "Ponzo" figures conveyed different depth interpretations with the obliques appearing to recede backward, to project forward toward the apex, or apparently to straddle the horizontal lines. One hundred subjects were informed of the different depth interpretations and they were instructed to maintain these depth interpretations while assessing the magnitudes of the horizontal lines. A typical Ponzo-type illusion was found for each configuration and no difference existed among average illusion magnitudes for the five figures.

Fisher also applied similar modifications to the composite Mueller-Lyer figure with the modifications conveying different depth interpretations (see Figure A-15). An additional 100 subjects were informed of the different depth interpretations and again were instructed to maintain these depth interpretations while assessing the size of the shafts in the figures. The results showed that all four different configurations resulted in significant, similarly sized, average distortions in the same direction as in the conventional Mueller-Lyer figure. Fisher (1970) did not, however, assess whether the magnitudes of the distortions found in the modified figures differed from those found in conventional Mueller-Lyer and Ponzo illusions. Thus, Fisher's (1970) demonstration suggests that altering or even reversing the apparent depth of traditional illusion figures does not alter the direction of the distortion typically found; the direction of an illusion does not necessarily follow apparent depth cues. These results do not necessarily cast doubt on Gregory's theory. The various depth interpretations in Fisher's modified figures do not seem too compelling and it may be that they do not obfuscate what may be more primitive, "typical" depth cues contained in the display. These primitive cues may be registered at some level by the visual system and may trigger Gregory's primary constancy scaling mechanism, thereby producing the distortion in the direction typical of the illusion.

Georgeson and Blakemore (1973) altered the apparent depth of the fins for two versions of the Mueller-Lyer illusion (a featherhead and an arrowhead version). Using binocular disparity as a cue to depth and presenting the stimuli in a stereoscope, each of the two illusions was seen in nine different depths, with the stereoscopic tilt of the fins varying from forward to flat to backward. Georgeson and Blakemore (1973) predicted that when the stereoscopic tilt of the fins was in accord with or confirmed the "typical" perspective interpretation (i.e., forward fins for the featherhead version, backward for the arrowhead) the illusion would be enhanced, whereas if the stereoscopic tilt of the fins contradicted the typical perspective cues (what Gregory might call primary constancy scaling data), the illusion would be reduced or perhaps even reversed. When the stimuli were presented to seven subjects, the results were not in line with the predictions. On average, illusion magnitude reduced from 10% to 7% when the fins were tilted in <u>any</u> direction. Georgeson and Blakemore's predictions were based on the assumption that primary and secondary constancy scaling processes summate. Perhaps this is not the case. Perhaps, for example, primary constancy scaling operates as Gregory suggests at a primitive level and is not influenced by rather sophisticated distance information such as binocular disparity (Robinson, 1972).

Other attempts to verify Gregory's misapplied constancy theory of visual illusions have taken an approach which tests the assumption that if size constancy scaling is responsible for the distortion typically measured for the Mueller-Lyer illusion, then constancy scaling should operate uniformly across the whole figure. Specifically, the apparent length and the apparent width of the central shaft should be distorted similarly. Thus, for example, the central shaft of the featherhead version of the Mueller-Lyer figure should not only appear longer, it should also appear wider. Noting that central shafts of Mueller-Lyer figures consist of relatively fine lines, Waite and Massaro (1970) employed thicker central shafts (ranging form 27 to 64 mm) in which any distortion of apparent width should be readily discernible and measurable. Both featherhead and arrowhead versions of the Mueller-Lyer were investigated; these provided the same perspective depth cues (i.e., direction of the fins) as typical Mueller-Lyer figures. Fourteen subjects judged both the apparent length and the apparent width of the test figures. The results showed that while the typical length distortions occurred, the central shaft of the featherhead figure appeared to be significantly <u>narrower</u> than the central shaft of the arrowhead figure, opposite to what one would expect if constancy scaling were operating homogeneously across the figure.

Dengler (1972) and Griggs (1974) have been able to replicate Waite and Massaro's findings. While it would seem that these results do not lend support to Gregory's theory, Coren and Girgus (1978a) have noted that actual pictorial arrays that are meant to reflect the projection of a three-dimensional scene often contain similar asymmetries in size constancy.

In other tests of Gregory's misapplied constancy theory several investigators have varied the typical Ponzo configuration by substituting two separated vertical lines for the usual horizontal lines (see Figure A-9). If constancy scaling is set by perspective cues, then the vertical line nearer the apex of the two converging obliques should appear longer than the other, physically equal, vertical line. Humphrey and Morgan (1965) were the first to suggest this modification while Gillam (1973) and Schiffman and Thompson (1978) have tested the modified figure and found that subjects perceive the two vertical lines as being equal in length. Gregory (1965b) has suggested that this may have resulted because the vertical lines may be too far removed from the inducing lines for primary constancy scaling to be triggered or, alternatively, it may be due to the difference between shape and size constancy (with the implication being that if shape constancy were invoked by this figure, the tendency would be for the two lines to appear equal).

While the majority of the evidence would appear not to lend support to Gregory's misapplied constancy theory of visual illusions, the aforementioned studies have not directly examined the actual relationship specified by Gregory; namely that between size constancy and geometric optical illusions. Given that individual differences exist both in the degree to which size constancy is manifested (Thouless, 1932) and in the magnitude of the illusions (Coren & Girgus, 1978a), it is somewhat surprising that only two studies to date have explicitly examined the covariation between subjects' size constancy and visual illusions. By examining the extent and direction of this covariation, an individual differences approach provides a uniquely direct method of evaluating Gregory's theory.

Hamilton (1966) examined the relationship, hypothesizing that people who manifest a greater degree of size constancy would show greater illusion magnitude for illusions with perspective cues. Hamilton used two groups of subjects; one group of 20 male subjects (average age 12.2 years) was recruited from a normal school while another group of 20 male subjects (average age 12.6 years) was recruited from a school for the "educationally subnormal" (on the assumption that children with low intelligence would not have achieved the degree of cognitive maturity which allows for full constancy responses). Size constancy was assessed under full-cue conditions (i.e., binocular viewing under typical daylight levels of illumination) by having subjects judge the size of three distant objects. Hamilton's instructions to subjects emphasized objective size matches. That is, subjects were asked to adjust the size of the variable stimulus so that it would be physically equal to the standard stimulus. The Mueller-Lyer illusion was used in this study as it is a commonly cited exemplar of an illusion that has been explained in terms of the misapplied constancy theory. Illusion magnitude was assessed by having subjects adjust the featherhead end of a sleeve-slide apparatus which depicted the composite version of the Mueller-Lyer figure (see Figure A-16). Hamilton's results provide little support for Gregory's theory, in that no significant correlation was found between illusion magnitude and size constancy estimates.

Around the same time as Hamilton's study, J. A. Carlson (1966) conducted a similar test of Gregory's theory. One hundred and twenty-eight subjects were divided into two groups, one skilled and one unskilled in perspective drawing. The two groups were assessed on four tasks (size constancy, shape constancy, Mueller-Lyer illusion, and the Sander's Parallelogram illusion) under two sets of instructions. Under the "objective instructions" subjects were asked to adjust a variable stimulus so that it would be physically equal to the standard stimulus. The "apparent instructions" had subjects adjust the variable stimulus so that it would be equal to the standard stimulus in apparent size (i.e., so that the two stimuli "looked" equal). As in Hamilton's (1966) study, J. A. Carlson did not find significant correlations under either of the instructional sets between measures of size constancy and illusion magnitude, again not supporting Gregory's misapplied constancy theory.

Despite what would seem to be considerable evidence against Gregory's theory it is still one of the most frequently investigated theories of visual illusions and numerous investigators hold the view that misapplied constancy scaling contributes, at least partially, to a number of illusion configurations such as the Ponzo, the Mueller-Lyer, and the horizontal-vertical (e.g., Coren & Girgus, 1977; 1978a; Day, 1972; Deregowski, 1980; Gillam, 1980; Green & Stacey, 1966; Madden & Burt, 1981; Pike & Stacey, 1968; Stacey, 1969). Given that the misapplied constancy theory of visual illusions is still seen by many investigators as a viable explanation for some illusions, the present study attempts to test directly the relationship between size constancy and geometric optical illusions. The present study will employ the individual differences approach taken by Hamilton (1966) and J. A. Carlson (1966). Several methodological improvements will be incorporated in the present study in order to improve on shortcomings in the two aforementioned studies.

Rationale for the Present Study

Any one or more of several factors may have resulted in the lack of significant correlations between the size constancy measures and illusion magnitudes in both Hamilton's (1966) and J. A. Carlson's (1966) studies. Two possible problems arise from the fact that the composite version of the Mueller-Lyer figure was used in both studies. Firstly, Gregory's (1963; 1968) explanation of the Mueller-Lyer illusion is based on two separate figures; the arrowhead and the featherhead versions. A perspective interpretation of the composite figure has not been offered, as the central shaft would necessarily have to be at two different depths simultaneously, depending upon whether the figure was seen to be bound by the arrowheads or the featherheads. Gregory's theory does not usually attempt to explain the composite Mueller-Lyer figure, as this figure contains conflicting, atypical perspective cues. While this is a shortcoming of the theory, a fair test of the theory should include figures it typically claims to explain.

A confound in the two previous experiments may have resulted from the use of the composite version of the Mueller-Lyer figure, in that illusion magnitude was assessed without taking into account possible errors of the standard. As B. P. Christie (1969) and P. S. Christie (1975) have demonstrated, observers' erroneous judgements of the standard (i.e., the shaft without any inducing lines) can contribute to the measurement of the magnitude of illusion, so that any correlation between illusion magnitude and size constancy responses might have been contaminated and presumably attenuated by this possible source of error. In light of this possible confound, and the preceding considerations, a re-evaluation of Gregory's theory should include separate arrowhead and featherhead versions of the Mueller-Lyer illusion, and both illusions should be measured in such a manner that one can take into account the error of the standard.

As previously mentioned, one consistent criticism of experimental evaluations of the misapplied constancy theory commonly provided by Gregory is that the investigators do not take into account the distinction between primary and secondary constancy scaling (Gregory 1965b; 1967). In both Hamilton's (1966) and J. A. Carlson's (1966) studies the degree of size constancy was assessed under full-cue conditions with binocular viewing. If primary constancy scaling is a separate scaling mechanism (as Gregory postulates), it may be expected that measuring subjects' degree of size constancy under monocular viewing more closely resembles the conditions in which Gregory suggests primary constancy scaling is triggered (i.e., by cues to distance rather than by apparent distance). Hence, it would be of great interest to assess the degree to which subjects manifest size constancy under both monocular and binocular viewing conditions.

The present investigation is undertaken to evaluate Gregory's misapplied constancy theory of visual illusions with all of the above considerations in mind. The arrowhead and the featherhead versions of the Mueller-Lyer illusion are considered separately. Further, a more stringent testing procedure is employed by examining both monocular and binocular size constancy judgements and a larger number of illusions than in the two previous investigations.

The logic of the testing procedures loosely parallels the process of convergent and discriminant validation. Specifically, it is hypothesized that if the misapplied constancy theory is correct, then constancy scaling should operate to produce the distortions in illusion figures with identifiable perspective cues. On the other hand, if the illusion figure lacks perspective cues, or has ambiguous perspective cues then constancy scaling should not contribute to the magnitude of illusion. If these hypotheses are correct then one would expect the following pattern of correlations:

1. there should be high correlations among degrees of illusion for the illusions with identifiable perspective cues (as they are related to the operation of a common factor or underlying mechanism - size constancy)

2. degree of illusion and size constancy (monocular constancy at least) should be correlated for illusions with depth cues;

3. degree of illusion and size constancy should not necessarily be correlated for illusions without, or with ambiguous, depth cues.

Method

Subjects

Sixty-seven female students attending the University of Calgary were recruited from the Psychology department's subject pool for the present study. Their ages ranged from 17 to 37 years with an average of 22.2 years (*SD*= 4.6 years). While visual acuity was not formally assessed, participants were asked to wear any corrective lenses that they may have had prescribed for distance viewing. Further, only female subjects were used, as it has been shown that there is an interaction between gender and size constancy (Crookes, 1957; Thouless, 1932). Although the restriction of participation to one gender somewhat limits the generalizability of the results, it was concluded that, given the experimental logistics that of necessity restricted sample size, the more homogeneous sample would produce more reliable and stable data.

Apparatus

Size Constancy

Size constancy was measured in a dimly lit, black, windowless room that was 20 m long by 2.5 m wide by 3 m high. The subject sat in a chair facing the stimuli, her chin in a chin rest positioned on a table that was covered by a black cloth. The chin rest was adjusted so that the subject's eyes were approximately 127.5 cm above the level of the floor, 3 m from the proximal (i.e., variable) stimulus, and 6 m from the distal (i.e., standard) stimulus.

The standard stimulus, a white plastic equilateral triangle 13.5 cm in altitude, was mounted on a 244 cm high by 122 cm wide sheet of particle board that had been painted flat black. So that the entire stimulus could be mobile, the sheet of particle board was mounted on wheels and this added another 5.5 cm to its height. The base of the equilateral triangle was mounted 127.5 cm from the floor, and thus was along the subject's line of sight. The altitude and base of the standard were 1.29^{o} and 1.49^{o} of visual angle respectively.

The variable stimulus was mounted on an identically prepared sheet of particle board and, like the standard stimulus, was a white plastic equilateral triangle. However, it was possible for the experimenter to raise or lower this triangular stimulus through a slot such that the subject could see the stimulus vary in altitude from 0 to 30 cm. The opening of the slot, and therefore the base of the equilateral triangle, was, as in the standard stimulus, 127.5 cm above the floor. Finally, from the line of sight, the centre of the standard subtended an angle of 5.4°, while the comparable angle for the variable stimulus was 10.6°.

Illusions

The illusion stimuli for this study met two criteria; either they were figures with typical (identifiable) perspective cues or they were figures with ambiguous, or lacking obvious, perspective cues. Four configurations were chosen from each category. Those selected on the basis of their identifiable perspective cues were the two Mueller-Lyer figures (i.e., the arrowhead and featherhead versions), the Ponzo figure, and the horizontal-vertical figure (cf., Brown & Houssiadas, 1965; Collani, 1985; Girgus & Coren, 1975; Green & Stacey 1966; Pike & Stacey, 1968). The four illusion figures selected because they lacked, or had ambiguous, perspective cues were both the inward and outward going dumbbell figures (Day, 1972), Judd's figure (Morgan, 1969), and Titchener's circle (Robinson, 1972).

All illusion stimuli were drawn in black ink on 21.6 cm by 27.9 cm sheets of white paper. Each sheet was divided into two sections by a horizontal line positioned 16 cm from the top of the page. The upper section of the page was reserved for the illusion stimuli. In the lower section, an 8 cm horizontal response line was drawn 6 cm from the top, and 9 cm over from the left hand side of the page. The response line was thus offset from the segments of the stimuli that the subjects were required to estimate (see example of typical control figure in Appendix B).

For the Mueller-Lyer figures the 5 cm horizontal shafts were 10 cm down from the top of the page and 6 cm over from the left hand side. Each fin was made 2 cm long so that the shaft-fin ratio would yield relatively large illusions (Dewar, 1967; Robinson, 1972). Each fin met the shaft at a 30° angle in the arrowhead version (see Figure A-1) and a 150° angle in the featherhead version (see Figure A-2). Fins at these angles have been reported to produce significant illusory effects (Robinson, 1972).

The two 8 cm converging oblique lines in the Ponzo configuration met at the apex to form an angle of 60°. Pressey (1974) has shown that when the obliques form such an angle, a relatively large Ponzo illusion results. The apex of the angle was located 7 cm down from the top and 9 cm over from the left hand side of the page. The pair of

2 cm horizontal lines were located directly down from the apex at distances of 2.3 and 4.6 cm (see Figure A-3).

The 5 cm horizontal line of the horizontal-vertical configuration was drawn in exactly the same location as the horizontal shaft used for the Mueller-Lyer illusions. A 5 cm vertical line was drawn perpendicularly from the left hand end of the horizontal line with the vertical line pointing toward the top of the page. The resultant "L-shaped" version of the horizontal-vertical illusion was used in the present study, as it may be regarded to be more purely a horizontal-vertical illusion than the more frequently used "inverted-T" configuration (see Figure A-17). The latter configuration confounds two sources of illusion; the typical horizontal-vertical illusion and the bisected line illusion (cf., Coren & Girgus, 1978a; Robinson, 1972).

The dumbbell illusions were drawn using horizontal shafts identical in location and size to the shafts used in the Mueller-Lyer figures. Circles, 1.5 cm in diameter that extended either inwards (see Figure A-5) or outwards (see Figure A-6) were added to the ends of the shafts. In Judd's figure the horizontal shaft was again identical in location and size to the shafts used in the Mueller-Lyer figures. The shaft was bisected and 2 cm fins met the left and right ends of the shaft at 150° and 30° angles respectively. Thus, two 60° arrowheads were formed and these pointed to the right hand side of the page (see Figure A-7). A shaft the same as that in Judd's figure was used in Titchener's circle with a 2.5 cm diameter circle bisecting the shaft and enclosing the right hand side of the shaft (see Figure A-8).

In addition to the eight stimuli described above three control figures were included. Several investigators (e.g., Adam & Bateman, 1980; 1983; B. P. Christie, 1969; P. S. Christie 1975) have noted that the error of the standard can contribute to the measurement of the Mueller-Lyer illusion. It was therefore decided that control figures should be used in assessing the magnitudes of this and the other illusions. For the different illusion figures, the control figures consisted of the test lines presented without the inducing lines. Obtaining judgements for control figures of this kind allows one to account for any possible overestimation or underestimation of the test lines that might occur even when the inducing lines are absent. In all instances the control stimulus was drawn in the same location on the page as the corresponding judged segment(s) of the corresponding illusion figure. Thus, for the horizontal-vertical, the dumbbell, and the Mueller-Lyer illusions, a 5 cm horizontal shaft served as the control figure. A 5 cm bisected shaft served as the control stimulus for Judd's figure and Titchener's circle, while two 2 cm horizontal lines served as the controls for the Ponzo illusion.

Thirteen stimulus sheets were required to measure the eight illusions (including the control figures) and these materials were photocopied and presented in a booklet. Each booklet contained the 13 stimuli collated in random order with unmarked sheets of 75g/m^2 buff-coloured paper separating the stimulus sheets. Specific instructions appeared on each stimulus sheet with the general instructions appearing as follows on the cover of the first booklet:

INSTRUCTIONS

1. Each of the following sheets is divided into two sections. The top half contains a figure and the bottom contains a straight line.

2. On each sheet there are instructions to indicate the apparent length of a specific segment of the top figure on the lower straight line.

3. With the pencil provided mark off from the <u>LEFT</u> of the bottom straight line the apparent length of the segment specified on the sheet..

4. Do not measure the line, simply indicate on the bottom straight line how long the specific segment of the top figure looks.

Please remember to indicate the apparent length from the left on the lower line.

5. A blank sheet has been placed between the sheets with figures on them. You may ignore these sheets.

6. Work through the sheets in the order they appear and please do not refer back to previously completed sheets.

7. There is no time limit. You may work through the sheets at your own rate.

Subjects completed five booklets during the course of the experiment with a set of simple arithmetic problems separating each booklet.

Additional apparatus included a paper tube (2 cm in diameter and 28 cm long) and an eyepatch.

Procedure

Subjects were tested individually in sessions lasting approximately 60 min. First, within each session, subjects' size constancy responses were obtained in the laboratory arranged for this purpose. Immediately after this assessment was complete, their susceptibilities to the illusions were measured in a different, normally illuminated, room.

Size Constancy

Once taken into the laboratory, subjects were given a form to read that outlined the procedures of the experiment. After agreeing to participate, the subjects were seated in a chair facing the back wall with the stimuli positioned on either side of the line of sight. The subject's preferred eye was then identified by having the subject pick up a paper tube in front of her and pretend that she was looking through a telescope (Porac & Coren, 1976). The stimuli were then arranged so that the variable stimulus was located on the side of the subject's preferred eye (J. A. Carlson, 1966). The subject was then read the following instruction set:

> Your task is to instruct me to stop adjusting the variable triangle (the one on your left/right side) when it looks equal to the standard (the one on your right/left side) in apparent visual size. It may also be equal in actual physical size at that point, or it may not - I am not concerned about that. Instruct me to stop adjusting the variable triangle when it appears equal to you visually, whether you think it is equal in actual size or not.

These instructions are almost identical to those suggested for use by V. R. Carlson (1977) who has labelled them "neutral-apparent-size" instructions. It has been shown that the experimental variable that has the strongest effect in size constancy experiments is the type of instruction given to the subjects (Gilinsky, 1955; Leibowitz & Harvey, 1969). Generally, studies that have instructed subjects to match the sizes of the two objects in terms of their apparent size have found average matches which fall short of perfect constancy (e.g., Gilinsky, 1955; Singer, 1952), whereas studies that have included instructions for subjects to match the sizes of the objects in terms of their objective or physical size have consistently resulted in average settings greater than perfect constancy (e.g., V. R. Carlson, 1960; Holway & Boring, 1941; Rock, 1975). V. R. Carlson (1960; 1977) has suggested that a reason for the large effect of instructions is the general belief of subjects that the apparent size of an object becomes smaller at greater apparent distances: a belief that V. R. Carlson calls the "perspective attitude". V. R. Carlson (1977) has noted that the neutral-apparent-size instructions may minimize the bias resulting from a subject's perspective attitude, as they do not specify any tangible criterion (e.g., physical size) for the subject to use in matching the sizes of the stimuli. Thus, according to V. R. Carlson, a subject adopts the "simplest" criterion of equality of perceived size in performing the matching task. Several experiments that have used neutral-apparent-size instructions with full-cue binocular viewing have indicated that, on average, perfect constancy results (V. R. Carlson, 1960; 1962).

After the subject indicated that she understood the instructions, she was asked to place her chin in the chin rest. Size constancy responses were then measured for both monocular (with preferred eye) and binocular viewing conditions using the method of limits (Guilford, 1954). Subjects received two practice trials (one ascending, one descending) and four experimental trials (two ascending, two descending) under both viewing conditions. The variable stimulus was adjusted by the experimenter in a continuous fashion, at the rate of approximately 1.5 cm/sec. At random, half of the subjects received an ascending trial first while the other half received a descending trial first. Similarly, random assignment was used to determine whether the subjects were first tested under binocular or monocular viewing.

Although the room in which size constancy was assessed was dimly lit, it was possible to see the texture of the walls and the floor. The walls were covered with panels of dark gray, felt-like material, and these panels could be seen to overlap. The floor was covered with black carpeting. Under monocular viewing conditions, then, subjects would have been able to use texture gradient, a form of perspective, as one possible source of depth information. Under binocular viewing, subjects presumably had both this cue and the binocular cues such as retinal disparity and convergence. It is doubtful that accommodation provided much depth information, given the distance of the stimuli from the subjects.

Illusions

Having completed the size constancy assessment, subjects were taken to another room where they worked through the five booklets with the illusion stimuli. Because the covariation of a number of different illusion figures was of interest, it was considered important to ensure that all the required judgements be as similar as possible so that any differences in responses would not be a result of different measuring procedures. It was decided that all illusions would be assessed using the method of reproduction. In this method, the subject is asked to reproduce the perceived illusory distortion either by drawing it, or by indicating an appropriate extent on a comparison figure (Coren & Girgus, 1972). Both Pressey (1974) and Coren and Girgus (1972) have noted that this method can produce valid and reliable measures of illusion magnitudes. Further, as indicated earlier, all judgements were estimations of a horizontal linear extent of some segment of each stimulus.

For the Mueller-Lyer, the dumbbell, and the horizontal-vertical figures, subjects were instructed to mark off the apparent length of the horizontal segment (shaft) of the figure on the response line. In Judd's figure the subjects were instructed to indicate, on the response line, the apparent length of the horizontal line from the tip of the left arrowhead to the bisection mark on the line. In the case of Titchener's circle, the subjects were asked to indicate on the lower response line the apparent length of the horizontal line from the left hand side to the point where the circle first intersects that line. For the Ponzo illusion, subjects were presented with two separate (although identical) Ponzo figures in each booklet and were required to indicate on the response line the apparent length of either the upper or lower horizontal line in the figure. Control figures were also included in the booklets. For these figures the subjects indicated on the lower response lines the apparent lengths of the segments that corresponded to the judged components of the illusion stimuli. Upon completion of the five booklets subjects were requested to provide a brief description of what the various stimuli "most looked like". These descriptions were obtained in order to determine the frequency of phenomenal depth interpretations of the stimuli.

Results

Size Constancy

All subjects' size constancy judgements were measured to the nearest mm for each of the four trials (two ascending and two descending) under the two viewing conditions (monocular and binocular), and these measures were averaged for each subject. As Table 1 indicates, subjects on average significantly underestimated (by about 9%) the size of the standard stimulus under the monocular viewing condition (t (66) = -5.07, $p < .01$). Under the binocular viewing condition, there was no significant difference between the subjects' average estimation of the standard stimulus and veridical size. A significant difference between monocular and binocular size constancy judgements was found within subjects (t (65) = 6.87, $p <.01$), with the correlation between the size constancy measures under the two viewing conditions also being significant (r (65) = 0.78, $p < .01$). Reliability of the size constancy measures was estimated by examining the internal consistency across trials; using Cronbach's (1951) coefficient alpha for these data, both size constancy measures demonstrated a high degree of reliability (alpha > .90), as shown in Table 1.

TABLE 1

Size Constancy Judgements: Summary Statistics

A. Absolute Magnitude of Judgements of Standard Figure in mm (veridical size 135 mm)

VIEWING CONDITION	MEAN	SD	ALPHA
Monocular	123.26 **	18.941	0.956
Binocular	133.45	16.944	0.925

B. Percentage Underestimation of Veridical Size

VIEWING CONDITION	AVERAGE
Monocular	8.69 **
Binocular	1.15

** mean significantly different from veridical $p < .01$ (two-tailed significance levels)

N = 67
SD = Standard Deviation
ALPHA = Cronbach's Reliability Coefficient Alpha

Illusions

Subjects' responses (i.e., the estimated lengths of the judged components of the various figures) for each of the 13 stimuli that were used to assess illusion magnitude were measured to the nearest mm. In each case, the veridical length of the segment was then subtracted from the measured value. This measurement procedure results in negative values being associated with segments that are underestimated by the subject and positive values being associated with any overestimated segments. The means and standard deviations of these measures across the five trials are reported in Table 2. For each of the stimuli, a one factor (trials) repeated measures analysis of variance was performed so that any differences in average magnitude across the trials could be detected. The results of these analyses indicated that there were no systematic changes in average magnitude across trials for any of the 13 stimuli. Thus, in order to have more stable measures of illusion magnitude, subjects' responses across the five trials were averaged.

The means and standard deviations of the averaged responses are reported in Table 3. For each of the 13 stimuli, the mean value was subjected to a t-test

TABLE 2

Averages (in mm) of Illusion and Control Stimuli Across Trials

VARIABLE	TRIAL 1 MEAN SD	TRIAL 2 MEAN SD	TRIAL 3 MEAN SD	TRIAL 4 MEAN SD	TRIAL 5 MEAN SD
Horizontal Control	0.985	-0.418	0.388	-0.313	-0.254
	4.925	3.635	3.794	4.113	4.794
Mueller-Lyer Acute Angle	-4.537	-6.075	-5.970	-5.761	-5.567
	4.922	5.185	5.611	4.764	5.719
Mueller-Lyer Obtuse Angle	7.716	6.134	6.522	7.209	6.075
	4.644	4.562	5.372	4.385	4.844
Dumbbell Figure Inward	-0.164	-2.045	-2.746	-2.388	-2.179
	7.057	7.577	7.256	7.642	7.321
Dumbbell Figure Outward	9.687	7.985	7.418	6.672	7.424
	4.878	4.368	5.628	5.476	4.340
Horizontal Vertical	2.731	1.224	0.612	0.851	0.701
	4.416	3.424	4.818	3.928	4.546
Bisected Control	1.761	2.227	2.269	2.000	1.224
	2.834	3.181	3.578	2.970	2.735
Judd's Figure	3.925	3.776	4.299	5.090	3.940
	3.543	3.424	3.920	6.161	4.018
Titchener's Circle	2.881	2.866	3.000	3.031	3.333
	3.033	4.063	4.479	4.987	4.171
Ponzo Upper Control	2.090	1.925	1.879	1.940	2.478
	2.745	2.531	2.737	2.860	2.507
Ponzo Lower Control	1.597	1.672	1.761	2.328	1.910
	2.243	2.776	2.297	2.671	2.448
Ponzo Upper Experimental	2.716	2.358	2.418	2.851	2.866
	3.152	2.978	2.934	2.607	2.844
Ponzo Lower Experimental	1.851	2.552	1.970	2.433	2.164
	2.914	3.120	2.455	3.163	2.750

TABLE 3

Magnitudes of Average Illusion and Control Judgements

VARIABLE	PERCENT	MEAN	SD	*t*		ALPHA
Horizontal Control	0.155	.078	3.006	0.21		0.743
Mueller-Lyer Acute Angle	-11.164	-5.582	3.978	-11.49	**	0.814
Mueller-Lyer Obtuse Angle	13.463	6.731	3.595	15.33	**	0.809
Dumbbell Figure Inward	-3.809	-1.904	6.280	-2.48	**	0.905
Dumbbell Figure Outward	15.642	7.821	3.579	17.89	**	0.762
Horizontal Vertical	2.448	1.224	3.064	3.27	**	0.768
Bisected Control	7.576	1.894	2.337	6.63	**	0.819
Judd's Figure	16.824	4.206	3.135	10.98	**	0.773
Titchener's Circle	12.264	3.066	3.602	6.97	**	0.903
Ponzo Upper Control	10.332	2.066	2.135	7.92	**	0.857
Ponzo Lower Control	9.269	1.854	1.983	7.65	**	0.854
Ponzo Upper Experimental	13.209	2.642	2.395	9.03	**	0.881
Ponzo Lower Experimental	10.970	2.194	2.347	7.65	**	0.870

** indicates mean significantly different from veridical $p < .01$ (two-tailed)

N = 67
PERCENT = Percentage Illusion
MEAN = Average Illusion Magnitude in mm
SD = Standard Deviation
ALPHA = Cronbach's Reliability Coefficient Alpha

in order to determine whether or not it differed significantly from the veridical value. As Table 3 indicates, significant differences from veridical size were found for all stimuli except the horizontal control. The reliability of the averaged measures was assessed by examining their internal consistency across the five trials and calculating Cronbach's Alpha. The obtained reliability estimates are included in Table 3 and are all relatively high, with values of the coefficient ranging from 0.743 to 0.905.

As mentioned in the Method section, errors of the standard may contribute to the measurement of various illusions. While the horizontal control shaft was not significantly overestimated or underestimated in the present study, the magnitudes of the remaining control figures were significantly overestimated. To correct for this consistent overestimation, and to ensure consistency of measurement procedure across the different illusions, all illusions were measured as deviations from their appropriate control figures. Specifically, for each of the five trials, for a given subject, the control judgement was subtracted from the judgement for the corresponding illusion figure. These values were then averaged across the five trials.

It should be noted that further rationale for using the method of illusion measurement described above can be found by examining the correlations between the illusions and their corresponding control figures. As Table 4 shows, the uncorrected judgements for each illusion figure are significantly correlated with the corresponding control figure judgements; this applies not only to those control figures which yielded significant deviations from the veridical, but also to the horizontal control, for which the judgements did not deviate significantly from the veridical. Furthermore, as is indicated by the $\underline{r}^2$ values in Table 4, considerable amounts (from 25 to 74%) of the variances in the illusion figures can be accounted for by their linear relationships with the appropriate control figures. Based on the above factors, the inclusion of the control correction in the measurement of the illusions appears to be a valid and important procedure.

Table 5 reports the means and standard deviations for the eight corrected illusions (averaged across both subjects and trials). All of the corrected illusions, with the exception of the Ponzo, were significantly different from veridical size. However, the horizontal shaft in the horizontal-vertical figure was significantly overestimated, whereas it was expected that this segment would have been

TABLE 4

Correlations Between Illusions and Their Control Figures

		r	r^2
A.	Horizontal Control		
i.	Mueller-Lyer Acute	.5005 **	.2505
ii.	Mueller-Lyer Obtuse	.6462 **	.4178
iii.	Dumbbell Inward	.5462 **	.2983
iv.	Dumbbell Outward	.6222 **	.3871
v.	Horizontal Vertical	.7181 **	.5157
B.	Bisected Control		
i.	Judd's Figure	.6571 **	.4318
ii.	Titchener's Circle	.5144 **	.2646
C.	Ponzo		
i.	Upper Experimental	.8598 **	.7393
ii.	Lower Experimental	.7756 **	.6016

$N = 67$ ** $p < .01$ (one-tailed significance level)

TABLE5

Illusion Magnitudes Subtracting Control Judgements

VARIABLE (Averages)	PERCENT	MEAN	SD	t		ALPHA
Mueller-Lyer Acute Angle	-11.319	-5.660	3.591	-12.90	**	0.646
Mueller-Lyer Obtuse Angle	13.463	6.654	2.827	19.26	**	0.535
Dumbbell Figure Inward	-3.809	-1.982	5.278	-3.07	**	0.827
Dumbbell Figure Outward	15.642	7.725	2.922	21.64	**	0.475
Horizontal Vertical	2.293	1.146	2.280	4.11	**	0.297
Judd's Figure	9.269	2.322	2.380	7.98	**	0.437
Titchener's Circle	4.540	1.135	3.093	3.00	**	0.790
Ponzo	1.138	.228	1.578	1.18		-0.068

** indicates mean significantly different from veridical $p < .01$ (two-tailed)

N = 67
PERCENT = Percentage Illusion
MEAN = Average Illusion Magnitude in mm
SD = Standard Deviation
ALPHA = Cronbach's Reliability Coefficient Alpha

underestimated. The reliabilities of the corrected illusions were estimated by using Cronbach's coefficient alpha. Table 5 indicates that a wide range of reliability estimates (from -0.068 to 0.827) resulted, with all of the corrected measures being less reliable than the corresponding uncorrected measures (cf., Table 3). The decreases in reliability were not atypical, however, as it has frequently been cited that difference scores are often less reliable than the components used in calculating such scores (e.g., Cronbach & Furby, 1970; Linn & Slinde, 1977).

In order to examine the relationships among the various illusions, a factor analysis of the correlation matrix for the eight corrected illusions was performed, using common factor extraction with an orthogonal rotation. Several factor analysts (e.g., Gorsuch, 1983; Nunnally, 1978) suggest that if the number of variables in the correlation matrix being factored is relatively small (i.e., fewer than 10), then instead of having unities as the values along the diagonal of the matrix, the squared multiple correlations between each variable and the remaining variables in the matrix should be used. This substitution results in a relatively conservative analysis, as Guttman (1956) has proved that the squared multiple correlation is a lower bound for a variable's communality;

which can be defined as the proportion of that variable's variance that can be accounted for by the common underlying factors (Gorsuch, 1983). Common factor analysis of this kind (using principal axis extraction), when performed on the adjusted correlation matrix of the illusion measures, suggested the presence of three factors. The extracted factors were subjected to a Varimax (orthogonal) rotation; Table 6 shows the rotated factor pattern matrix, with factor loadings greater than 0.300 underlined. Three illusions loaded highly (i.e., > 0.300) on Factor 1 (namely the Mueller-Lyer featherhead figure, the dumbbell figure with outwardly directed bells, and the horizontal-vertical figure), with this factor accounting for approximately 24% of the variance in the correlation matrix. The Mueller-Lyer arrowhead figure and the dumbbell figure with inwardly directed bells loaded highly on Factor 2, which accounted for approximately 14% of the remaining variance. Titchener's circle and Judd's figure loaded highly on the third factor extracted, which accounted for 8% of the variance. The three factors together accounted for a total of 46.5% of the variance of the variables in the correlation matrix. The Ponzo figure did not load highly on any of the three factors; this was not unusual, however, given the Ponzo's low estimated communality ($\underline{h}^2 = 0.03841$).

TABLE 6

Rotated Factor Matrix - Principal Axis Extraction with Varimax Rotation

	FACTOR 1	FACTOR 2	FACTOR 3
ML FHEAD	.913	-.061	-.130
DUMB OUT	.742	-.056	.100
HOR VERT	.441	.253	.132
ML AHEAD	.266	.948	.160
DUMB IN	-.063	.307	-.035
TITCHENER	-.007	.133	.756
JUDD	.296	.128	.447
PONZO	-.019	-.095	.170
Eigenvalues	1.931	1.138	0.650
Variance Accounted for:	24.1%	14.2%	8.1%

ML FHEAD = Mueller-Lyer Figure - Featherhead Figure
DUMB OUT = Dumbbell Figure - Outward Facing Bells
HOR VERT = Horizontal Vertical Figure
ML AHEAD = Mueller-Lyer Figure - Arrowhead Figure
DUMB IN = Dumbbell Figure - Inward Facing Bells
TITCHENER = Titchener's Circle
JUDD = Judd's Figure
PONZO = Ponzo Figure

The frequency of reports of phenomenal depth in the illusion figures was assessed by examining subjects' responses to the questions which had asked them what the various stimuli "most looked like". The content of the responses was read by the experimenter in order to establish whether or not the responses included any impression of depth relevant to Gregory's theory. The Mueller-Lyer illusion featherhead figure elicited depth responses most frequently, with 25% of the subjects' reports incorporating an impression of depth. Three other figures elicited depth impressions, with frequency of depth responses for the figures as follows:

Judd's Figure	10%
Horizontal Vertical	9%
Ponzo	6%

However, these responses were not uniformly in accord with Gregory's reasoning. Furthermore, for the other four illusions, none of the subjective reports indicated depth interpretations either concordant with, or opposed to, Gregory's theory.

Illusions and Size Constancy

The appropriateness of Gregory's misapplied constancy theory was evaluated by correlating subjects' corrected illusion magnitudes with their size constancy judgements.

Table 7 reports these values and none of the correlations are significantly different from zero (p <.01)

In order to determine the effect that unreliability of measurement of size constancy and illusion magnitude might have had on the correlation coefficients obtained between the two measures, correlations were corrected for attenuation using the previously reported reliabilities for those measures. However, any correlation involving the Ponzo figure was not corrected as the negative value associated with the reliability estimate of the figure made such corrections incalculable. Correlations corrected for attenuation are presented in Table 7 and, while there is no commonly adopted procedure to test such correlations for significance, it would seem clear that the correction had minimal impact on the magnitudes of the correlations, with the pattern of corrected correlations being similar to the pattern of the uncorrected correlations.

TABLE 7

Correlations (Attenuated and Corrected) between Average Size Constancy Judgements and Average Illusion Magnitudes (Controls Subtracted)

	UNCORRECTED CORRELATIONS		CORRELATIONS CORRECTED FOR ATTENUATION	
VARIABLE	MONOCULAR VIEWING	BINOCULAR VIEWING	MONOCULAR VIEWING	BINOCULAR VIEWING
Mueller-Lyer Acute	0.0626	-0.1248	0.080	-0.161
Mueller-Lyer Obtuse	0.0642	0.0335	0.090	0.048
Horizontal Vertical	-0.0066	-0.0689	-0.012	-0.131
Ponzo	-0.2739	-0.1919		
Dumbbell Figure Inward	-0.1486	-0.1699	-0.167	-0.194
Dumbbell Figure Outward	-0.0841	-0.0463	-0.125	-0.007
Judd's Figure	0.0931	0.1629	0.144	0.256
Titchner's Circle	0.1723	0.1690	0.198	0.198

** indicates significant correlation $p < .01$ (two-tailed)

$N = 67$

Discussion

Generally, the results from this study are consistent with those found in the two previous correlational evaluations of Gregory's misapplied constancy theory (viz., J. A. Carlson, 1966 and Hamilton, 1966), in that no significant relationships (i.e., correlations) were found between subjects' size constancy judgements and their susceptibilities to illusions with perspective cues. In addition, however, the present study has incorporated several features, with respect to both size constancy and illusions, which may be seen to have allowed for a considerably more rigorous evaluation of Gregory's theory than the two previous investigations.

Size Constancy

In this study subjects' size constancy judgements were measured under both monocular and binocular viewing conditions, whereas J. A. Carlson (1966) and Hamilton (1966) used only binocular viewing. Gregory (1963; 1968) has emphasized that the distortions in the illusions are a result of the inappropriate operation of primary constancy scaling, a mechanism that he suggests is triggered by the depth cues in the two-dimensional figures. It can be argued, then, that subjects' size constancy responses measured under monocular viewing are more closely related to Gregory's conception of primary constancy scaling than are size constancy responses measured under binocular viewing. Under binocular viewing subjects are able to use more sophisticated cues to distance such as retinal disparity and convergence, cues which Gregory does not cite as triggering primary constancy scaling. The present study, then, allows for a more stringent evaluation of Gregory's theory by establishing whether or not different patterns of relationships exist between the two types of size constancy estimates and subjects' susceptibilities to various geometric optical illusions.

The instructional set used to obtain subjects' size constancy estimates in this study was, as previously mentioned, designed to control for bias resulting from subjects' perspective attitude. Specifically, it was assumed that the neutral-apparent-size instructions would, under binocular viewing, produce results on average that reflect perfect constancy. As the average of subjects' size constancy judgements under binocular viewing in the present study is not significantly different from the veridical size, it would seem that the instructions were effective in controlling for any attitudinal biases that the subjects may have had. Further, as the monocular viewing condition resulted in average size constancy judgements that were significantly less than veridical (by about 9%), it would appear that this manipulation was effective and produced results in the direction expected; it has been demonstrated that reductions in available depth cues result in size constancy judgements that are increasingly based on visual angle matches (e.g., Holway & Boring, 1941; Rock, 1975).

Illusions

An examination of the subjects' average magnitudes of illusions is informative in that the present results can be compared with previous findings. Subjects' average size distortions for the eight illusion figures (corrected for control judgements) varied considerably across the different figures. For the Mueller-Lyer figure, the shaft of the featherhead version (Figure A-2) was judged on average to be 24.6% longer than the shaft in the arrowhead version (Figure A-1). The magnitude of the difference obtained between these estimated sizes in the present study is consistent with results from previous investigations. Coren and Girgus (1978a) note that the shaft in the featherhead figure is typically estimated to be 25 to 30% longer than the shaft in the arrowhead figure.

Unfortunately, "typical" illusion magnitudes are not available for the other figures used in the present study (as none has been as extensively studied as the Mueller-Lyer). However, the direction, and to a limited extent, the magnitude, of the distortions in the other figures can be compared to the findings from other studies using similar stimuli.

As expected from the results of previous studies (e.g., Porac, Coren, Girgus, & Verde, 1979), the shaft of the dumbbell figure with the bells extending outwards from the shaft (Figure A-6) was estimated to be 19% longer than the shaft of the dumbbell figure with the bells bounded by the shaft (Figure A-5). For the left hand halves of the shafts in Judd's figure (Figure A-7) and Titchener's circle (Figure A-8), subjects on average overestimated the sizes by 9% and 5%, respectively, with these distortions also being in the direction expected from previous research (e.g., Morgan, 1969; Robinson, 1972).

The horizontal shaft in the horizontal-vertical figure has seldom been employed as the standard against which comparisons are made in assessing the magnitude of illusion. Rather, subjects have been typically asked to judge the apparent size of the vertical shaft (with this shaft generally being overestimated) (e.g., Collani, 1985;

Schiffman & Thompson, 1975). However, for the purpose of ensuring consistency in the type of response that subjects in the present study were required to make across the various illusions, subjects were asked to indicate the apparent length of the horizontal shaft. The expectation derived from Gregory's theory was that the average apparent length of the horizontal shaft would be shorter than its veridical length. As Gregory (1963) himself states, the following generalization should hold for all illusion figures that can be thought of as flat projections of typical objects lying in three-dimensional space: "The parts of the figures corresponding to distant objects are expanded and the parts corresponding to nearer objects are reduced" (p. 678). Gregory's explanation of the arrowhead version of the Mueller-Lyer illusion states that it is a typical projection of an outside corner of a house (or a box) with the converging lines (i.e., the fins) receding into the distance. As such, the shaft corresponds to a "nearer" object and is thus, reduced. Applying a similar explanation to the horizontal-vertical illusion results in the expectation that, if the vertical line is a projection of an extent receding into the distance, then the horizontal line should correspond to a nearer line and primary constancy scaling should be triggered so that a reduction in the apparent size of the horizontal line is noticed. The results from the present study, however, show that this extent was, on average, significantly overestimated (by 2%). These results do not provide support for an interpretation of the horizontal-vertical illusion based on Gregory's general explanation of illusions.

The magnitude of illusion in the Ponzo figure was defined in the present study as the difference between a subject's estimate of the size of the lower horizontal line in the figure and her separately obtained estimate of the size of the upper horizontal line (with estimates of the horizontal lines having been corrected by subtracting the appropriate control judgements). This measurement procedure resulted in an average distortion for the Ponzo that was not significantly different from zero. This is a somewhat surprising finding given that other investigators have used the method of reproduction to assess the degree of illusion in the Ponzo figure and have reported distortions in the expected direction (e.g., Coren, Girgus, Erlichman, & Hastian, 1976; Porac et al., 1979; Pressey, 1974; Pressey & Wilson, 1978). However, several differences exist between the procedures followed by other investigators and the approach taken in the present study.

Pressey and his associates (Pressey, 1974; Pressey & Wilson, 1978) included and measured only the upper horizontal line in their version of the Ponzo figure. Further, the horizontal line was positioned so that there was no gap between the ends of this line and the obliques (which did not converge to form an apex). This type of figure is quite different in appearance from the "classic" Ponzo figure, with the classic Ponzo being more similar to the version used in the present study (compare Figure A-18 and Figure A-3). Thus, the use of quite markedly different figures might account for differences between present results and those found by Pressey. Furthermore, although Pressey and his associates accounted for errors of the standard by including a control figure, measuring the Ponzo figure as they have done does not eliminate the possibility that the estimated size of a horizontal line may vary depending upon its position with relation to the oblique lines.

Quina and Pollack (1971; 1972) have provided results which indicate that it is important to consider the position of the test line (in terms of its proximity to the apex of the angle formed by the obliques) when assessing the magnitude of distortion in the Ponzo figure. They have shown that, in terms of veridical size, lines nearest the apex are overestimated, whereas lines that are furthest from the apex (but still within the angle formed by the obliques) are underestimated. Quina and Pollack (1971; 1972) suggest, then, that the classic Ponzo illusion is really the summation of two separate distortions. Coren and his associates also take the position that the Ponzo illusion consists of an underestimated and an overestimated segment (Girgus & Coren, 1982). This is reflected by the manner in which they have used the method of reproduction to assess the degree of distortion. Coren et al (1976) included two separate Ponzo figures, one with a horizontal line near the apex of the oblique lines and one with an horizontal line relatively far from the apex. They found distortions in expected directions. They did not, however, include control figures; their measurements were therefore confounded by any errors of the standard.

In the present study, the upper horizontal line in the Ponzo figure was overestimated on average by 13%, with the corresponding line in the control figure being overestimated by 10%. Similarly, the lower horizontal line in the Ponzo figure was overestimated by 11% while the corresponding line in the control figure was overestimated by 9%. Correcting for errors of the standard resulted in average reductions of the distortions to 3% for the upper line and 2% for the lower line. Clearly, at least in terms of the above results, this study demonstrates that errors of the standard can confound measurement of the components of the Ponzo illusion. Furthermore, the present findings do not support the view that the Ponzo illusion consists of two separate distortions; the corrected judgements for the two lines were not significantly different. However, as the lower horizontal line in the present study was not positioned exactly as Quina and Pollack's (1971) study would indicate for maximum underestimation, and as methods of illusion measurement differed between the two studies, this disconfirmation is somewhat tentative.

The inclusion of control figures is an important feature of the present study. Errors of the standard were not taken into account in either J. A. Carlson's (1966) study or Hamilton's (1966) study. However, the results from the current investigation indicate that subjects on average significantly overestimated the lengths of three out of the four control figures (see Table 3). Specifically, although correcting for the overestimation of the control figure resulted in a decrease in average illusion magnitude of only less than 1% for figures requiring the horizontal control, the remaining corrections were 8%, 9%, and 10%. These results reveal the contributions that errors of the standard may make to the apparent magnitudes of illusions, and demonstrate the importance of correcting for such errors.

The procedure used here to control for errors of the standard was the subtraction of subjects' judgements of the control figures from their judgements of the corresponding illusion stimuli. It should be noted, that while the subtraction procedure does take into account errors of the standard, the corrected measures may be less reliable than the uncorrected measures. Decreases in reliability of measurement were noticeable in the present study, as can be seen by comparing the alpha estimates of reliability for the uncorrected illusion judgements (cf., Table 3) with those for the corrected judgements (cf., Table 5). However, although the incorporation of the control judgements in the measurement of the illusions was achieved only at the expense of some reliability of measurement, the tradeoff between corrected measures and decreases in reliability would seem justified given that the correction in some cases was as great as 10%.

An aspect of the present study that has allowed for a unique approach to be taken in evaluating Gregory's theory is the inclusion of a relatively large number and variety of illusion figures. Gregory's misapplied constancy theory postulates that the distortions observed in the geometric optical illusions result from size distortions produced by primary constancy scaling when it is inappropriately triggered by perspective cues in the two-dimensional display. That is, a common mechanism is responsible for producing the distortions in the different illusions that contain perspective cues. It follows, then, that a subject's degree of susceptibility to one illusion figure in this category should be similar to her degree of susceptibility to each other illusion in the same category. In other words, one should be able to identify a common factor underlying illusions with perspective cues.

The results of the common factor analysis performed on the correlation matrix of the magnitudes of the illusion figures in the present study do not support this contention. A three factor solution was obtained and there is no evidence to suggest the existence of a "perspective" factor. Factor 1 appears to represent some type of "expansion" dimension, as the three illusion measures that load highly on it (i.e., the arrowhead version of the Mueller-Lyer, the dumbbell figure with outward bells, and the horizontal-vertical figure) all involve the overestimation of some linear extent (unexpectedly so in the case of the horizontal shaft of the horizontal-vertical figure) . Factor 2 would appear to tap some type of "shrinkage" dimension in that the two illusion measures that load highly on this factor (i.e., the arrowhead version of the Mueller-Lyer and the dumbbell figure with inward bells) involve the underestimation of a linear extent. The third factor may be tentatively considered to be related to some type of "displacement" dimension, as the two illusions that load highly on it (i.e., Judd's figure and Titchener's circle) both involve the perceptual shifting of the midpoint of a shaft. Again, as mentioned in the Results section, the Ponzo figure did not load highly on any of the extracted factors, but this is not surprising given the low estimated communality for the Ponzo. In sum, the results from the present factor analysis in no way support the conception that a common factor underlies illusions with perspective cues.

A previous factor analytic investigation of illusions by Coren et al (1976) provides partial confirmation of the results from the present analysis. In an attempt to develop a taxonomy of visual illusions, Coren et al (1976) examined the covariation among a large number (45) of illusions and then performed a factor analysis which suggested the presence of five factors. As in the present study, no "perspective" factor was found. They did, however, find two factors that were remarkably similar to those in the present study. Coren et al (1976) report a factor (their Factor III), typified by illusions involving overestimation, on which their featherhead Mueller-Lyer loaded highly, as did their dumbbell figure with outward facing bells. Factor 1 in the present study would seem to parallel this. Illusions that involved the underestimation of some linear extent loaded highly on Factor IV in Coren et al's study. Both the arrowhead version of the Mueller-Lyer and the dumbbell figure with inward bells loaded highly on this factor which would appear to be similar to Factor 2 in the present study. Unfortunately, Coren et al (1976) did not include in their illusions anything resembling either Judd's figure or Titchener's circle. Thus, comparisons across studies can not be made for these figures. Generally though, the results from the factor analyses in the present study and in Coren et al (1976) are quite comparable and neither suggests the presence of some type of "perspective" factor as one would expect if Gregory's misapplied constancy theory were valid. The present study, then, may be seen as the first investigation explicitly to take a factor analytic approach in an evaluation of Gregory's theory.

The incorporation of a large number and variety of illusions in the present study has also permitted a more stringent evaluation of Gregory's misapplied constancy theory than have previous correlational investigations using the individual differences approach. J. A. Carlson (1966) and Hamilton (1966) established the appropriateness of Gregory's theory solely by examining the correlations between subjects' size constancy estimates (measured only under binocular viewing) and their susceptibilities to one or two illusions with perspective cues; thus attention was wholly focussed on convergent validity. The present investigation examined not only the convergent validity of Gregory's theory, but also the theoretically derived predictions that subjects' size constancy judgements would be differentially related to their degrees of susceptibility to illusions, depending upon whether or not the illusion figures contained perspective cues. Specifically, it was hypothesized that, if Gregory's theory were valid, then subjects' size constancy judgements would not be significantly correlated with their degrees of illusion for figures lacking obvious (or having ambiguous) perspective cues. This hypothesis is supported as all of the correlations between subjects' size constancy judgements (under both viewing conditions) and their susceptibilities to the four illusions lacking perspective cues are non-significant (cf., Table 7). This finding, however, does not provide any convincing support for the theory unless another hypothesis can also be confirmed. This second hypothesis is that if Gregory's theory were valid, then subjects' susceptibilities to illusions with identifiable perspective cues would be significantly related to their size constancy judgements, with the relationship being more evident when degree of size constancy is estimated under monocular viewing conditions. This hypothesis is clearly not supported by the data, as there are no significant correlations (in the direction predicted based on expectations derived from Gregory's theory) between subjects' judgements for any of the four illusions with identifiable perspective cues and subjects' size constancy judgements obtained under either of the two viewing conditions (cf., Table 7). Evidently, then, even size constancy judgements obtained under monocular viewing are not related to degree of illusion for figures with identifiable perspective cues. Further, when the above correlations are corrected for attenuation, there are only minimal differences between the uncorrected and the corrected correlations, indicating that any relationship between degree of size constancy and susceptibility to illusions is not masked by unreliability of measurement. Thus, the present study clearly demonstrates that, at least for the illusions investigated, subjects' size constancy judgements are <u>not</u> related to their magnitudes of illusions, regardless of whether or not an illusion has identifiable perspective cues. These findings obviously do not support Gregory's misapplied constancy theory, and, given the rigorous testing procedures employed in the present study, it would seem unlikely that any relationship exists between size constancy and illusion magnitude.

Examining the subjects' responses in the present study to the question, "what do these figures most look like?", provides an additional source of evidence which does not support Gregory's theory. One approach that has been taken to evaluate the theory has been to examine the frequency with which illusion figures with perspective cues elicit phenomenal reports of depth from subjects (Ward et al., 1977; Worrall & Firth, 1971). An analysis of the present subjects' descriptions produced results that are consistent with previous reports. The figure that most frequently elicited responses that indicated depth was the Mueller-Lyer featherhead figure, with 25% of subjects providing depth responses. This result is similar to that obtained by Ward et al (1977), who found that 34% of their subjects provided depth-type responses to their featherhead figure. The "L"-shaped version of the horizontal-vertical figure used in the current study elicited phenomenal impressions of depth from only 9% of the subjects. While this version of the horizontal-vertical figure has not been included in other similar studies, the inverted "T" form of the horizontal-vertical figure has elicited depth-type responses from 21% of the subjects in one study (Ward et al., 1977). Thus, neither of the two versions of the horizontal-vertical illusion appear consistently to elicit phenomenal interpretations of depth.

Only 6% of the subjects in the present study provided subjective responses to the Ponzo figure that indicated an impression of extended depth. This finding is remarkably similar to the frequency of depth reports found in response to the presentation of just the oblique lines in previous studies. Worrall and Firth (1971) reported that 7% of their subjects provided responses indicating extended depth, while Ward et al (1977) found that 3% of their subjects provided such responses. As a whole, these studies would seem to indicate that the inclusion of the horizontal test lines in the angle formed by the converging oblique lines has negligible effect on the frequency of phenomenal depth reports. That is, the perspective cue in the Ponzo figure (i.e., the convergence of the inducing lines) elicits subjective reports of depth just as infrequently as does the entire Ponzo figure. Thus, although the Ponzo figure is often cited as an exemplar of an illusion with an identifiable perspective cue embedded in the inducing lines, the results from the present study, from Worrall and Firth (1971), and from Ward et al (1977) indicate that neither the inducing lines alone nor the entire figure itself elicit frequent phenomenal impressions of depth.

While there is relative consistency in terms of the frequency of depth-type response for similar figures common to the present study and previous reports, a marked discrepancy exists with regard to one figure: The arrowhead version of the Mueller-Lyer . Forty-six percent of the subjects' responses to the arrowhead version of the Mueller-Lyer in Ward et al's (1977) study included some impression of depth, whereas none of the subjects' responses to a similar figure in the present study could be interpreted as implying depth (with the majority of the responses being "a double-headed arrow"). One possible reason for this discrepancy could be minor differences in the stimuli used in the two studies. The size of the acute angles between the shaft and the fins in the arrowhead version of the Mueller-Lyer figure used in the present study was 30°. Although Ward et al (1977) do not report the exact dimensions of the figures used in their investigation, it would appear from an inspection of the figures provided in their paper that the angles between the shaft and the fins in their arrowhead version were approximately 60^{o}. Differences in the size of the angle between the shaft and the fin are known to affect the magnitude of the Mueller-Lyer illusion (Dewar, 1967; Robinson, 1972) so it would stand to reason that such differences may also affect the frequency of elicitation of phenomenal reports of depth.

In summary, while the figures with depth cues tended to elicit depth-type responses more frequently than did figures lacking (or having ambiguous) depth cues, there was in this study, as in previous ones, no marked tendency for subjects to provide such responses to the figures with identifiable perspective cues. Considered as a whole, these results do not provide much support for Gregory's misapplied constancy theory, as illusion figures with perspective cues do not consistently elicit phenomenal reports of depth. It should be mentioned nevertheless that these results do not necessarily imply that the perspective cues cannot evoke constancy scaling at some registered, but unconscious, level - the level at which Gregory (1963) suggests primary constancy scaling operates. However, as Humphrey and Morgan (1965) have noted, "...a theory which appeals to the idea of automatic compensation for unconsciously perceived depth is in obvious danger of being irrefutable" (p. 744).

Taken in their entirety, the results from the present investigation are generally consistent with previous research and thereby refute Gregory's misapplied constancy theory of geometric optical illusions. Several different approaches have been adopted here to evaluate the theory, with the findings from the different methods providing unanimity in their disconfirmation of theoretically derived hypotheses. As such, this study represents a rather comprehensive evaluation and subsequent refutation of one of the most enduring theories of visual illusions. While some (e.g., Gregory) might suggest that, as in previous investigations, the critical relationship was not tested (i.e., between primary constancy scaling and illusions), it has become increasingly apparent that due to the nature of primary constancy scaling, this exact relationship is untestable. It would appear further that, until a rather conclusive demonstration of the validity of Gregory's misapplied constancy theory has been provided (and replicated), the theory should be more accurately viewed as being intuitively appealing, but critically unsubstantiated.

While the results from this study strongly illustrate the inappropriateness of one theoretical explanation of visual illusions, implications for future research are also evident. With regard to the Ponzo illusion, the question raised by examining the present results is whether or not one can conceive of the illusion as being two separate illusions (as Quina & Pollack and Coren and his associates do), with the apical test line being overestimated and the other test line being underestimated. An investigation of this question, perhaps using several different methods of illusion measurement, would seem required.

The entire issue of method of illusion measurement also requires in-depth investigation. The validities of different methods need to be established for a wider variety of illusion figures than that obtained by Coren and Girgus (1972) and the reliabilities of these different measures also need to be determined. Further, the effects of controlling for errors of the standard may be of additional interest here, in that there may be some type of differential effect across methods of measurement. Clearly, this would seem to be a productive area for further work.

The results from the present factor analysis and that performed by Coren et al (1976) are consistent in that both suggest an overestimation and an underestimation factor. However, as in Coren et al's paper, the present results are merely descriptive, in that no underlying mechanism readily suggests itself as being responsible for producing the obtained distortions. A replication of these analyses using a different method of measurement would be able to substantiate the factor structure found here and in Coren et al. Until such confirmation is established, the search for underlying mechanisms might be fruitless, since the obtained factors may be an artifact of method of illusion measurement, although the mechanisms responsible for assimilation and contrast would appear promising candidates for consideration (Girgus & Coren, 1982).

Most researchers presently working with geometric optical illusions would agree that these phenomena are not caused by a single underlying mechanism, but rather are due to a multiplicity of factors working in concert (e.g., C. R. Carlson et al, 1984; Coren & Girgus, 1978b; Coren & Porac, 1984; Goryo, Robinson, & Wilson, 1984). However, it would appear that most investigations of illusions, including the present one, have focussed rather exclusively on either developing or testing a specific theory. Few investigations have attempted to examine the interplay of several factors operating simultaneously. Perhaps by adopting this type of eclectic approach, future researchers may finally be able to answer the perceptual questions posed by the geometric optical illusions.

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Appendix A - Illusion Figures

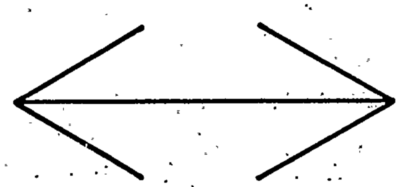

Figure A-1: The Mueller-Lyer (Arrowhead Version)

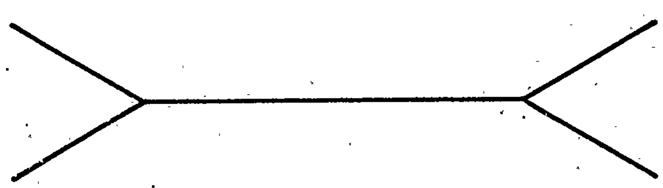

Figure A-2: The Mueller-Lyer (Featherhead Version)

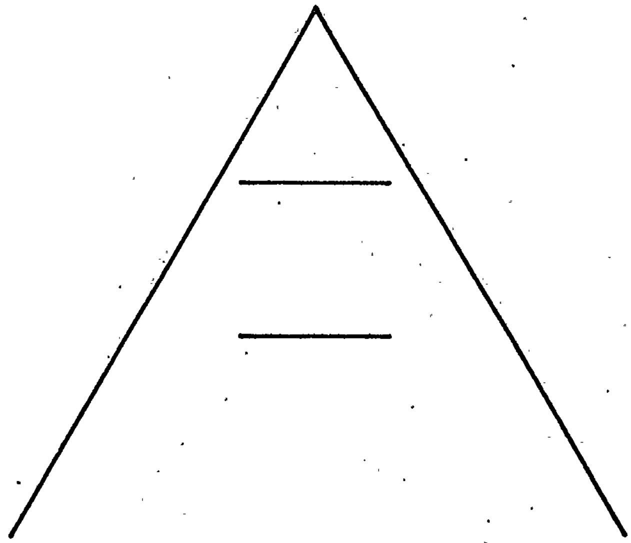

Figure A-3: The Ponzo Figure

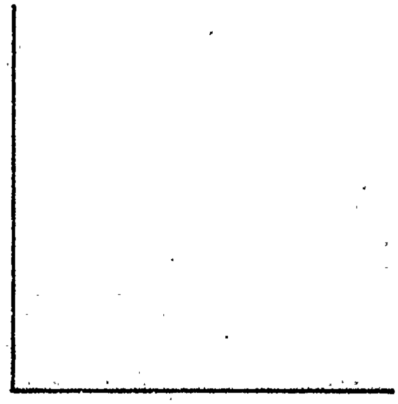

Figure A-4: The Horizontal-Vertical Figure
("L" form)

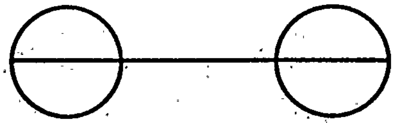

Figure A-5: The Dumbbell Figure - Inward Bells

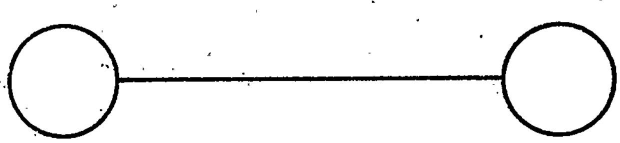

Figure A-6: The Dumbbell Figure - Outward Bells

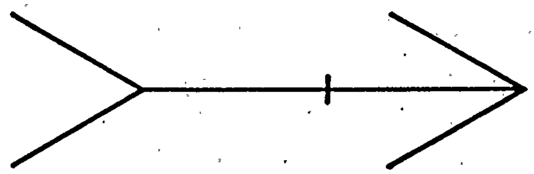

Figure A-7: Judd's Figure

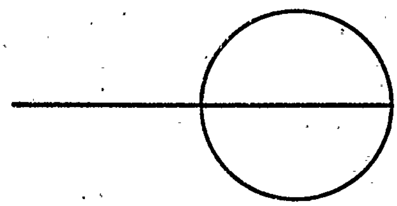

Figure A-8: Titchener's Circle

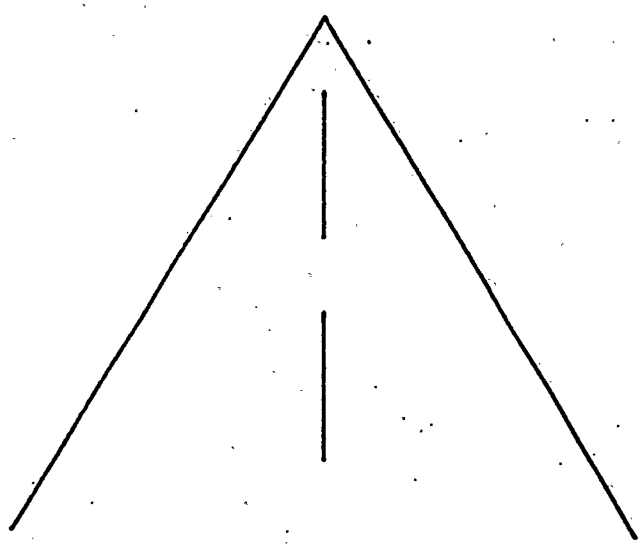

Figure A-9: Modified Ponzo Figure

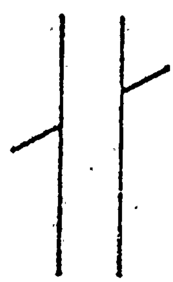

Figure A-10: The Poggendorf Figure

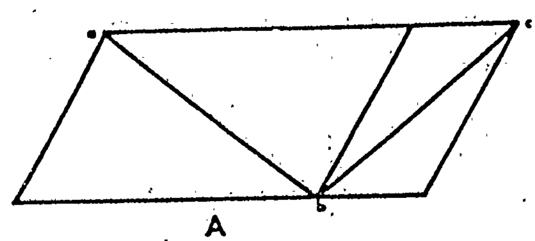

Figure A-11: Sander's Parallelogram

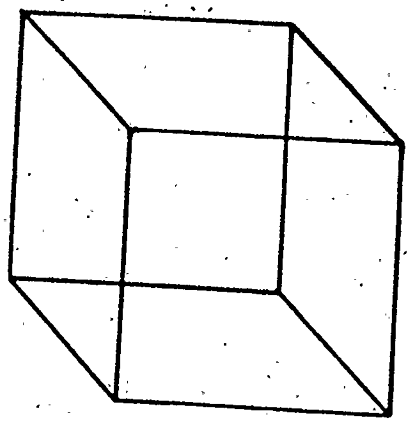

Figure A-12: Necker Cube

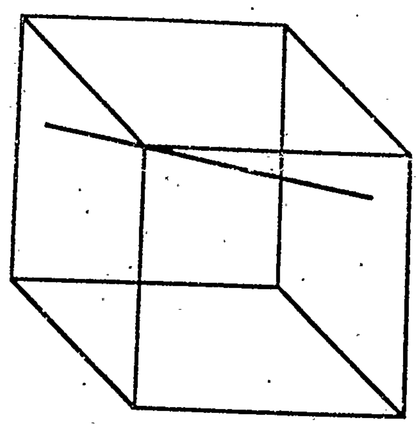

Figure A-13: Modified Necker Cube
(taken from Gregory, 1963, Figure 4(b))

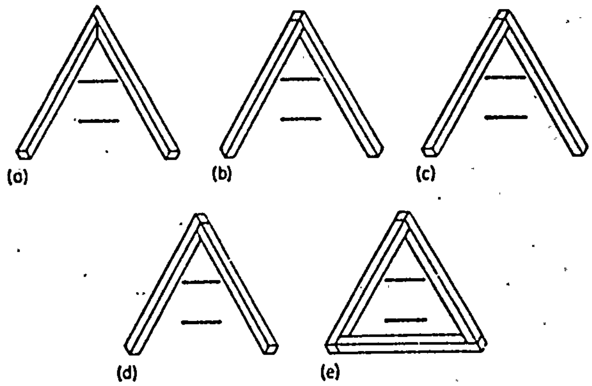

Figure A-14: Modified Ponzo Figures Conveying Different Depth Impressions (taken from Fisher, 1970, Figure 2)

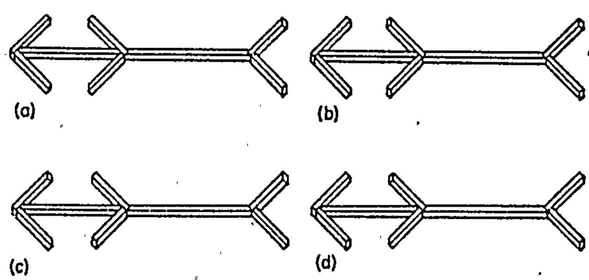

Figure A-15: Modified Mueller-Lyer Figures Conveying Different Depth Impressions (taken from Fisher, 1970, Figure 3).

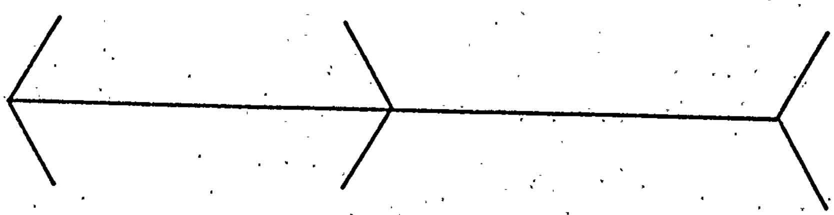

Figure A-16: Composite Mueller-Lyer Figure

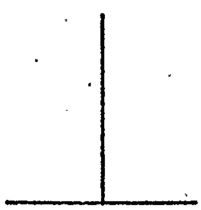

Figure A-17: Horizontal-Vertical Figure
(inverted "T" form)

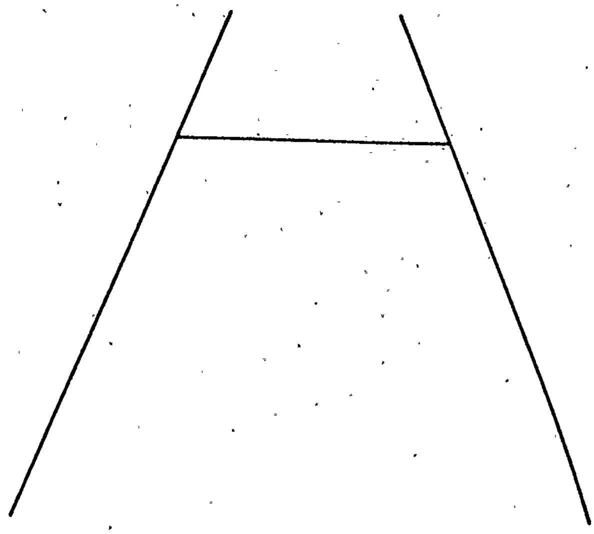

Figure A-18: Modified Ponzo Figure
(taken from Pressey, 1974, Figure 1)

Appendix B - Typical Page Used For Method of Reproduction

(bisected control figure)

On the line below indicate the apparent length of the left segment of the divided line above.