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Wallpaper illusion: cause of disorientation and falls on escalators

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Abstract. The wallpaper illusion, first described over a century ago, can occur when a person with normal binocular vision views a pattern that is periodic in the horizontal meridian of the visual field. Escalator treads present such a pattern. Evidence is presented favoring the view that disorientation experienced by escalator riders is caused by this illusion. Possibly some of the estimated 60 000 escalator falls occurring in the United States each year are linked to it.

1 Introduction

Stairs, elevators, and escalators are the most common ways in which people travel vertically. Escalators are unique in that they all provide essentially the same visual stimulus to the human observer. Consider the visual stimuli available to an escalator rider poised to board the machine from the top. Ahead and down are the treads. To each side of these are the featureless buffed stainless steel skirts. The tread surface is marked by alternating cleats and grooves, each about 3 mm wide. Usually, though not always, the grooves are painted black at the time of manufacture. The cleats are initially polished and retain a bright appearance due to continuous abrasion from users' footwear. We have made measurements showing that this stimulus is approximately a triangle-wave grating.(1) If the rider is looking at nearby treads and is of average height, the grating has a spatial frequency of about 6 cycles deg^{-1}, which has been shown (Campbell and Green 1965) to be the most visible spatial frequency in the fovea of the light-adapted eye. Contrast of a target is defined by the maximum deviation from average brightness. It is a parameter that strongly determines stimulus visibility (Stromeyer and Klein 1974). The contrast of this grating (about 0.98) is uncommonly high compared to the contrast of other targets most usually encountered in our environment. The escalator skirt with its far broader spectral content and far lower contrast can scarcely compete with the powerful visual stimulus provided by the escalator tread.

Now consider the conditions likely to lead to the 'wallpaper illusion', an illusion of depth described first by Helmholtz (1909/1962). It occurs when the two eyes adopt an angle of convergence that is inappropriate to the actual distance of the object but which, because of periodicity in the object, allows fusion to take place. The illusion is described as 'disorienting' (Blakemore 1970) and has been recorded for periodic stimuli other than wallpaper (Ittleson 1960). It would seem that the escalator tread(2),

(1) Luminance measurements were made with a Spectra Pritchard Photometer. Wear round the cleats tends to sharpen the reflectivity function away from a square wave, that might be expected on geometrical grounds, towards a sawtooth pattern. Luminance measurements reveal strong periodicity under a variety of commonly encountered lighting conditions.

(2) The periodic structure of the cleat-groove arrangement of the escalator tread is necessitated by the presence of comb plates at upper and lower thresholds, mandated by code A17.1-1981 [*Safety Code for Elevators and Escalators* 1981 (New York: American Society of Mechanical Engineers)]. Interdigitation of comb-plate and tread allows for smooth, safe transition from moving to stationary surfaces. These same considerations apply to the step riser of the escalator, to the surface of certain moving walkways, and to varieties of flooring that contain periodic patterns.

with its strong periodic nature, might give rise to the same illusion. Figure 1 illustrates this viewing situation. If the two eyes fixate a common point b then the images to both eyes will be fused. Under these conditions of viewing a normal percept should result because the angle of convergence of the eyes is appropriate to the distance of the object. If, on the other hand, the left eye fixates b and the right eye fixates b′ there is fusion with an inappropriate angle of convergence. Under these conditions the object appears to lie in a plane passing through the point labelled a (Ittleson 1960). This latter perception competes with other cues that portray the correct distance of the object. The ambiguous sensation is probably what causes observers to report that such stimuli make them dizzy or disoriented.

The sensation of dizziness or disorientation on escalators has long been known. The cause has generally been ascribed either to movement of the machine or to viewing from a height although no evidence has been advanced in support of either possibility. A depth illusion has not heretofore been examined as a possible cause of disorientation on escalators. The purpose of this paper is to present evidence consistent with the hypothesis described above that disorientation on an escalator can be due to a visual depth illusion. We have concentrated on subjective reports of disorientation under different viewing conditions chosen either to support or to abolish the depth illusion. We find that the disorientation measured in this way is correlated with the depth illusion.

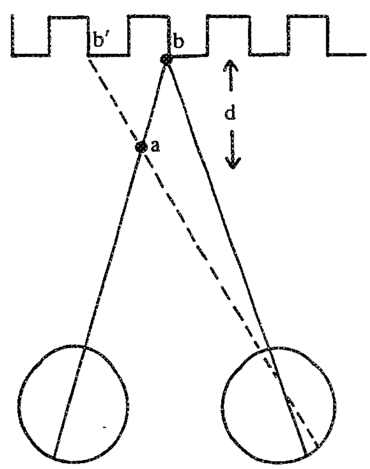

Figure 1. Schematic representation of eye misalignment on viewing a periodic target. If the observer fixates point b with both eyes, the angle between them is appropriate to the distance of the object from the observer. If the observer fuses adjacent similar features, such as the cleat corners shown at b and b′, the eyes adopt the wrong angle of convergence for the distance of the object. In this case disparities of points on the object lead to a sensation that it is closer. For the viewing conditions cited in the text, the misalignment leads to a depth illusion of 6% error for each integral number of periods of misalignment. Thus, fusing cleats that are separated by one period of the pattern would lead to a depth error of 6%, by two periods to a 12% error, and so on.

2 Methods

In order to examine this illusion we chose to elicit subjective reports of disorientation while subjects looked at an escalator under the test viewing condition (binocular viewing, fixating the center of a tread about seven feet distant). Since other factors such as the escalator movement or its height could also lead to a report of disorientation, we designed control tests where two alternative viewing conditions were used, neither of which could support the wallpaper illusion but which controlled for movement and height, respectively. These were (i) monocular viewing and (ii) viewing with the head tipped. Under monocular viewing (one eye occluded by the observer's hand) the depth illusion is abolished since the sensation of depth (stereopsis) requires two eyes. The second control condition, tipping the head about 45 ° towards the shoulder but viewing with two eyes, removes the periodic structure of the tread from the horizontal meridian at leading and trailing edges of the tread. This too should abolish the wallpaper illusion. If the wallpaper illusion causes disorientation, then we predict that subjects will report disorientation more often under the test condition of normal viewing than under the control conditions. If a report of disorientation is due to a factor other than the wallpaper illusion, no effect would be predicted because all three viewing conditions would be disorienting. Moreover, the judgement should be quite difficult.

2.1 *Subjects*

Observers included fifty-five students of optometry and eight employees of the Bay Area Rapid Transit District (BART). All were naive as to the purpose of the experiment. A binocular vision screening test was administered so as to exclude observers with clinically important binocular anomalies who would not be expected to experience a depth illusion. Phoria and tropia were subjectively assessed using a standard optometric clinical test (cover test). Observers who showed detectable tropias, as well as hyperophoria, were excluded. On this basis, four observers were excluded, leaving fifty-nine subjects. Subjects ranged in age from 21 to 36 years with a mean age of 25.4 years and a standard deviation of 3.2.

2.2 *Procedures*

Observers were allowed a brief view, under each of the three viewing conditions, of an empty down-moving escalator while standing on the stationary platform at the top of the machine. The three viewing conditions were presented always in this order: monocular, binocular (normal), and binocular with the head tipped. Each condition was employed for about 10 s. Observers were instructed to rank the viewing conditions from least to most disorienting (disorienting was not defined for participants). The ranks were assigned numerical labels from 1 to 3. Observers were also asked to categorize the judgement as 'easy' or 'difficult' to make (these terms were also left undefined). Reports from observers who categorized the task as easy were analyzed separately from those who found the task difficult. This was thought to have the effect of minimizing the influence of (i) observers who did not experience the illusion; (ii) observers who experienced disorientation under all viewing conditions, which might have been due to viewing height, stimulus movement, or other unknown factors; and (iii) observers who experienced no disorientation.

3 Results

The results of this experiment were consistent with the idea that the escalator does lead to a depth illusion like the wallpaper illusion and that this illusion is a cause of disorientation. For those subjects who found the task easy, we found a clear effect in the direction predicted and this is shown in table 1a. We also show the results for subjects who found the judgement difficult displayed separately. For subjects who found the task easy, binocular viewing was ranked most disorienting more often than it was ranked in the other two categories, and it was ranked more disorienting than were the other two viewing conditions. The association between viewing condition and disorientation rank is statistically significant ($\chi^2_4 = 15.9$, $p < 0.0025$). It appears that some individuals experience a depth illusion while viewing an escalator even if the stimulus is present for as little as 10 s. We found that when subjects who found the task difficult and those who found it easy were combined, the significance level for the disorientation effect rose to about $p < 0.10$. This does not necessarily mean that subjects who found the task difficult were unable to experience the illusion and its potential disorienting effects; it may only mean that our measurement technique (which depended upon comparison of two other viewing conditions which in themselves may be disorienting to some subjects) lacked the sensitivity to detect the effect in many subjects. Or it may mean that height and/or movement, common features of all three viewing conditions, can also cause disorientation.

The data for those subjects who found the judgement easy were examined more closely by pairwise comparisons of viewing conditions. Normal binocular viewing is both more disorienting than monocular viewing ($\chi_1^2 = 4.28$, $p < 0.025$) and more disorienting than viewing with the head tipped ($\chi_1^2 = 5.57$, $p < 0.01$). These results also serve to reject, for those who report disorientation, two commonly advanced hypotheses of escalator disorientation cited above, namely that it may be due either to the movement of the machine or to viewing from a height. Since movement and height are constant features of the test, they cannot explain what makes normal binocular viewing seem the most disorienting of the three viewing conditions. On the other hand, these results do not exclude these other causes as contributory factors to feelings of disorientation. The perceptions of height and movement, which in this instance do not depend upon stereopsis, and which are largely a consequence of the monocular visual cues, are present in all three experimental conditions.

A second test, performed on the same observers a week after the first test, was designed to serve as an additional control for the first. This test was performed upon fifty-three of the fifty-five optometry students, but not the eight BART employees. We wanted to ensure that normal binocular vision was not intrinsically disorienting irrespective of what was being looked at. In this test many of the observers were required to render the same judgements as in the first test while looking down into a lecture hall from a height. The same three viewing conditions were employed. Table 2 displays only the results for binocular viewing of the lecture hall scene plus the comparable figures for viewing the escalator from table 1. It should be noted that for the data in this table subjects were not asked to compare the escalator scene with

Table 1. Number of observers assigning indicated disorientation rank to a given viewing condition, categorized into subjects who judged the task as easy and difficult.

Viewing condition	Disorientation rank			Disorientation rank		
	1 (least)	2	3 (most)	1 (least)	2	3 (most)
	Easy			*Difficult*		
Monocular	16	7	8	7	8	10
Binocular, tipped	7	17	7	11	6	10
Binocular, normal	8	7	16	8	12	6

Table 2. Number of observers assigning indicated disorientation rank to binocular viewing for the given scene who judged the task as easy and difficult.

Scene Viewed	Disorientation rank			Disorientation rank		
	1 (least)	2	3 (most)	1 (least)	2	3 (most)
	Easy			*Difficult*		
Escalator	8	7	16	8	12	6
Lecture hall	10	4	4	17	4	5

the lecture hall scene, but only to rank what they saw under the available viewing conditions. It is inferred that the escalator would have been judged distinctly more disorienting than the control scene when comparison was made from the two independent samples and the result is also significant ($\chi_1^2 = 8.00$, $p < 0.0025$). This table shows that simply viewing a scene from a height is unlikely to evoke a response of disorientation when the scene is viewed binocularly.

The subjects were also asked to retrospectively compare the lecture hall scene with the escalator scene. By comparing the two scenes when viewed binocularly, twenty-five of the observers found the escalator more disorienting than the lecture hall and three found the opposite (ten subjects found the two scenes equally disorienting and were excluded as 'ties'). This result (not displayed in a table) is also significant ($p < 0.001$, binomial test).

Observers who found the judgement difficult nonetheless exhibited more disorientation looking at the escalator than when looking at the lecture hall. Table 3 shows the results of comparing normal, binocular viewing ranks in the lecture hall and escalator scenes, separated by the criterion of judgement difficulty. The t-test[3] was applied to the algebraic difference between the binocular ratings for the two viewing conditions, and the correction for continuity was applied. While subjects who found the judgement easy produced larger differences in the two viewing conditions, a significant effect was found also in subjects who described the task as difficult.

Table 3. Statistical summary for results of comparisons in table 2.

Subjects	t-values with continuity correction		
	t-value	df	p-value
Subjects judging easy	3.27	21	0.005
Subjects judging difficult	2.58	26	0.02
All subjects	4.32	48	0.00001

3.1 *A test altering the stimulus configuration*

Since it is the periodic nature of the escalator tread plate that is capable of inducing the wallpaper visual illusion, we conducted a final test by comparing subjects' responses to the standard escalator and to an otherwise identical escalator which had been treated by painting a high contrast, black and white, nonperiodic pattern designed to disrupt the binocular illusion. For this test, a separate group of optometry students was recruited. Subjects viewed the bottom tread plate of nonmoving escalators, alternating the viewing conditions (binocular, monocular, and binocular with the head tipped) every 10 s. Subjects were asked to judge whether the treated escalator or the untreated escalator was more disorienting. The order of viewing (treated, untreated versus untreated, treated) was randomly chosen, along with the manner in which the judgement was obtained. Roughly half the subjects were asked which was 'less disorienting', while the other half were asked which was 'more disorienting', giving rise to a 2×2 contingency table. The results of this experiment are shown in table 4. As before, subjects who found the judgement 'difficult' were excluded. Table 4 shows that most subjects found that the untreated escalator was more disorienting than the treated escalator, and the results were significant ($p < 0.05$, χ_1^2 test). In addition, since the stimulus escalator was viewed from the

(3) The t-test was employed upon the comparison of ranks, following the recommendations of Snedecor and Cochran (1980). For large sample sizes ($N > 12$), the t-test gives tail probabilities very comparable to those provided by Fisher's randomization test, which is a nonparametric alternative.

bottom and was not moving, this test, unlike the first, establishes that reported disorientation can be due solely to the wallpaper illusion.

In a further effort to characterize the visual characteristics of those subjects who found the judgement easy and difficult, we examined the relationship between the disorientation ratings under binocular viewing and phorias. We reasoned that the existence of phoria might increase the likelihood of binocular dissociation and false fusion. Figure 2 shows the disorientation rating versus phoria, separated by task difficulty. Regressions, which were separately calculated, showed a slight though not significant negative correlation between disorientation rank and phoria, the correlation being most pronounced for subjects who found the judgement easy. These limited data suggest that phoria is a poor predictor for the wallpaper illusion.

In sum, the escalator is a disorienting visual stimulus, under conditions that favor the binocular depth, or wallpaper, illusion. The next point to be examined is the consequence this might have for untoward occurrences on escalators.

Table 4. Binary judgements of observers viewing treated and untreated stationary escalators from the bottom tread plate. Subjects in the first column identified the escalator (treated or untreated) that was 'least disorienting' while subjects in second column identified the escalator that was 'most disorienting'.

Viewing condition	Disorientation rank	
	'least'	'most'
Treated (painted)	8	1
Untreated (unpainted)	1	14

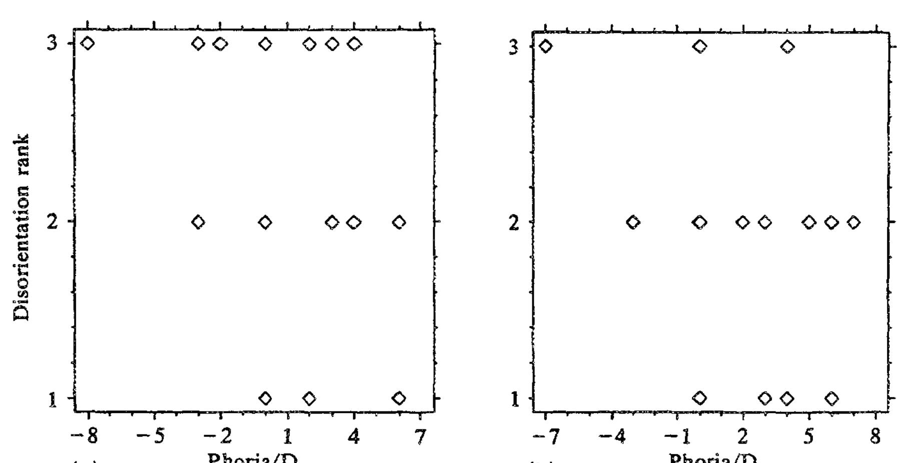

Figure 2. Plot of relation between disorientation ranks for the binocular condition of escalator viewing versus phoria. Phoria was estimated with the use of the cover test. Exophoric values were given negative signs. The panels show the relation for subjects who described the task as (a) easy, and (b) difficult. There was an almost significant association between phoria and rankings in subjects who found the task easy.

4 Discussion and policy implications

Escalator falls may be caused by the depth illusion. It is estimated that 8 out of 10 000 000 escalator rides result in a fall. For the Bay Area Rapid Transit District (which operates some 135 escalators) a recent two year accumulation of incidents reveals an average of two falls per year per machine that may be linked to disorientation. When that is extrapolated to a nationwide figure, the number becomes 60 000 year^{-1} in the USA. Not all falls are debilitating, but as many as 10000 escalator incidents are estimated to lead to emergency room attention each year and the great majority of these are falls.[(4)]

4.1 *Proposed link between disorientation and falls*

By its nature a visual illusion is a private sensation that has external correlates. It is known that maintenance of one's normal posture is imperfect, exhibiting random variation (Dornan et al 1978). Moreover, the error in posture is greatly increased when the eyes are closed (Dornan et al 1978) indicating that posture depends upon the information available from the eyes. One could assume that the error might also increase in the presence of a depth illusion.

We have tested this idea both with laboratory and with field tests of postural stability and the results all tend to support the view that the escalator tread can worsen postural stability (Lasley et al 1991). Factors that would exacerbate such events would then be expected to worsen the risk of falls. Indeed, the elderly and individuals under the influence of alcohol may be more likely to be involved in escalator falls (Fruin et al 1978).

Disorientation, even without falls, may present a problem of public policy in its own right. The escalator is the most efficient level-change conveyance available (Strakosch 1967), and it thus plays a pivotal role in modern urban mass transit systems, for it is the principal means of entry and egress for such systems. Yet many individuals are afraid to use the escalator because of disorientation, and so disorientation may limit access to transit. Further study of disorientation, including means of preventing it, seems warranted.

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[(4)] Police and station agent reports were summarized and coded by BART safety staff and a summary listing was provided. Incidents were deemed falls if 'fall' was used as a descriptor. Disorientation was suspected if it or related words ('dizzy', 'lost balance') were used. Falls resulting from collision, interaction with other passengers, etc were excluded. The estimate of emergency room use came from the Consumer Product Safety Commission, National Injury Information Clearinghouse, "Elevator and escalator accident and injury report", 1970-1980.

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