

Effects of Intervals between Roadside Columns on Speed Perception in Human Walking and Running Speed

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Abstract—This study aimed to examine the effects of intervals between roadside columns on human speed perception. A virtual reality aided experiment was conducted, with 20 college students as participants. Each participant was asked to sit in front of a screen upon which interactive virtual space was projected. Within this space, columns emerged on the right and left of the screen at regular intervals. Participants could control the speed with which the columns moved on one side of the screen, using a mouse to move a virtual slider bar. The participants were asked to synchronize the speeds with which the controllable and uncontrollable columns moved in each experimental trial. The most important results of this study were that participants tended to increase the speed with which controllable columns moved when the intervals between them were longer relative to those between the uncontrollable columns. Results indicated that controlling the intervals between roadside columns also affected the perception of human walking and running speeds.

Keywords- *Speed Perception; Optic Flow; Peripheral Vision; Virtual Reality; Driving Simulation*

I. INTRODUCTION

Human speed perception involves a combination of several types of environmental information received via sensory organs such as the eyes, ears, and skin. Of this sensory information, visual stimuli in the peripheral visual field provide the most important clues as to the relative speed with which objects surrounding the individual move. Gibson described the flow of visual stimuli through the peripheral visual field as “optic flow” [1].

The earliest work examining the effects of peripheral visual patterns on human speed perception was conducted by Denton [2][3]. The results of this research generally demonstrated that human speed perception was differentially influenced by the visual patterns that were presented to drivers’ eyes.

Kircher [4] conducted a simulator experiment to determine how driving performance was influenced by design factors, tunnel wall color, and illumination. The results indicated that tunnel design exerted an influence on drivers’ behavior, and light-colored tunnel walls were of greater importance, relative to that of strong illumination, in keeping drivers’ visual attention focused forward.

Manser [5] also conducted a simulator experiment to determine the effect of visual patterns applied to transportation tunnel walls on driving performance. Results indicated that participants reduced their driving speeds gradually when exposed to decreasing visual pattern width and increased their driving speeds when exposed to increasing visual pattern width. These findings suggest that human speed perception was modified by visual patterns expressed on the tunnel wall.

Allpress [6] conducted an open-road investigation to evaluate the effects of even and decreasing roadside cone spacing at a roadwork site on traffic speed. The results showed that although both types of spacing were highly effective at reducing driving speed, uneven cone spacing led to a marked reduction in the number of speed-related accidents observed.

Godley [7] conducted an experiment using a driving simulator, in which participants drove toward intersections with peripheral transverse lines at both reducing and constant spacing. The results showed that although both types of

peripheral transverse line led to a greater reduction in speed relative that of the no-line condition, speed perception was not influenced by a decrease in the spacing of the peripheral transverse lines.

Katz [8] conducted a similar experiment to investigate the effects of peripheral transverse lines. They found no significant difference between various patterns of peripheral transverse lines applied to the roadside of a simulated roadway. However, the results also indicated that the driving lane positions were significantly farther from the centerline in the design alternative involving two and four bars per second.

The objective of the present study was to examine the effects of peripheral visual stimuli presented at human walking or running speed on human speed perception. Almost all studies in this field have involved the control of driving speed, as it is one of the most effective methods for reducing

the incidence of speed-related traffic accidents. This knowledge-based environmental design method for controlling human speed perception is expected to be effective in planning and designing an improved pedestrian environment, in which people undertake comfortable walking or fun running without excessive speeding.

With respect to the Methods section, in Subsection A, we describe the ethical issues considered in conducting the study; in Subsection B, we describe the study design; in Subsection C, we describe details of the experimental equipment and setup; in Subsection D, we describe the features of the experimental virtual space; in Subsection E, we describe the verification of the column parameters; in Subsection F, we describe the experimental conditions.

With respect to the Results section, in Subsection A, we describe the results concerning adjusted C-column speeds with a fixed U-column speed of 1.5 m/s; in Subsection B, we describe the results concerning adjusted C-column speeds with a fixed U-Column speed of 3.0 m/s; in Subsection C, we describe the results concerning adjusted C-column speeds with a fixed U-Column speed of 6.0 m/s.

In the Discussion section, we interpret the relevance of the findings with respect to those of previous studies and describe the limitations of the study. In the Conclusion and Future Work section, we summarize the main findings of the study and suggest directions for future research.

II. METHODS

A. Ethics

Written informed consent was obtained from all participants prior to the publication of this case report and the accompanying images. Participants were permitted to take short breaks as required, which increased the total experimental period.

B. Design

The participants were 20 college students (10 men and 10 women, mean age: 22.1 years). They were asked to sit on a chair in front of a wall-mounted screen, with one hand on a computer mouse placed on a desk (Figure 1).

Several types of interactive virtual movie were projected onto the screen. Two rows of columns emerged from the center of the screen and flowed to the right and left of the screen at regular intervals. Participants were able to control the speed with which one of the rows of columns moved, using the mouse to move a virtual slider bar. Participants were asked to use their own judgment to synchronize the speeds with which the controllable and uncontrollable columns moved in the experimental trials (Figure 2).

Participants were expected to be unable to adjust the speed with which the controllable columns moved to match that with which the uncontrollable columns moved when the intervals between the two types of column differed. The effects of different intervals between roadside columns on human walking speed perception were examined by comparing the adjusted speed of controllable-column movement and the fixed speed of uncontrollable-column movement.

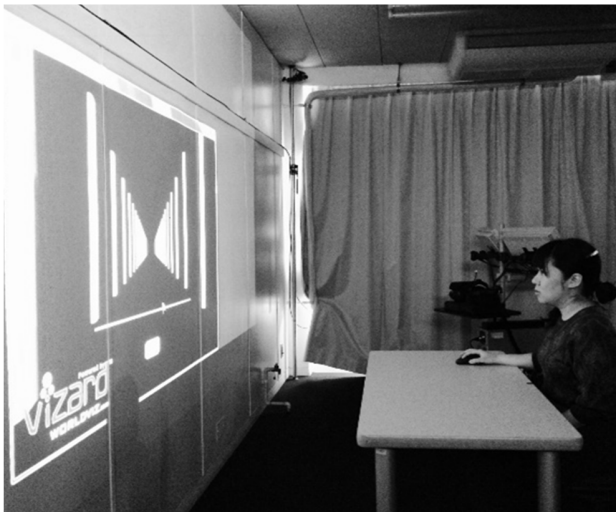


Figure 1. Experimental Setup

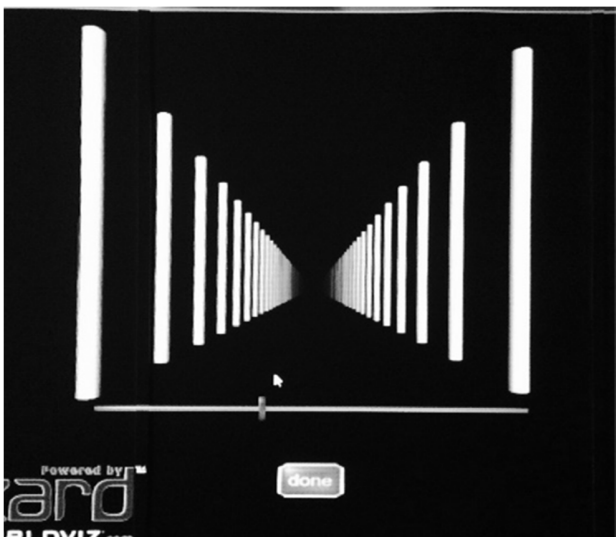


Figure 2. Projected Virtual Space

C. Equipment and Setup

The size of the screen upon which the virtual space movie was presented was 2,200 mm wide and 1,760 mm high. Participants were asked to find a comfortable point with their eyes at a vertical distance of exactly 1,900 mm from the center of the screen, to ensure a horizontal angle of 60 degrees for the field of view on the screen.

The movie was projected using a high-contrast projector (TAXAN/KG-PH202X, Brightness: 3,500 lm, Contrast: 1/2,000) connected to a workstation (DELL/Precision M3800). The interactive virtual space was described using computer graphics software (WorldViz: Vizard5.0).

D. Virtual Space

The background to the projected virtual space was entirely black, with no earth or sky. The virtual space contained a virtual thin black fog, which gradually obscured the virtual elements within the space, with the two rows of columns hidden entirely at a depth of 100 m from the virtual viewpoint.

A horizontal angle of 60 degrees was applied to the forward field of view in the virtual space, as this corresponded to the angle of the participant's viewpoint in real space, considering the screen width and shape. The height of the viewpoint in the virtual space was set at 1,500 mm, with the vanishing point in the movie set to the vertical centerline of the screen.

E. Columns

Two rows of virtual columns emerged from the vanishing point at the center of the virtual space on the projected screen. The two rows of columns were set at a distance of 7,000 mm apart, on the right and left of the mid-horizontal ground line, toward the vanishing point on the screen (Figure 2).

The intervals between the columns were set to certain values according to experimental condition. However, in all experimental conditions, the cross-sectional shape of the columns was circular (diameter: 300 mm) and the height of the columns was 6,000 mm.

One of the two columns in each experimental condition moved at a continuous fixed speed. In this study, fixed-speed columns were known as uncontrollable columns (U columns), while columns for which the speed was controlled using the virtual slider bar were known as controllable columns (C columns).

F. Experimental Condition

There were fifty-four experimental conditions designed according to the following factors: three U-column speeds, three U-column intervals, three C-column intervals, and two right-left arrangements (one with the U columns on the right and C columns on the left, and one with the opposite right/left combination). Each participant completed fifty-four trials representing all possible combinations of these factors.

U-column speed varied according to three levels: 1.5 meters per second (m/s), 3.0 m/s, and 6.0 m/s. These three speeds represented walking, running and riding a bicycle.

U-column and C-column intervals varied according to three levels: 3.1 m, 5.9 m, and 9.7 m. These values were set at 10% of the prime numbers 31, 59, and 97, to ensure that they

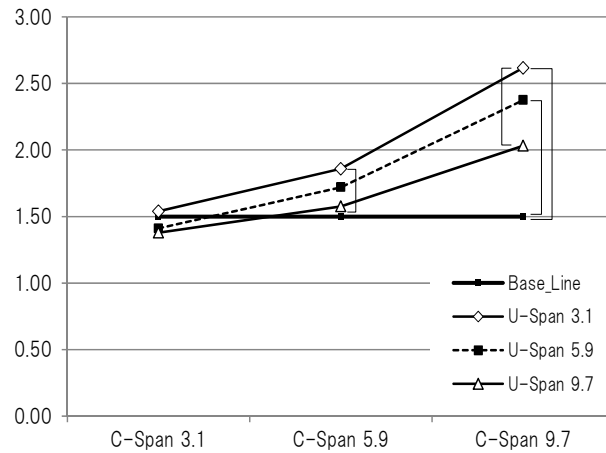


Figure 3. Transition of Mean Adjusted C-Column Speeds with Fixed U-Column Speeds of 1.5 m/s (m/s)

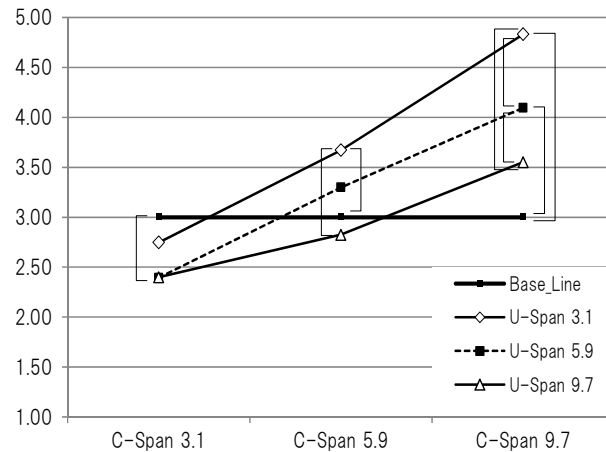


Figure 4. Transition of Mean Adjusted C-Column Speeds with Fixed U-Column Speeds of 3.0 m/s (m/s)

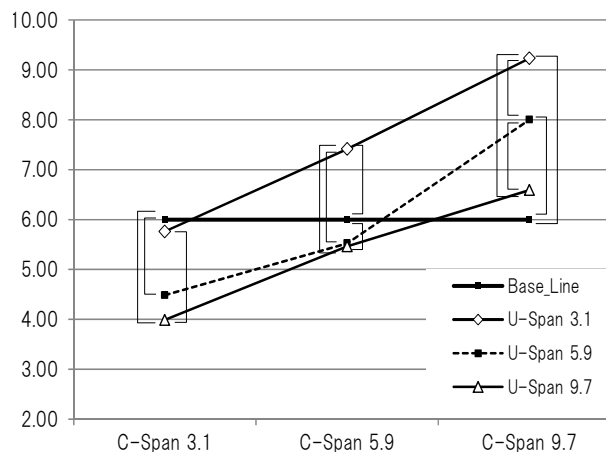


Figure 5. Transition of Mean Adjusted C-Column Speeds with Fixed U-Column Speeds of 6.0 m/s (m/s)

were similar to the numbers 3, 6, and 9, which were not used, because participants would have been able to use lower multiples of these numbers to determine common multiples of the intervals for the two rows of columns at a glance and adjust C-column speed by simply counting the number of columns flowing past on each side.

For example, if there were 3-m intervals between the right-hand columns and 6-m intervals between the left-hand columns, the third right-hand column and second left-hand column would be at the same position. Participants could adjust C-column speed by simply counting the number of columns flowing past on each side of the screen.

Participants were asked to adjust the C-column speed continuously to match the U-column speed, based on their own judgment. The virtual slider bar was placed in the lower area of the screen for ten seconds in each trial.

III. RESULTS

Mean C-column speeds, which were adjusted by participants in each condition, are shown in Figures 3, 4, and 5. Each figure shows the aggregated data for the different fixed U-column speeds.

All main and interaction effects were analyzed using a multi-way repeated ANOVA, with significant differences in the main effects analyzed via Bonferroni post-hoc paired-comparison tests. Analyses were performed using a significance level of $p = 0.01$; significant results are shown in square brackets.

A. Adjusted C-column Speeds with a Fixed U-column Speed of 1.5 m/s

Figure 3 shows the transition of mean C-column speeds adjusted by participants to match the fixed U-column speed of 1.5 m/s, or walking speed.

Fixed U-column and adjusted C-column speeds did not differ significantly with the regular intervals between the C columns (C span) set at 3.1 m.

However, when the C span was 5.9 m, mean adjusted C-column and fixed U-column speeds differed significantly with the intervals between U columns (U span) set at 3.1 m and used as a baseline ($p = 0.006$). This result suggests that, with a C span of 5.9 m, C-column speed was perceived to be slower relative to that of U-Columns with a U span of 3.1 m at walking speed.

In addition, when the C span was 9.7 m, adjusted C-column and fixed U-column speeds differed significantly with U spans of 3.1 m and 5.9 m ($p < 0.001$, $p = 0.001$, respectively). This result suggests that, when the C span was 9.7 m, C-column speed was perceived to be slower relative to that of U columns with U spans of 3.1 m or 5.9 m at walking speed.

In contrast, in comparisons of pairs of adjusted C-column speeds, there were no significant differences observed between pairs of C-column speeds with C spans of 3.1 m and 5.9 m. However, with a C span of 9.7 m, however, with a C span of 97 m, in which the intervals between columns were larger relative to those with C spans of 3.1 m and 5.7 m, adjusted C-column speeds with U spans of 3.1 m and 9.7 m differed significantly ($p < 0.001$).

As there were no significant differences between pairs of adjusted C-column speeds when C spans were 3.1 m or 5.9 m, the overall picture of results shown in Figure 3 indicates that the speeds of peripheral flowing columns with intervals of 9.7 m were perceived to be slower relative to those of columns with intervals of 3.1 m at walking speed.

B. Adjusted C-column Speeds with a Fixed U-Column Speed of 3.0 m/s

Figure 4 shows the transition of mean adjusted C-column speeds of 3.0 m/s, with fixed U-column speed set at running speed, for all participants. In a comparison of fixed U-column and adjusted C-column speeds, significant differences between speeds were observed with C spans of 3.1 m, 5.7 m, and 9.7 m.

First, when the C span was set at 3.1 m, mean adjusted C-column and fixed U-column speeds differed significantly when U spans of 5.9 m or 9.7 m were used as a baseline ($ps < 0.001$). These results suggest that, when the C span was 3.1 m, C-column speed was perceived to be faster relative to that of U columns with U spans of 5.9 m or 9.7 m at running speed.

Second, when the C span was 5.9 m, mean adjusted C-column and fixed U-column speeds differed significantly when the U span was 3.1 m ($p = 0.005$). These results suggest that, with a C span of 5.9 m, C-column speed was perceived to be slower relative to that of U columns with a U span of 3.1 m at running speed. In contrast, in a comparison of pairs of adjusted C-column speeds, no significant differences were observed between pairs with U spans of 5.9 m and 3.1 m or 5.9 m and 9.7 m; however, pairs with U spans of 3.1 m and 9.7 m differed significantly.

Third, when the C-Span was 9.7 m, mean adjusted C-column and fixed U-column speeds differed significantly when U spans were 3.1 m and 5.9 m ($p < 0.001$ and $p = 0.003$, respectively). These results suggest that, with a C span of 9.7 m, C-column speed was perceived to be slower relative to that of U columns with U spans of 3.1 m or 5.9 m at running speed. In a comparison of pairs of adjusted C-column speeds, significant differences were observed between pairs with U spans of 3.1 m and 5.9 m, 5.9 m and 9.7 m, and 3.1 m and 9.7 m ($p < 0.001$, $p < 0.007$, and $p < 0.001$, respectively).

The overall picture of results shown in Figure 4 indicates that the speed of peripheral flowing columns with intervals of 9.7 m was perceived to be slower relative to that of those with intervals of 3.1 m or 5.9 m at running speed.

C. Adjusted C-column Speed with a Fixed U-Column Speed of 6.0 m/s

Figure 5 shows the transition of mean values for adjusted C-column speeds of 6.0 m/s, with fixed U-columns set at bicycle speed, for all participants. A comparison of fixed U-column and adjusted C-column speeds revealed significant differences between all comparable pairs.

With a C span of 3.1 m, mean adjusted C-column and fixed U-column speeds differed significantly when U spans were 5.9 m and 9.7 m ($ps < 0.001$). These results suggest that, when the C span was 3.1 m, C-column speed was perceived to be faster relative to that of U columns with U spans of 5.9 m or 9.7 m at bicycle speed.

With a C span of 5.9 m, mean adjusted C-column and fixed U-column speeds differed significantly when U spans were 3.1 m and 9.7 m ($p < 0.002$ and $p < 0.006$, respectively). These results suggest that, when the C span was 5.9 m, C-column speed was perceived to be faster relative to that of U columns with a U span of 3.1 m and slower relative to that of U columns with a U span of 9.7 m at bicycle speed.

With a C span of 9.7 m, mean adjusted C-column and fixed U-column speeds differed significantly when U spans were 3.1 m and 5.9 m ($p < 0.001$ and $p < 0.007$, respectively). These results suggest that, when the C span was 9.7 m, C-column speed was perceived to be slower relative to that of U columns with intervals of 3.1 m or 5.9 m at bicycle speed.

As pairs of adjusted C-column speeds with C spans of 3.1 m, 5.9 m, and 9.7 m differed significantly, the overall picture of results shown in Figure 5 indicates that the speed of peripheral flowing columns with intervals of 9.7 m was perceived to be slower relative to that of those with intervals of 3.1 m or 5.9 m; in addition, the speed of peripheral flowing columns with intervals of 5.9 m was perceived to be slower relative to that of those with intervals of 3.1 m at bicycle speed.

IV. DISCUSSION

The results reported herein generally indicate that participants tended to adjust C-column speed (the speed of controllable columns) to be faster, relative to that of U-column speed (the speed of the fixed columns), when the C span (regular intervals between the controllable columns) was wider relative to the U span (regular intervals between the fixed columns), in all three U-column speed conditions. This finding suggests that C-column speed was perceived to be slower, relative to U-column speed, when the C span was wider relative to the U span, regardless of U-column speed condition.

In contrast, the results also indicate that the participants tended to adjust C-column speed to be slower, relative to U-column speed, when the C span was narrower relative to the U span, in all three U-column speed conditions. This finding suggests that C-column speed was perceived to be faster, relative to U-column speed, when the C span was narrower relative to the U span, regardless of U-column speed condition.

This tendency can be summarized as follows: the speed of columns with wider spans was adjusted to be faster relative to that of columns with narrower spans, and the speed of columns with narrower spans was adjusted to be slower relative to that of columns with wider spans. The results also show that this tendency increased when U-column speed was faster in the 6.0 m/s, 3.0 m/s, and 1.5 m/s U-column speed conditions.

The tendency observed in the current study was similar to that of Manser's achievements in simulator experiments in which vehicle drivers reduced their driving speeds gradually when exposed to decreasing visual pattern width and increased their driving speeds when exposed to increasing visual pattern width expressed on the peripheral walls [5]. The findings also complemented Allpress' observation in an open-road investigation, in which the uneven spacing arrangement of roadside cones at a roadwork site were highly effective at

controlling driving speeds and led to a reduction in the number of speed-related accidents [6].

The findings of the current study also suggest that the speed modification method based on the nature of human speed perception, which involves controlling the design of visual stimuli expressed in the peripheral visual field, could be applicable at the slower speeds of walking or running.

However, the findings of the current study are inconsistent with Godley's [7] and Katz's [8] findings. Both studies reported that speed perception was not influenced by decreasing spacing of peripheral transverse lines on the roadside of a simulated roadway. The difference between the results of the current study and those of the earlier studies could be due to differences in the sizes of visual stimuli presented in the peripheral visual fields. In both earlier studies, the visual stimuli effects were verified via transverse bars, which were very short white lines at the side of the roadway surface. In contrast, the visual stimuli in the current study were columns of 6 m in height. Large and three-dimensional objective visual stimuli, rather than the surficial visual stimuli used in the earlier studies, could have exerted a significant effect on human speed perception.

The first limitation of the current study was that the experiment was conducted using a movie projected on a flat screen, which entailed a horizontal visual angle limited to 60 degrees. A different visual angle on the screen or an immersive experimental instrument, such as the vehicle simulator used in the earlier studies, could have yielded different results. The second limitation was that the background of the scene, which included earth and sky, was removed from the virtual space. Numerous factors could affect human speed perception, and different combinations of these factors yield different results. Other factors should be considered in future studies.

V. CONCLUSION AND FUTURE WORK

The following results constitute the most important findings of the study:

- At 1.5 m/s, human walking speed, the speed of peripheral flowing columns with intervals of 9.7 m was perceived to be slower relative to that of those with intervals of 3.1 m.
- At 3.0 m/s, human running speed, the speed of peripheral flowing columns with intervals of 9.7 m was perceived to be slower relative to that of those with intervals of 3.1 m or 5.9 m.
- At 6.0 m/s, bicycle speed, the speed of peripheral flowing columns with intervals of 9.7 m was perceived to be slower relative to that of those with intervals of 3.1 m or 5.9 m.
- At 6.0 m/s, bicycle speed, the speed of peripheral flowing columns with intervals of 5.9 m was perceived to be slower relative to that of those with intervals of 3.1 m.

The main finding was that, as peripheral visual stimuli, intervals between roadside columns exerted a significant influence on human speed perception.

The most memorable finding was that controlling the intervals between roadside columns affected the perception of human walking and running speeds, which were slower relative to those used in early driving studies in which environmental roadside design was effective in controlling driving speeds; in other words, the findings of the present study indicated that the effects observed for higher speeds in driving studies could also be observed with slower speeds.

Future studies should examine human speed perception by varying the height and thickness of roadside columns. If future studies also find strong relationships between these parameters and human speed perception, the collective knowledge provided by their findings and those of the current study could be useful in designing an improved pedestrian environment to ensure comfortable walking and fun running.

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