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Rapid Communication

Evaluation of Human Behavior in Collision Avoidance: A Study inside Immersive Virtual Reality

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Abstract

During our daily displacements, we should consider the individuals advancing toward us in order to avoid a possible collision with our congeneric. We developed an experimental design in a virtual immersion room, which allows us to evaluate human capacities for avoiding collisions with other people. In addition, the design allows participants to interact naturally inside this immersive virtual reality setup when a pedestrian is moving toward them, creating a possible risk of collision. Results suggest that the performance is associated with visual and motor capacities and could be adjusted by cognitive social perception.

Introduction

In recent years, there has been a growing interest in understanding pedestrians' behavior and their daily displacement inside urban spaces.[1] Collision avoidance is an important aspect of pedestrian daily displacement. It reflects, to some extent, the constraints and actions imposed by the behavior of one person on the perception of others. Pedestrians circulating and crossing each other's paths, changing direction, slowing or stopping, and so on, generate considerable dynamics of movement to which we must frequently react in a quick and precise manner. Walking on a busy sidewalk, in a shopping mall, or in the subway are a few good examples of these conditions. However, what essential characteristics must we consider in order to avoid a possible collision with other pedestrians when we decide to move? Is it necessary to consider the whole of the body or to segment the information produced by movement dynamics? The brain must distinguish local motion within the scene from the global image drift, but it must also consider the social characteristics generated by the event.

Materials and Methods

Participants

Thirteen students from Université de Montréal participated, 5 women and 8 men. Participants were between 22 and 28 years old (*M* 24, *SD* 2.7), right-handed, and had normal or corrected-to-normal vision. They presented no motor handicaps. None of the participants were aware of the experiment objectives.

Stimuli

In order to eliminate the emotional attributes produced by a "character," biological motion was used to produce the pedestrian stimulus.[2] Open GL® (Open Graphics Library) was used for drawing the spheres to the articulation (upper neck, wrists, elbows, shoulders, hips, knees, and ankles), and motion capture was used to produce the animation. The result enabled a real-time rendering of a very natural human gait using low system resources. When the stimulus was presented in control conditions, the spheres were presented randomly in a matrix, which respected the pedestrian stimulus space and temporal properties. This control condition was used in order to ensure that participants could discriminate the human biological movement from a random motion point display. The pedestrian stimulus was represented in translation in seven different directions (Fig. 1).

In order to obtain an equivalent collision limit for each participant, we developed an algorithmic animation determining the direction according to the participants' shoulder widths with the pedestrian's stimulus shoulder widths. The collision point was applied close to the external part of the observer's shoulder (0.25 inch). All animations started from the center of the immersion room. Simulations were presented randomly for durations corresponding to the initial distance of the pedestrian stimuli relative to the participants'. Therefore, the pedestrian stimulus took 2, 2.5, and 3 seconds

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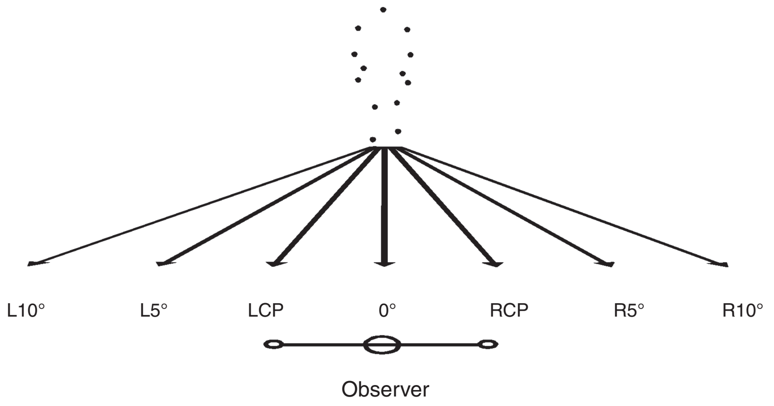

FIG. 1. Pedestrian movement could occur in seven directions. Collision point on the left, (LCP), 5° left (L5°), 10° left (L10°), 0° facing the observer, collision point on the right (RCP), 5° right (R5°), 10° right (R10°).

respectively at a constant speed to be in contact with the observer. The pedestrian stimulus was 5 feet 8 inches in height with a shoulder width of 18 inches. Video animation of the stimulus during the experiment: http://video.google.fr/videoplay?docid=-7284933202475650558&hl=fr

Apparatus

Simulations took place in a virtual reality room (CAVE®) made up of four projection surfaces (3 walls and 1 floor) of 8 cubic feet. Projections on the wall were produced by four Christie projectors, Marquee Ultra 8500 projection system with a resolution of 1350 × 1100 ANSI pixels. Stereo was generated by Crystal eyes stereoscopic glasses. Simulations were computed with an SGI Onyx 3200 computer allowing graphic display and mathematical calculations with six 400 MHz processors, MIPS R12000 and two Infinite Reality 2 graphic boards.

Procedure

Before beginning the experiment, we measured the width of the participants' shoulders in order to produce an equivalent possibility of collision for each observer. Participants were upright in a square (18 × 18 in.) represented on the floor in the center of the immersion room. A first simulation began when one participant took a seat in the square. The task of the participant was to move either to the left or to the right when a collision was identified with the pedestrian stimulus (moving forward was considered a wrong answer). When no collision was identified, the participant was to move forward (moving to the left or right was considered a wrong answer). When the stimulus was presented in control conditions, the participant moved backward. After each simulation, the participant returns and stands up to the square, and the next simulation begin 200 ms later. Motor responses, in addition to reaction times of participants, were measured with a magnetic tracking system (Flock of Bird®) linked to a sensor mounted on shutter glasses. These simulations were randomly presented 20 times, using the method of constant stimuli for 840 presentations. The experiment lasted 40 minutes on average. All 14 simulations (normal and control) were first presented to the participant to familiarize them with the nature of the experiment. During the experimentation, the participants were videotaped for their safety and to make sure they respected the instructions.

Statistical analysis

Data analysis was performed using analysis of variance with three repeated factors: Experiment (control/experimental), Direction (10°L, 5°L, LCL, 0°, RCL, 5°R, 10°R), and Distance (12 ft, 10 ft, 8 ft), follow by Bonferroni contrasts. In case of interaction, separate analysis of variance was performed for each direction and distance. The results were considered statistically significant if probability (p) values were less than 0.05. All analysis was done with SPSS, version 15.0.

Results

Regardless of the angle or the distance from the pedestrian stimulus, the percentage of correct answers from both sides was higher when normal biological motion was presented (70.5%) than when the control condition was presented (67.7%), $F(1.11) = 6.835$, $p = 0.024$. Reaction time was significantly higher on the right side when the control condition was presented as compared to normal biological motion, $F(1.11) = 6.884$, $p = 0.024$.

The results show a main effect for the distances, $F(2.22) = 7.132$, $p = 0.004$, and the angle of presentations regarding the percentage of correct answers, $F(6.66) = 25.130$, $p = 0.0001$. However, there is an interaction between both factors, $F(12.132) = 6.447$, $p = 0.0001$. Therefore, we present the results independently for each distance according to the angle of directions of the pedestrian stimulus. As we can see in Figure 2, when the pedestrian began the walk cycle from a distance of 12 feet, advancing toward the observer from the front, the percentage of accurate answers was 96.25%. The percentage of correct answers for the collision point was 87.7% on the left side and 89.8% on the right, $F(6.66) = 14.442$, $p = 1.000$. When the pedestrian deviated from the collision limit, we observed a marked drop-off in performance. At 5° on the left side, it was 59.4%, and on the right, 30.7%. We observed an improvement in performance at 10°: 82.1% on the left and 30.7% on the right. In addition, there was a significant difference between the right collision limit and the angle of presentation 5° on the right side, $F(6.66) = 14.442$, $p = 0.003$. We also observed a significant difference between the angle of presentation 5° on the right side and 10° on the right, $F(6.66) = 14.442$, $p = 0.007$). When the pedestrian began the walk cycle at 10 feet, we observe equivalent results. Still, when the pedestrian came from the front, the percentage of correct answers was near the ceiling at

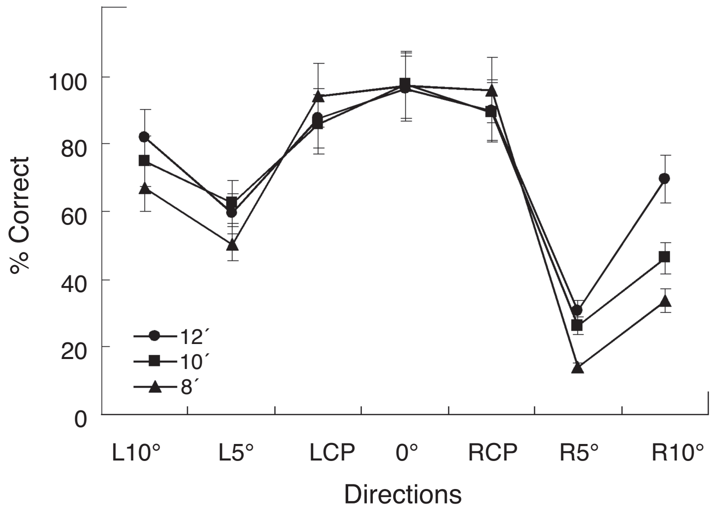

FIG. 2. Percentage of correct answer according to the directions and the distance from the observer. Error bars represent standard error of the mean.

97.5%. The percentage of correct answers for the collision point was 85.8% on the left side and 89.4% on the right, $F(6.66) = 15.980$, $p = 1.000$. At 5°, it was 62.7% on the left and 26.2% on the right, $F(6.66) = 15.980$, $p = 0.002$. At 10°, it was 75.0% on the left and 45.2% on the right, $F(6.66) = 15.980$, $p = 0.038$. We also observed a significant difference between the right collision point and the angle of presentation 5° on the right, $F(6.66) = 15.980$, $p = 0.004$. The distance effects were more significant when the pedestrian began the walk cycle at 8 feet relative to distances from 10 and 12 feet. Similar to other distances, when the pedestrian came from the front, the percentage of correct answers was near the ceiling at 97.3%. The percentage of correct answers for the collision point was 91.7% on the left side and 96.0% on the right, $F(6.66) = 15.980$, $p = 1.000$. At 5°, it was 50.4% on the left and 13.0% on the right, $F(6.66) = 15.980$, $p = 0.001$. At 10°, it was 66.9% on the left and 33.7% on the right, $F(6.66) = 15.980$, $p = 0.005$. We observed a significant difference between the left collision point and the angle of presentation 5° on the left, $F(6.66) = 15.980$, $p = 0.016$. There was also significant difference between the right collision points and the angle of presentation 5° on the right, $F(6.66) = 15.980$, $p = 0.0001$, and 10° on the right, $F(6.66) = 15.980$, $p = 0.002$.

Discussion

The first results demonstrate that humans are very clever at avoiding collisions with fellow human beings, even if the approaching person is represented only by point-light display (biological motion). When the pedestrian stimulus advances toward the observer from the front, the percentage of accurate responses is near the ceiling. Moreover, the percentage of correct answers for the collision limits is higher regardless of the distance from the pedestrian stimulus. Consequently, the participants adopt the appropriate behavior 88% of the time on average (and collision occurs 22% of the time). They move to the left or to the right according to the pedestrian trajectory. When the pedestrian stimulus advances toward participants at 5° on the left or 5° on the right side, we could anticipate results similar to those observed for the collision limits. Because there is more space between the pedestrian and the participants, the task should be easier. Obviously, participants commit false positives and persist in avoiding collision even when no collisions would have happened. Therefore, the results decrease according to the side of presentation and the distance. For example, at 8 feet, when the pedestrian approaches on the right side, the participants move to the left side approximately 87% of the time, whereas they need not have moved left to avoid collision but could have continued to move forward. When the distance between the pedestrian and the participants is greater with an angle of 10°, participants seem more confident. We also observed an increase in performance, which was more pronounced on the left side. However, performance stayed very weak on the right side with distances of 10 and 8 feet.

What are the essential characteristics to take into account in order to avoid a collision with other pedestrians when we decide to move? Several psychophysical studies support the assumption that the visual recognition of biological motion depends on a mechanism of large space treatment.[2,3] However, local and global mechanisms are difficult to define in absolute terms. Several studies on biological motion perception define the local analysis as the treatment of a specific articulation or the treatment of the relation between two points or articulations—for example, the influence of the hips and the shoulders in recognizing gender.[4] The global analysis of local motion elements is directed through a much broader area and involves the whole of the biological motion.[5] When identifying the collision point (e.g., shoulder), it has been stated that global processing is not effective. The visual system must accurately distinguish local motion within the scene from the global image drift, allowing the motor system to react adequately to avoid a collision. For example, when participants direct their attention to the global features of an object, activity increases in visual area V2. Attention to the local features activates visual area V3.[6] However, the contributions of the local movement analysis in collision avoidance do not clearly explain the behavior that remains when the pedestrian is outside of the collision point (e.g., 5° to the left side). Under these conditions, when participants are close to the collision point, the decision tends to be directed in favor of perceptual social analysis if the directions are not sufficiently distinct between the participant and the pedestrian. Consequently, the behavior adopted by the participant in this experiment seems partly generated by cognitive social perception, which refers to the initial stages of dealing with information, leading to a specific analysis of another individual's arrangements and intentions.[7] Based on this premise, we can assume that an individual will not intentionally collide with another pedestrian but will prevent the collision risk until he or she is certain that contact can be avoided. Additionally, in the context of our daily displacements, we reproduce the same behavior that participants adopted inside virtual reality.

Neuropsychological assumptions seem also to emanate from this behavior. Some evidence implies that the superior temporal sulcus (STS) plays an important role in the interpretation of biological motion and in social interactions. For example, the STS area is sensitive not only to biological motion but also, more broadly, to stimuli that provoke an intention or an intentional activity.[8,9] This area receives converging entries from the dorsal and ventral pathways.[10] Integration could contribute to perception and interpretation of biological motion direction. Moreover, recent fMRI experiments demonstrate an activation of the premotor cortex, in addition to the STS, in the perception of actions produced by biological movements.[11] The most important functions of the prefrontal association area are to evaluate the consequences of future actions and to plan and organize these actions accordingly. The prefrontal association area is also engaged in tasks that require a delay between a stimulus and a behavioral response or that depend on recent experience for achievement. To select the appropriate motor responses, the frontal association areas must integrate sensory information from both the outside world and the body. All the premotor areas project to the primary motor cortex. The primary motor cortex receives input from the posterior parietal area, and we know that parietal areas are involved in integrating multiple sensory modalities for motor planning. The functionality of premotor circuits involves the ability to organize a behavioral response and to generate motor programs. Visual projections from the parietal cortex connections are primarily directed to the dorsal and lateral cortex, including robust connections in the premotor cortex,[12,13] which receives input from area V3 (V3 is involved in the local motion detection). Thus, the behavior we observed by participants in this experiment when they avoid collision with the pedestrian (when there is no collision risk), suggests that the signal received by the premotor cortex, and coming from visual area V3 is suppresses by the prefrontal cortex. Under these conditions, where participants are outside to the collision points, we observed a marked drop-off in performance. The decision tends to be directed in favor on perceptual social analysis if the distance between the participant and the pedestrian are not sufficiently distinct.

Disclosure Statement

The authors have no conflict of interest.

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