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LOCOMOTION THROUGH A COMPLEX ENVIRONMENT WITH LIMITED FIELD-OF-VIEW [1,2]

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Summary.—Restrictions of field-of-view are known to impair human performance for a range of different tasks. However, such effects on human locomotion through a complex environment are still not clear. Effects of both horizontal (30°, 75°, 112°, 120°, 140°, 160°, and 180°) and vertical (18° and 48°) field-of-view restrictions on the walking speed and head movements of participants maneuvering through an obstacle course were investigated. All field-of-view restrictions tested significantly increased time to complete the entire course, compared to the unrestricted condition. The time to traverse the course was significantly longer for a vertical field-of-view of 18° than for a vertical field-of-view of 48°. For a fixed vertical field-of-view size, the traversal time was constant for horizontal field-of-view sizes ranging between 75° and 180° and increased significantly for the 30° horizontal field-of-view condition. In the restricted viewing conditions, the angular velocity of head movements made while stepping over an obstacle increased significantly over that for the unrestricted field-of-view condition, but no difference was found between the different field-of-view sizes. Implications of the current findings for the development of devices with field-of-view restrictions are discussed.

In this study effects of field-of-view restrictions were investigated on locomotion by participants maneuvering through a course with horizontal and vertical obstacles. Several studies have shown that field-of-view restrictions degrade human observers' performance on a range of different tasks (Dolezal, 1982; Wells & Venturino, 1990; Alfano & Michel, 1990; Arthur, 2000; Watt, Bradshaw, & Rushton, 2000; Jennings & Craig, 2000; Lin, Duh, Parker, Abi-Rached, & Furness, 2002; Van Erp & Padmos, 2004; Wade, Weimar, & Davis, 2004; Loftus, Murphy, McKenna, & Mon-Williams, 2004; Creem-Regehr, Willemsen, Gooch, & Thompson, 2005; Chevaldonné, Ballaz, Mérienne, Neveu, Chevassus, Guillaume, & Arbez, 2006; Wells, Venturino, & Osgood, 2006). However, the relationship between maneuvering performance and field-of-view size is currently not fully understood.

Head-mounted displays with field-of-view limited to 40° to 70° are frequently deployed in virtual environments for training and rehearsing tasks involving human locomotion through complex environments (e.g., first re-

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sponder actions, military operations in urban terrain), for the evaluation of designs (e.g., buildings, ships, and factories), and for entertainment purposes (e.g., gaming). Dismounted soldiers performing nighttime operations in urban terrain frequently deploy night-vision goggles, with field-of-view typically limited to 30° to 40° (RCTA, Inc., 2001). In these applications the field-of-view is considerably smaller than the unrestricted field-of-view, which has an average horizontal angle of approximately 200° and an average vertical angle of about 135° (Werner, 1991). Restricting the human visual field may compromise an observer's ability to control heading or process spatial information (Patterson, Winterbottom, & Pierce, 2006), can influence estimates of distance (Watt, *et al.*, 2000), and compromises postural stability (Dolezal, 1982; Amblard, Cremieux, Marchand, & Carblanc, 1985; Alfano & Michel, 1990; Turano, Herdman, & Dagnelie, 1993). Most of these tasks require analysis of spatial relations between objects in the environment, control of heading during locomotion through the environment, and continuous maintenance of postural equilibrium. Any restriction of the peripheral visual field may then be detrimental for performance of a locomotion task. Increasing the amount of peripheral information by extending the field-of-view of head-mounted displays and night-vision goggles is costly, reduces their resolution, or makes them heavier and therefore less comfortable to wear (Latham, 1999). Moreover, for applications in a virtual environment wider fields-of-view yield greater sensations of motion sickness (Pausch, Crea, & Conway, 1992; Psotka & Lewis, 1995). To evaluate trade-offs between human performance, cost, and ergonomic aspects, one must know how field-of-view restrictions affect human locomotion through complex structured environments.

In this study locomotion performance was characterized by (1) the time participants took to walk as fast as possible through an obstacle course while making as few errors as possible and by (2) the angular velocity of head movements they made just before crossing one of the obstacles. The first hypothesis was that participants would need more time to complete the course when the field-of-view was restricted. The second hypothesis was that participants would try to compensate for the field-of-view restrictions by making increased head movements. More specifically, vertical field-of-view restrictions were hypothesized to contribute to an increase of the pitch and roll components of head movement (rotations along, respectively, the left-right and forward-back axes), while horizontal restrictions would increase the yaw component (rotation along the vertical body axis).

Method

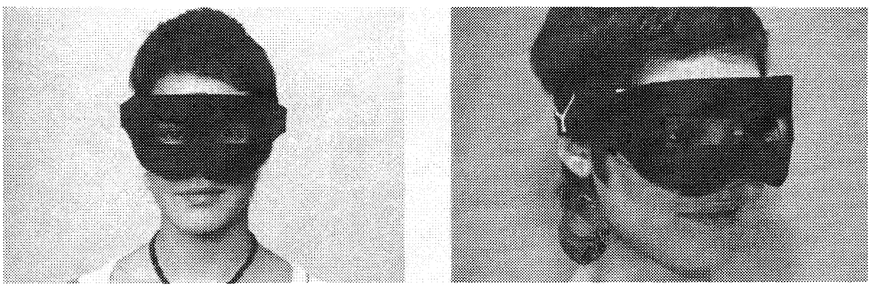
Participants

A total of 12 paid participants, six men (*M* age = 21.8 yr., *SD* = 2.2 yr.)

and six women (M age = 21.2 yr., SD = 2.1 yr.) were tested. Participants were students who reported normal (20/20) or corrected-to-normal vision (by wearing contact lenses) and stated they were free of impediments to normal locomotion. The experimental protocol was approved by the TNO Human Factors internal review board for experiments with human participants. Participants gave their informed consent prior to testing.

Goggles

Ski goggles from which the lenses had been removed were used to restrict the field-of-view. The different conditions of field-of-view restriction were achieved by attaching black cardboard masks with rectangular openings of different sizes to the goggles by means of Velcro tape (cf. Fig. 1).



(a) (b)

FIG. 1. Participant wearing the goggles with different field-of-view restricting masks: (a) 48° vertical/75° horizontal; (b) 48° vertical/120° horizontal.

The (horizontal and vertical) physical aperture or size of the templates were estimated from the geometry of the environment in which a participant wearing the goggles is standing in front of a vertical office wall to which two (horizontally or vertically separated) markers were attached, such that the (horizontal or vertical) spatial interval defined by the markers just fitted their field-of-view.

The set of masks provided two vertical and seven horizontal field-of-view restrictions. The vertical field-of-view sizes were, respectively, 18° and 48°, and the horizontal field-of-view sizes were, respectively, 30°, 75°, 112°, 120°, 140°, 160°, and 180°. The vertical and horizontal field-of-view sizes were combined such that a total of 14 (2×7) masks with different field-of-view combinations were constructed.

The masks with 30° and 75° horizontal field-of-view sizes differed from the others because the smaller horizontal fields-of-view also restricted overlap of the images from both eyes. For larger field-of-view sizes this restriction decreased (cf. Fig. 1).

Obstacle Course

The obstacle course was an 8-m long and 135-cm wide straight-walled course. The walls were made of wooden frames covered with white linen sheets. These walls simplified the visual environment and eliminated occurrence of visual distractions during the experiment.

Obstacles were placed at three different locations along the course, with a distance of 115 cm between the starting point and the first obstacle, 160 cm between two consecutive obstacles, and 115 cm between the last obstacle and the end of the course (cf. Fig. 2). Each obstacle required performance of different bodily movements to cross them.

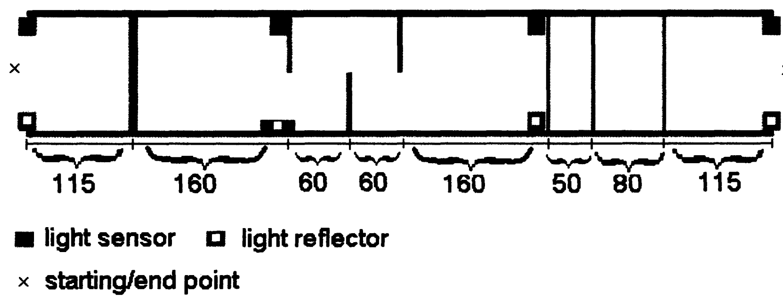


FIG. 2. Top view of the course with the three different obstacles (all dimensions are given in cm). From left to right: the bar, the three dividers, and the three shelves. Light sensors and reflectors were placed at four locations along the course, dividing it into three segments with lengths (left to right) of 275 cm, 280 cm, and 245 cm, respectively.

One of the obstacles was a cardboard bar (cf. Fig. 3a), mounted such that its midpoint was always 110 cm above the ground, while the bar could be placed in either a horizontal or diagonal orientation. The bar was made of soft material to prevent participants from hurting themselves. This obstacle was located at a distance of 115 cm from the nearest entrance of the course. Participants had to stoop underneath the bar to cross this segment of the course (cf. Fig. 3a).

The second obstacle was placed in the middle of the course and consisted of three dividers made from the same material used in constructing walls of the course. Two dividers were attached perpendicular to one wall of the course, one behind the other with a distance of 120 cm between them. The third divider was attached perpendicular to the opposite course wall, such that it was located at the midpoint of the 120-cm interval defined by the first and last divider (cf. Fig. 2). Thus, the separation between the two consecutive dividers was 60 cm, and the overall length of this obstacle was 180 cm (cf. Fig. 2). To traverse this segment of the course, participants had to follow an S-curved trajectory along the three dividers.

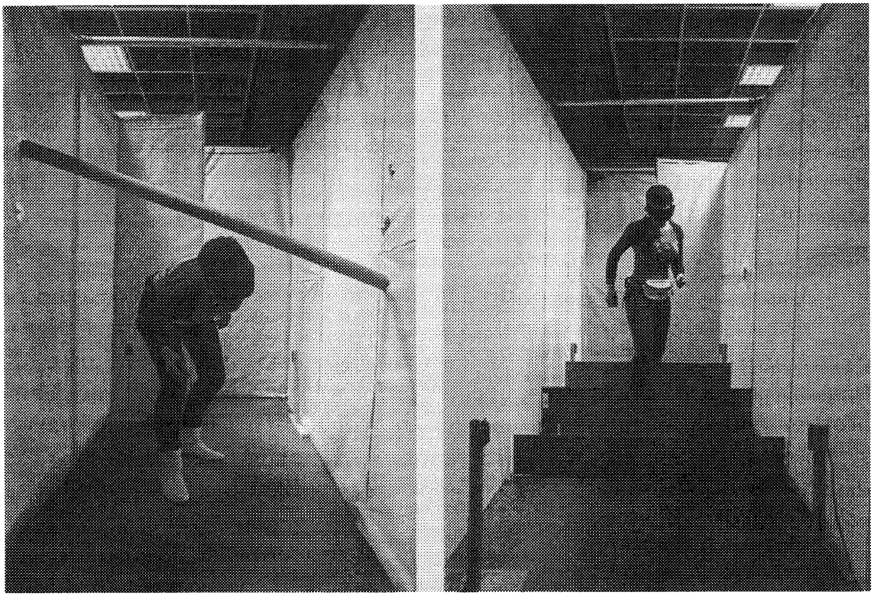


FIG. 3. The obstacle course: (a) participant ducking to avoid hitting the bar; (b) participant stepping over shelves.

The third obstacle consisted of three thin wooden shelves, with heights of 20, 30, and 40 cm, respectively. The shelves were placed in an upright position on the ground, perpendicular to the walls. The distance between the first and second shelves was 50 cm, and the distance between the second and third shelves was 80 cm, giving an overall obstacle length of 130 cm. This obstacle was located at a distance of 115 cm from the nearest entrance of the course. As a safety measure, the shelves were not rigidly fixed on the ground to assure that physical contact between a participant and a shelf would displace or tip over a shelf. To cross this obstacle participants had to step over each shelf (cf. Fig. 3b).

Time Registration

To register the time participants needed to traverse the entire course and the time needed to cross each obstacle, four pairs of poles equipped with infrared light-emitting-diodes, photoelectric beam sensors, and retro reflectors (type Velleman PEM5D; www.velleman.be) were used. The devices emitted and registered the return of an infrared light beam, which was reflected by a small mirror on the opposite pole. Whenever a participant interrupted a beam, the moment of interruption was registered by the time acquisition system. One pair of poles was placed at the beginning and one at the end of the course. The third pair was placed just before the first divider of the second obstacle, when viewed from the side of the bar. Finally, the last pair of poles was placed just before the first shelf of the last obstacle when viewed from the side of the three dividers (cf. Fig. 2). Thus, the course was divided into three segments: the bar segment of length 275 cm, the divider segment of length 280 cm, and the shelf segment of length 245 cm.

Registration of Head Movement

A specially developed registration system was used, which consisted of a small block ($18 \times 19 \times 26$ mm, 13 g) housing six Murata Gyrostar piezoelectric gyroscopes (Type ENC-03J; www.murata.com), to register three orthogonal angular velocity components (pitch, roll, and yaw) of participants' head motion during their traversal of the course. This motion-registration system was connected to a small data logger. Sampling rate was 50 Hz. The data logger registered each trial as a separate data file which was stored on a compact flash card.

In the full field-of-view condition, the detector was attached by Velcro tape onto the backside of a headband worn by each participant. In the restricted field-of-view conditions, it was attached to the goggles band located at the back of the head. The data logger was placed in a hip bag worn by the participant.

Video Registration

Three observation cameras were used to register and observe participants' behavior during traversal of the course. Two cameras were mounted on top of the middle divider of the second obstacle, each at one side of the divider. One of these cameras was aimed at the first part of the course and the other at the last part. The third camera was mounted on the ceiling, right above the middle part of the course, looking straight down. This way it was possible to oversee the entire course.

Video registrations were made of each trial to enable closer inspection of behavior which might contribute variance in the measurements, in addition to that by the independent variables. Recorded data have not been analyzed further within this study because no unusual behavior occurred during these experiments.

Design

A 7 (horizontal field-of-view) $\times$ 2 (vertical field-of-view) repeated-measures within-participants design was used. To balance possible learning effects, the different field-of-view conditions and the two different starting and end points were balanced over trials using a Latin square design (Wagenaar, 1969). In addition to the restricted field-of-view conditions, the full field-of-view condition was tested at the beginning and at the end of the experiment. This provided a check for a possible overall learning effect which might be related to participants' becoming familiar with the course during the experiment.

Dependent Variables

The first dependent variable was the time needed to perform the locomotion task. This variable had two components, the time in seconds to complete the entire course and the time in seconds to cross each of the individual obstacles.

The second dependent variable consisted of head movements made during an interval of 1 sec. just before crossing an obstacle, expressed by the mean angular velocity (deg./sec.) of, respectively, the yaw, pitch, and roll components of head movement. A 1-sec. interval prior to crossing the obstacle was chosen because it was expected that participants would try to compensate for the field-of-view restrictions by making extra head movements during the last phase of their approach (Wells & Venturino, 1990; Szoboszlay, Haworth, Reynolds, Lee, & Halmos, 1995; Kasper, Haworth, Szoboszlay, King, & Halmos, 1997; Gallimore, Brannon, & Patterson, 1998), whereas additional head movements were not needed far before an obstacle or during the actual traversing of an obstacle.

Also, subjective feelings about the effects of the imposed restrictions, as expressed by the participants, were recorded.

Procedure

First, each participant was asked to complete an informed consent statement. Then, each was given written and verbal instructions about the course, the three different obstacles, the goggles, and the head-movement detector. A participant was then asked to take his place at a cross marked on the ground at one entrance of the course and to stand still for 5 sec. with the head in an upright position, facing the entrance and looking straight ahead. After 5 sec. a start sign was given by the experimenter, and each participant had to traverse the course as fast, but also as safely, as possible (i.e., without hitting any part of the course). The cameras mounted on the ceiling above the setup provided an overview of the course and allowed the experimenter to observe each participant's actions. Trials on which the participant collided with any part of the course were repeated and not included in the data analyses. This happened only a few times during the entire experiment. A cross marked on the ground at the opposite side of the course indicated the end of the trial, at which the participant had to stop and again stand still in an upright position for 5 sec.

At this stage there were two alternative return routes. The first option was to turn 180° and retraverse the course from that point. The second option was to walk along a route on the outside of the obstacle course, back to the initial starting position, and to begin a retraversal of the course from that point. These two different walking routes were balanced over trials to reduce possible learning effects. The experimenter indicated the new starting position after the finish of each trial. In this way the different field-of-view conditions were tested, and each specific condition was repeated three times. The first of these three runs served as a practice trial, allowing the participant to become familiarized with the new field-of-view condition. Only the last two measurements were subjected to analysis. Between the different field-of-view conditions there was a short rest during which the field-of-view restrictions were removed to reduce possible transfer effects of the last condition to the following trial. During these breaks participants had the opportunity to give their subjective impression about the effects of the restriction on their performance and to express other feelings they thought relevant for the experiment.

To reduce possible learning effects (adaptation to the course), the three wooden shelves were randomly reordered each time a participant had completed seven trials, and the orientation of the bar was also altered in a random order.

Data Analysis

To compare the effects of the different field-of-view restrictions on time, a repeated measures analysis of variance was performed, with seven horizontal restrictions and two vertical restrictions as the within-subject factors. This was done for the entire course and also for every obstacle segment individually. If significant overall effects were found, a paired-samples *t* test was applied to assess pairwise differences (α set to 5%).

A MATLAB script (The Math Works; www.mathworks.com) was used to process and display the angular velocities of the recorded head-movement data. A Gaussian function ($\sigma = 40$ samples, corresponding to a temporal interval of 0.8 sec.) was used to smooth the angular velocity data of the yaw, pitch, and roll components. This served to filter small variations in head movement and to display only the relevant trends. Then the angular velocity of the head movements made before crossing each obstacle was computed. STATISTICA 7.0 (StatSoft, Inc.) was used to analyze the data. For every obstacle individually, three repeated measures analyses of variance (one test for each component of head movement, with seven horizontal field-of-view restrictions and two vertical field-of-view restrictions as the within-subject factors, were performed to compare the effects of the different field-of-view conditions on the angular velocity of the head movements. Whenever these tests showed significant overall effects, paired-samples *t* tests were performed to evaluate the pairwise differences (α was set to 5%).

Results

Time Data

The horizontal field of view had a significant main effect on the mean time needed to traverse the entire course ($F_{8,88} = 102.2$, $p < .01$; cf. Fig. 4). Also, a significant difference was found between the two vertical field-of-view restrictions ($F_{1,11} = 21.0$, $p < .01$).

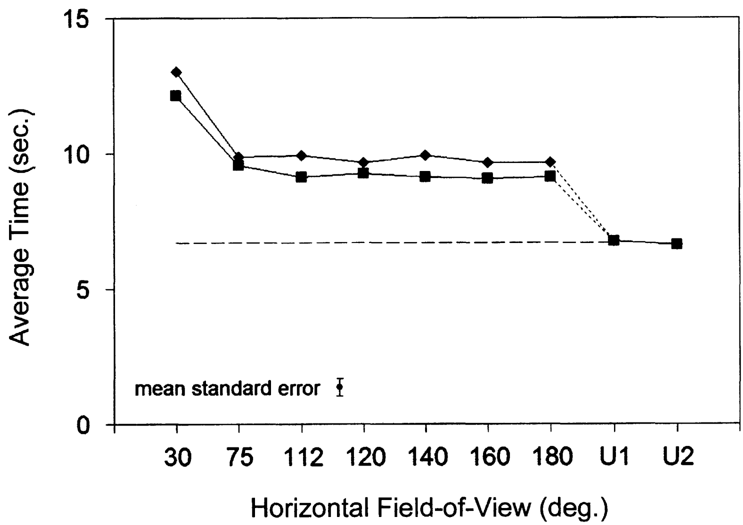


FIG. 4. Influence of field-of-view on mean time to traverse the entire course. U1 refers to the unrestricted field-of-view condition tested at the start of the experiment, and U2 indicates the same condition tested at the end of the experiment. The dashed line indicates the mean value of U1 and U2 and represents a performance baseline: (18° vertical ◆, 48° vertical ■).

A paired-samples *t* test showed that for most horizontal field-of-view restrictions the two vertical field-of-views had a significantly different effect on the mean time needed to traverse the course, 75° and 120° horizontal fields-of-view. Fig. 4 shows the mean time to traverse the entire course was shorter with a 48° vertical field-of-view than with 18°. The *post hoc* test for the horizontal field-of-view variable identified significant differences between the two full field-of-view conditions and all restricted field-of-view conditions ($p \leq .01$). The results were similar for both vertical fields-of-view. Fig. 4 illustrates a restriction of the horizontal field-of-view yielded an increase in mean time to traverse the entire course. The same test also specified a significant difference between the most restricted horizontal field-of-view condition (30°) and all other restricted horizontal field-of-view conditions: the most restricted horizontal condition yielded the largest mean time ($p \leq .01$).

No significant differences were found for the other restricted field-of-view conditions. Finally, there was no significant difference between the full field-of-view condition tested at the start of the experiment (datapoint U1 in Fig. 5) and the one tested at the end of the experiment (datapoint U2 in Fig. 5), meaning that there were no overall learning effects.

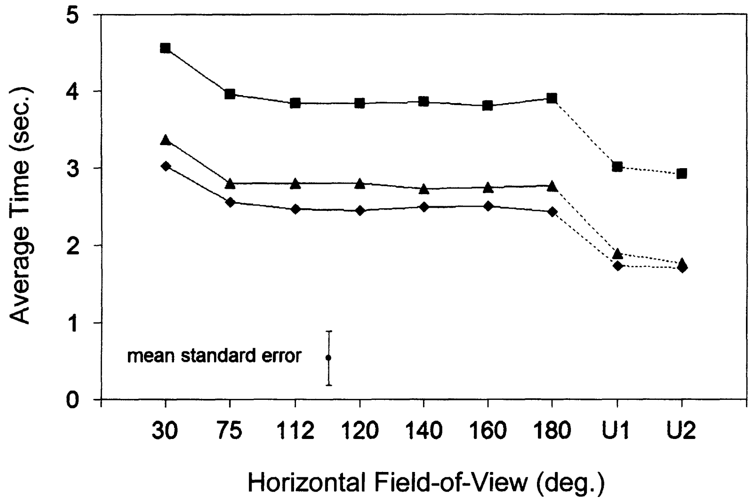


FIG. 5. Effects of field-of-view restriction on mean time to cross each of the three individual obstacles (the bar, the dividers, and the shelves). U1 refers to the unrestricted field-of-view condition tested at the start of the experiment, and U2 indicates the same condition tested at the end of the experiment: (dividers ■, shelves ▲, bar ◆).

The statistical tests indicated that the effects of field-of-view restrictions on the mean speed to traverse each obstacle were generally similar to those on the mean time needed to pass through the entire course. This can also be seen in Fig. 5, which shows similar curves for the mean speed of crossing each obstacle as a function of horizontal extent of field-of-view.

Head Movement Data

Effects of different field-of-view conditions on the angular velocity of head movements made during a period of 1 sec. just before crossing each obstacle were examined. Statistical tests showed only a significant main effect of field-of-view restrictions on the angular head velocity for obstacle 3 (the three shelves) and exclusively on the yaw and roll components of head movement. On the yaw component there was a significant effect of horizontal field-of-view ($F_{8,88} = 7.75$, $p < .01$). The *post hoc* test identified a significant difference only between the unrestricted field-of-view conditions and all the restricted horizontal field-of-view conditions ($p \leq .05$). Fig. 6 shows the in-

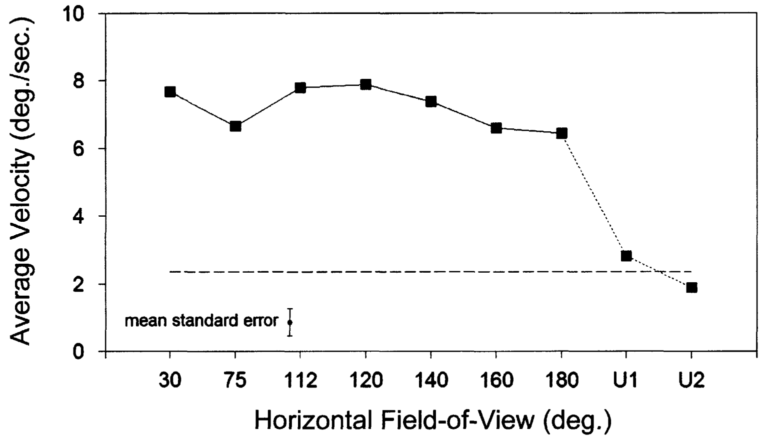


FIG. 6. Effect of horizontal field-of-view restriction on the average angular head velocity (deg./sec.) along the yaw component of head movement just before crossing obstacle 3. U1 refers to the unrestricted field-of-view condition tested at the start of the experiment, and U2 indicates the same condition tested at the end of the experiment.

crease in the average angular velocity along the yaw component for the restricted field-of-views compared to the unrestricted field-of-views.

For the roll component of head motion, a significant effect was found for both horizontal and vertical field-of-view size (respectively, $F_{8,40} = 11.62$, $p < .01$; $F_{1,5} = 30.10$, $p < .01$). The *post hoc* tests specified a difference between the horizontal field-of-view restrictions and the unrestricted field-of-view ($p \leq .05$). The mean angular velocity was larger in the restricted field-of-view conditions (Fig. 7). Furthermore, in the range of 120° to 180° horizontal field-of-view there appeared to be a difference between 18° and 48° vertical fields-of-view. However, the paired-samples *t* test showed no significant pairwise differences. Therefore, it is only possible to state the data in Fig. 7 suggest within this range of horizontal field-of-view sizes the angular velocity may have increased when the extent of vertical field-of-view decreased, a statement which requires further study.

Subjective Data

During the experiment 6 of the 12 participants reported a feeling of dizziness when they had to walk while wearing the goggles with field-of-view restrictions. Also, they reported that they felt tired, especially in the conditions with the greater field-of-view restrictions.

DISCUSSION

The present study investigated effects of both horizontal and vertical field-of-view restrictions on human locomotion through a complex labora-

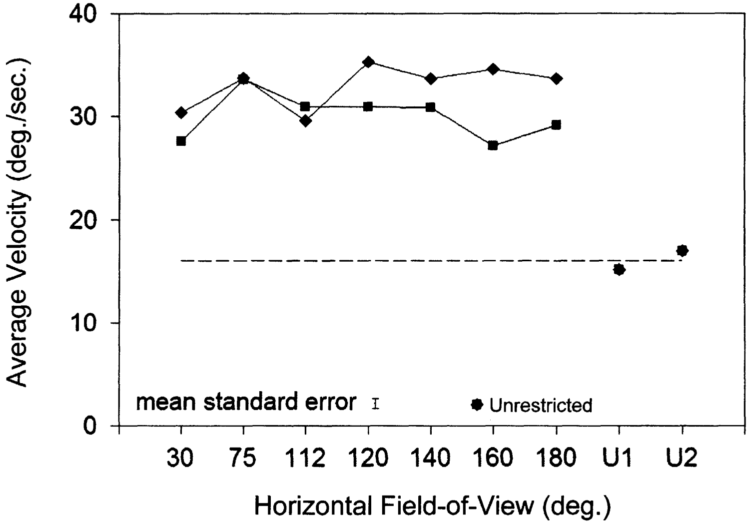


FIG. 7. The influence of field-of-view size on the average angular head velocity (deg./sec.) along the roll component of head movement on obstacle 3. U1 refers to the unrestricted field-of-view condition tested at the start of the experiment, and U2 indicates the same condition tested at the end of the experiment: (18° vertical ◆, 48° vertical ■).

tory environment. In particular, the influence of horizontal and vertical field-of-view restrictions were measured as time to traverse the course containing different obstacles. Also, the relation between field-of-view restrictions and head movements made while performing the same task were examined. Results confirm the first hypothesis that participants needed significantly more time to complete the course when the field-of-view was restricted than when walking with unrestricted vision. The second hypothesis is only partly confirmed: horizontal field-of-view restrictions increased the yaw component of head motion, whereas vertical field-of-view restrictions increased the roll component. However, vertical field-of-view restrictions had no significant effect on the pitch component. Field-of-view restrictions showed the same effect for each of the three individual obstacles, so the effect is robust, and the results were not characteristic of just one particular kind of obstacle or for the nature of movement required to cross them.

There was a significant difference between locomotion performance in the most restricted horizontal field-of-view condition (30°) and that in all other restricted field-of-view conditions; however, no significant differences appeared among the other restricted field-of-view conditions. This indicates that the field-of-view restriction on locomotion is not a gradual effect but more like a stepwise relationship. The current results show the mean walking time was constant for horizontal field-of-view sizes ranging between 75°

and 180°, an unexpected finding. A possible explanation may be that participants were free to make head movements. Previous studies have shown that observers tend to compensate for a reduction in their visual field by making larger head movements (Wells & Venturino, 1990; Szoboszlay, *et al.*, 1995; Kasper, *et al.*, 1997; Gallimore, *et al.*, 1998). It appears that the effects of field-of-view restrictions can be compensated to some extent through the construction of an "effective field-of-view," which can be obtained by sweeping the field-of-view over a larger region of space (i.e., through head movements) (Knapp & Loomis, 2004). Research involving distance-estimation tasks indicates the importance of head movements in estimations of object distance (Knapp & Loomis, 2004; Wu, Ooi, & He, 2004). Present data indicated that when stepping over obstacles, the angular velocity of head movements was larger in the restricted field-of-view conditions than in the unrestricted condition, but no difference was found between the different field-of-view restrictions. It has also been observed that loss of peripheral vision decreases situational awareness, which in turn leads to a decreased confidence (Dolezal, 1982; Alfano & Michel, 1990). Participants may then report feeling less confident when wearing goggles. This may motivate participants to reduce their uncertainty by making large (maximal) compensatory head movements to acquire as much visual information as possible. A maximal compensation strategy may explain the identical head movements in the different field-of-view conditions. The process of gathering additional visual information about the environment by making compensatory head movements may also require additional time and may explain the reduced maneuvering speed in restricted field-of-view conditions. A maximal compensation strategy may also explain the lack of difference in mean walking time in the range of 75° to 180° fields-of-view. In addition to inducing additional head movements, field-of-view restriction may also change the participants' eye-movement behavior. It has been reported that gaze direction is an important factor during avoidance of obstacles and that gaze is fixated on the approaching obstacle to acquire necessary visual information for controlling the swing trajectory of a limb (Hollands, Patla, & Vickers, 2002; Mohagheghi, Moraes, & Patla, 2004; Patla & Vickers, 2005). Yet, at the smallest field-of-view used in this study (30° horizontal) even the maximal compensation by head movement and probably by eye movement is not enough to compensate for the adverse effect of field-of-view restriction. Further research is required to assess in more detail possible compensatory head-motion strategies, probably in combination with eye movements, deployed during locomotion through a complex environment.

There was a significant difference between locomotion performance with each horizontal field-of-view restriction tested in this study and also with the unrestricted field-of-view. This holds even for the 180° field-of-view condition, which is almost equal to a full horizontal field-of-view of about 200°. This effect is likely associated with the vertical field-of-view restriction. The importance of the vertical extent of field-of-view can also be deduced from the significant effect of head movement observed only on stepping over an obstacle (obstacle 3). Successful crossing of this obstacle depended on the availability of visual information along the path of travel. The availability of this information is compromised when the vertical field-of-view is restricted. Data showed that vertical field-of-view restrictions are associated with an increase in angular velocity of head movements on the pitch component of head movement. This indicated that participants indeed deploy an up-and-down head movement strategy to gather more visual information about the direction of the path of travel as they approach the obstacle to be stepped over. This result agrees with the finding that observers with field-of-view restrictions can make accurate absolute distance estimates by scanning the environment from near to far (Wu, *et al.*, 2004).

That participants reported a sensation of dizziness when they had to walk while wearing the field-of-view restricting goggles agrees with the results of other studies in which visual-field restrictions induce feelings of bodily discomfort (e.g., Dolezal, 1982; Alfano & Michel, 1990). Such an effect is probably related to problems with the maintenance of postural equilibrium which arises when the amount of available peripheral information decreases with field-of-view restrictions (Amblard & Carblanc, 1980; Amblard, *et al.*, 1985). This effect may also contribute to the additional time taken to complete the course when the field-of-view is restricted. Also, that participants were not used to wearing goggles may have contributed to the overall effect of field-of-view. In this view, any field-of-view restriction may disturb normal performance. Such reasoning suggests some issues for further research. In the first place two other control conditions are recommended. (i.e., full horizontal vs restricted vertical and full vertical vs restricted horizontal) instead of only the unrestricted field-of-view condition (full vertical vs full horizontal). In the full horizontal versus restricted vertical condition, it should be possible to control for the effects of horizontal restrictions, while the full vertical versus restricted horizontal condition should provide control over the effects of vertical restrictions. Then, further research could include a condition with only the goggles and no other field-of-view restrictions to rule out the possibility that simply wearing the goggles contributed to the observed effects.

That no performance degradation was noted over the range of 75° to 180° fields-of-view may have implications for the development of head-mounted displays and other field-of-view restricting devices used in combination with human locomotion tasks. Because field-of-views in the range of 75° to 180° yielded similar performance, it may not be necessary to make the horizontal field-of-view larger than 75° to study this type of locomotion task. If so, production costs could be reduced and positive ergonomic aspects (higher resolution, less weight, less chance of motion-sickness sensations) would be achieved.

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