MANUSCRIPT SUBMITTED FOR PUBLICATION

Gaze-direction and steering effects while driving

Wilson O. Readinger,[1,2] Astros Chatziastros,[1] Douglas W. Cunningham,[1]
Heinrich H. Bülthoff,[1] & James E. Cutting[2]

1. Max-Planck Institute for Biological Cybernetics; Tübingen, Germany
2. Cornell University Department of Psychology; Ithaca, NY, USA

1. ABSTRACT

Instructions given to novices learning certain tasks of applied navigation often suggest that gaze-direction ("line of sight") should preview the path the operator desires to take (e.g., Bondurant & Blakemore, 1998; Motorcycle Safety Foundation, 1992; Morris, 1990), presumably because looking behavior can ultimately affect steering control through hand, arm, or leg movements that could lead to undesired path deviations. Here, we control participants' gaze-direction while driving an automobile in virtual reality, and find that gaze-eccentricity has a large, systematic effect on steering and lane-position. Moreover, even when head-position and postural effects of the driver are controlled, there remains a significant bias to drive in the direction of fixation, indicating the existence of a perceptual, and not merely motor, phenomenon.

2. BACKGROUND

The issue of steering, especially as it relates to driving an automobile, has been a topic of interest recently as the use of in-vehicle navigation systems and cellular telephones while driving is being re-evaluated in light of safety issues involving these devices. Of primary concern is the allocation of attentional and perceptual resources associated with the coupling of requirements normally associated with the driving task and the addition of these extraneous factors. Drivers are often required to direct their attention to instruments inside the car or objects outside of the vehicle while at the same time maintaining a consistently safe road position. However, there is substantial anecdotal evidence from experts in several different navigation tasks that eccentricity of gaze can affect heading control. Important variables, however were not brought under experimental control in the development of these claims, and the mechanisms or underlying causes of the phenomenon could not therefore be determined. With this in mind, we sought to investigate the possible presence of this effect under controlled conditions and determine the extent of the effect and its potential practical importance especially for driving and other everyday tasks of navigation.

3. METHODS

3.1 Participants

All subjects were naïve to the purposes of the study, ranged in age from 16 to 42 years, and 92% of the subjects were in possession of a German drivers' license for at least 1 year.

3.2 Materials & apparatus

Participants in all experiments reported here used a forced-feedback steering wheel to control a car at a constant speed of 20 m/s in a virtual environment simulation. The environment was richly textured and always featured a perfectly straight road (7.5 m in width), the edges of which were delineated with relatively bright white lines. Presentation of the stimuli took place in a half-cylindrical, 180-degree horizontal field-of-view projection theater controlled by a Silicon Graphics Onyx2 virtual reality engine (Fig. 1).

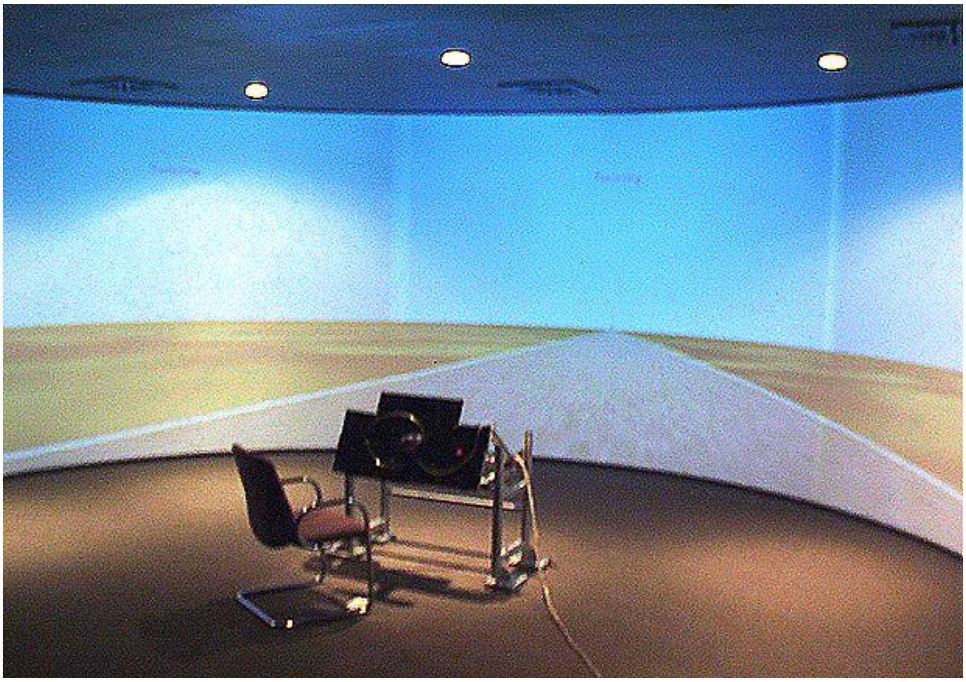

Figure 1. The experimental apparatus and virtual reality environment used in these experiments. Shown here is the projection screen at the start of a trial. The simulation began with the car in the center of the street, but always had a small, random deviation in the heading direction of the car, forcing the subject to engage in minor corrective steering behaviors from the beginning of each trial. The projection screen was a half-cylinder with a diameter of 7.5 m and a height of 3.15 m.

3.3 Procedure

Instructions in each condition were simple and similar: subjects were asked to fixate a Landolt-C figure, subtending 0.65º of visual angle, projected on the screen at different eccentricities and respond (via pressing a button mounted on the steering wheel) to random changes in the roll orientation of the figure, while driving as close to the center of the road as possible. Thus, subjects performed a simple attention task in detecting the changes in the figure, and this ensured their fixation at a desired eccentricity. (Wann et al. (2000) have emphasized the importance of not only *looking at*, but *attending to* points away from the direction of travel in this type of research.) Trials in which detection performance was slow or otherwise poor were excluded from the analyses, although this occurred on fewer than 2% of all trials. Lateral position on the street was measured and recorded for each trial.

The fixation figure was planted in coordinates of the screen, which remained constant despite translation and rotation of the car model, and thus produced a gaze-eccentricity that was constant throughout each trial, and similar to driving while looking at a bug on one's windshield (without changes in accommodation or convergence). In the first condition reported here, 8 subjects randomly completed 7 repetitions of each of 7 different eccentricities: 15, 30, and 45º left and right of center-screen, and 0º (straight ahead). Each trial began with 5 seconds in which the fixation figure was in the center of the screen, after which the figure moved to a randomly selected eccentricity and began to rotate about the roll axis in non-sequential 90º steps; timing of these changes in rotation was randomized between 0.5 and 1.5 s (mean = 1.0 s).

a. b.

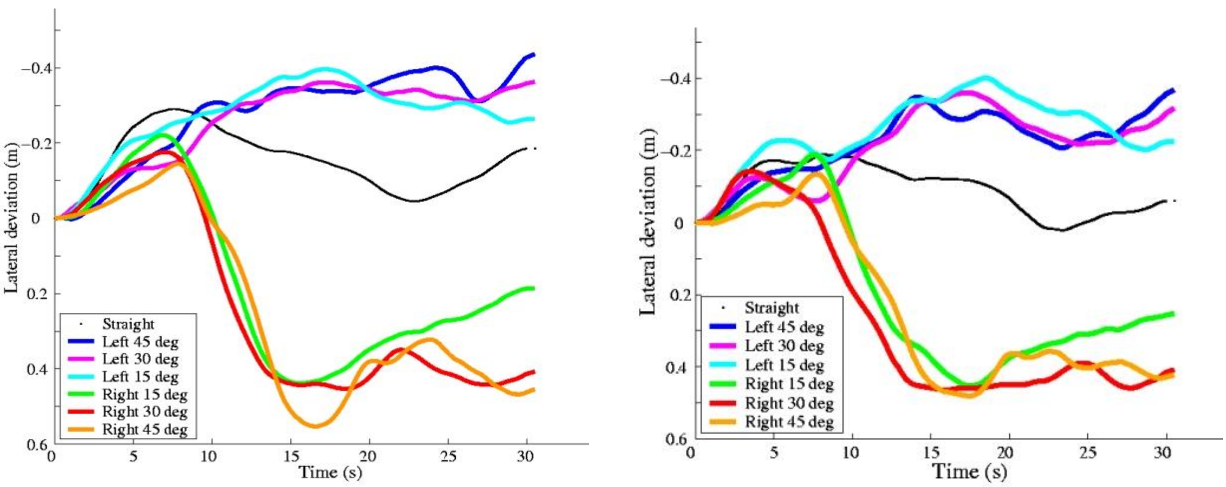

Figure 2. (a) Average lateral deviation from the center of the street for all subjects in the unrestricted body/head-position condition. Negative lateral position indicates movement to the left of the street's center. During the first 5 seconds of a trial the fixation is directly ahead of the driver. However, very quickly after the position of the fixation object changes, road position is affected. The initial movement to the left of the street in these cases corresponds to the driver attempting to center the *virtual car* on the street, and not their own actual body position (which would correspond to 0). The size of this artifactual effect is quite close to the actual distance a driver is located to the left of the center of a typical automobile while situated in the driver's seat. Note the lack of specific eccentricity effects, a trend which continues in conditions using a chin-rest and the reverse steering task. **(b)** Average lateral deviations in the reverse-steering task; the pattern of results is quite similar to the conditions in which subjects steered in a normal fashion. These results certainly suggest that drivers in these situations are executing a steering behavior in order to achieve a visual effect in the environment, and not simply as a response to the physical or bio-physiological demands of the task. If one will assume that drivers typically look in the direction they are traveling, the pattern of retinal flow (Cutting et al., 1992) that results from driving straight ahead and fixating to the left, for example, is similar to that of looking straight ahead, and driving towards the right. Given this correspondence, it might seem natural for subjects to correct this apparent movement to the right by initiating movement to the left.

4. RESULTS

4.1 Experiment 1

It was found that there was a significant effect of gaze-direction ($F=10.723$, $p<0.0001$) on road position, but no reliable effects for the amount of eccentricity on either side of 0º. Figure 2A represents the average lateral deviation from center for all subjects in this condition. That is, generally looking to the left, for example, led drivers to steer in that direction (and looking right led to steering towards the right), but the extent of the gaze-eccentricity had no significant effects on this trend (e.g., 15° led to a very similar average deviation when compared to 45°).

4.2 Experiment 2

It might be argued that the hands of an experienced driver tend to simply follow the eyes, in the form of a fixed action pattern or tonic reflex. To control for this possible explanation, 8 naïve subjects completed the task as originally described, but with a reversal of steering control. That is, turning the steering wheel counter-clockwise led to the car moving towards the right, and vice versa. Initially, subjects found the task difficult, but after each completed approximately 45 minutes of training using this steering method, their performance, judged by road-position during the last practice trials, was similar to that of subjects in the normal-steering conditions. The pattern of results for this condition is displayed in Figure 2B. One immediately notices that the pattern of positions on the street is quite similar to that of the normal-steering condition, indicating that in this reverse-steering task drivers, while looking *left*, for example, tended to steer to the *right* in order to initiate a movement of the car to the left. This is obviously quite the opposite of what one would expect if the hands of drivers were simply reflecting some variant of a tonic reflex (i.e., Werner, et al., 1953).

4.3 Experiment 3

It has been suggested that the execution of head movements alters the control of eye-movements and shifts of gaze in humans (Freedman & Sparks, 2000), and that the eccentricity of the head alone can influence some types of steering control (Heuer & Klein, 2001). With this in mind, we sought to separate these factors and consider only the eccentricity of the eyes in the results discussed above. For this reason, we performed an otherwise identical version of the first (normal-steering) condition with a single change: head-movements were restricted using a chin-rest and head-strap. In this condition, body position and head position of the participants were controlled and the only difference between trials was the eccentricity of the eyes. Results were very similar to those for the condition in which free head- and body-movements were allowed (see Fig. 3A for a comparison of the first 3 conditions).

4.4 Experiment 4

When walking, humans tend to spend a very small percentage of their time looking within 5º of straight ahead (Wagner et al., 1980), perhaps because sufficient information for determining heading is available in the area generally surrounding the actual direction of travel (Cutting, et al., 1999; Wang & Cutting, 1999). It has been accepted for nearly 50 years, however, that drivers do tend to look closer to their heading point, especially as their speed increases (Calvert, 1954). In a third variation of the original experiment described above, therefore, we sought to investigate effects of smaller eccentricities (looking closer to the edge of the road) which may be more representative of realistic attentional allocation during the driving task. Figure 3B represents the most important findings in this condition. As can be seen, even at eccentricities as small as 5º from center screen, the general effect of gaze remains, however in this case the relationship between eccentricities is linear, across a range of 20°, suggesting that, in terms of lateral position on the street, a point of saturation is reached around 10° from straight ahead.

4.5 Typical trial data

While this finding illustrates a consistent bias in initiating movement towards the direction of gaze that is present across subjects and trials, a typical trial example can perhaps be more useful in describing the magnitude and time-course of these effects (Fig. 4). Participants consistently drove in the direction of their fixation until noticing their error (often, when they approached the edge of the road at roughly 2.5-3.0 meters from center), correcting, and then repeating the process. The most striking trend is the sinusoidal pattern of deviation in the direction of the fixation, followed by a period of correction towards the center of the street, and then another similar cycle. When looking at an individual trial, it can be seen that the average deviations from center (as in Figures 2 and 3) can be somewhat misleading in their relatively small magnitude. Because, of course, the maxima and minima of these sinusoids will not correspond completely between trials and subjects, the lateral deviation averaged across trials will appear to move towards fixation and then level-off. In fact, quite the opposite is the case: drivers appear to be in a constant state of fluctuation between the gravity of their fixations and a correction to return to the middle of the road as instructed.

a. b.

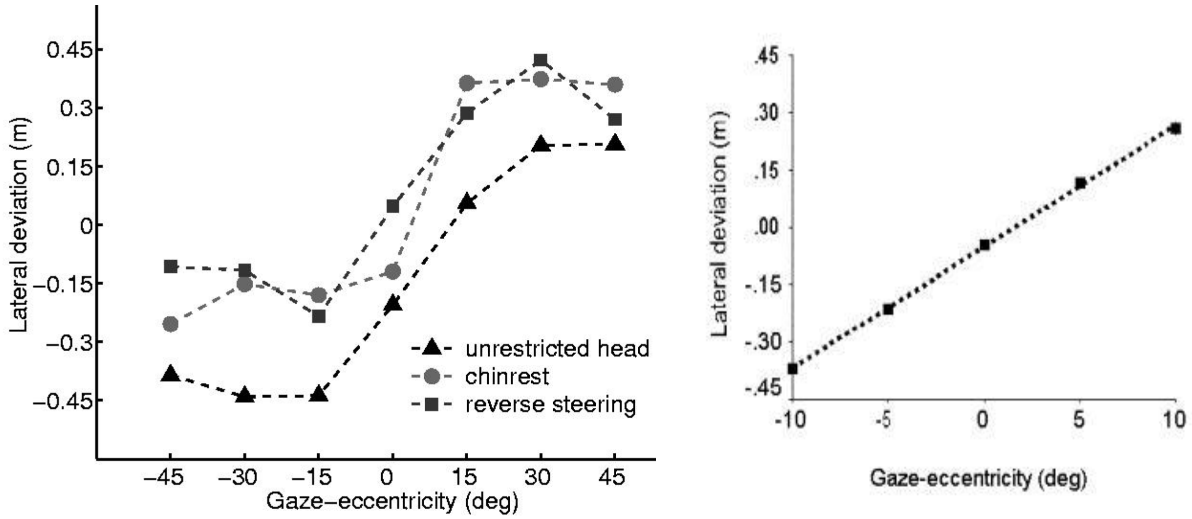

Figure 3. (a) Comparison of average lateral deviations between all large-eccentricity conditions. Calculations are based on the 25 seconds between the initial displacement of the fixation figure and the end of the trial. Note the marked change in average position on the street in all driving conditions between generally Left-looking and Right-looking trials. There was a strong overall effect of eccentricity ($F=21.404$, $p<0.0001$), but no further significant main effects between any of these conditions ($F=0.612$, $p=0.552$, ns), indicating that drivers responded comparably in similar eccentricities regardless of the steering control or head position. **(b)** Average lateral deviations for the smaller-eccentricities condition. Methods for this condition were identical to those in the larger-eccentricities conditions described above. With these decreased gaze-eccentricities, the effect of gaze on position on the road increases linearly with increasing eccentricity of fixation from straight ahead, as opposed to the saturation effect observed in the earlier situations.

5. GENERAL DISCUSSION

5.1 Heading perception and the control of locomotion

Clearly, then, driving behavior is affected by gaze-eccentricity, but why should this be the case? The retinal flow information available to drivers becomes increasingly complex as (1) the subject fixates away from the direction of travel and (2) adds additional rotational flow to the equation by minute alterations to the heading of the virtual car. However, in previous work where subjects were asked to judge their heading direction in cases of relatively simple radial flow (Warren et al., 1988), as well as more complex patterns including the compensations for eye-movements (Royden et al., 1992) and head-turns (Crowell et al., 1998), responses were often exceedingly accurate. Although direct comparisons between the results of these experiments and the present work is difficult, particularly due to the nature of the stimulus environments and the demands of the tasks, one would expect even in the experiments reported here that drivers would be more resistant to small deviations in gaze. We suggest that the valuable information for the drivers in these tasks comes not necessarily from the 'eye-position,' but from the 'eye-movement.' That is, the additional information that humans tend to use (often quite successfully) about extra-retinal signals becomes less valuable over periods of extended fixation. Compensation and performance are increasingly based on visual information, and less on efferent signals from the eyes, head, and neck. The results presented here may provide further evidence for the convincing argument that control

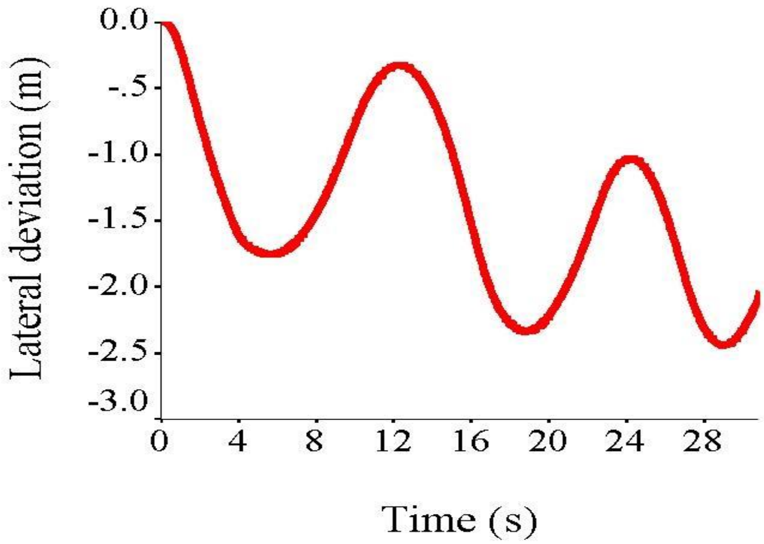

Figure 4. A typical trial showing the sinusoidal pattern of driving behavior often observed in these experiments. The first local minimum from the start of the trial reaches 1.81 m, the second reaches 2.31 m, and the maximum deviation during this trial is 2.45 m at the lowest point of the third local minima. During debriefing, many subjects reported a constant perceptual battle between the gravity of their fixation and the instructions to drive as close to possible to the middle of the road.

of locomotion may not be dependant on an accurate perception of heading (Wann & Land, 2000) and thus, the notion of a “do it where you look strategy" (Land & Lee, 1994) takes on a new significance.

5.2 Some practical implications and considerations

Land (e.g., Land & Lee, 1994; Land, 1992; Land & Horwood, 1995) and others (e.g., Ballard, et al., 1992) have demonstrated the importance of, not to mention the capacity for, sophisticated perception-action coordination (especially eye-hand relationships) while driving. In supplement to these findings, we show here that when a point is fixated away from the direction of travel, meaningful, systematic steering behaviors accrue in this direction of fixation. Those things which draw our attention (and subsequent eye and head movements) during driving are quite rarely located along our path; in fact, the anticipation/reaction loop involved in steering is designed to keep objects such as pedestrians and other vehicles *away* from our direction of travel. Furthermore, in a highway driving situation, where the task required at the point of fixation may be considerably more complex than we have presented here (e.g., using a street sign to plan an exit from the highway), lateral movement of the order we have demonstrated is certainly sufficient to pose meaningful problems for operators. So, while many novice (and experienced) drivers have probably heard the admonition “Look where you’re going!” it seems also quite practically important to realize that they might “go where they’re looking.”

5.3 Future directions

The anecdotal evidence which led to the research presently described failed to control for several variables sufficiently to provide a meaningful scientific evaluation of the relationship between gaze-direction and steering behaviors. In moving the experiment into the laboratory, however, we have fundamentally altered the nature and phenomenology of the driving experience, and the potential influence of this factor should be explored in the future through recordings of road position and steering behavior taken from participants during actual driving on a closed circuit. Similarly, the qualities of the environment in which one is asked to perform perceptual tasks have profound effects on the execution of (even over-learned) behaviors, as well as the perception of the visual world. Thus, we expect that in a more realistic stimulus environment (i.e., the real world), the presence of this effect would be mediated by many factors including, but not limited to, traffic density, road texture and curvature, lighting conditions, and landscape, not to mention more internal factors such as driver characteristics and handling of the automobile. Obviously, none of these important influences are manipulated or discussed here, but we hope that the steering effects of gaze-eccentricity will be further studied within the context of these and other considerations.

6. REFERENCES

Ballard, D.H., Hayhoe, M.M., Li, F. Whitehead, F., Frisby, J.P., Taylor, J.G., & Fisher, R.G. (1992). Hand eye coordination during sequential tasks. *Philosophical Transactions of the Royal Society*, B**337**, 331-339.

Bondurant, R. & Blakemore, J. (1998). *Bob Bondurant on high performance driving*. Osceola, WI: Motorbooks International.

Calvert, E.S. (1954). Visual judgments in motion. *Journal of the Institute of Navigation, London* **7**, 233-251.

Crowell, J.A., Banks, M.S., Shenoy, K.V., & Anderson, R.A. (1998). Visual self-motion perception during head turns. *Nature Neuroscience,* **1**, 732-737.

Cutting, J.E., Springer, K., Braren, P.A., & Johnson, S.H. (1992). Wayfinding on foot from information in retinal, not optical, flow. *Journal of Experimental Psychology: General,* **121**, 41-72.

Cutting, J.E., Wang, R.F., Flückiger, M., & Baumberger, B. (1999). Human heading judgments and object-based motion information. *Vision Research,* **39**, 1079-1105.

Freedman, E.G. & Sparks, D.L. (2000). Coordination of the eyes and head: Movement kinematics. *Experimental Brain Research,* **131**, 22-32.

Heuer, H. & Klein, W. (2001). Eccentric head positions bias random generation of leftward and rightward handle-bar rotations. *Acta Psychologica*, **106**, 23-49.

Land, M.F. (1992). Predictable eye head coordination during driving. *Nature*, **359**, 318-320.

Land, M.F. & Horwood, J. (1995). Which parts of the road guide steering. *Nature,* **377**, 339-340.

Land, M.F. & Lee, D.N. (1994). Where we look when we steer. *Nature,* **369**, 742-744.

Morris, G.H. (1990). *Hunter seat equitation* (3rd Ed.). New York, NY: Doubleday.

Motorcycle Safety Foundation. (1992). *Evaluating, coaching, and range management instructor's guide* Irvine, CA: Author.

Royden, C.S., Banks, M.S., & Crowell, J.A. (1992). The perception of heading during eye movements. *Nature,* **360**, 583-587.

Wagner, M., Baird, J.C., & Barbaresi, W. (1980). The locus of environmental attention. *Journal of Environmental Psychology,* **1**, 195-206.

Wang, R.F. & Cutting, J.E. (1999). Where we go with a little good information. *Psychological Science,* **10**, 72-75.

Wann, J.P. & Land, M.F. (2000). Steering with or without the flow: Is the retrieval of heading necessary. *Trends in Cognitive Science,* **4**, 319-324.

Wann, J.P., Swapp, D., & Rushton, S.K. (2000). Heading perception and the allocation of attention. *Vision Research,* **40**, 2533-2543.

Warren, W.H., Morris, M.W., & Kalish, M. (1988). Perception of translational heading from optical flow. *Journal of Experimental Psychology: Human Perception and Performance,* **14**, 646-660.

Werner, H., Wapner, S., & Bruell, J.H. (1953). Experiments on sensory-tonic field theory of perception 6: Effect of position of head, eyes, and of object on position of the apparent median plane. *Journal of Experimental Psychology,* **46**, 293-299.

7. ACKNOWLEDGMENTS

This research was supported by a J. William Fulbright Fellowship to the first author, and carried out at the Max-Planck Institute for Biological Cybernetics. The authors would like to thank Fred Owens and Mike Land for valuable comments and suggestions on this work.