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Effects of a target movement direction cue on head-tracking performance

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Keywords: Head tracking; Target cueing; Helmet-mounted displays; Predictive displays.

A review of the literature has shown that most investigations of head-tracking performance have used symmetrically shaped targets. This paper identifies a problem in using circular targets to represent the movement of complex targets (i.e. targets giving directional cues). Two experiments investigated the effects of a target direction cue on head-tracking performance. In the first experiment, practice did not improve performance when tracking either with or without a 'look-ahead trace' showing all target positions 160 ms into the future. A second experiment utilized a 'look-ahead trace' showing target positions with eight different lead-times (0 – 560 ms). With lead-times of 160 ms or more, significant improvements in tracking performance and subjective difficulty ratings were obtained. Tracking responses were also significantly affected. The results suggest caution when performance data obtained with a symmetrical target are generalized to predict tracking performance with a real target giving cues to the direction of movement. The look-ahead trace offers a systematic means of bridging the gap between a symmetrical target and a real target having direction of movement cues.

1. Introduction

A good understanding of the complex human visual-motor responses is required for the optimum design of control and display instruments (Boff and Lincoln 1988). With advances in head-mounted sights and head-mounted displays, new types of head-controlled displays and devices have been developed (e.g. head-steered guns, Williams 1987; virtual reality simulators, Geltmacher 1988, Haworth *et al*. 1989, Barfield and Furness 1995). A head-mounted display projects images in front of an operator's eyes, while a head-mounted sight measures the head-pointing angle for steering an aiming or tracking device. To optimize the design of head-steered devices, head-tracking responses have been studied (e.g. Catling 1987, Wells and Griffin 1987, Lifshitz and Merhav 1992, So and Griffin 1992, 1995, 1996, Nathan and Meehan 1996).

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A review of literature concerning continuous head-tracking performance indicates that targets with symmetrical shapes (e.g. a circle) have been used in most head-tracking studies (e.g. smooth pursuit head-tracking performance, Shirachi *et al*. 1978; tracking performance with a helmet-mounted sight, Wells and Griffin 1987; tracking performance with a head-coupled virtual display with lags, So and Griffin 1995, 1996). A summary of target types used in studies of continuous head-tracking performance is shown in table 1. Studies investigating discrete head aiming performance have been excluded (e.g. Gauther *et al*. 1987). The results of the review indicate that > 75% (16 of 21) of the studies with head-tracking performance used a symmetrical target, which provides no cue to the direction of movement (e.g. a circle, a cross, or a diamond-shaped symbol). To confirm this result, a further search of the open literature between 1984 and 1998 was performed. The results identified more than 150 papers, when using various combinations of search words

Table 1. Review of the type of target used in studies concerning continuous head-tracking performance (head-aiming and target acquisition studies are excluded).

Author(s)	Use symmetrical target? y/n	and types of target	Variable(s) investigated
Barnes and Sommerville (1978)	y	a cross '+ '	Target velocity and frequency
Catling (1987)	n	Simulated aircraft(s)	Simulation exercises comparing head steered and manual steered missile systems
Fearnside *et al*. (1997)	n	Simulated aircraft(s)	Symbologies on a HMD
Grossman (1974)	n	Used filmed aircraft(s)	g force and personal equipment
Grunwald *et al*. (1991)	y	Diamond-shaped '◇'	Image update lag and types of target movement
Grunwald and Kohn (1994)	y	Diamond-shaped '◇'	Lags in a head slaving system
Henke (1970)	y	Shape not specified	Reticle shape and types of target movements
Hornseth *et al*. (1976)	y	a circular spot '●'	Target movement frequency
Levison and Zacharias (1981)	y	a circular spot '●'	Target movement axes and comparison with manual tracking
Lifshitz and Merhav (1992)	y	a cross '+ '	Aircraft and head vibration
Monk *et al*. (1978)	y	Shape not specified	Eye dominance
Nathan and Meehan (1996)	n	Simulated aircraft(s)	Compare helmet-mounted sight with head-up display
Nicholson (1966)	y	a cross '+ '	Target velocity
Sandor and Leger (1991)	y	a circular spot '●'	Visual field-of-view
Shirachi *et al*. (1978)	y	a circular spot '●'	Target span and helmet weight
So and Griffin (1992, 1995, 1996)	y	a circle '○'	Image update lag and lag compensation algorithm
Verona (1978)	y	a circular spot '●'	Types and weight of helmet, floor vibration, and eye dominance
Wells and Griffin (1987)	y	a circular spot '●'	Target position and frequency; personal equipment
Williams (1987)	n	Simulated aircraft(s)	Simulation training

relevant to helmet-mounted sight, head-tracking tasks, head control tasks, and performance. Review of these studies indicated that only five papers concerned experimental studies of continuous head-tracking performance and all of them had already been included in table 1. Some recent studies concerning manual task performance in a head-tracked virtual environment were identified (e.g. Kawara *et al*. 1996, Watson *et al*. 1997), but excluded from our literature review because they did not investigate continuous head-tracking performance. Similarly, head-aiming studies with stationary targets in a head-tracked virtual environment were also not included in table 1 (e.g. Venturino and Kunze 1989, Venturino and Wells 1990). Visual search experiments not studying continuous head-tracking performance were also excluded (e.g. Bauer and McFadden 1997, Lubow and Kaplan 1997, Nelson *et al*. 1998).

A review of the 21 studies listed in table 1 indicates that all the generic target symbols used were of symmetrical shapes (16 studies in total). The five non-symmetrical targets all used images of a specific object, an aircraft. Pointed symbols giving cues to the direction of target movement were not used. Studying assessment criteria for target tracking and acquisition performance of moving ground vehicles, Gerhart (1991) reported that a shaped target with motion cues would result in better performance than a rectangular target. A review of literature concerning the effects of cues on both head and manual continuous tracking performance publications since 1980 located more than 80 studies, but none investigated the effects of target shape (or other direction cues) on continuous head or manual tracking performance. Peripherally relevant studies included cueing for visual search tasks (e.g. Kinchla *et al*. 1995, Lubow and Kaplan 1997), cueing for target identification tasks (e.g. Astley *et al*. 1993, Scialfa and Thomas 1994, Humphreys and Boucant 1997), and auditory cueing (e.g. Mondor and Zatorre 1995, Strybel *et al*. 1995). One reason for the lack of recent literature might be that the subject has already been studied thoroughly in the past (i.e. before 1980): there were many experimental studies of manual tracking performance between 1950 and 1980 by researchers such as Elkind, Ferell, Jex, Krendel, Levison, McRuer, Poulton, Sheridan and Taylor. Models describing and predicting manual control performance were proposed, e.g. a quasi-linear model by McRuer and Jex (1967), an optimal control model by Sheridan and Ferell (1974), and Levison (1982). Review of the experiments conducted to support and validate the various operator control models indicate that most of the manual tracking tasks (both compensatory and pursuit tracking) involved the use of symmetrically shaped targets (e.g. a line as the target: Warrick 1949, Russell 1951, Goodyear 1952, Jex and Allen 1970, Levison *et al*. 1979, or a dot as the target: Taylor 1949, Ellson and Hill 1948, Elkind 1956, Rockway 1954, Chernikoff and Taylor 1957, Jex and Cornwell 1961, Pew 1966, Poulton 1967, Baty 1971, Poulton 1974). In some studies, although pointed-target symbols were used, the orientations of the targets were not used to indicate the directions of movement of the targets (e.g. a triangle as the target: Davis 1956). Many classical manual control studies utilized flight simulators, but symmetrically shaped target symbols were still used in these studies (e.g. tracking a circular target pip presented on a display mounted inside the F-80A simulator: Krendel 1951, 1952a, b, Krendel and Barnes 1954, McRuer and Krendel 1957, tracking a rolling or a pitching line (artificial horizon) inside a roll-axis motion-based T-33 flight simulator: Goodyear 1953, 1955).

Many of the classical studies of manual control were performed between 1950 and 1960 when raster displays were not common. Oscilloscopes were then the most popular displays for presenting target information. Given the limitations of oscilloscopes at that time, it is understandable that a circular shaped target and a straight line were used as the most straightforward forms of generic target symbols. Moreover, most of the classical manual control studies were performed to study pilot performance in aircraft control and, in those years, flight control instruments consisted of mostly symmetrically shaped symbols (e.g. line symbols: artificial horizon and altitude indicator; or circular symbols: compass headings). Consequently, there may not have been an obvious need to study tracking performance with pointed targets giving direction cues. Nonetheless, some studies related to the use of look-ahead cues in manual tracking have been identified. These studies were mainly motivated by time delay problems in manual control dynamics. In 1966 Pew reported the benefits of a velocity-augmented display with a one-dimensional continuous manual-tracking task. A line vector, whose length and direction were proportional to the instantaneous target velocity, was superimposed on top of a circular target. This work was later extended to two-dimensional manual tracking tasks during which subjects could preview part of the future target path (Drewell 1972, Poulton 1974). Both studies reported that tracking errors reduced as the operators were allowed to preview part of the future target paths. In 1981 Jensen investigated the use of a 'look-ahead' pointer (a dot) to aid flight path control performance. The position of this pointer was calculated from the derivatives of the current target position. In the Engineering Data Compendium, this technique has been referred to as a 'predictor display' (Boff and Lincoln 1988). Both Jensen (1981) and Boff and Lincoln (1988) reported that the predictive information of a target position can help an operator in flight path control and vehicle control tasks with long delays (e.g. ships and submarines whose delays in control dynamics are measured in seconds). Although the use of 'predictor displays' and previews of future target positions have been shown to give improved manual tracking performance, the use of symmetrical target symbols has remained a common practice in head-tracking performance studies (table 1). Reviews of both 'classical literature' (1950–80) and more recent literature (1980–97) suggest that there have been no studies of the effects of target direction or movement cues on continuous head-tracking performance.

With the advance of head-tracking technology, the use of natural head movements to steer machinery is now a reality. Examples include the head-steered machine gun on board an AH-64 Apache ground attack helicopter (Albrecht 1989) and its simulators (Drew *et al*. 1987), head-steered cameras and sensing probes in remote-control vehicles (Earnshaw and Vince 1995); and head-steered missile seekers on fixed-wing fighter jets (Lovesey 1989) and fight simulators (e.g. Woodruff *et al*. 1986, Fearnside *et al*. 1997). In these applications, operators will track targets having well-defined front and rear parts giving cues to the directions of target movement. A symmetrical symbol, such as a circle, does not have a front or a rear part and so its direction of movement is less predictable than such targets. Head-tracking performance in these head-steered applications may be expected to differ from that with a symmetrical target. Two experiments have been performed to study head-tracking performance with a target giving direction and movement cues.

To provide a direction cue to a circular target moving along a predetermined random path, future target positions can be shown in advance to the subjects in the form of a trace (figure 1). The length of the trace (referred to as a 'look-ahead trace') is determined by the lead-time of the future target positions. This set up is similar to

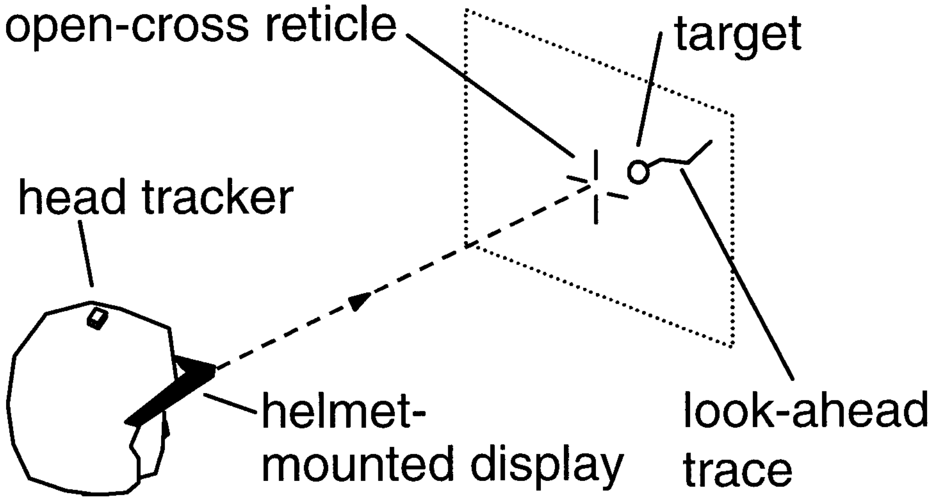

Figure 1. Subject's view of a target with a 'look-ahead trace'.

that used by Poulton (1974) in a study of manual tracking performance. Tracking with this 'look-ahead trace' is analogous to driving at night where the headlights enable a driver to see part of the road ahead. Just as the power of the light beam determines how far ahead the driver can see, the lead-time of the 'look-ahead trace' determines how much of the future target position the subject can perceive.

2. Methods

2.1. *Objectives and hypotheses*

Two experiments were conducted to investigate: (1) the effects of practice with a 'look-ahead trace' and (2) the effects of the variation in lead-time of a 'look-ahead trace' on head-tracking performance. It was hypothesized that: (1) the effects of practice with a 'look-ahead trace' will be small since head-tracking with a target giving direction cues is common in daily life; (2) an increase in lead time of the 'look-ahead trace' will reduce the perceived task difficulty; and (3) the use of a 'look-ahead trace' will reduce the head-tracking phase lag and, hence, tracking errors.

2.2. *Tasks, subjects, and design of experiment*

In each tracking condition, subjects were asked to move their heads to track a circular target, 1° in diameter, moving along a predetermined random path in the pitch and the yaw axes for 120 s. A 'look-ahead trace', whose length depended on the lead-time, was added to the target as a direction cue. An open-cross reticle sight was used (inner diameter 1.2°; outer diameter 3.6°; figure 1). Both the target and reticle were presented on a head-mounted display. While the reticle was always displayed at the centre of the display, the target position was controlled by a host computer according to a predetermined target motion and the instantaneous helmet orientation. The yaw axis target motion was a random function integrated once, high-pass filtered at 0.01 Hz (24 dB/octave), and low-pass filtered at 1.2 Hz (120 dB/octave). The pitch axis target motion was the same as that of the yaw axis but was presented in reverse order. Both experiments were within-subject experiments using full factorial designs. During the second experiment eight target motions with the same frequency content were used to balance the sequence of presentation of the conditions. An 8×8 Latin square design was used.

The first experiment investigated the effects of practice. The subjects performed the tracking task eight times, first without a 'look-ahead trace' and then with a 'look-ahead trace' showing target positions up to 160 ms ahead. In the second experiment, 'look-ahead traces' showing targets with eight different lead times were presented (0, 80, 160, 240, 330, 400, 480, 560 ms). The same eight healthy male subjects participated in both experiments. The subjects were university students and staff aged 19 – 26 years. The study was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research at the University of Southampton.

2.3. *Apparatus*

The dual-axis-tracking task was presented on an experimental head-coupled virtual reality system. The system consisted of a Hughes Aircraft monocular helmet-mounted display (HMD) with $17 \times 17°$ field-of-view, a Ferranti SPASYN magnetic head-tracking system, and a host computer workstation. The HMD was mounted on a US Air Force helmet. During the experiment the surroundings were darkened so as not to distract the subjects. There was a baseline lag of ~26 ms between the moment a subject moved his head and the moment the target image responded. This lag was the sum of the inherent delays in measuring the head position and updating the target image on the display. An analysis of this baseline lag can be found in So (1995). Since this lag was constant throughout all the experimental conditions, its effects, if any, should be constant among the different conditions and not affect the conclusions.

2.4. *Measurements and analyses*

A quasi-linear model of the head-tracking system is shown in figure 2. Head positions in response to the target motions were measured (point B, figure 2) and expressed as head-tracking transfer functions. The moduli (i.e. gains) and phases of such transfer functions were used as indicators of the head-tracking responses. The head-tracking transfer functions were calculated using:

$$\text{Head tracking transfer functions} = [G_{oi}(f)/G_{ii}(f)],$$

where, $G_{oi}(f)$ is the cross-spectral density between the measured head position ($o(t)$ at point B, figure 2) and the input target position ($i(t)$ at point A, figure 2); and $G_{ii}(f)$ is the power spectral density of $i(t)$. This method of calculating transfer functions was adapted from previous studies (e.g. Lewis and Griffin 1979, So and Griffin 1995). The theory involved is documented in Bendat and Piersol (1980: 264 – 281).

Mean radial head-tracking errors and subjective difficulty ratings were also measured. A six-point (0 – 5) absolute difficulty rating scale was used to determine subjective difficulty: 0 = not difficult; 1 = a little difficult; 2 = fairly difficult; 3 = difficult; 4 = very difficult; 5 = extremely difficult. This scale has been used in previous studies of head-tracking performance (e.g. So and Griffin 1992). The mean radial tracking errors were calculated using:

$$\text{Mean radial tracking error} = \sum \{[x^2(t) + y^2(t)]^{1/2}\}/N,$$

where $x(t)$ and $y(t)$ are the instantaneous head-tracking errors (in degrees) in the yaw and pitch axes respectively, and N is the total number of samples.

3. Results

3.1. *Effects of practice*

Head-tracking transfer functions for the yaw axis with eight practices are shown in figure 3. With and without the use of a 'look-ahead trace', a trend can be observed for the moduli (i.e. tracking gains) to decrease with increasing practice. The Friedman two-way analyses of variance by ranks were performed on the tracking gains at both 0.6 and 0.8 Hz. Results showed that the effects of practice on tracking gain were significant without the trace ($p < 0.01$ at both 0.6 and 0.8 Hz) and not significant with the trace ($p > 0.1$ at both 0.6 and 0.8 Hz). The median data and their ranks, according to the Friedman test, are shown in table 2. The phase lag responses at 0.6 and 0.8 Hz in the transfer functions appear to

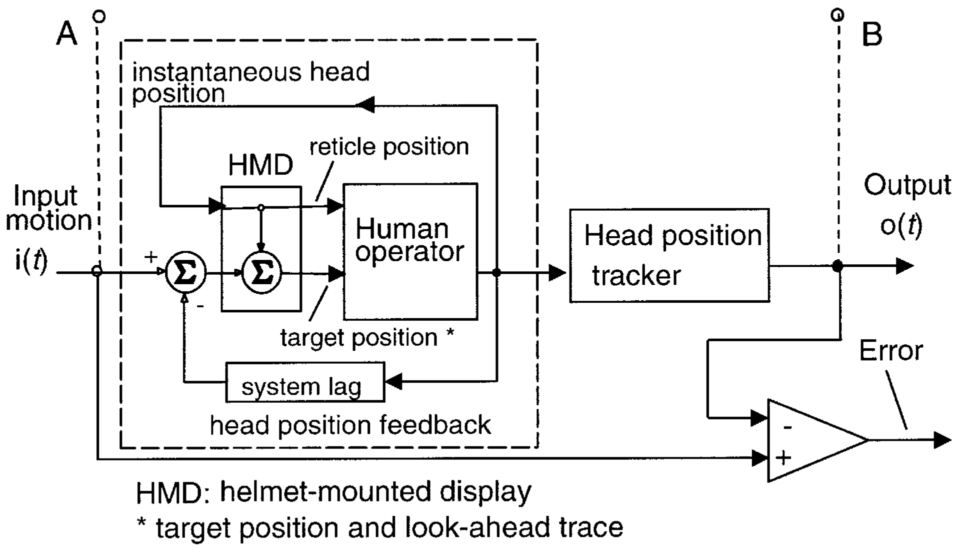

Figure 2. Quasi-linear model of the head-tracking system.

Table 2. Medians of yaw axis head-tracking moduli at 0.6 and 0.8 Hz as functions of practice (ranks assigned by the Friedman two-way analyses of variance are shown in square brackets).

No. of practice	Medians of yaw axis head-tracking moduli and [ranks]*			
	Without trace		With trace (160 ms lead-time)	
	at 0.6 Hz	at 0.8 Hz	at 0.6 Hz	at 0.8 Hz
1	1.06 [7.5]	1.09 [6.8]	0.98 [6.3]	1.10 [6.7]
2	0.97 [6.3]	1.01 [5.4]	0.92 [4.0]	0.94 [5.1]
3	0.90 [4.3]	0.95 [5.5]	0.78 [4.0]	0.84 [3.6]
4	0.88 [3.8]	0.94 [5.3]	0.89 [4.0]	0.89 [4.4]
5	0.88 [3.9]	0.88 [4.1]	0.83 [3.0]	0.86 [3.5]
6	0.83 [2.5]	0.85 [3.3]	0.95 [5.4]	0.93 [5.0]
7	0.88 [4.2]	0.83 [3.3]	0.92 [5.4]	0.92 [4.4]
8	0.88 [3.7]	0.81 [2.5]	0.85 [4.0]	0.86 [3.4]

increase slightly with practice but the effects were not statistically significant with or without the trace ($p > 0.1$: with 'trace' at both 0.6 and 0.8 Hz; $p > 0.4$: without 'trace' at both 0.6 and 0.8 Hz, Friedman). Results from the pitch axis were similar. According to the definition of the tracking transfer function, a unity tracking gain means that the subjects could follow the target without over-shoots or under-shoots. Figure 3 also reveals that as the number of practices increased the median tracking modulus reduced and deviated further from unity. A possible reason is that as practice increased subjects put less effort into their pursuit of the target. This may suggest that the head-tracking task in the experiments with and without the 'look-ahead trace' was intuitive and subjects became more and more relaxed as practice increased. The effect of practice on the mean radial tracking error was also tested using Friedman two-way analyses of variance. The results indicated that with and without a 'look-ahead trace' the median tracking errors were not significantly affected by practice (with 'trace': $p > 0.9$; without 'trace' $p > 0.6$). It is therefore reasonable to conclude that the task of head tracking, with or without a 'look-ahead trace', does not require much learning.

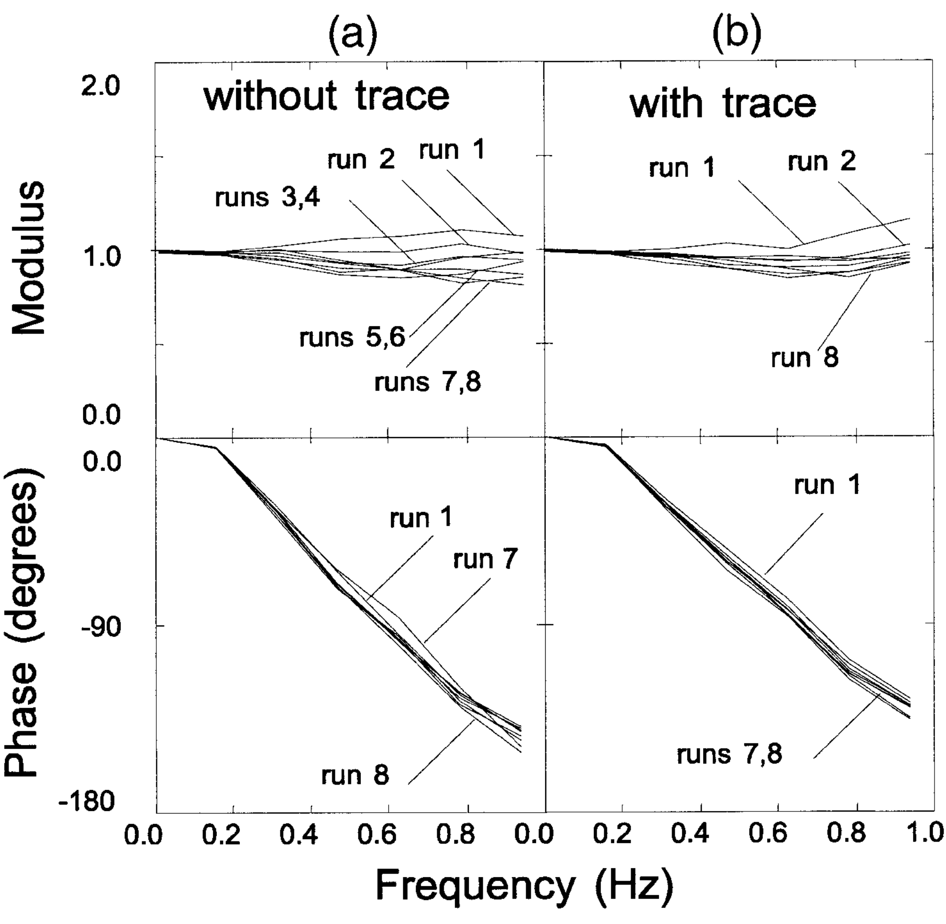

Figure 3. Yaw axis head-tracking transfer functions obtained in eight repeated-runs with and without a 160 ms 'look-ahead trace' (median data from eight subjects).

3.2. *Effects of 'look-ahead' cue*

Head-tracking transfer functions with 'look-ahead traces' of different lead-times are shown in figure 4. The phase lags show that the subjects' head positions followed the target position with a delay. With a randomly moving circular target without a

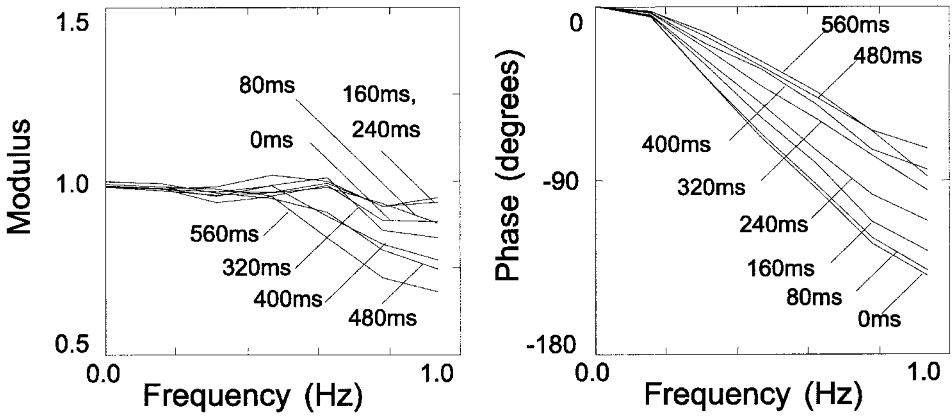

Figure 4. Yaw axis head-tracking transfer functions with a 'look-ahead trace' showing future target positions at different lead times (median data from eight subjects).

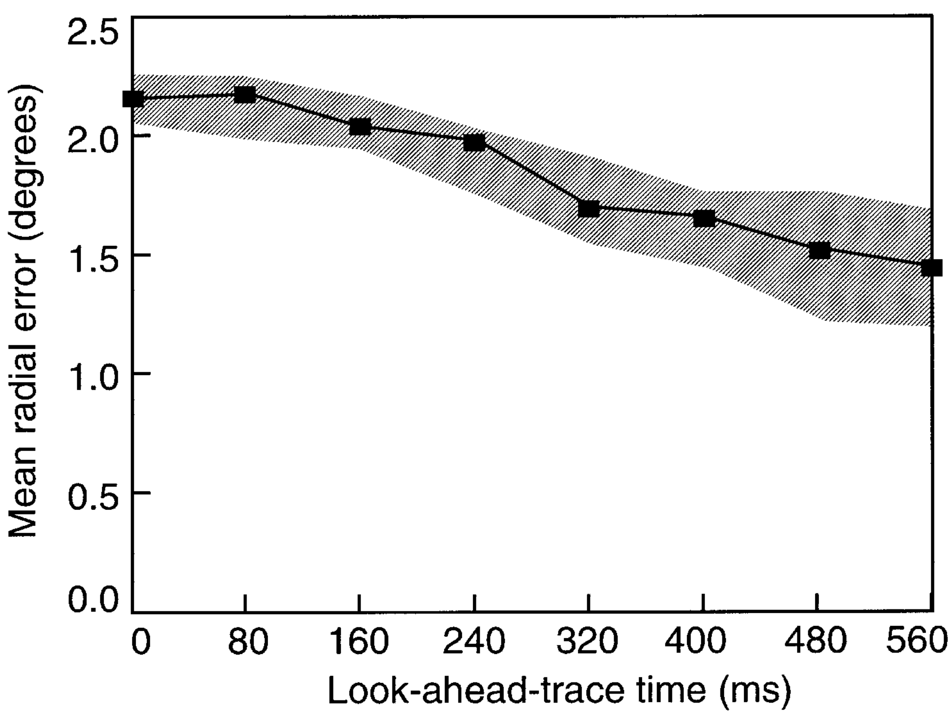

Figure 5. Medians (and interquartile ranges) of mean radial head-tracking error with a randomly moving circular target with a 'look-ahead trace' showing future target positions at different lead times (data from eight subjects).

'look-ahead trace', a lag was expected as subjects could not predict where the target would move. If a subject could predict the movement of the target, the phase lag would reduce. Barnes and Sommerville (1978) reported a head-tracking phase lag of zero or negative magnitude when tracking pure sinusoidal target motions of frequencies up to 0.8 Hz. Figure 4 shows that as the lead time of the trace increased, the head-tracking phase lags decreased ($p < 0.001$ at 0.6 Hz; < 0.001 at 0.8 Hz; Friedman two-way analyses of variance by ranks). This suggests that with the help of the trace, subjects could predict the target's future position. Reductions in tracking phase lags were associated with reductions in radial tracking error. Friedman analyses showed that as the lead-time of the 'look-ahead trace' increased, the mean radial tracking error decreased significantly ($p < 0.001$, figure 5). Further analysis using Wilcoxon matched-pairs signed ranked tests indicated that for a 'look-ahead' lead-time of 160 ms or more, the use of the 'look-ahead' trace significantly reduced head-tracking errors.

At 0.8 Hz, the moduli (i.e. tracking gains) decreased as the trace lead-time increased. The reduction was statistically significant ($p < 0.005$, Friedman). The median tracking gains at 0.8 Hz for different trace lead times and their associated mean ranks, according to the Friedman tests, were: 0 ms: 0.78 [rank: 5.3]; 80 ms: 0.85 [4.9]; 160 ms: 0.86 [6.0]; 240 ms: 0.85 [6.2]; 320 ms: 0.75 [4.9]; 400 ms: 0.65 [4.0]; 480 ms: 0.56 [2.9]; and 560 ms: 0.43 [1.7]. The reduction of tracking gains with

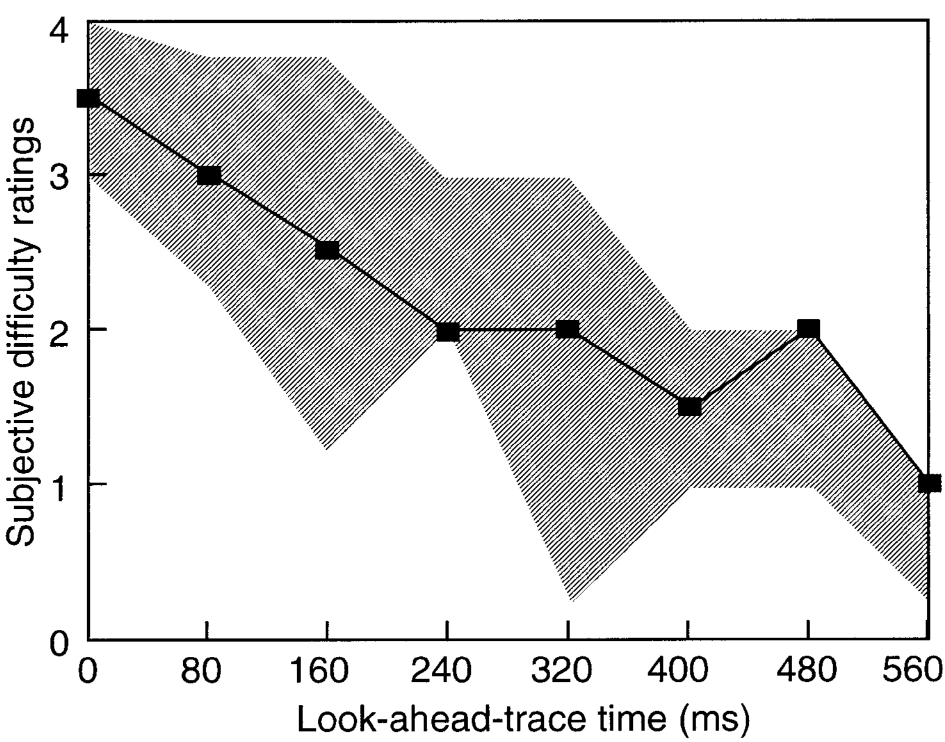

Figure 6. Medians (and interquartile ranges) of subjective difficulty ratings of a head-tracking task with a randomly moving circular target with a 'look-ahead trace' showing future target positions at different lead times (data from eight subjects).

increasing trace lead-time suggests that the subjects may have changed their tracking strategies according to the duration of the 'look-ahead trace'. Head-tracking transfer functions for the yaw axis were similar to those for the pitch axis. Subjective difficulty ratings also decreased with increasing duration of the 'look-ahead trace' ($p < 0.001$, Friedman; figure 6).

The reduction in tracking phase lag (in degrees) at 0.8 Hz with different 'look-ahead trace' durations is shown in figure 7. The reductions were calculated by normalizing the phase responses at 0.8 Hz obtained with different 'look-ahead traces' against the phase responses obtained without a 'look-ahead trace'. As the trace duration increased, the phase reductions increased. However, the phase reductions were always less than the phase of the 'look-ahead' information provided by the trace. This suggests that the subjects did not fully-utilize the cueing information provided by the 'look-ahead trace'.

4. Discussion

There are many ways in which an observer can predict the future position of a target. This may be implied by the direction of a non-symmetrical target moving mainly towards its front. In the case of an aircraft there may be cues from a change in wing surfaces or afterburners. Additionally, the past behaviour, the physical limitations of the target and the constraints of the world in which the task is being performed all provide cues to future position. The results of the present study confirm the expectation that head-tracking performance may be significantly improved by the

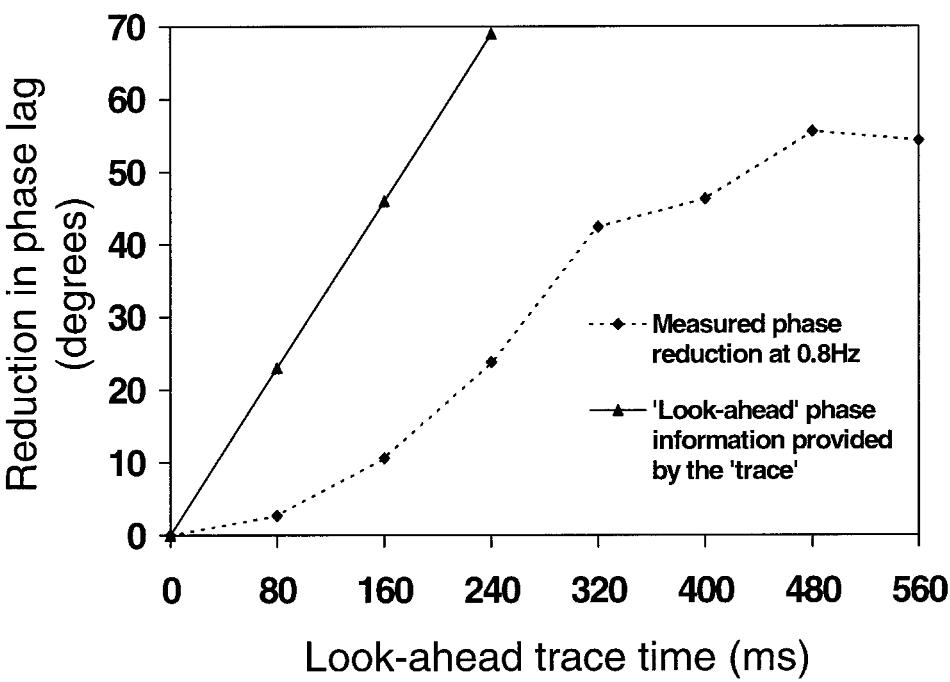

Figure 7. Reductions in tracking phase lag at 0.8 Hz with a 'look-ahead trace' of different lead times (medians of eight subjects) (the 'look-ahead' phase information provided by the traces is also shown).

presentation of cues to future target movements. This finding is consistent with the literature concerning the use of predictive cues on manual tracking performance (e.g. Poulton 1974, Jensen 1981). The manual tracking literature led to the development of predictor displays for manual control systems (e.g. flight path estimation pip for aircraft navigation). This study suggests that predictor displays will also assist the performance of head control systems.

In some head-steered systems, it may be possible to program a 'look-ahead trace' for a target because the system has 'knowledge' about the likely future positions of the target. Examples include the spatial presentation of radar signatures of distant targets on the helmet-mounted visor of a pilot. The target signatures may be represented by a 'pointed symbol' (e.g. a circle with a 'look-ahead trace'). With some head control systems, it may be possible to enhance an electronically presented view of a target so as to show artificial cues to future target positions. For example, with head-steered tele-control application, in addition to the video picture of a target, which may be delayed by several frames, a symbol representing the current position of the target might be presented based on instantaneous data collected by sensors. With pure, non-assisted, head-tracking tasks, the results of the present studies may merely emphasize the benefits of an operator 'thinking ahead'.

The present study shows that the addition of a cue to the future target direction and movement can significantly reduce head-tracking errors, change tracking strategies, and reduce subjective ratings of task difficulty. As explained above, real targets in most head-tracking applications contain direction and movement cues (e.g. aircraft in air-to-air combat, Fearnside *et al*. 1997; a space station docking connector viewed on a head-steered camera, Shepherd 1988; and a landing platform on an offshore oil-rig viewed by a helicopter pilot). The findings suggest that head-tracking behaviour and performance data collected with symmetrically shaped targets will differ from those with real targets containing cue information. Data presented in this study provide a link between head-tracking performance using symmetrical symbols as targets (table 1) and head-tracking performance with real 'pointed-targets' having movement cues. Unlike images of specific targets (e.g. a simulated aircraft), the 'look-ahead trace' provides a way of systematically increasing the predictability of any moving target.

The absence of a significant effect of practice with the use of the 'look-ahead trace' suggests that the trace provided a natural way to provide direction and movement cues to a target. This study showed that the task was perceived as being easier when the duration of the 'look-ahead trace' increased. It may be expected that this corresponded to a reduction of workload, which may make the task easier to learn. The reduced task difficulty might also be expected to allow improved performance of other, secondary tasks.

The results of the two experiments indicate that the 'look-ahead' information provided by the 'trace' was not fully utilized. Inspection of figure 7 indicates that the reduction in phase lag was greatest with lead times from 160 to 320 ms. Beyond $\sim$480 ms, the reduction in phase lag levelled out. The levelling of the phase reduction led to stagnation in tracking performance when the lead times increased beyond 480 ms. If the lead-time increased to, say, a few seconds, then subject performance might reduce due to overloading with unwanted information, but this is outside the scope of the present study. Further studies of different methods of presenting the 'look-ahead' cue so as to optimize the utilization of the 'look-ahead' information would be desirable.

5. Conclusions

A review of literature showed that the effects of many factors on head-tracking performance have been investigated (e.g. update lag, g-force, vibration, air-borne personal equipment, eye-dominance, target velocity, target frequency, and target movement axis). However, >75% of head-tracking studies have used targets with symmetrical shapes; there appears to have been no study of the effects of target movement cues on continuous head-tracking performance.

The results of the experiments reported here show that when tracking a circular target, the use of a 'look-ahead trace' can reduce head-tracking phase lags, head-tracking errors, and subjective ratings of task difficulty. Based on these results, head-tracking performance data obtained with symmetrical targets are expected to underestimate performance with targets having shapes that indicate direction or speed of movement. The 'look-ahead trace' simulates the information provided by non-symmetrical targets and may be useful in some future studies of head-tracking performance.

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