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# On-line feedback control of human visually guided slow ramp tracking: effects of spatial separation of visual cues

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**Abstract**

Visual feedback control of tracking movements is dependent upon a visual comparison of the guiding target and moving limb positions but the human fovea greatly restricts the area of high acuity vision. The effect of vertically separating the target and movement cues in a slow movement task is investigated. Subjects track a slow constant velocity target in the horizontal plane with wrist flexion controlled cursor movements. The effects of changes in the vertical distance between the two cues upon tracking performance were observed. When both cursors were at the same level, tracking was most accurate but showed significant intermittency around 2 Hz in frequency. Increased separation of cues reduced significantly both accuracy and intermittency; tracking was smoother but less accurate. Thus, feedback control is dependent upon the efficiency of positional comparison and hence becomes less effective as the cue separation increases. These results also support previous studies suggesting each cue makes an equal contribution to visuomotor feedback control, each acting as a reference to the other.



*Keywords:* Visually guided ramp tracking; Visual feedback; Visuomotor control; Intermittency

Visually guided ramp tracking tasks have been used as experimental paradigms for investigating slow, goal-directed limb movements. Simple display arrangements with a slowly moving visual target and a visual representation of the limb movement allow easy comparison of the intended and the actual movements, and hence highlight the 'on-line' visual feedback control. Such experiments can easily be used to test how the availability of the visual feedback information affects tracking performance. In particular, the characteristic intermittency of tracking can be studied with various different manipulations of the available visual information (e.g. Ref. [7,10]). Miall et al. [8] showed that when the visual representation of the movements was turned off, the intermittency of wrist tracking significantly reduced. Recently, visually guided tracking studies have been used to study movement disorders due to cerebellar damage [1–4] and also intention tremor caused by multiple sclerosis [5,6]. However, the contribution of different visual cues to the control of tracking is still debatable. Cody et al. [3] showed guiding target display suppression during tracking tasks with cerebellar lesion patients had no obvious influence on their performance, in contrast to visual movement feedback suppression. In contrast, our previous studies [5] on multiple sclerosis patients showed withdrawal of the target cue had a similar effect to withdrawal of the movement cursor, both significantly decreasing tracking accuracy and intermittency. Thus, it may be that one visual cue simply acts as a spatial reference for the other.

This study investigates the effects of manipulating the visual display by vertically separating the guiding target from the movement cursor during ramp trackings in the horizontal plane. Most efficient comparison of target and movement cursor positions can be made when the two cursors are at the same vertical level and both can be viewed simultaneously in, or close to, central vision. We hypothesised that less efficient visual spatial comparisons would be made when there is vertical separation between the two, and this may affect the error-signal-dependent feedback control, reducing both the accuracy and intermittency of tracking.

Ten naïve subjects were tested, each with normal/-corrected to normal vision (five male, five female: range

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20–23 years; mean 21 years; three left-handed, seven right-handed). Subjects were instructed to track a visual target moving horizontally across a screen with a visual cursor controlled by a joystick. Movements of the cursor represent rotation of the joystick during wrist flexion movement. Experimental methods have been described previously [5] and are summarised here. A $12 \times 12$ pixel, hollow white square target was displayed on a black background VGA computer screen at the subject's eye level. Initially stationary on one side of the screen, at the start of each trial the target moved horizontally at a constant speed to the other side of the screen at one of four velocities (13.64, 9.27, 7.50, or 5.50°/s) randomly allocated over eight trials (two trials at each velocity), and then stopped. The subject held with a normal 'hammer' grip a low resistance joystick. The subject's forearm was supported in a channel fixed to the arm of the chair, positioned for each subject to immobilise the forearm and allow easy flexion and extension wrist movements $\pm 30°$ from the neutral position, to cover the required tracking movements of $\pm 20°$. The joystick position was represented by a $6 \times 6$ pixel, hollow, white square cursor which comfortably fitted inside the target cursor when the two were aligned horizontally. Subjects attempted to keep the joystick-controlled cursor aligned with or as near as possible to the moving target. Flexion movements only were measured on both hands. Several practice trials were allowed before testing. The target remained at the middle level of the screen, while the joystick cursor was positioned at the target level (Gap 0), 4.5 cm (3.2° measured at the eyes) above (Gap + 1) and below (Gap − 1), and 9.0 cm (6.4°) above (Gap + 2) and below (Gap − 2, Fig. 1). Subjects were instructed to focus upon the target cursor, but to use peripheral vision to monitor the joystick cursor movements. This attempted to minimise eye movements between the two cursors, which were not monitored in this study.

Movements of the joystick produced a voltage signal, amplified and digitally sampled with 12-bit resolution at 70 Hz, then converted into a value for movement velocity in terms of the changing joystick angle with time and allowing comparison of joystick velocity with target velocity. A computer algorithm selected tracking segments starting 1 s after the target started moving, and continuing to the end of the trial, eliminating the reaction delay and acceleration movements, and concentrating on the subject's attempt to match the constant velocity target movement. The movement velocity (MV) and the standard deviation of the movement velocity (SD-MV) for each of the eight trials were computed from data in this selected segment. MV described movement accuracy as percentage mean velocity of joystick movement relative to that of the target; for perfect tracking, MV = 100%. MV control inaccuracies were represented by the absolute percentage error in the MV relative to the target velocity (Error Velocity, EV). The SD-MV was calculated as a measure of tracking smoothness; for perfectly smooth tracking, SD-MV = 0. Frequency composition of the tracking records was computed on the same data segments; the mean velocity was removed from each segment, data were padded with zeros to provide 1024 points per segment, and a fast-Fourier transform was performed. Power spectra of each trial were averaged over 8 trials for each hand.

Finding no significant difference in tracking performance of dominant and non-dominant hands across all movement cursor positions (tested using two-factor analysis of variance; ANOVA), further analysis was based on the number of hands rather than subjects. To eliminate inter-hand and inter-subject variance, data from each hand was normalised to tracking performance for position Gap 0; data at other positions were presented as a percentage of that value. Analysis of the variation in performance with position was then performed using single-factor ANOVA. Results showed that EV increases ($P < 0.01$, $n = 20$) as cursor separation increases, while SD-MV ($P < 0.01$, $n = 20$) is reduced (Fig. 2). Fig. 3 shows mean power spectra for each display arrangement (frequency analysis results) calculated with data from both hands recorded across all subjects (first 5 Hz only are shown). The expected 2 Hz (1.4–2.3 Hz) component is evident in the Gap 0 position, but is greatly reduced in other positions. The difference between the mean power value of this component at Gap 0 and at other positions is highly significant ($P < 0.001$, $n = 20$). Thus, it appears the display arrangement does affect visual-feedback dependent intermittency in tracking, with increased cursor separation eliminating intermittent movements. A paired $t$-test showed no significant differences in tracking performance between joystick cursor positions (Gap + 1 vs. Gap − 1 and Gap + 2 vs. Gap − 2). It therefore seems that actual visual field position may not be the important factor, rather the vertical separation of target and joystick cursor.

Previous work has highlighted the role of error-correction based feedback control of slow visually guided tracking

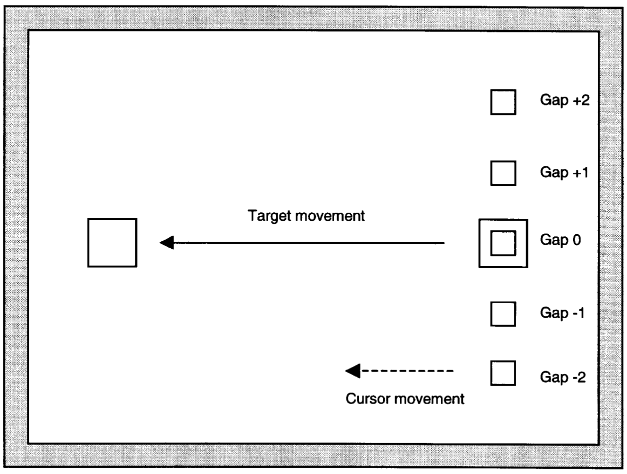


Fig. 1. Vertical separation of the guiding target and movement cursor in all possible positions. In each session, the movement cursor appeared in only one of five possible vertical positions.

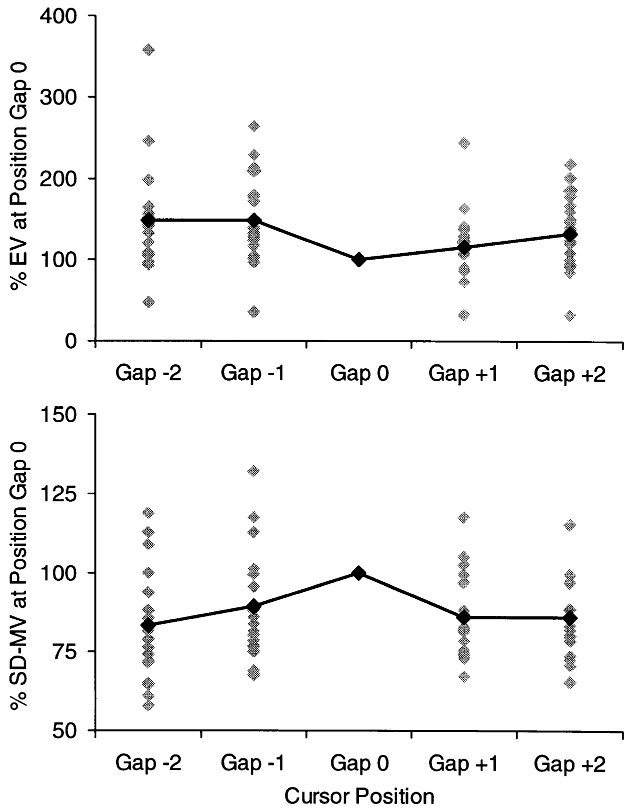


Fig. 2. Mean (black line) and individual values of normalised EV (top) and SD-MV (bottom) data for all hands across all subjects. EV is shown to increase, while SD-MV decreases, with increased cursor separation.

movements [1,2,8,11]. This study investigated the effects on tracking performance following changes in available visual information in a manner not tried before (i.e. introducing vertical spatial separation between the guiding target and movement cursor) while the target was tracked in the horizontal plane. The main findings of this study can be summarised as follows; as vertical separation of target and movement cursor increases, so the accuracy and intermittency of the tracking movements decreases. The increased cursor separation reduced the ease and efficiency of making spatial comparisons of their positions, and thus the ability of the visual system to detect errors in the movement relative to the guiding target was undermined. Effectively, the threshold for the detection of errors, the 'error deadzone' [11], seems to increase with cursor separation. As the results show, subjects make fewer voluntary correction movements, and so tracking is less intermittent; smoother, but less accurate. There was a notable disappearance of the intermittent responses in the range of 1.4–2.3 Hz between the frequency power spectra for the Gap 0 position and positions with a vertical cursor separation. This particular component differs from any involuntary movements the subject may make due to, for example, a physiological tremor (usually in the range of 8–12 Hz), so this provides more evidence of the much attenuated role of visuomotor feedback when there is a spatial separation between visual cues.

These findings compliment our previous experiments [5, 8] in which removing one cursor or the other is used to abolish availability of direct spatial comparison of two visual cues. The present experiment provides a different manipulation of feedback availability, using increased cursor separation to change the threshold for error detection (or increase the size of the error 'deadzone'). Both types of study show tracking accuracy and intermittency are dependent upon the availability of visual feedback information, as in both cases tracking was smoother but less accurate with altered visual information. This suggests that the two visual cues contribute equally to the visual feedback error signal (generated by spatial comparison of their positions) such that each simply acts as a reference to the other.

The visually guided wrist tracking task is a convenient tool for investigating visually guided motor control. To minimise possible complicating mechanical factors, this study tested only wrist flexion movements. It was hoped this

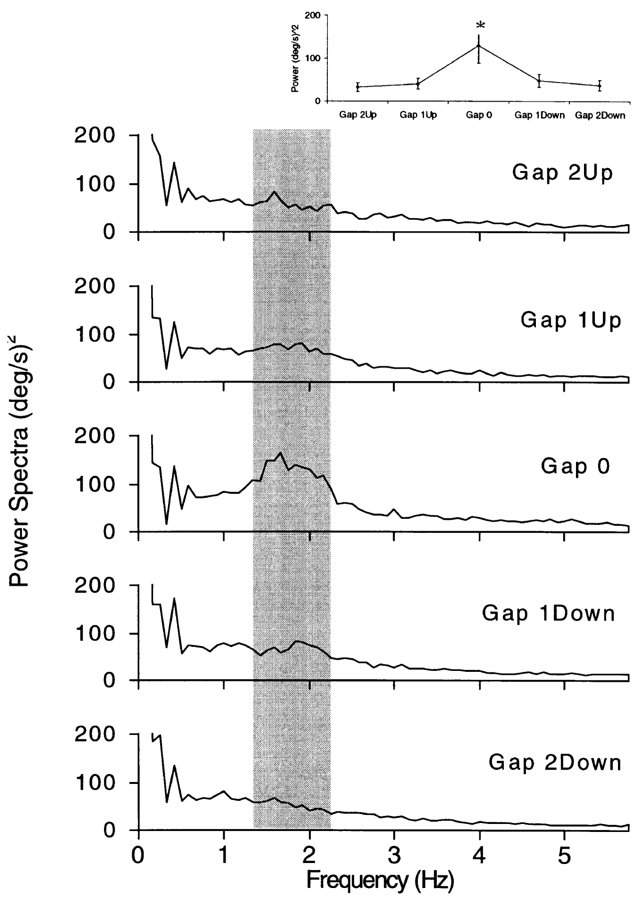


Fig. 3. Power Spectra averaged across all hands for each display arrangement. Grey bar highlights frequency range of intermittent movements (1.4–2.3 Hz), maximal at Gap 0 and decreasing when the movement cue is placed in difference position vertically. Upper right: A plot of mean power values and S.E. for all cursor positions over the frequency range of 1.4–2.3 Hz. $*P < 0.001$ (single factor ANOVA).

would mean the only variable was the availability of tracking information. However, the role of wrist proprioception in tracking performance is unclear. Whilst undoubtedly critical in apparatus familiarisation with practice, it is uncertain how influential proprioception becomes once subjects can easily make the joystick-to-cursor-movement transformation. As the transformation from a rotational wrist movement in the horizontal plane to a horizontal cursor movement on the computer screen is a relatively simple transformation compared to, for example, the rotation-to-vertical movement transformation used by Cody et al. [3], it seems likely that wrist proprioception could still be involved. Prablanc et al. [9] showed correction movements in the visual control of reaching movements can be made even when no visual limb position signal is available. Thus, they proposed comparisons could be made between the target position and the efferent copy/kinaesthesia of the arm movements. In contrast, however, Miall et al. [8] showed that if only proprioceptive information was available in wrist-tracking tasks (i.e. when the movement cursor is removed), such intermittent corrective movements were not made. This suggests proprioceptive – visual comparisons may not be so influential in error-based feedback control of movements. Miall et al. [8] concluded that when visual information is available, proprioception has only a minor role in motor control. However, the present task may not be sensitive enough to test the possibility that as visual information is compromised by the increased separation of the two cursors, proprioception may play an increasing role.

In conclusion, this study confirms that the accuracy and intermittency of visually guided slow tracking movements are based on visual detection of error between the target and movement cursor positions. We have shown that when it is made more difficult to detect such errors by inserting a vertical separation between the cursors and hence inhibiting direct positional comparisons, the accuracy and intermittency in tracking are significantly reduced.

## References


[1] H. Beppu, M. Nagoaka, R. Tanaka, Analysis of cerebellar motor disorders by visually guided elbow tracking movement, Brain 107 (1984) 787–809.

[2] H. Beppu, M. Nagoaka, R. Tanaka, Analysis of cerebellar motor disorders by visually guided elbow tracking movement: 2, contribution of the visual cues on slow ramp pursuit, Brain 110 (1987) 1–18.

[3] F.W.J. Cody, B. Lövgreen, W. Schady, Increased dependence upon visual information of movement performance during visuo-motor tracking in cerebellar disorders, Electroenceph. Clin. Neurophysiol. 89 (1993) 399–407.

[4] B.L. Day, P.D. Thompson, A.E. Harding, C.D. Marsden, Influence of vision on upper limb reaching movements in patients with cerebellar ataxia, Brain 121 (1998) 357–372.

[5] X. Liu, R.C. Miall, T.Z. Aziz, J.A. Palace, P.N. Haggard, J.F. Stein, Analysis of action tremor and impaired control of movement velocity in Multiple Sclerosis during visually guided wrist tracking tasks, Mov. Disord. 12 (1997) 992–999.

[6] X. Liu, T.Z. Aziz, R.C. Miall, J. Rowe, S.H. Alusi, P.G. Bain, J.F. Stein, Frequency analysis of involuntary movements during wrist tracking: a way to identify MS patients with tremor who benefit from thalamotomy, Stereotactic Func. Neurosurg. 74 (2000) 53–62.

[7] R.C. Miall, D.J. Weir, J.F. Stein, Visuomotor tracking with delayed visual feedback, Neuroscience 16 (1985) 511–520.

[8] R.C. Miall, D.J. Weir, J.F. Stein, Intermittency in human manual tracking tasks, J. Mot. Behav. 25 (1993) 53–63.

[9] C. Prablanc, D. Pélisson, M.A. Goodale, Visual control of reaching movements without vision of the limb: I, role of retinal feedback of target position in guiding the hand, Exp. Brain Res. 62 (1986) 293–302.

[10] D.J. Weir, J.F. Stein, R.C. Miall, Cues and control strategies in visually guided tracking, J. Mot. Behav. 21 (1989) 185–204.

[11] D.M. Wolpert, R.C. Miall, J.L. Winter, J.F. Stein, Evidence for an error deadzone in compensatory tracking, J. Mot. Behav. 24 (1992) 299–308.