DAA/AMES

# Hesitations in Continuous Tracking Induced by a Concurrent Discrete Task

Stuart T. Klapp, Patricia A. Kelly, and Allan Netick

California State University, Hayward

(NASA-CR-177019) HESITATIONS IN CONTINUOUS TRACKING INDUCED BY A CONCURRENT DISCRETE TASK (California State Univ., Hayward.) 40 p CSCL 05I

N86-29503

Unclas G3/53 43285

Running head: Hesitations in tracking

Send correspondence to:

Stuart T. Klapp
Department of Psychology
California State University, Hayward
Hayward, CA 94542

## Abstract

Subjects performed a continuous visually-guided pursuit tracking task with the right hand. From time to time ( intervals averaging 30 sec.) an auditory tone appeared signalling the subjects to perform a discrete response with the left hand. The presence of this tone was frequently associated with a hesitation in right-hand tracking which lasted 1/3 sec or longer. The rate of occurrence of these hesitations was about the same when the left-hand response involved a choice between competing responses as when the left hand responded in a predetermined direction. Hesitations occurred for three different mechanical tracking manipulanda using different controlling muscles, and appeared to be due to freezing rather than to relaxation of muscular action. The rate of occurrence of hesitations declined with practice, and this improvement in right-hand performance was accompanied by an improvement in performance of the concurrent left-hand response. The presence of hesitations, and their reduction with practice, can be interpreted within several theoretical viewpoints.

# Hesitations in Continuous Tracking Induced by a Concurrent Discrete Task

Stuart T. Klapp, Patricia A. Kelly, and Allan Netick
California State University, Hayward

This report describes a particular type of error which appears when subjects are required to track with one hand while simultaneously performing another motor task. This error mode involves a hold or hesitation in which all movement of the tracking hand stops abruptly for periods of 1/3 sec. or longer. This effect was first reported by Cliff (1973) for compensatory tracking accompanied by vocal shadowing. Here we report hesitations induced into pursuit tracking by a concurrent manual response with the non-tracking hand.

The usual measure of error in tracking, root mean squared departure from target location, may conceal the universality of this phenomenon by averaging this particular error along with other sources of error. Extracting this source of error from the aggregate, and studying it in isolation can complement the results obtained in studies based on servo-control theory which employ analytic techniques that are not particularily tuned to detect this error mode (see Wickens, 1984a, Chapter 11 for a review). The practical consequences of hesitations for situations such as flight control are potentially serious, and accounting for them presents a challenge to existing theories.

A major goal of the present research was to determine the circumstances under which hesitations do and do not occur. Variables considered include type of tracking manipulandum ("joy stick"), and the cognitive demands of the secondary manual task.

The relation between the timing and accuracy of the two responses was considered in some detail. Of special concern was the role of practice in reducing the frequency of hesitations.

## General Method

### Overview

Subjects were required to combine continuous visually-guided pursuit tracking (right hand) with occasional discrete handle movements under auditory control (left hand). The basic goal was to measure performance in tracking a particular segment of a forcing function with no stimulus for left-hand responding and to compare that performance with tracking the same segment when a tone stimulus for left-hand responding occurred. Because the same forcing function segment was tracked in both the control and probed (left-hand stimulus) conditions, any difference in tracking performance is attributable to the presence of the additional stimulus and response. Data were collected only from the critical control and probed tracking segments. Thus, the majority of the session was devoted to "filler" tracking activity so that the critical forcing function events would not be anticipated. Left-hand task performance (reaction time) was also measured.

### Apparatus and procedure

A custom-made system of three linked microprocessors was designed for these experiments. The visual display was generated by a graphics microprocessor. This was under the control of another microprocessor dedicated to controlling and recording right-hand stimulus and response events. The third microprocessor controlled and recorded the left-hand stimulus and response events. These microprocessors ran independently except that they operated from a common clock and program executions were intitiated stimultaneously. This provided for synchronization of the systems, while maintaining independence so that simultaneous events could occur in the right-hand and left-hand channels. As a check on system performance and synchronization, and to provide an analog representation of the data, all stimulus and response events were recorded on a polygraph, as well as in digital form by the microprocessors.

Data analysis concentrated on the digital data. The position of the tracking cursor was sampled at the rate of 60 times per sec. during the first 2 sec. after a stimulus for left-hand response, and during the corresponding control right-hand only segment. Note that the analysis was focused on the few seconds of critical tracking behavior, rather than averaged across all of the tracking response.

The subject and experimenter were in separate rooms. The subject was seated with eyes 55 cm from the CRT display for tracking. The target to be pursued was a square 3.3 deg. on each side, which moved up and down through a visual angle of 13 deg. The task was to keep a cross-shaped cursor centered within the target rectangle. The manipulanda (joy sticks) which controlled cursor movement varied among experiments, and are described in the experiment-specific method sections below.

The forcing functions for right-hand tracking were random-appearing with changes in velocity occurring no more often than once per 167 ms. Within the forcing functions were four critical segments which repeated as needed to provide eight probe and eight control test events. Thus, for each tracking forcing function segment which was accompanied with a probe stimulus for the left hand, there was an identical forcing function segment for the control case in which no stimulus for the left hand appeared. These repeating segments comprised 7.8% of the total time on scored trials, and did not appear at all on the unscored trials.

Each subject participated in one-hour sessions on separate days. Each session was comprised of eight 3 min. trials, separated by rest periods of approximately 1.5 min. The only scored trials were 3,4,7, and 8 which contained the critical test segments.

The left-hand response was to move a switch handle at least 1.0 mm. to the left or right as commanded by tones of 2000 Hz. or 500 Hz. Instructions emphasized accuracy with no mention of minimizing reaction time. The details of the assignment of tones to movement directions differed across experiments, and are described below. Tones occurred at times which appeared to be random to the subject, but half of which were associated with the test forcing function. The average rate of occurrence was one tone every 30 sec. The tone remained on until the subject made the correct response. If the subject made a response in the wrong direction, a subsequent correct response was ignored for 700 ms., and the tone remained on. This was to discourage a strategy of toggling the switch quickly in both directions as a standard response to both tone stimuli.

<u>Definition of hesitation</u>

Major interest was focused on the occurrence of hesitations in tracking. In order to qualify as a hesitation, the cursor had to remain at a fixed location for at least 1/3 sec. Response holds during which the tracking error was minimal might represent correct responding rather than errors. Therefore, response holds, or portions of response holds, which resulted in minimal difference between cursor position and the center of the target rectangle (less than 1/2 of the upward or downward tolerance defined by the target rectangle) were considered to be correct responses rather than error hesitations. Because we were interested in hesitations induced by the left-hand stimulus and/or response events (and in corresponding events during the control segments), we also imposed a time of occurrence criterion on events to be considered as hesitations. In order to qualify, a hesitation had to begin sometime between the start of the left-hand stimulus, and 1 sec. after that stimulus (or within the corresponding time in control segments).

<u>Subjects</u>

The subjects were students in Introductory Psychology at California State University, Hayward who participated as one option of a course requirement, and in some cases for pay as well as credit. All subjects reported that they were right-handed, and all signed their names with the right hand. All subjects passed a simple test of tracking performance prior to data collection.

## Experiment 1

The previous report (Cliff, 1973) demonstrated hesitations in compensatory tracking induced by concurrent vocal responses. The present research involves pursuit tracking with the right hand, and discrete manual responses with the left hand. As in the earlier experiment, we wanted to assure that hesitations occur more often on the probed (concurrent left-hand stimulus and response) tracking segments than on the control segments. The occurrence of hesitations was observed for simple and choice reaction time versions of the left-hand task, and across conditions of relative emphasis on left-hand and right-hand (tracking) performance.

### Method

The tracking joy stick was a handle which was gripped by the entire hand and moved by wrist and arm muscles (Figure 1). The handle extended 16 cm. above its pivot, moved through an angle of 7 deg., and required a torque of approximately 2750 gram-cm to overcome static friction and 1650 gram-cm to overcome kinetic friction. These torques correspond to forces of 400 and 235 grams respectively at the point of contact of the palm of the hand on the handle. Thus, this was a large and rather "sticky" handle.

INSERT FIGURE 1 ABOUT HERE

Subjects were tested over two daily sessions, using the procedure indicated in the general method section above. The 12 subjects were divided into three groups with assignment rotated across conditions as the subjects reported for the experiment. The conditions differed according to emphasis. In the track-emphasis group, tracking was emphasized both by instruction and by the presence of an unpleasant auditory alarm which sounded when the tracking cursor was beyond the boundaries of the target rectangle. For the left-emphasis group, the left-hand response was emphasized by instruction, and by the same alarm which sounded when the incorrect directional response was made. The remaining group received no emphasis instruction and no alarm.

All subjects were instructed to move the left-hand switch handle to the right for a high-frequency tone, and to the left for a low-frequency tone. The time of occurrence of these tones was random. For half of the subjects ( in each emphasis group) the appearance of high and low tones was also random, and hence the left-hand response was a choice reaction time paradigm. For the remaining subjects the tone pitch (high or low) was announced in advance, so that the left-hand task was a simple reaction time paradigm.

Results and discussion

Hesitations in tracking. Averaged across the emphasis and simple vs. choice conditions of testing, hesitations occurred more often (48% of the opportunities) when the left-hand stimulus was present than on control opportunities (6.5%), $F(1,11) = 27.0$, $p < .001$. This indicates that the hesitations were produced by the left-hand secondary task, replicating the findings reported by Cliff (1973), and showing that hesitations occur for manual as well as vocal secondary tasks, and for pursuit as well as compensatory tracking. The analyses to follow describe the hesitations which occurred when the secondary task was present.

The frequency of hesitations depended on emphasis condition. When tracking was emphasized, the rate of hesitations was 29%, compared to 76 % when left-hand performance was emphasized, $F(1,6) = 7.4$, $p < .05$. An intermediate rate of hesitations (37%) occurred with no emphasis instruction or alarm. Note that emphasis on tracking tended to eliminate the longer hesitations (Table 1).

We had thought that hesitations might be attributable to the necessity of making decisions concerning which response to generate with the left hand. Thus, we expected to find more right-hand hesitations for the choice RT left-hand condition than for the simple RT left-hand condition. Contrary to this expectation, there was no hint of reduced right-hand hesitations when the concurrent left-hand task was simple RT rather than choice RT. The rate of hesitations was 53% for simple RT, and 42% for choice RT, a trend contrary to that predicted. Apparently hesitations in right-hand tracking are not attributable to decision-making concerning the left-hand response, although they are attributable to perceptual-motor aspects of left-hand responding.

The overall distribution of the durations of the hesitations which occurred in the dual-task trials appears in Table 1. The shortest hold that met our definition of a hesitation was 333 ms and hence no shorter hesitations are tabulated. Table 2 presents the number of hesitations as a function of the time at which the hesitation started, measured as the delay from the stimulus for left-hand responding to the start of the right-hand hesitation. The longest delay which we considered to be a hesitation due to the left-hand response was 1 sec.

INSERT TABLE 1 AND TABLE 2 ABOUT HERE

One possible interpretation of hesitations is that they result from response interference. In this view, the demands of making the left-hand response are inconsistent with continued tracking, so that the onset of the left-hand response produces a concurrent hesitation onset in the right hand. Contrary to this view, 74% of the hesitations started before, rather than after, the onset of the left-hand response. Overall, the mean RT prior to hesitation onset (418 ms) was significantly shorter than the RT for left-hand responding (629 ms), $F(1,11) = 12.8$, $p < .01$. Apparently this response interference interpretation does not account for hesitations.

Another possible model of hesitations is that they might occur when things get "out of control", i.e. when the tracking error becomes excessive and the subject "gives up". By contrast, Cliff (1973) reported that hesitations tended to start when tracking was in a low-error state, suggesting that extra attention was allocated to the secondary task only when tracking seemed to be well under control. Neither the low-error nor high-error viewpoints was supported by the present data. In this analysis, a hold in tracking in the low-error state was not considered to be a true hesitation (because it might be an appropriate tracking response). Thus, none of the hesitations reported here occurred when tracking was in a low-error state. Furthermore, the average error at hesitation onset ( 1.61 deg. of visual angle) did not differ significantly from the overall average error of tracking (1.56 deg.), $F(1,10) < 1$. A similar model for hesitation termination would assume that subjects resume tracking, ending the hesitation, when the target returns to the vicinity of the fixed cursor position. However, the average error at hesitation exit (3.45 deg.) was higher than the overall error (1.56 deg.), $F(1,10) = 217.9$, $p < .001$. Thus, neither the onset nor the termination of hesitations is predictable from the tracking performance itself.

Left-hand responding. As Table 3 indicates, subjects tended to make errors of moving the left-hand response switch in the incorrect direction primarily in the choice RT condition where response selection was required. The median reaction time (RT) was computed for each subject and the mean of these medians appears in Table 3. Consistent with the usual finding, overall RT was longer for the choice RT left-hand response than for the simple RT response, $F(1,10) = 17.55$, $p < .01$. The rather long overall level of RT may be due to the lack of an emphasis on reducing RT in the instructions.

The effect of emphasis on left-hand performance was rather complex as indicated in Table 3. Although the apparent trends were nonsignificant, it may be useful to note the data pattern. For the simple RT task, emphasis on the left-hand task appeared to reduce RT. By contrast, this relation did not appear in the

choice RT data. Thus, there is a suggestion (in the simple RT data) that the emphasis instruction, which clearly reduced the frequency of hesitations, may have also led to a longer left-hand RT, so that the emphasis instruction may control the trade-off between right-hand and left-hand performance.

INSERT TABLE 3 ABOUT HERE

*Relation between left-hand and right-hand accuracy.* Consider next right-hand tracking performance in the absence of hesitations. This analysis excluded all trials on which a hesitation occurred, and then compared right-hand tracking error on trials in which the left-hand stimulus appeared with control tracking performance. The root mean squared tracking error in the first second following a stimulus for the left hand was 2.12 deg. of visual angle compared to 1.86 deg. for the control tracking segments, a difference which is rather small and nonsignificant, $F(1,11) = 2.66$, $p > .1$. ( Because holds of less than 1/3 sec. did not meet our definition of a hesitation, the slight trend toward higher error in the dual-task situation could be due to the presence of brief holds in the trials considered to be hesitation-free). Apparently the effect of the left-hand stimulus on tracking is to induce hesitations on some of the trials, and to leave the other trials unaffected.

Next consider left-hand performance as a function of right-hand hesitation. Overall data on left-hand performance was separated into two pools, one for those trials on which the right-hand tracking task exhibited a hesitation and one for those trials on which no hesitation occurred. Surprisingly, left hand performance did not differ as a function of this distinction. The mean left-hand RT was 629 ms (error rate 4.2%) when the right hand hesitated, compared to 648 ms (error rate 4.6%) when the right hand did not hesitate. The RT means did not differ significantly, $F(1,11) < 1$. Cliff (1973) also indicated that secondary-task performance did not differ as a function of whether tracking exhibited a hesitation.

## Experiment 2

In Experiment 2, subjects were tested at a higher level of practice to determine whether the frequency of hesitations would decline as practice progressed. A "joy stick" which used the finger muscles, rather than the arm and wrist muscles (Experiment 1) was used to determine whether the presence of hesitations would generalize across muscle groups and mechanical devices.

### Method

The eight subjects were tested with a procedure which corresponded to the simple reaction time with tracking emphasis condition of Experiment 1, except that the subjects were tested for six days. Data were scored on the first two and last two days of practice. The "joy stick" (Figure 2) was changed drastically in comparison to Experiment 1. A small handle, extending 0.6 cm above its base, was grasped by the fingers, and moved in sliding action over a distance of 4.5 cm using primarily the finger muscles which had to exert a force of approximately 90 grams to overcome static friction, and 80 grams to overcome kinetic friction.

---

INSERT FIGURE 2 ABOUT HERE

---

Results and discussion

Hesitation rates and left-hand RT means appear in Table 4. The first two days represent the same degree of practice as that of Experiment 1, so that data for the two different joysticks can be compared. The rate of hesitations with a concurrent left-hand task (20%) was comparable to the corresponding tracking emphasis condition of Experiment 1 (29%), even though the joy stick was very different. The durations of the hesitations were also comparable to those of the corresponding ( tracking emphasis, early practice condition) of Experiment 1. There were 19 hesitation events of duration 333-483 ms, 6 between 484-667 ms, and none longer. As in Experiment 1, the rate of hesitations was higher for the dual-task trials compared to control track-only trials, $F(1,7) = 11.3$, $p < .05$ for the first two days, and $F(1,7) = 7.6$, $p < .05$ across all four of the scored days.

---

INSERT TABLE 4 ABOUT HERE

---

The rate of hesitations in the dual-task condition declined as a function of days of practice, $F(3,21) = 3.6$, $p < .05$. During the last two days all hesitations were less than 483 ms This improvement in right-hand performance was not a matter of changing the criterion of trade off between right-hand and left-hand performance because left-hand RT also improved over the scored days of practice, $F(3,21) = 10.5$, $p < .001$. There were no left-hand errors. Thus, practice improved both left-hand and right-hand performance.

As in Experiment 1, the left-hand RT data were separated into pools for which the right hand did hesitate, and cases for which the right hand did not hesitate. Because of the low rate of hesitations in the last two days, this was done only for days 1 and 2. In agreement with Experiment 1, there was no significant difference in mean left-hand RT when the right hand hesitated (444 ms) compared to the cases with no right hand hesitation (438 ms), $F(1,7) < 1$.

Table 5 displays the root mean squared tracking error for those trials on which no hesitation occurred. Performance was measured during the first second after the left-hand stimulus, and on the corresponding control tracking segments. The tracking error was smaller late in practice than early in practice, $F(1,7) = 6.4$, $p < .05$. Early in practice the error was slightly but significantly larger on the dual-task trials compared to control, $F(1,7) = 5.87$, $p < .05$, but by the final stage of practice tracking error was independent of dual-task versus single-task , $F(1,7) < 1$. However, the apparent practice by single-dual interaction was nonsignificant, $F(1,7) = 1.7$, $p > .1$.

INSERT TABLE 5 ABOUT HERE

## Experiment 3

The purpose of Experiment 3 was to determine whether hesitations represent relaxation of control or freezing of the muscles. The manipulanda used in Experiments 1 and 2 had high friction and no spring loading. Hence, relaxation of the controlling muscles would let the manipulanda remain "stuck" at one position. Thus, these hesitations could have been produced by either relaxation or freezing of the muscles. By contrast, the manipulandum of Experiment 3 had very low friction and was spring loaded in one direction. This joy stick is difficult to hold in a constant location, and relaxation of muscles leads to movement in the direction of the spring force. If hesitations occur with this manipulandum, we could conclude that they represent freezing of the muscles, rather than release of control.

### Method

The eight subjects were tested on two daily sessions, using the simple reaction time, tracking-emphasis procedure. The joy stick manipulandum (Figure 3) was a 7 cm.-long lever which moved through 60 deg. It was held between the thumb and forefinger, and was operated by the finger and wrist muscles. Compared to the manipulanda of the previous experiments, this device had very low friction. With the spring bias removed, a torque of only 35 gram-cm. was required to initiate movement. This represents 5 gram force at the end of the stick. In the actual experiment the handle was spring loaded with a torque of 400 gram-cm. in the direction of rotation corresponding to downward movement of the cursor. Thus, the spring loading was far greater than the friction, making it difficult to hold the handle in a fixed location. This should discourage hesitations unless they are generated by actively freezing the muscles.

INSERT FIGURE 3 ABOUT HERE

Results and discussion

Although it was difficult to hold this joystick in a constant position, the rate of hesitations (27.6%) was about the same as in the comparable conditions of the other experiments (29% for Experiment 1 and 20% for Experiment 2). Also, the distribution of the durations of the probe-induced hesitations (Table 6) was similar to that of the previous experiments. As in the previous experiments there were more hesitations when there was a left-hand task (27.6%) than without the task (4.69%). This relationship between hesitations and left-hand task held for 7 out of 8 subjects ( $p < .05$, sign test), but was not quite significant when assessed by analysis of variance, $F(1,7) = 3.79$, $.05 < p < .10$

INSERT TABLE 6 ABOUT HERE

From these results it is clear that making the joy stick difficult to hold in a fixed position did not reduce the frequency or duration of the observed hesitations. This suggests that hesitations are an active freezing of the muscles, rather than a release of control or relaxation.

To determine whether the spring bias on the joystick had any influence on responding, the possibility that the motion during hesitation-free tracking episodes might be biased in the direction of force applied by the spring was considered. Examination of the polygraph recording indicated that there were no patterns which corresponded to total release of the joy stick to move under spring control. As a more sensitive assessment of the possible influence of the spring bias, the direction of the cursor error with respect to the spring bias was observed for those trials on which the cursor was off-center by one half or more of the tolerance, but on which the tracking response did not hesitate. If the spring had no influence on the response, these errors should be equally distributed between those in the direction of the spring bias, and those opposed to the spring bias. However, the proportion of errors with the spring (.61) was greater than the proportion against the spring (.39), $F(1,7) = 11.2$, $p < .05$. This relation appeared both on trials with a stimulus for left-hand responding and on controls, leading to no significant interaction of condition by direction, $F(1,7) < 1$. We conclude that the spring bias did influence tracking. However, as was pointed out earlier, this spring bias did not prevent hesitations from occurring at the same rate as in the other experiments.

As in the other experiments, the left-hand mean RT with no right-hand hesitation (486 ms) was about the same as the corresponding mean RT when the right hand hesitated (467 ms), $F(1,7) < 1$. Also consistent with previous results, the tracking error in the absence of hesitations was about the same when a left-hand stimulus occurred ( 1.84 deg. of visual angle) compared to control tracking (1.70 deg.), $F(1,7)= 1.4$, $p > .1$.

## General Discussion

### Summary of major findings

Hesitations in pursuit tracking of at least 1/3 sec. duration were observed with a large, high-friction joystick operated by hand, wrist, and arm muscles (Experiment 1), with a small high-friction slider operated by finger muscles (Experiment 2), and with a spring-biased low-friction finger joy stick (Experiment 3). Hence the occurrence of hesitations generalizes across particular muscles and mechanical devices used for tracking. The fact that manual secondary responses ( these experiments) as well as vocal secondary responses (Cliff, 1973) induced hesitations suggests that the details of the muscular action of the secondary task may not be critical either.

Although both the present research and the previous report (Cliff, 1973) demonstrated hesitations, there are important differences in the procedures and results which should be noted. We observed hesitations with a low rate of secondary-task events ( 1 per 30 sec.). Cliff observed hesitations only with a fast rate of vocalization (1.5 numbers per sec.), and none at the slower rate ( 1 per sec.), which nevertheless was far faster than our rate of secondary-task events. Whereas Cliff indicated that subjects tended to start hesitations when tracking was in a low-error state, our subjects started hesitations at an error state indistinguishable from that observed overall. Thus, the hesitations we report in pursuit tracking induced by left-hand responses and those observed by Cliff in compensatory traking with vocal responding might represent different phenomena, i.e., the hesitations might be due to distinctly different mechanisms.

In the present research hesitations occurred even for a joystick which was difficult to hold in a fixed location because of low friction and spring bias in one direction (Experiment 3). This suggests that hesitations are produced by freezing the muscles in a rigid fixed location, rather than by relaxation of muscular control.

These tracking (right-hand) hesitations occurred much more often when subjects were required to perform another response than with comparable control cases of tracking alone (all three Experiments; Cliff, 1973). Thus, hesitations are attributable to interference between tracking and some aspect of the auditory stimulus or the corresponding secondary muscular response. However, hesitations occurred equally often for simple RT left-hand responses and for choice RT responses (Experiment 1). Therefore, selection between one of two possible left-hand responses on a trial by trial basis was not a necessary condition to produce hesitations.

A trade-off model of hesitations can be rejected. The notion that on some occasions subjects try especially hard to reduce left-hand RT, and in the process hesitate with the right hand has no support because left-hand performance (RT) was no better when the right hand hesitated than when it did not hesitate (all three experiments). After six one-hour sessions, the frequency of hesitations was greatly reduced, and the speed of the left-hand response was also improved (Experiment 2). Thus, there was no evidence to suggest that hesitations were reduced by favoring right-hand tracking over left-hand responding.

The fact that hesitation onset tended to occur prior to onset of the left-hand response (Experiment 1) suggests that response interference or response competition are not viable interpretations of the underlying cause of hesitations. These views suggest that the onset of the left-hand response causes the onset of the hesitation, so that the left-hand response should start before, or at the same time as, hesitation onset.

Possible cause of hesitations

The present findings, together with those reported by Cliff (1973), can be accommodated by a model which assumes that hesitations result from diversion of attention away from the tracking hand toward the stimulus for the other task. Consistent with this view, the onset of hesitations occurred prior to the onset of the left-hand response to which attention had been diverted. In the present experiments, the infrequent auditory stimulus may "grab" attention, possibly through a mild form of the "startle reaction" (Landis & Hunt, 1939). In contrast to the slow rate of stimlui for the left hand in the present experiments ( 1 per 30 sec.), Cliff (1973) reported hesitations only for a faster rate (1.5 per sec) of stimulus input, and no hesitations for a slow rate ( 1 per sec), which was far faster than our rate. Thus, a different mechanisms of attention diversion seemed to be operating in Cliff's experiment. Perhaps attention can be diverted away from tracking by either an abrupt, startling input ( our experiments), or by a task demanding a high rate of information processing (Cliff's faster rate).

Although differing as to the cause of the diversion of attention, both studies may converge on the same symptom of such diversion -- a freezing of muscular action. Why freezing rather than some other response such as continuation of on-going action or muscular relaxation? We can suggest that a neural mechanism to generate freezes may have adaptive significance. For example, a tree-clinging animal will survive longer it it responds to a diversion of attention away from the clinging hand by freezing the unattended muscles, rather than by continuation of ongoing movement or by relaxation.

This model must be elaborated to account for the fact that the frequency of hesitations became lower with practice (Experiment 2). As was noted earlier, this improvement was not a matter of changing the criterion of trade-off between the two competing respones because both responses improved together with practice. One possiblity is that reduction in hesitations may represent adapation to the startle-inducing quality of the auditory stimulus. However, changes in behavior which reflect attentional processes are customarily given other kinds of interpretations that may also apply in the present context. Some possible interpretations based on these perspectives are considered next.

Cognitively-oriented theories of improvement with practice..

In our interpretation, hesitations result from a diversion of attention away from right-hand tracking toward left-hand responding. Several theories have developed within cognitive psychology to explain improvement with practice within this attention perspective.

According to the automatic processing viewpoint (Schneider, 1985; Shiffrin & Schneider, 1977), one of the two responses may operate without the need to draw attentional resources from the other because one response has become resource-free, i.e. "automatic." But, automatic processes are assumed to develop only with extensive practice. By contrast, good left-hand responding without hesitations of right-hand tracking occurred on many occasions even early in practice. Furthermore, hesitations were minimized without the extensive practice usually assumed to be needed for automaticity. Thus, for the automatic processing interpretation to fit the present data, the theory would need to be modified by removing the requirement of high practice, or by postulating (ad hoc) that a high degree of relevant pre-experimental practice had occurred on one of the tasks.

According to integration theory (Klapp, Hill, Tyler, Martin, Jagacinski, & Jones, 1985; Kramer, Wickens, & Donchin, 1985), the two responses might occur together without interference because they are perceptually and cognitively integrated into a unitary response, and are no longer processed as two distinct and potentially interfering responses. This seems to be an unlikely interpretation of the present data because previous examples of integrated responses have tended to have a common goal. By contrast, the tracking and tone-extinguishing responses of the present experiments have very diverse goals.

A plausible approach for understanding why people can sometimes combine left-hand responding with right-hand tracking (without hesitations) would appeal to resource independence (Navon & Gopher, 1979; Wickens, 1984b; Wickens, Sandry, & Vidulich, 1983). However, current versions of multiple resource theory do not specifically address the issue of achieving an increasingly more optimum resource allocation through practice. This additional assumption would be needed for the resource perspective to account for the improvement of both right-hnad and left-hand performance as practice progresses.

Another approach which might account for the present findings is based on an extension of the implications of a strongly established perceptual phenomenon. This phenomenon, known as perceptual streaming, is easiest to describe in the auditory modality. If two trains of timed stimuli are comprised of tones which differ greatly in frequency across trains, then the two trains are perceptually organized into two distinct and independent streams (Bregman & Campbell, 1971; Jones,1976). The listener no longer hears a single coherent sequence involving all of the tones, but instead reports two co-occurring sequences with all the high-pitched tones in one sequence and all the low-pitched tones in the other. This compelling perceptual effect is supported by the objective finding that, whereas people can determine the temporal order of events within a stream, corresponding judgements across streams are of much lower accuracy (Bregman & Campbell, 1971; Dannenbring & Bregman, 1976; Jones, Maser, & Kidd, 1978).

Perhaps streaming is a basic phenomenon which can be extended beyond a strictly perceptual domain. For example, the same principle may underly the possiblity that two cognitive processes can be carried out independently, as in the report of simultaneous reading and transcribing spoken material (Hirst, Spelke, Reaves, Caharack, & Neisser, 1980). However, there is reason to be cautious about extending the notion of streaming to the sensory-motor actions of the present experiments. Because perceptual streaming is known to make response integration difficult (Klapp, et al, 1985), one might suppose that it would reduce rather than facilitate coordination of left-hand and right-hand responses. Indeed, reduced performance with streamed stimuli was reported for two-hand tapping (Klapp, et al, 1985, Experiment 3). However, this may not be an issue for pairs of responses, such as tracking and handle movement, for which response integration is unlikely even under favorable perceptual circumstances. Where integration of the two responses cannot occur, streaming may be the only feasible way to generate the two concurrently without mutual interference.

As is evident, several divergent models might be adapted to account for the reduction of hesitations with practice. Some of these models arise from the tradition of cognitive psychology, and another is based on an extension of the phenomenon of the startle reaction. These interpretations all have problems, and we are not in a position to recommend one over the others on the basis of available data.

*Implications for aviation settings*

Even in the absence of a complete theoretical understanding of the phenomenon of hesitations, we can observe that there is no doubt that people hesitate in continuous tracking for as long as 1 sec. when required to perform a concurrent task with the other hand. Although hesitations were reduced in frequency and in duration by practice and by emphasizing tracking, they were not completely eliminated. Hesitations could be dangerous in situations such as helicopter flight control in nap-of-the-Earth flight. This suggests that flight-control systems should be made tolerant and forgiving of this type of error to whatever extent possible, and that task analysis and task design should be directed at finding and then eliminating requirements for secondary tasks during phases of flight which would not tolerate control-system freezes.

The conclusion that the effect of practice is to produce a higher proportion of instances in which tracking and left-hand responding occur without mutual interference is quite encouraging in that it suggests that skilled pilots may learn to combine flight control and needed auxillary tasks. However, one is left with a lingering concern that the achievement of apparent parallel processing may be through the use of a rather unstable mode of performance which could easily be disrupted by emergency situations.

Acknowledgements

This research was supported by NASA-Ames Cooperative Agreement NCC2-223. E. James Hartzell was technical officer, and his advice is acknowledged with appreciation. The authors also express their appreciation for the assistance of Vernol Battiste, Sherry Dunbar, George Eggleton, Christopher Morgan, Tom Palmer, and John Tyler. Portions of these data were presented at the Annual Conference on Manual Control at Sunnyvale, CA. , June, 1984, and at Columbus, OH., June, 1985.

# References

Bregman, A.S., & Campbell, J. (1971) Primary auditory stream segregation and perception of order in rapid sequences of tones. Journal of Experimental Psychology, 89, 244-249.

Cliff,R.C. (1973) Attention sharing in the performance of a dynamic dual task. IEEE Transactions on Systems, Man, and Cybernetics, SMC-3, 241-248.

Dannenbring, G.L., & Bregman, A.S. (1976). Stream segregation and the illusion of overlap. Journal of Experimental Psychology: Human Perception and Performance, 2, 544-555.

Navon, D. & Gopher, D. (1979) On the economy of the human processing system. Psychological Review, 86, 214-255.

Hirst, W., Spelke, E.S., Reaves, C.C., Caharack, G., & Neisser, U. (1980) Dividing attention without alternation or automaticity. Journal of Experimental Psychology: General, 109, 98-117.

Jones, M.R. (1976) Time, our lost dimension: Toward a new theory of perception, attention, and memory. Psychological Review, 83, 323-355.

Jones, M.R., Maser, D.J., & Kidd, G.R. (1978). Rate and structure in memory for auditory patterns. Memory & Cognition, 6, 246-258.

Klapp, S.T., Hill, M.D., Tyler, J.G., Martin, Z.E., Jagacinski, R.J., & Jones, M.R. (1985) On marching to two different drummers: Perceptual aspects of the difficulties. Journal of Experimental Psychology: Human Perception and Performance, 11, 814-827.

Kramer, A.F., Wickens, C.D., & Donchin, E. (1985) Processing of stimulus properties: Evidence for dual-task integrality Journal of Experimental Psychology: Human Perception and Performance, 11, 393-408.

Landis, & Hunt (1939) The startle pattern New York: Farrar

Schneider, W. (1985) Toward a model of attention and the development of automatic processing. In M. Posner, & O. Marin (Eds.) Attention and Performance XI. Hillsdale, N.J.: Erlbaum.

Shiffrin, R.M., & Schneider,W. (1977) Controlled and automatic human information processing II. Perceptual learning. Psychological Review, 84, 127-190.

Wickens, C.D. (1984a) Engineering Psychology and Human Performance Columbus, Ohio: Charles Merril Co.

Wickens, C.D. (1984b) Processing resources in attention. In R. Parasuraman and D.R. Davies (Eds.) _Varieties of Attention_ New York: Academic Press

Wickens,C.D., Sandry,D.L., & Vidulich, M. (1983) Compatiblity and resource competition between modalties of input, central processing, and output. _Human Factors_, 25, 227-248.

## Figure Captions

Figure 1. Manipulandum ("joystick") for Experiment 1.

Figure 2. Manipulandum for Experiment 2.

Figure 3. Manipulandum for Experiment 3.

| Duration range (ms) | Total number of hesitations | Breakdown by Emphasis condition: Track | None | Left |
|---|---|---|---|---|
| 333-483 | 33 | 10 | 9 | 14 |
| 484-667 | 28 | 7 | 8 | 13 |
| 668-833 | 17 | 1 | 4 | 12 |
| 834-1000 | 5 | | 1 | 4 |
| >1000 | 5 | | 1 | 4 |

Table 1. Distribution of hesitation durations, Experiment 1

| Delay from left Stimulus to hesitation (ms) | Number of hesitations |
|---|---|
| 0-150 | 3 |
| 151-332 | 15 |
| 333-483 | 48 |
| 484-650 | 6 |
| 651-817 | 12 |
| 818-1000 | 4 |

Table 2. Distribution of hesitations as a function of delay from left hand stimulus, Experiment 1.

| Task | Emphasis condition: Left hand | None | Right hand | Mean RT |
|---|---|---|---|---|
| Simple | 375 (0%) | 514 (6.6%) | 533 (0%) | 474 |
| Choice | 917 (6.3%) | 680 (9.4%) | 751 (3.2%) | 782 |

Table 3. Reaction time (ms) and error rates for left hand, Experiment 1

| Day | Hesitations Dual task | Control | Left hand RT |
|---|---|---|---|
| 1 | 26.6% | 0 | 480 |
| 2 | 13.1% | 0 | 416 |
| 5 | 9.8% | 0 | 380 |
| 6 | 4.7% | 3.1% | 362 |
| Mean | 13.6% | 0.78% | 409 |

Table 4. Hesitation rate and left hand RT (ms) for Experiment 2

| | Dual task | Control |
|---|---|---|
| Days 1,2 | 1.71 | 1.49 |
| Days 5,6 | 1.50 | 1.46 |

Table 5. Average tracking error in degrees of visual angle in the absence of hesitations, Experiment 2.

| Duration range, ms. | Number of observations |
|---|---|
| 333-483 | 23 |
| 484-667 | 8 |
| 668-833 | 3 |
| 834-1000 | 0 |
| >1000 | 1 |

Table 6. Distribution of hesitation durations, Experiment 3