PROPRIOCEPTION AS A MEDIATOR IN THE TIMING OF MOTOR RESPONSES

RICHARD A. SCHMIDT 1 AND ROBERT W. CHRISTINA 3

Department of Physical Education, University of Maryland

The hypothesis that proprioceptive feedback from early portions of a total movement may serve as a cue for the anticipation and timing of a later portion was tested using 48 Ss. The right-hand task involved anticipation (with no preview) of the coincidence of a moving and a stationary pointer, and proprioceptive feedback was manipulated by having Ss make a minimal movement or a small or large rotary movement with the left hand during the interval to be timed. Although neither absolute nor algebraic error was affected by the treatments, the number of beneficial anticipations (absolute errors less than 133 msec.) was significantly larger for intermediate than for minimal left-arm activity, supporting the view that proprioceptive feedback serves as a mediator in tasks requiring precise anticipation and timing.

It has been well established that proprioceptive feedback serves as a regulatory mechanism that helps S discriminate correct movements from incorrect ones and that works in addition to other senses (e.g., vision, touch) to make responses more proficient. Adams and Creamer (1962) have hypothesized an additional role for proprioceptive feedback as a mediator of anticipatory timing responses. They hypothesized that if S makes a response at time \( t \), the proprioceptive feedback from the response enters short-term memory (STM) and decays predictably as a function of time. If an additional response is to be made at time \( t + \Delta t \), it is possible that S can use the predictable, time-varying properties of the decaying trace as a time standard, thereby enabling him to make the timing of the response at time \( t + \Delta t \) more accurate. Adams and Creamer tested their decay hypothesis using a repetitive, temporally predictable step-tracking task that required a change to a different position either every 2 or 4 sec. Thus, during the interval, S's arm was static and permitted decay of feedback produced by movement to that position and no additional movement feedback input. While movement feedback failed to be a significant variable, support for the decay hypothesis was claimed when increased spring tension on the control resulted in greater anticipatory timing accuracy. However, the spring tension was applied both prior to and during the interval \( t \) to \( t + \Delta t \), which does not make it possible to attribute the increased anticipation solely to the decay of proprioceptive feedback since increased timing accuracy could be the result of the decay or the input (or both) of proprioceptive feedback during the interval.

Although no support was found for a proprioceptive decay hypothesis for anticipation (Schmidt, 1968), there is considerable evidence that proprioceptive decay or input (or both) are related to anticipation. In addition to the spring tension effects found by Adams and Creamer (1962), Ellis, Schmidt, and Wade (1968) supported this view using a task in which S moved a hand-operated slide so that the total movement duration was exactly 2.00 sec. They manipulated proprioceptive feedback by varying the load and movement distance and found that moving 65 cm. resulted in greater timing accuracy than moving 2.5 cm. but, unlike Adams and Creamer, that load failed to be a significant variable. Using essentially the
same task, Ellis (in press) found that different forms of resistance to the movement (60 cm.) of the control (e.g., inertial, frictional) resulted in differential accuracy, with inertial resistance being more accurate than a low-feedback control condition (moving a toggle switch). In addition, Ellis found that spelling two-, three-, and four-letter words (producing feedback from the larynx and diaphragm) during the interval to be timed (with audition blocked by white noise) resulted in progressively increased accuracy. The conclusion drawn from these studies was that increased proprioceptive feedback produced by the response variables (e.g., load) during the interval to be timed provided 5 with a more accurate time standard than he had without the feedback and that reliance on the time-varying properties of either the input or the decay (or both) of the trace resulted in more accurate anticipatory responding.

One drawback to the above studies, with the possible exception of Ellis (in press) (larynx and diaphragm feedback), was that the feedback was manipulated in the same limb that effect the response. Thus it was possible that manipulating response variables (e.g., spring loading) may have increased timing accuracy simply because it created a more favorable mechanical system for responding. Schmidt (1969) found that loaded responses tended to make arm movements more consistent, and it is possible that load increased accuracy in the Adams and Creamer (1962) and Ellis (in press) studies simply because it made the responses more consistent. A similar case could be made for movement distance in the Ellis et al. (1968) study. Thus, the evidence in support of a mediational view of proprioceptive feedback has confounded the mediational and purely mechanical effects of the response variables.

Another test of this mediational view of proprioceptive feedback for timing responses would involve manipulation of proprioceptive feedback in a different limb from that in which the response is effected. The present study manipulated positional feedback from the left elbow and shoulder joints by having minimal movement, or a moderate- and large-sized rotary movement of the left arm, and having 5s execute the timing response with the right hand. If a mediational view of proprioceptive feedback has credence for motor responses, the feedback generated by the movements of the left arm should provide 5 with enhanced proprioceptive feedback, the time-varying properties of which 5 can use as a time standard. Thus, it was hypothesized that greater left-arm activity during the interval to be timed should result in increased timing accuracy. Although it is of interest to differentiate between a decay vs. an input hypothesis for the mediation of timing, positive findings for proprioceptive feedback in the present study do not make this distinction possible.

**Method**

The basic task involved lifting a finger from a reaction key at the moment a moving pointer (no preview) became aligned with a stationary one. Thus, it involved anticipation of the coincidence of the two pointers and required a timed response.

**Apparatus.**—The apparatus consisted of a long (144-in.) motor-driven v-belt with a 2-in.-high pointer attached, so that the pointer moved horizontally at a speed of 4.15 ft/sec. A similar stationary pointer was attached to the apparatus at one end of the moving pointer's travel. A shield was placed over the path of the pointer so that only the 3-in. portion of the travel bracketing the stationary pointer was visible to 5. A standard chair with attached writing arm positioned 5 directly in front of the stationary pointer so that the pointer travel was perpendicular to the direction 5 was facing and approached from his right.

The apparatus for the manipulation of left-arm movement was situated to 5's left. A large (6-in.) handle was attached to a long (21-in.) lever attached one-third of the way along its length to an axle that rotated through 350° about a horizontal axis in 5's sagittal plane. A stop defined a starting position 30° above the horizontal so that 5 reached ahead and slightly to the left to place his hand on the handle.

Before a trial, the movable pointer was positioned 61 in. from the fixed pointer. When 5 rotated the handle backward-upward through 33°, a cam operated two microswitches, one starting the belt motor and the other starting two 1/100-sec. timers (Standard Type S-1). A third microswitch was mounted near the fixed pointer and was operated by a cam on the belt when the moving pointer reached the stationary one and stopped one of the clocks, giving the time from the pointer's first movement until it had reached the fixed pointer (nearly constant at 1.50 sec.). The second clock stopped when
S released the reaction key and measured the time from the pointer's first movement until S responded. The difference between these two times was the basic measure of error for a particular trial.

The rotation of the left-arm apparatus was recorded by means of a linear potentiometer attached to the axle. After 68° rotation, the potentiometer became engaged, after which it was directly attached to the axle. The potentiometer modulated a battery-driven voltmeter, whose deflection was a function of handle position. When S lifted the response key, further changes in the handle position were not recorded and the voltmeter remained in that position. Actually, there was some decay of the needle position as a function of time, but it occurred at a rate with a full-scale half-life of 2 min. Reading the dial immediately after the key was released resulted in minimal decay.

Proprioceptive feedback.—Three levels of left-arm activity were used. In the intermediate-feedback (IFB) and high-feedback (HFB) conditions, S grasped the handle and started the belt by rotating the handle upward-backward through 33°. He was instructed to continue to move the handle slowly and smoothly until after he had responded to the main task with the right hand. The intermediate and high levels of feedback were differentiated by having the radius of rotation of the handle set at 3.5 and 11.5 in., respectively. In the minimal-feedback condition (MFB), the handle was removed and S placed his thumb on the extension of the lever situated near his left knee. In order to start the trial, S pushed the extension of the lever downward-forward sufficiently far to activate the microswitches (about \( \frac{1}{4} \) in.). After pushing the lever, S rested his hand on his left knee until after he had responded to the main task. Thus, the left-arm activity involved either a small, brief push with the thumb or a small or large rotary motion with the left arm, and it was assumed that the amount of proprioceptive feedback generated would be related to the size of the limb movements.

Procedure.—The Ss were administered 30 trials of the main task under one of the left-arm feedback conditions. Instructions emphasized that the primary concern was main task accuracy, but that S was to move the left arm smoothly and continuously until after he had responded. A trial was begun with the signal "Start" from E, at which time S moved the handle starting the belt. When the belt started, a buzzing noise was simultaneously switched on (presented to S through earphones), which continued until the belt had stopped after S responded. The noise was designed to mask distracting noises and served as a cue to S that the interval to be timed (1.50 sec.) had begun.

During the 30-sec. intertrial interval, knowledge of results was given and was either "Early," "Late," or "Hit" (an error of less than .03 sec.). After the score was read, S returned the handle to the starting position, depressed the reaction key, and waited for the next trial.

Subjects.—The 48 graduate and undergraduate male volunteer Ss were randomly assigned to one of the three feedback conditions, with the restriction that each condition have 16 Ss.

RESULTS

Timing accuracy.—The performance curves over the first 30 trials with the left-arm-movement groups plotted separately showed no obvious among-groups differences using either absolute or algebraic error. As major learning trends appeared to be essentially over by Trial 18, the mean of Trials 19–30 was used as the criterion for timing accuracy and among-groups differences were analyzed in a one-way analysis of variance. For algebraic error, \( F(2, 45) = 1.82 \), and for absolute error, \( F(2, 45) = 1.84 \), indicating that there was no evidence that average performance was influenced by the nature of the left-arm activity.

Beneficial anticipations.—Adams and Xhignesse (1960) used an additional measure of anticipatory responding, number of beneficial anticipations, defined as the number of responses on which the absolute errors were less than 133 msec. Adams and Creamer (1962) also used this measure, but with the criterion being 117 msec. Responding with errors this small was considered anticipatory since lags of 133 msec were smaller than values for classical reaction times for which there is no anticipation. The present data were analyzed using a 133-msec. criterion, and the number of beneficial anticipations in each of three

![Fig. 1. Percentage of beneficial anticipations for the three experimental conditions.](image-url)
trial blocks (1–10, 11–20, and 21–30) were computed for each of the treatment groups. These values are presented in Fig. 1. For all groups, percentage of beneficial anticipations tended to increase with practice, and it appeared that Groups IFB and HFB were superior to Group MFB at the end of practice. Beneficial anticipations were computed on Trials 16–30 for each S, and a one-way among-treatments analysis of variance yielded $F(2, 45) = 3.68$, $p < .05$. A Scheffé test indicated that only the difference between Group IFB and MFB was significant. Thus, even though larger left-arm movements (HFB) did not cause more anticipatory responding than the smaller movements (IFB), the moderate activity yielded greater anticipation than did the minimal activity (MFB). This supported the hypothesis that feedback generated by the left arm provided a basis for anticipation and timing in the main task.

Attention to feedback.—One simple strategy in which S could use proprioceptive feedback would be to respond when the left arm reaches a certain position. Thus, if S moved too slowly on a given trial, his response with the right arm would be too late, and moving too fast would have the opposite effect. Evidence for such a strategy would be a relationship between the extent of left-arm movement on a given trial and the algebraic error on that trial for each S considered separately. Within-S correlations (Grose, 1963; Schmidt, 1969) were computed that considered movement-error pairs over trials for each S separately (with the hypothetical $N$ being the number of trials). The coefficients were calculated for the Ss in Groups IFB and HFB. The coefficients ranged from −.43 to .70, and the average (for the 32 Ss in both groups) was .32. With the hypothetical $N$ of 30 (the number of trials over which the coefficients were computed), a coefficient needed to be greater than .42 to be significantly different from zero at the .01 level. Sixteen Ss had coefficients that were greater than .42, indicating that at least half (16/32) of the Ss tended to covary the movement in the left arm with the time of the response of the right.

Additional support for this hypothesis would be advanced if the relationships between movement and algebraic error were larger for Ss in Group HFB than for Ss in Group IFB. However, when the coefficients were converted to $z'$ scores and an analysis of variance was computed between groups, the computed $F(1, 30) < 1.00$, indicating no tendency for a greater covariance between movement and algebraic error.

Left-hand consistency.—The finding that Group HFB had fewer (but not significantly fewer) beneficial anticipations than Group IFB was contrary to the prediction that increased feedback would result in greater anticipation. However, in order that S use the feedback as a time standard, it would seem necessary that the pattern of feedback be consistent from trial to trial. Thus it was possible that the large movement (HFB) was more inconsistent than the smaller one (IFB) and that the feedback from it provided S with a poor basis on which to anticipate. The distance the left hand had traveled when S responded with the right hand was obtained for each trial, and this indicated that Ss in both IFB and HFB were nearly always in the “down” position (elbow flexed 90°, upper arm vertical) when they responded, having moved through approximately 240°. The mean intra-S variabilities (the standard deviations of S's responses about his own mean for Trials 11–30) of the left-hand movement were used as indexes of consistency and were 1.88 (IFB) and 6.37 in. (HFB), which yielded a between-groups $F(1, 30) = 25.31$, $p < .05$. With the handle in the down position, horizontal movement of the hand resulted in nearly proportional angular movement of the shoulder joint, and, similarly, inconsistency of hand movement resulted in a nearly proportional inconsistency in shoulder movement. Thus, it is possible that the inconsistency from a large rotary movement in HFB could have reduced the effectiveness of the feedback.
DISCUSSION
Treatments presumably differing along the dimension of amount of proprioceptive feedback in the left arm produced differences in the amount of anticipatory responding in the main (right-arm) task. However, the treatment groups were not ordered as predicted, with only the group with smaller movement (IFB) being significantly superior to the minimal-feedback condition (MFB). One of the seemingly necessary conditions for anticipation to be based on proprioceptive feedback is that the feedback be consistent from trial to trial so that S can learn its time-varying properties. Thus, the marked inconsistency of shoulder movement in the large (HFB) as opposed to the small (IFB) left-arm response might explain why the smaller movement resulted in greater anticipation. Taken together, the findings supported the view that proprioceptive feedback, in addition to its commonly accepted role as a regulatory mechanism, may also serve as a mediator in tasks requiring precise anticipation and timing of motor responses. The present results support earlier findings (Adams & Creamer, 1962; Ellis, in press; Ellis et al., 1968), which indicated that task variables that influenced proprioceptive feedback in the limb effecting the main task provided a basis for anticipation. The present results extend these findings since feedback increased anticipatory responding even when it was not generated in the main task effector.

There is still some question as to how the left-arm movement influenced anticipation. Since the movement of the lever was not hidden from S's view, it is possible that S was responding to purely visual cues. This seemed very unlikely, however, since Ss appeared to be intensely directing visual attention to the stationary pointer. Also, the lever was to the side of S's head, which would make it very difficult to discriminate changes in position accurately. It seemed more likely that the left-arm movement provided a proprioceptive basis for timing. If proprioception is the basis, it is possible that S responded to the decay of proprioceptive feedback in STM as Adams and Creamer (1962) have suggested, but the present results offered a different possibility. The finding in the present study that at least some Ss tended to covary the length of the movement with the time of responding to the main task indicated that one probable strategy would involve S's responding with the right hand when the left arm had reached a certain position. In this case, Ss would not be responding to the decay of feedback from an earlier movement but the time-varying pattern of input generated by the left-arm movement. However, both mechanisms might operate, and the present study did not provide a basis for discriminating between these views. Of course, it is possible that some Ss do not use this strategy (e.g., those Ss who did not exhibit a relationship between movement and error), but use the feedback in some other way, or choose to respond using purely "cognitive" mechanisms.

REFERENCES

(Received October 11, 1968)