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Information Feedback and the Learning of Multiple-Degree-of-Freedom Activities

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ABSTRACT. The influence of information feedback on the learning of a multiple-degree-of-freedom activity, the overhand throw, was investigated. During learning, feedback was presented in the form of knowledge of results, knowledge of performance, knowledge of performance with attention-focusing cues, or knowledge of performance with error-correcting transitional information. Across 12 practice sessions, performance was assessed with respect to both throwing distance and throwing form. Subjects provided with knowledge of performance along with transitional information demonstrated significant gains in throwing distance, compared with subjects receiving knowledge of performance or knowledge of results alone. Movement form ratings followed the same trend. Providing learners with cues to focus their attention on the relevant aspects of knowledge of performance or directly providing transitional information was a better aid to the acquisition of throwing form than providing knowledge of results or knowledge of performance alone. These results support the hypothesis that knowledge of results may not be the most potent form of feedback in multiple-degree-of-freedom activities and that knowledge of performance, when combined with additional information, can lead to significant gains in skill acquisition.

Key words: knowledge of performance, skill learning, throwing, videotape feedback

The presentation of information feedback is critical for the learning of motor activities. Although this statement is self-evident, there is some question as to the nature of the information that should be presented to the learner and the most effective way to present the information. Early research on feedback and motor skills focused on the role of knowledge of results (KR) (e.g., Adams, 1971; Bartlett, 1948; Holding, 1965), suggesting that KR is the single most important variable governing the acquisition of motor skill. This concept was supported by traditional associative theories of learning as well as the findings that more specific KR leads to faster rates of learning motor activities (e.g., Rogers, 1974; Towbridge & Cason, 1932) and that learning does not occur in motor activities in the absence of KR (e.g., Towbridge & Cason, 1932). An additional source of feedback for motor activities, information about the way the movement is produced, has received increasing attention over the last 20 years. This type of information feedback has been termed *knowledge of performance* (KP) by Gentile (1972). Even though logical and theoretical distinctions between these two broad classes of movement feedback have been made, an operational distinction between them is often lacking (Magill, 1989).

Much of the work demonstrating the importance of KR has been conducted using tasks that require the appropriate scaling of a single-degree-of-freedom movement. Under these conditions, KR specifies all of the information that is required to learn the positioning or timing of the single-dimension response (Newell, Quinn, & Carlton, 1987). In the case of multiple-degree-of-freedom tasks, where the appropriate outcome depends on the appropriate interaction among movement segments, it has been hypothesized (Newell & Walter, 1981) that information in the form of movement kinematics or kinetics may be more important than KR alone. This phenomenon has been documented using one- and two-degree-of-freedom tasks. Providing subjects with information about movement kinematics facilitated learning beyond the presentation of KR alone (Newell, Carlton, & Antoniou, 1990; Newell et al., 1987). Young and Schmidt (1990) have recently demonstrated that KR can be used to appropriately change movement kinematics when subjects search for an optimum combination of movement velocity and spatial error in a simulated striking activity. The striking task involved only one degree of freedom (elbow rotation), and as the number of degrees of freedom increases, there may be no direct association between KR and specific kinematic features of the movement.

If movement dynamics in the form of KP or movement kinematics becomes more important with multiple-degree-

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of-freedom tasks, it would be logical to assume that videotape replay would be a useful tool for the acquisition of motor skill. This source of information feedback has the advantage of providing precise feedback about the kinematics generated by previously produced movements, without long delays. Rothstein and Arnold (1976), in an extensive review of videotape replay and the acquisition of motor skill, found limited support for the use of videotape feedback. Less than 40% of the 50 studies reviewed showed a positive effect of videotape feedback on skill learning. Although many of these studies were methodologically deficient, these deficiencies did not seem to provide an explanation for the inconsistent results. Based on the results of their review, a number of hypotheses about the role of videotape feedback on motor skill learning were made, the following two of which relate to the current experimentation: (a) Videotape feedback should be used over an extended time period (a minimum period of 5 weeks), and (b) cues should be used to direct the learner's attention to the most appropriate aspects of the videotape feedback.

Since Rothstein and Arnold's review (1976), there have been a number of investigations examining the efficiency of videotape feedback as a form of KP and the influence of a variety of factors associated with videotape feedback presentation. The general strategy has been to optimize the possible effectiveness of videotape feedback by using adequate practice time (see suggestion [a] above) and controlling or manipulating other aspects of videotape feedback that are thought to influence skill acquisition. These variables have included task characteristics (e.g., Cooper & Rothstein, 1981), simultaneous presentation of a model and videotape feedback (Rikli & Smith, 1980), and experience level of the learner (Emmen, Wesseling, Bootsma, Whiting, & Van Wieringen, 1985; Rikli & Smith, 1980; Van Wieringen, Emmen, Bootsma, Hoogesteger, & Whiting, 1989). Like the review by Rothstein and Arnold, these and other studies on videotape feedback have produced equivocal results. An example is a series of studies examining the learning of the tennis serve (Cooper & Rothstein, 1981; Emmen et al., 1985; Hegmann, 1974; Rikli & Smith, 1980; Van Wieringen et al., 1989). Cooper and Rothstein found higher achievement test results among subjects than among controls, and Rikli and Smith found improved service form as a function of videotape feedback. Emmen et al. (1985), however, with novice players, and Van Wieringen et al. (1989), with intermediate level players, found no benefits when performance and movement form scores were compared with those of groups receiving an equal amount of practice without videotape feedback.

One variable, implicated by Rothstein and Arnold (1976) in their review of the literature, has received little experimental attention—the role of attention-focusing cues. Less than 30% of the reviewed studies in which cues were not provided to the learner showed positive results, as compared with over 60% of the studies in which cues were provided. Unfortunately, studies using cueing uniformly failed to indicate how the cues were used and how the cue was defined for the particular study or to provide any guidance that would be useful for isolating important cue characteristics.

The term *cue* can generally be defined as a stimulus, be it intrinsic or extrinsic, that focuses the performer's attention on the relevant aspects of a task. With respect to the use of videotape feedback, cues typically are used to focus the learner's attention on a particular aspect of the visual information available. It has been suggested (e.g., Newell & Walter, 1981) that a videotape replay may provide too much information to the learner and that providing cues to focus attention on critical aspect(s) of the task is an important consideration in using this technique.

Even with the presentation of cues to help the learner focus his or her attention on the most relevant aspects of information feedback, it must be remembered that KR and KP provide information only about movement outcome and movement dynamics. The learner must still decide what and how to change his or her performance on subsequent trials. Although this information may allow the learner to acquire the appropriate movement pattern, it may be inefficient in doing so. An alternative is to provide the learner with what has been termed *transitional information* (Newell, Morris, & Scully, 1985). Newell (1991a, 1991b) has suggested that when a qualitative change in the coordination pattern is required, traditional information feedback may be insufficient to produce the required changes, and that augmented information from an outside source, such as an instructor, can be provided to promote qualitative changes in the coordination mode. Thus, transitional information provides information about what to change and how to change the movement to bring about modifications in movement coordination.

The present experiment examined the effectiveness of four information feedback conditions on the learning of the overarm throw. Subjects were given only KR, KP by means of videotape replay, KP plus attention-focusing cues, or KP plus transitional information about the nature of the required correction. The experimental manipulations allowed for a separation of the influence of KR from other feedback information. Only the KR group received information about the outcomes of their throws. The task provides a basis for a separation of the outcome and the movement pattern itself (movement form). That is, there are a number of patterns that can lead to the same outcome, and presentation of the outcome alone may not result in a general improvement in form. In addition, the biomechanics and the development of the overarm throwing pattern have been studied extensively. This information was used to evaluate throwing form as well as to guide the experimenter in providing cues and transitional information. Throws were made with the nondominant arm, and this resulted in a novel task for which the learner's movement coordination was generally at an immature level. An attempt was made to maximize the effectiveness of the information feedback by using a relatively large number of trials, a short intertrial interval, and the presentation of a model.

Method

Subjects

The subjects were 48 individuals ranging in age from 15 to 40 years. Only subjects with limited experience in throwing and similar activities, such as the tennis serve, participated, and none of the subjects had any experience throwing with the nondominant arm. None of the subjects described themselves as ambidextrous.

Apparatus

The study was conducted in a large gymnasium (24.5 m × 18.3 m). Subjects were positioned at one end of the gymnasium, and their task was to throw a ball with the nondominant hand as far as possible. A "nerf" ball was used. The ball was made of soft spongy material, was of light mass (30 grams), and was slightly larger than a baseball (28 cm in circumference). The light weight of the ball was necessary to restrict the maximum throwing distance to the length of the gymnasium. A tape measure, graduated in feet and inches, was extended along the floor from a ball release line to the opposite end of the gymnasium. A partition, 2 m high and 1 m wide, was positioned next to the release point for the throw. The partition was made of opaque material. A Sony color camera in coordination with a Sony Beta videotape recorder and Sony color monitor (64-cm screen, measured diagonally) was used for recording and playback of throwing movements.

Procedure

The description of the procedure involves two parts: first, the experimental conditions for the practice portion of the experiment, and second, a description of the testing procedure.

There were a number of experimental procedures that were common to all subjects. Subjects were informed that the task was to throw the ball as far as possible along a straight line. Subjects were given the ball approximately one step behind a ball-release line. At ball release, subjects were asked to close their eyes and to take one step sideways so that they were behind the opaque partition. The distance of ball throw was measured, and the ball was picked up. Thus, subjects were not allowed to see the flight path of the ball or to observe the throwing distance. All subjects completed 12 practice sessions, 3 sessions per week for 4 weeks. There were 50 practice trials per practice session. This procedure resulted in a total of 600 practice trials.

Subjects were provided a model that served as a template of correct throwing form. The model was a highly skilled left-handed thrower and exhibited a throwing form consistent with a highly developed throwing pattern (e.g., Atwater, 1979). The model was videotaped at a 45° angle (midway between a front and side view) so that subjects could easily see the left arm during the throwing motion. Two repetitions of the model were shown on the video monitor after every 10th trial, beginning with Trial 11. The first view was at regular speed, and the second was in slow motion. The monitor was placed approximately 2 m to the side of the subject.

Subjects were randomly assigned to one of four experimental groups: KR, KP, KP with cue, or KP with transition. Subjects under the KR condition received KR after every trial in terms of distance thrown in feet and inches. The KR was given verbally by the experimenter. Subjects in the KP condition did not receive KR after the trial but instead were given a videotape replay of their throwing pattern on the just-completed trial. Subjects in the KP-with-cue condition, in addition to viewing the just-completed trial on the video monitor, were given a cue, before viewing the trial, indicating where they should focus their attention while viewing the videotape replay. Subjects in the KP-with-transition condition, along with viewing the just-completed response, were instructed what to do to improve throwing distance on the following trial. The three groups receiving videotape feedback viewed all responses at normal speed. Subjects were also shown every fifth trial in slow motion.

Although the procedures for the KR and the KP groups were fairly straightforward, further elaboration is required about the KP-with-cue, and KP-with-transition groups. For these two conditions, an attempt was made to provide additional information that either would cue the subject as to where to look while viewing the previously produced movement or would provide some direct information about what changes should be made on the following trial. The cue or transitional information was given prior to viewing the movement and was based on biomechanical analyses of the optimal overarm throwing motion (Atwater, 1979; Joris, Edwards van Muyen, Van Ingen Schenau, & Kemper, 1985; Tarbell, 1970). Collectively, this work indicates that the skilled overarm throw consists of a sequentially timed coordination of accelerations and decelerations of the body segments that originates with the left foot and progresses to the distal segment of the right hand and fingers (for a right-handed throw).

The information to the cue group was used to focus or cue the subjects' attention upon 1 of 10 areas of importance when comparing their movement pattern to that of the model. The following cues were given:

1. Focus on the initial position of the body.
2. Focus on the initial movement of the trunk.
3. Focus on the left arm during the preparatory phase of the left arm swing.
4. Focus on the right foot during the throwing phase.
5. Focus on the hips during the throwing phase.
6. Focus on the shoulders during the throwing phase.
7. Focus on the upper arm and elbow during the throwing phase.
8. Focus on the left hand and the ball during the throwing phase.
9. Focus on the left arm at the point of ball release.
10. Focus on the left arm during the final phase of the throw.

11. Good throw.

The experimenter's decision as to which of the cues to give to the subject was based on the first observed deviation from the sequential pattern of the model. For example, if the initial body position was correct and the initial movement of the trunk was incorrect, Cue 2 was given. The decision was made from the experimenter's observation of the throw during the trial.

A similar rationale was used for providing transitional information. One of the following 15 suggested corrections was specified:

1. (a) Align your body so the right shoulder faces the target area.
   (b) Place the feet close together and parallel to each other and at a 90° angle to the target area.
2. Rotate the hips 15–20° from left to right during the initial phase of the throw.
3. (a) Keep the left arm relatively straight during the backswing.
   (b) During the backswing, raise the left arm until even with the shoulder.
   (c) At the end of the backswing, flex the elbow and allow the hand and ball to drop down the back.
4. Stride forward with the right foot toward the target area.
5. Rotate the hips from left to right during the throwing phase.
6. Rotate the shoulders left to right during the throwing phase.
7. Lag the movement of the upper arm and elbow behind the rotation of the shoulders during the throwing phase.
8. Lag the movement of the hand and ball behind the upper arm and elbow during the throwing phase.
9. Extend the left arm at ball release.
10. (a) Release the ball earlier in the movement.
    (b) Release the ball later in the movement.
    (c) Keep the left arm extended as you follow-through down and across to the right side of the body.
11. Good throw.

The procedure determining the selection and presentation of the instructions was the same as that used for the cue condition.

The testing procedures were the same for all subjects. In Session 1, after subjects were given instructions, 10 test trials were administered. Each of the trials was videotaped, and the distance the ball was thrown was measured. No information about the distance thrown (KR) or about the throwing pattern was given. After completion of the 10 test trials, the remaining 40 trials for Session 1 were performed. The same testing procedures were used for Trials 15 through 24 in Sessions 3, 6, 9, and 12, with the exception that the test trials were performed on Trials 15–24 instead of Trials 1–10. This procedure resulted in a no-KR transfer test for learning, but not a true retention test, because subjects received 14 trials of practice before the administration of the test trials (see Salmoni, Schmidt, & Walter, 1984, for a discussion of transfer tests and learning). The intertrial interval was approximately 20 s. The throwing distance and movement pattern records from the test trials were kept for further analysis.

Design and Analysis

The data were analyzed with respect to movement outcome and movement form. Distance thrown was used as the measure of movement outcome. Throwing distance was measured from the ball-release line to the first point of ground contact. Two measures of throwing form were used. Three untrained judges rated each test trial on a scale from 1 to 7, with 1 representing a very poor throw and 7 representing excellent throwing form. Before rating the experimental trials, the judges viewed the model throw 10 times and also viewed 25 randomly selected test trials that represented a range of throwing forms. The judges viewed the trials on the video screen from a distance of 1.5 m. The trials were presented at normal speed and in random order.

A second rating of throwing form was performed based on the overhand throwing evaluation scale developed by Leme and Shambes (1978). The Leme/Shambes scale breaks down the throwing pattern into 10 stages of skill development. Three judges with knowledge of the mechanics of the overarm throw, based on previous work in biomechanics, participated in a training session designed to familiarize themselves with the Leme/Shambes scale. Judges were presented with a series of randomly selected test trials, and differences in the scores given by the judges were discussed. After the training, judges evaluated 50 previously unseen trials. Correlations among the judges was high (M = .99), and, therefore, only one of the judges evaluated each of the test trials.

Distance thrown and subjective form ratings were analyzed using a 4 × 5 (Information Presentation × Testing Session) mixed-design analysis of variance. Information presentation was the between-subject factor and testing session was the within-subject factor. Because the Leme/Shambes ratings were based on a single observer rating, only descriptive statistics were computed.

Results

Cues and Transitional Information

With the exception of the test trials in Sessions 1, 3, 6, 9, and 12, attention-focusing cues or transitional information was given to subjects in these groups on each trial. The frequency of cues and transitional information, outlined in the method section, as a function of practice session are presented in Tables 1 and 2. As shown in Table 1, a majority of cues given in Session 1 related to problems generated early in the movement pattern, especially the initial position of the feet and body. By Session 2, these deficiencies had been corrected. The most prevalent cue types given after Session 1 related to the lag of the upper arm and elbow with respect to the shoulder (Cues 7 and 8), and ball release re-

TABLE 1
Cue Given to Subjects, as a Percentage of Total Trials, Over Day of Practice

Cue	Day 1	2	3	4	5	6	7	8	9	10	11	12
1	25											
2	20						4	2				
3	10	2	2	5	4	4	3					
4	2											
5												
6												
7	15	15	35	13	22	24	36	16	7	8	10	
8	4	12	12	17	12	5	6	9	13	13	13	10
9	23	30	25	28	32	33	22	23	26	24	32	25
10		31	17	13	7	5	5	17	17	18	3	17
11	1	10	13	24	23	29	24	31	37	36	42	48

TABLE 2
Transitional Information, as a Percentage of Total Trials, Over Day of Practice

Cue	Day 1	2	3	4	5	6	7	8	9	10	11	12
1a												
1b	1											
2	13											
3a	12						2					
3b	15	5		5								
3c	8	20	10	5	3	3	7	15	7	7	5	
4												
5	3			5			2					
6												
7			4	5	2		5				12	
8	5	6										
9	13	12	13	7	7	13	10	10	10	13	10	4
10a	13	20	26	18	26	13	14	15	10	22	10	1
10b	7	20	27	30	27	36	24	20	35	16	25	27
10c	10	7	7	5	7	5	8	5	7	6	10	20
11		10	13	20	28	30	28	35	25	35	34	52

TABLE 3
Mean Distance Thrown (m) for the Four Information Presentation Conditions as a Function of Testing Session

Group	Testing session 1	2	3	4	5
KR					
M	8.2	8.7	8.9	8.9	9.1
SD	1.4	1.4	1.3	1.4	1.4
KP					
M	7.6	8.0	8.2	8.3	8.0
SD	0.8	1.6	2.0	1.9	1.5
Cue					
M	7.2	7.8	7.8	8.0	8.8
SD	1.0	1.4	1.5	1.3	1.2
Transition					
M	7.6	8.1	8.7	8.8	9.7
SD	1.3	2.0	1.9	1.6	1.8

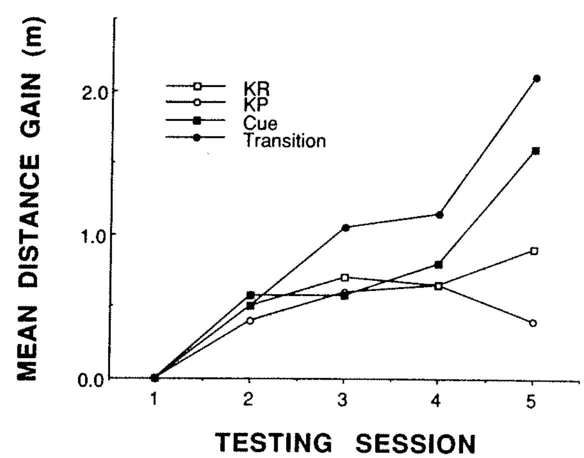

FIGURE 1. Gain in throwing distance over the 12 days of practice.

lated to arm extension (Cues 9 and 10). The other noticeable trend was the increase in the number of "good throws" (Cue 11) as a function of practice session.

Transitional cue frequencies (Table 2) showed a smaller number of instructions related to feet and body position (Transition Cues 1a and b). It generally took only one presentation of transitional information to eliminate these particular problems. Most of the information presented related to aspects of the arm and hand around the time of ball release (Transition Cues 9; 10a, b, c; 11). Again, the number of "good throws" (Transition Cue 11) increased with practice session.

Throwing Distance

The mean ball throw distances are presented in Table 3. The statistical analysis resulted in a nonsignificant effect for information-presentation condition, $F(3, 44) = 1.06$, $p > .10$; a significant effect for session $F(4, 176) = 19.03$, $p < .01$; and a significant Information Presentation × Session interaction, $F(12, 176) = 2.18$, $p < .05$. The significant interaction revealed that whereas all groups improved in performance with respect to Session 1, improvements were greater for the cue and the transition groups. Post hoc analysis revealed that transitional final performance (Testing Session 5) was significantly greater than the KR and KP conditions ($p < .05$).

The significant interaction can be seen more easily in Figure 1. Examination of test scores for the first 10 trials on Session 1 (pretest trials) revealed small (statistically nonsignificant) initial performance differences for the four groups. To examine improvements in performance uninfluenced by the differences in initial performance, we normal-

TABLE 4
Mean Subjective Form Rating Provided by the Three Judges

Group	Testing session 1	2	3	4	5
KR					
M	2.2	3.3	3.6	3.6	3.9
SD	0.9	0.8	0.9	1.0	1.2
KP					
M	2.5	3.4	3.8	4.0	4.0
SD	1.0	1.0	0.9	1.0	1.0
Cue					
M	1.7	4.1	4.3	4.7	5.0
SD	0.6	0.5	0.8	0.7	0.7
Transition					
M	2.4	5.0	5.4	5.7	6.1
SD	0.8	0.6	0.7	0.6	0.7

TABLE 5
Mean Leme/Shambes Form Ratings

Group	Testing session 1	2	3	4	5
KR					
M	5.1	7.0	7.1	7.4	7.5
SD	2.3	0.9	1.1	1.3	1.5
KP					
M	5.0	6.9	7.7	7.8	7.6
SD	2.3	1.1	1.2	1.3	1.1
Cue					
M	4.6	7.8	8.5	8.5	9.0
SD	2.5	1.9	1.2	1.3	1.2
Transition					
M	5.0	9.2	9.3	9.8	9.8
SD	2.0	1.1	0.9	0.4	0.4

ized the throwing distance data on the basis of Session 1 performance. Initial mean throwing distance scores (Session 1) were subtracted from the mean distance thrown for test trials in Sessions 3, 6, 9, and 12, for each subject. The resulting performance "gain scores" are presented in Figure 1. Whereas the transition, cue, and, to a lesser extent, KR groups showed steady improvements in performance over sessions, the KP group showed no improvements between Testing Session 2 and Testing Session 5. These results and the striking differences between the cue and transitional groups as compared with the KR and KP groups, suggests that presentation of outcome error or KP by itself is not sufficient for optimal learning of multiple-degree-of-freedom tasks.

Form Rating

Mean form ratings are presented in Table 4. There were significant main effects for information presentation, $F(3, 44) = 10.52$, $p < .05$; testing session, $F(4, 176) = 259.21$, $p < .01$; and a significant Information Presentation × Testing Session interaction, $F(12, 176) = 12.00$, $p < .05$. Neuman-Keuls post hoc analysis revealed that Testing Session 1 ratings were significantly lower than all other testing sessions for all groups. In addition, Testing Session 2 was significantly different from Testing Session 5 for the transition group. With respect to differences between information presentation conditions, post hoc analysis revealed that there were no significant differences in Testing Session 1 form ratings. The transition condition was significantly different from each of the other groups at all of the remaining testing sessions. The cue group was significantly different from the KR condition on Testing Session 4, and from both the KR and KP groups on Testing Session 5.

All groups showed the greatest improvement between Testing Sessions 1 and 2, with slower but consistent improvement thereafter. Generally, form scores were comparable for the KR and KP groups, with subjects receiving cues having somewhat higher scores from Testing Sessions 2–5. The transition group had the highest form rating throughout (Testing Sessions 2–5). These data are not entirely consistent with throwing distance, but by the end of practice both performance and form rating were greatest for the transition group.

TABLE 6
Leme/Shambes Throwing Mechanics Scores, as a Percentage of Total Trials, Averaged Over Days of Practice

Form score	Information feedback condition: KR	KP	Cue	Transition
1	0.0	0.0	3.0	0.0
2	3.3	5.0	6.6	1.6
3	5.0	4.3	3.3	7.0
4	0.0	0.0	0.0	0.0
5	8.3	1.3	0.0	1.6
6	0.6	0.0	3.3	0.0
7	69.3	70.6	32.5	10.0
8	0.0	1.8	0.0	5.8
9	6.6	7.9	29.0	16.3
10	6.6	9.8	21.8	54.3

Leme/Shambes Scale

The mean data from the analysis of throwing mechanics as developed by Leme and Shambes (1978) are presented in Table 5. The data closely correspond to the subjective evaluation of throwing form (Table 4). The transitional information group received the highest form ratings, followed by the cue, KP, and KR groups.

Table 6 provides a breakdown of the Leme/Shambes rating for the information presentation conditions. Subjects in the KP and KR conditions had difficulty producing a score beyond Level 7, whereas subjects in the cue and transition groups were able to produce a significant number of throws with a form characterized by advanced throwing mechanics. The failure of subjects in the KP and KR groups to advance beyond a score of 7 was due to (a) improper left arm movement during the backswing phase of the throwing motion, (b) improper left arm movement during the forward arm swing of the throwing motion, and (c) inadequate stride length.

Discussion

The present results provide support for a number of hypotheses concerning the use of information feedback and motor skill acquisition. Performance outcomes and form ratings indicated that the presentation of KR alone or KP without additional information may not be sufficient to learn multiple-degree-of-freedom whole body actions. Both of these groups were characterized by smaller gains in throwing distance and lower form evaluations. In contrast, providing cues to learners that allowed them to focus on the most relevant aspects of the movement kinematics, or presenting information about the nature of the correction to be made, led to larger performance gains and higher form ratings.

The actual increases in throwing distance were small, despite rather large improvements in throwing form. It should be mentioned that this is one of the interesting aspects of the task used in this experiment. Information about response outcome can be separated from information about form. Although biomechanically sound throwing form is necessary to optimize throwing distance, correct form does not necessarily result in long throws. Subjects might be able to produce reasonably good form, but may not be able to accomplish this with a great deal of force or arm velocity. Subtle deviations from the correct form can also lead to short throwing distances. For example, a throw might be rated as a 9 or 10 on the Leme/Shambes scale, but early or late ball release can greatly influence distance thrown. The short distances thrown and the small improvements in distance were related partly to the low mass of the ball. This was necessary to limit throwing distance to the length of the experimental room. The highly skilled model could throw the ball slightly less than 25 m. Also, subjects were inexperienced throwers using their nondominant arm. Although there was a considerable amount of practice over the 12 training sessions, large improvements in throwing distance were not expected. This is one of the limitations of using complex whole body actions in studies of learning.

One unanticipated result was the similarity of response outcomes and movement forms for subjects receiving only KR and only KP. It might have been expected that the group receiving outcome scores would have been able to use this information to improve this aspect of performance, whereas subjects receiving KP would have produced better form ratings. On the contrary, these groups were very similar in both aspects of performance. It appears that neither group received sufficient information for systematic improvements in one aspect of the task over the other. Combining KR and KP and the model may have facilitated learning, but this control condition was not run.

The finding that groups receiving cues and transitional information produced greater performance gains and form ratings brings into question two previous notions involving KR as a tool for learning: that KR is the most potent form of feedback available to the learner (e.g., Adams, 1971; Bartlett, 1948; Holding, 1965) and that no learning occurs without the presence of KR (Bilodeau, Bilodeau, & Schumsky, 1959; Towbridge & Cason, 1932). Not only did learning occur without KR, learning was enhanced with respect to the KR condition. There have been other studies that have observed learning without KR (e.g., Newell, 1976; Stelmach, 1970; Young & Schmidt, 1990), and it appears that this once-accepted tenet may hold only under a limited number of situations. When intrinsic information from performing the task provides an indication of response outcome, extrinsic feedback is probably not required for learning, even though a precise indication of performance outcome is not available. No-KR learning groups, however, usually are associated with performance and learning decrements in comparison with KR groups (e.g., Young & Schmidt, 1990). The larger performance improvements and form ratings of the cue and transitional groups as compared with the KR group is consistent with the suggestion that the task criterion specifies the appropriate information to be provided to the learner, and that the information provided must match the constraints imposed upon the response (Newell et al., 1987). When the learner must acquire a whole body action and a new coordination mode, the usefulness of KR is limited.

Providing subjects with attention-focusing cues was an important factor in the experiment, as witnessed by the differences in results for the KP and the KP-with-cue conditions. This is consistent with the review by Rothstein and Arnold (1976). The assumption behind providing attention-focusing cues is that the cues help the learner focus on the most relevant aspect of the feedback provided. When KP is given by presenting a videotape replay of previous trials, there is a great deal of kinematic information available that is not directly related to errors in movement form or, in fact, to the movement at all (e.g., my shoes were untied). The present data provide support for the use of videotape feedback for skill acquisition when attention-focusing cues are provided. It is not clear, however, whether videotape feedback is necessary when transitional information is presented. Further work is needed to determine whether combinations of information feedback, such as KP with transitional information or KP with KR, facilitate learning in comparison to the presentation of only one information feedback type. It is also unclear what the critical variables are that distinguish successful and unsuccessful videotape studies in the literature. One speculation is that task (Del Rey, 1971) and methodological differences may be critical factors. Variables such as the subject-to-experimenter ratio (e.g., Van Wieringen et al., 1989), the time between the completion of the response and the video feedback, the presentation of a model in addition to the video feedback, as well as a variety of other factors, have a potential influence in addition to the actual independent variables of interest in a particular experiment.

An effort was made in the present experiment to provide feedback under conditions that would maximize its potential for aiding skill acquisition and to document the nature of the cues given as well as their frequency. It should be pointed out that the actual cue or transitional information that was provided to the subject was based on evaluations by the experimenter. Not all subjects in the same condition were given exactly the same information. Whether the cues or the transitional information was successful was, in part, a function of the appropriateness of the information. Even though the experimenter was trained in the evaluation of the overarm throw, it is difficult to document the appropriateness of the cues and transitional information provided. As a result, the outcome of the experiment is highly influenced by the effectiveness of the experimenter. This is a general limitation in experiments where information feedback based on a subjective evaluation of performance is given to subjects.

It has yet to be verified that information feedback with regard to the kinematics of a movement is the most appropriate information feedback to provide a learner in order to optimize the learning of a skill. The findings from this study are consistent with the suggestion by Fowler and Turvey (1978) that the learner requires information directly about what to do next, as opposed to feedback about the just-completed response. It is also not clear what form this transitional information should take. In the present study, the information given was of a direct nature. Subjects were told what kinematic changes to produce to improve performance on the subsequent trial. These direct kinematic instructions are somewhat different from the concepts discussed by Newell (1991a) in which the augmented transitional information is viewed as instructions that help produce qualitative changes in the coordination mode, but are not necessarily direct kinematic prescriptions. An example might be an instruction such as "make your arm swing free," which, in this case, would not provide kinematic information. Distinguishing between what to do and how to do it is sometimes difficult, but this distinction may be important for generating coordination changes during skill acquisition.

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