Qualitative and Quantitative Knowledge of Results: Effects on Motor Learning

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OBJECTIVE. This study investigated the effects of qualitative and quantitative knowledge of results (KR) on the acquisition of a motor skill. It was hypothesized that there would be differences in performance during skill acquisition and retention, depending on the type of feedback given. Qualitative KR was in the form of verbal encouragement and quantitative KR was in the form of an algebraic number representing an error score.

METHODS. Seventy-seven adults were randomly assigned to one of four feedback conditions, Quantitative, Qualitative, Quantitative and Qualitative, and no feedback (Control). Participants learned an isometric force production skill. Data were collected during skill acquisition and retention phases. Computer hardware and custom software were used to collect data and administer the feedback conditions of the independent variable.

RESULTS. There was a statistically significant difference in the Acquisition Phase for the main effect of Condition $F(3,73) = 6.35, p < .05$, and for Block $F(9,657) = 2.07, p < .05$, but there was no statistically significant Condition X Block interaction $F(27,657) = 1.02, p > .05$. Pair-wise comparisons revealed statistically significant differences between conditions containing qualitative feedback and conditions containing no qualitative feedback ($p < .05$). The main effect of condition was significant $F(3,73) = 3.00, p < .05$ in the retention phase, however there were no significant pair-wise comparisons ($p > .05$).

CONCLUSION. The results of this study suggest that in a healthy adult population, qualitative feedback, by itself and when combined with quantitative feedback, resulted in superior skill acquisition, but not in the retention of that skill. The artificiality of the task along with differing modes of feedback (audible versus visual) are two potentially limiting factors to this study. Future research that controls for these factors may yield more definitive findings about the role that qualitative feedback has in improving motor performance and learning.


Occupational therapists are involved in helping people acquire relevant life skills. Therapy goals frequently involve teaching persons with disabilities new ways of doing things. Often this process entails the relearning of motor skills or learning new and different motor skills (Sabari, 2001), and a major role of the occupational therapist is to facilitate the learning process (Flinn & Radomski, 2002). Occupational therapists synthesize occupational forms to optimize patients’ learning. Put another way, occupational therapists structure the patient–environment interaction to enhance learning (Sabari, 2001). To this end, a thorough understanding of all aspects of learning by occupational therapists is critical to good practice. Knowledge of motor learning techniques can help the therapist design therapy sessions to maximize learning for the patient (Jarus, 1994; Tse & Spaulding, 1998). Manipulating the key variables of motor learning is essential to facilitate the teaching–learning process.

Motor learning is defined as a relatively permanent change in motor performance that occurs as a result of practice or experience (Salmoni, Schmidt, & Walter, 1984; Schmidt & Lee, 1999). Feedback is one of the key influential variables in the acquisition of motor skills, second only to practice (Bilodeau, 1966).
Feedback can be generated from the task itself; this is known as inherent or intrinsic feedback. Feedback can also come from sources other than the task, for example, from a therapist. This type of feedback is called augmented or extrinsic feedback. Augmented feedback has been classified into two types: knowledge of performance and knowledge of results (KR). Knowledge of performance is information about movement patterns, for example, “Your wrist is flexed.” Knowledge of results is defined as information about the outcome of the movement, for example, “The buttons are not lined up.” Both types of feedback are verbalized (or capable of being verbalized) and usually occur after the movement has been completed (Schmidt & Lee, 1999).

Knowledge of results can be quantitative or qualitative in nature. Precise quantitative KR has two components: magnitude and direction. Quantitative knowledge of results (e.g., “You were 5 cm short”), compared to qualitative knowledge of results (“You missed the target”), provides more information about the outcome of performance and suggests possible corrections. On the other hand, qualitative KR is often considered to have a reward component (“good job!”) and is sometimes considered as reinforcement (Schmidt & Lee, 1999).

There is a large body of research and theory about the role of knowledge of results in motor learning. A number of reviews summarize what is known about motor learning and include findings about knowledge of results (Adams, 1987; Newell, 1991; Salmoni, Schmidt, & Walter, 1984). The great majority of knowledge of results research has been done with young, healthy participants. Typical motor tasks involved in these studies were simple and very contrived. Furthermore, the knowledge is usually limited to quantitative information about how close motor outcome is to some particular target.

One important aspect of KR is timing relative to performance. Concurrent knowledge of results, that is, knowledge of results given during the performance of a motor skill, appears to impede motor learning (Annett, 1959). However, feedback given after completion of a motor task has a relatively strong positive influence on motor learning (Adams, 1971; Bilodeau, 1966; Newell, 1976).

The amount and frequency of knowledge of results play important roles in its effectiveness. Intermittent knowledge of results has been found to be more effective in promoting learning than constant knowledge of results (Baird & Hughes, 1972; Ho & Shea, 1978; Weinstein & Schmidt, 1990). Furthermore, fading KR results in increases in skill acquisition (Winstein & Schmidt, 1990). Research findings indicate that too much knowledge of results does not enhance learning. In fact, increasing the frequency of KR leads to decreased retention (Schmidt & Lee, 1999). Learners appear to become dependent on knowledge of results and when it is withdrawn, performance is degraded (Annett, 1969).

While knowledge of results given after every practice trial improves immediate performance, it does not lead to greater retention of skill. Salmoni et al. (1984) theorized that this is so because constant knowledge of results takes on a guidance role. Learners come to rely on KR when making adjustments to their motor performance and not other intrinsic sensory feedback. Consequently, the skill is not truly “learned.” Constant KR seems to be a distraction, or may be a “mental crutch,” and does not enhance motor learning. Knowledge of results seems to have a motivating effect but too much knowledge of results has been shown to interfere with a learner’s processing of intrinsic feedback (Salmoni et al., 1984). Constant knowledge of results prevents the learner from developing effective error-detection strategies.

Augmented feedback, properly employed, has an important place in occupational therapy. Patients with cognitive and perceptual impairments may not be able to use intrinsic feedback to guide their performance (Flinn & Radomski, 2002). Furthermore, because their own abilities to generate intrinsic feedback may be compromised by neurological sensory impairments, they may be more dependent on augmented feedback (Sabari, 2001). An occupational therapist seeking to encourage and support a client may find it difficult to take advantage of motor learning principles due to problems with generalizing many of the laboratory-based motor learning studies to clinical settings (Giuffrida, 1998). However, augmented feedback, given in the form of qualitative KR, may permit the therapist to provide motivation and support as well as valuable information about the outcome of motor performance.

In a therapy session, KR is not typically given as quantitative information about outcome. Generally, administration of quantitative KR requires an apparatus or an individual to measure error as well as communicate the error. It seems more likely that the therapist gives KR of a qualitative nature, with a reward or motivational component, with statements such as “You were almost there!” or “Just a little more!” or “Good job, you got it!” For the purposes of this study, this style of feedback is defined as qualitative knowledge of results because it contains both magnitude and direction, but does not give precise quantitative information.

Nelson (1994) described occupation as the relationship between occupational form (the environment) and occupational performance (voluntary doing). He stated that individuals ascribe personal meanings to form and perfor-
formance. Meaning in general affects the individual’s purpose, or desire for outcome, and in that capacity it has potential to affect occupational performance (Nelson, 1994). Qualitative KR may alter the meanings an individual associates with an occupation. It may influence meaning enough to cause a change in performance. Qualitative knowledge of results in the form of verbal encouragement has been found to increase performance of motor skills. In a study involving motor performance and verbal encouragement, verbal encouragement increased motor performance of participants not intrinsically motivated to exercise (Chitwood, Moffatt, Burke, Luchino, & Jordan, 1997). When a motor task has little meaning, in the laboratory, or in the clinic, verbal encouragement may serve to increase perceived meaning and purposefulness of the occupation thereby resulting in increased motivation for learning the task.

Another way that qualitative KR may facilitate motor learning is that it may be specific enough to be motivating, but general enough that the learner must take an active role in assessing his or her own performance. It this were the case, we would expect qualitative knowledge of results to be more effective than quantitative KR for the acquisition of a motor skill when the feedback is provided after every trial. This reasoning is consistent with Salmoni et al. (1984) “mental crutch” explanation of why constant KR results inferior learning compared to intermittent KR.

Few studies have examined the differences in motor learning based on whether qualitative or quantitative knowledge of results were provided. Jensen, Picado, and Morenz (1981) investigated varying levels of KR precision on motor learning in a normal population. These investigators defined quantitative knowledge of results as being the most precise error score in a timed task (e.g., .001 seconds) and qualitative knowledge of results as being the least precise error score (e.g., .1 seconds). These researchers found no statistical difference on motor learning between the qualitative versus quantitative knowledge of results conditions.

Haywood (1975) investigated three levels of KR in an anticipatory key press task. Seventy-five undergraduate students acted as participants and were randomly assigned to a quantitative KR, a qualitative KR, or a no-KR group. The task involved pressing a key at the moment a rolling ball crossed a target. The quantitative KR group received a directional algebraic error score in the form of the time difference between the time they pressed the key and when the ball actually crossed the target. The qualitative KR group received verbal feedback dependent on their performance. The investigator would say “very good” if the participant scored within a certain criterion. If the performance was below the criterion, the investigator would say, “you were a little off,” providing some information about magnitude, but not direction (the algebraic sign) of the error. The no-KR group received no feedback. Haywood found no statistical difference among the three groups’ ability to accurately perform this timing task.

As this current study incorporates an encouragement component to its qualitative feedback conditions it is important to mention pertinent studies investigating the influence of verbal encouragement on performance. Desrosiers, Rochette, and Boutin (1998) investigated the effects of immediate visual feedback and verbal encouragement on grip strength, with two populations: unimpaired adults and adults with physical impairments who resided in a long term care facility. There were two verbal encouragement conditions; one used a loud voice and the other used a “normal" voice to provide the verbal encouragement. Overall, there was no statistically significant difference between the visual feedback and verbal encouragement conditions within the unimpaired adults. However, grip strength in the population of adults with physical impairments did demonstrate a statistically significant performance in the loud verbal encouragement condition. There has been no study that investigated the effectiveness of feedback of a qualitative nature (i.e., an error score of magnitude and direction) versus feedback of a qualitative nature (i.e., having verbal encouragement with magnitude and direction).

This study examined the impact of two different types of augmented feedback, namely, quantitative and qualitative knowledge of results, on a simple motor learning task. Four conditions of feedback were used: Qualitative (Qual), Quantitative (Quant), Qualitative and Quantitative (Qual + Quant), and no augmented feedback (Control). The first hypothesis was that there would be a difference in performance during skill acquisition, depending on the type of feedback. The second hypothesis was that there would be a difference in performance during the retention test, depending on the type of feedback. Nondirectional hypotheses were constructed based on the inconclusive and scant evidence that is pertinent to this research problem.

Methods

Design

This study used the common KR paradigm, a two-phase design with a skill acquisition phase and a retention phase, with a 10-minute interval between the two phases (Schmidt & Lee, 1999). All four conditions of the independent variable (feedback) were administered during the acquisition
phase, but not during the retention phase. Salmoni et al. (1984) stated that the two-phase design allows the researcher to separate the temporary effects of feedback on performance from its more permanent effects on learning. The no-KR phase more closely parallels real life, outside of the clinic and without feedback from a therapist (Schmidt & Lee, 1999).

In the skill acquisition phase of this study, participants in the four conditions experienced different types of augmented feedback while learning a motor skill. In the retention phase, participants exercised the learned skill in a series of trials with no augmented feedback. The skill to be acquired during the acquisition phase is that of a force production task, applying a specific amount of force on a load cell with the index finger. An assumption that learning has occurred is demonstrated by the ability to produce the target force during the retention phase.

Participants

Participants were a convenience sample of 80 adults, (64 male and 16 female) including college students and members of the community, ranging in age from 18 to 55 years. Participants were recruited through advertisements posted on campus and through recruitment presentations to various college classes. By self-report, participants had no known neurological or physical disabilities that might have affected their ability to participate in the study. Data from one participant in the Control condition and two participants in the Quant condition were eliminated because their force production was below the sensitivity threshold of the apparatus. Therefore data from 77 participants were included in the analyses. The mean age of this sample population was 27.1 years with a standard deviation of ± 8.3 years.

Apparatus

The motor skill involved learning to apply a specific amount of pressure to a pressure sensitive load cell. The target pressure was based on a percentage of the participant’s maximum voluntary effort. Computer hardware and custom software were used to collect data and administer the augmented feedback conditions of the independent variable. An ELF load cell (Entran, Fairfield, NJ, model no. ELF-500-100-/R) was used to detect finger pressure (see Figure 1). The load cell had a sensitivity of 2.6 mV per pound with an excitation voltage of 15V. Data conversion was done using a 12-bit DAS-800 analog to digital data acquisition board (Keithley, Cleveland, OH), installed in a Gateway 133 MHz Pentium desktop computer. Force data were collected using Test Point 3.4 data acquisition software (Capital Equipment Corporation, Billerica, MA), at a sampling frequency of 60 Hz. Data were smoothed using a 10-point window moving average (Williams, 1997). A custom Test Point application interpreted the data and administered feedback, in the form of a visual algebraic display on the monitor and/or pre-recorded verbal phrases played via the sound card and speakers, according to the assigned condition. The testing setup is illustrated in Figure 2.

Procedure

There were four parts to the procedure: setup, the skill acquisition phase, the delay period, and the retention phase. Testing took place at a movement analysis laboratory at a Midwest college. The entire procedure took approximately 30 minutes.

All participants gave informed consent prior to their participation. Using a computerized number generator, participants were randomly assigned to one of the four feedback conditions, with 20 participants in each condition: Qualitative (Qual), Quantitative (Quant), Qualitative and Quantitative (Qual + Quant), and no augmented feedback (Control). Participants were told that the purpose of the study was to investigate the effects of different kinds of feedback on learning.
Setup consisted of collecting identifying data and calculating a target force, based on the individual participant’s maximum voluntary force. Participants were seated on a chair, 17 inches tall, in front of the testing apparatus, which was supported on a table 36 inches high. Each participant’s identification number and condition were entered into the computer. Participants were then instructed to press on the load cell with maximum pressure, using the index finger of their dominant hand, for a duration of 4 seconds, indicated by a start tone and stop tone. Participants had two trials in the setup phase, one for practice, and one to collect maximum force data. The computer captured the maximum force and calculated a target amount for the individual participant equal to 40% of the participant’s maximum. A percentage of maximum voluntary contraction was used to ensure that we were measuring motor learning and not fatigue.

There were 30 trials in the skill acquisition phase. Participants in each of the three feedback conditions received augmented feedback immediately after each trial. Participants in the control condition received no feedback. The interval between trials for all conditions was 10 seconds. The custom software measured performance, that is, target force achievement, in terms of constant error (CE). Constant error was used as the measure of accuracy and was calculated using the formula CE = x_i - T, where x_i was the amount of force exerted in the trial and T was the target force. The smaller the CE, the greater the accuracy. A positive CE score indicates the amount of force exerted was greater than the target force; conversely a negative CE score indicates the amount of force exerted was less than the target force. For the conditions containing quantitative feedback, (Quant and Qual + Quant), CE was visual in nature and was displayed as a signed number on the computer monitor.

The qualitative feedback in the Qual and Qual + Quant conditions was audible in nature and described the performance with incentive to make changes as well as some information about the direction of the change required to meet the target. Participants in the Qual + Quant condition received both types of feedback, that is, the verbal information and the signed number display. The appropriate qualitative feedback was determined by the following range of constant error as a percentage of the target force.

<table>
<thead>
<tr>
<th>Range of Error</th>
<th>Qualitative Knowledge of Results</th>
</tr>
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<tbody>
<tr>
<td>0 ± 2%</td>
<td>Excellent! You pressed just right!</td>
</tr>
<tr>
<td>± 2 ± 5%</td>
<td>Good! You pressed too hard/light.</td>
</tr>
<tr>
<td>± 5 ± 10%</td>
<td>Not bad! You pressed too hard/light.</td>
</tr>
<tr>
<td>± 10 ± 999%</td>
<td>Not so great. You pressed way too hard/light.</td>
</tr>
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</table>

In the acquisition phase, the 30 individual trials were sequentially aggregated into blocks of 3 trials with each block being represented by the mean of its three trials. A 4 X 10 (condition X block) analysis of variance (ANOVA) with repeated measures on the second factor was done on constant error. In the retention phase, the mean of the five trials was calculated to represent one block. A 4 X 1 (condition X block) ANOVA was done on constant error. The alpha was set at .05 for the analyses of variance. Post-hoc Bonferroni pair-wise comparisons were performed to compare the individual conditions with each other. A one-way ANOVA on condition was done for the first trial to test the assumption of homogeneity across all four conditions. Alpha was set at .05 for all statistical analyses.

Results

Data were not skewed and the assumption of homogeneity was supported. In the acquisition phase, there was a significant main effect difference by condition in performance. All possible pair-wise comparisons were statistically significantly different from each other except the Control and Quant comparisons and the Qual and Qual + Quant comparisons. There were no interactions between block and condition, meaning that regardless of condition, participants did not demonstrate significant differences in performance across the trial blocks. That is, the rate of change by conditions (i.e., the interaction between the conditions and block) was not statistically significantly different across blocks (see Table 1).

In the retention phase, there was a significant main effect difference by condition in performance (see Table 1). However, pair-wise comparisons revealed no statistically significant differences among any combination of conditions.

In the acquisition phase, means for pairs of conditions tended to cluster together, Qual with Qual + Quant, and Control with Quant. The Qual and Qual + Quant conditions showed noticeably smaller constant errors indicating relatively greater performance accuracy. Although not statistically significantly different, the means for Qual and Qual + Quant conditions across the blocks approached zero.

There was a 10-minute delay before the retention phase. During this interval, the researcher and participant played cards. In the retention phase, there were five trials. No feedback was administered in this phase. Participants were given the same instructions as in the skill acquisition phase. In addition, they were told they would not receive any information about how close they came to their target 40% force.

Data Analysis

In the acquisition phase, the 30 individual trials were sequentially aggregated into blocks of 3 trials with each block being represented by the mean of its three trials. A 4 X 10 (condition X block) analysis of variance (ANOVA) with repeated measures on the second factor was done on constant error. In the retention phase, the mean of the five trials was calculated to represent one block. A 4 X 1 (condition X block) ANOVA was done on constant error. The alpha was set at .05 for the analyses of variance. Post-hoc Bonferroni pair-wise comparisons were performed to compare the individual conditions with each other. A one-way ANOVA on condition was done for the first trial to test the assumption of homogeneity across all four conditions. Alpha was set at .05 for all statistical analyses.
sooner than for Control and Quant conditions (see Figure 3). Standard deviations were large for all conditions, but show the same pattern of clustering by condition, Qual with Qual + Quant, and Control with Quant. The Qual and Qual + Quant conditions had smaller standard deviations.

Means in the retention phase show the same clustering, Qual with Qual + Quant and Control with Quant (see Table 2). The mean for Qual is marginally smaller than that for Qual + Quant. As in the acquisition phase, standard deviations are large, with those for conditions Qual + Quant and Qual being smaller.

In both the acquisition and retention phases, the mean CE scores were negative, meaning that participants tended to press the load cell with less force than the target force. This was not true for all participants, in that the standard deviations were larger in magnitude than the absolute value of the means.

Discussion

Occupational therapists frequently provide qualitative knowledge of results feedback that contains verbal encouragement. The purpose of this study was to determine the effects of qualitative and quantitative feedback on motor learning in an unimpaired healthy adult population. The first hypothesis was supported in that there were significant differences in performance during the acquisition phase depending on the type of feedback given. The second hypothesis was partially supported in that there was a statistically significant difference among the conditions depending on the type of feedback given during the acquisition phase. However, the retention phase post-hoc comparisons revealed no statistically significant differences between conditions. That is, the difference found by the ANOVA was not strong enough for the post-hoc comparison to conclude that one type of feedback was statistically more effective for improving retention.

The smaller constant error scores for the conditions containing the qualitative feedback suggest that encouragement had a positive effect on motor performance. It enabled participants to more accurately adjust their force production to match their target force. The quantitative feedback did not appear to facilitate performance, as there was little difference between the performance of this group and the Control group’s performance.

The quantitative feedback provided specific information about performance in the form of a number representing...
ing the amount of force in grams away from the target and a sign indicating direction above or below the target force. Encouragement provided general information about performance ("a little too hard," "way too light"), along with an overall evaluation of performance ("good," "not so great"). These words may have influenced participants' performance, perhaps because they provided some level of meaning that was useful. It is possible that verbal encouragement enhances the meanings and purposes an individual ascribes to an occupation.

Conditions Qual and Qual + Quant showed better performance in the retention phase, but not statistically significantly different from the other conditions. One possible explanation is that participants may not have been particularly focused on learning a skill of little practical value. Participants were told at the beginning of the test session that they would have 30 trials in which to learn to press a load cell with a specific amount of force, a 10-minute break, and then 5 more trials. They were not told ahead of time that there would be no feedback given during the last 5 trials, the retention test. Some participants may have anticipated receiving continued feedback. A more vigorous emphasis on the need to "retain" may have improved all retention results.

Another possible explanation is that encouragement may work much like KR. Frequent quantitative knowledge of results improves acquisition performance, but can be detrimental to motor performance during retention (Baird & Hughes, 1972; Ho & Shea, 1978; Weinstein & Schmidt, 1990). Frequent knowledge of results is thought to be detrimental to retention because of its "guidance" effects (Salmoni et al., 1984), where individuals come to rely on the feedback to guide their performance and do not make the internal adaptations needed to truly acquire the skill. The encouragement administered in this study may have had the same effect. A third possibility is that the bandwidths, the ranges of constant error that determined the verbal phrase given as encouragement, may have been too challenging. High praise was reserved for performances with an error within ± 2% of the target, a demanding standard of performance. A fourth possibility is that, although there was a statistically significant main effect difference among the four conditions, this difference was not strong enough to yield statistical significance when the individual feedback conditions were compared with each other as dyads in the post-hoc analysis.

From an occupational therapy perspective, qualitative feedback (involving verbal encouragement) is an effective way to personalize feedback and to increase the meaning of a particular motor task. Such feedback can increase motivation and elicit better performance during practice (Chitwood et al., 1997). Additionally, it can be used to elicit more practice, an important factor in motor learning. Lastly, this type of feedback can be used when a patient or client is having difficulty processing other kinds of sensory or cognitive feedback. Hence, qualitative feedback may be a reasonable and effective way to enhance the acquisition of motor skill in clinical settings, though the retention of that motor skill may not be superior to other types of more quantitative feedback.

Limitations of the study included technical aspects of the apparatus, the artificiality and specificity of the task, and the participant population. With respect to the data collection apparatus, some data were lost because they were under the sensitivity threshold of the load cell. Producing a certain amount of force just to meet a target amount is a very artificial situation. The task and indeed the laboratory setting itself were non-naturalistic. In addition, the population was one of convenience. Hence, the data collection environment and sample of convenience limits generalizing the results to other, more natural settings and the general population. Another limitation was the use of two different media for the administration of the feedback conditions. Knowledge of results was presented as a visual display, while encouragement was given orally, by recorded voice. In addition, the recorded voice was familiar to some subjects, but not to others. The use of different sensory modalities to present feedback may have introduced confounding variables.

Further research is needed to understand the role of qualitative feedback and its effects on the acquisition and retention of motor skill. Consistency of media in the administration of feedback is needed to demonstrate the effectiveness of qualitative versus quantitative knowledge of results, specifically for the retention of motor skill. Also, this study used only healthy adults so results are limited to this population. Desrosiers et al. (1998) suggest that a population with physical impairments may benefit more from encouragement. Additional studies should be pursued with special populations to explore the effectiveness of different types of feedback (quantitative and qualitative) when persons have some kind of physical or cognitive compromise or both.

**Conclusion**

The results of this study suggest that in a healthy adult population, qualitative feedback, by itself and when combined with quantitative feedback resulted in superior skill acquisition, but not in the retention of that skill. The artificiality of the task along with differing modes of feedback (audible versus visual) are two potentially limiting factors to this study. Future research that controls for these factors may
yield more definitive findings about the role that qualitative feedback has in improving motor performance and learning. ▲

References


