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Does Mental Practice Work Like Physical Practice Without Information Feedback?

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The effectiveness of mental practice (MP; i.e., the imagination of performing a motor skill without overt movement) has been well documented (for reviews, see Feltz, Landers, & Becker, 1988; Grouios, 1992; Hinshaw, 1991). In general, MP has been found to be more effective for motor learning than no practice, but not as effective as physical practice. A combination of physical and mental practice, however, is often as effective as (e.g., Stebbins, 1968), or even more effective than, physical practice alone (e.g., Kohl, Ellis, & Roenker, 1992, Experiment 2; McBride & Rothstein, 1979; Ulich, 1967; White, Ashton, & Lewis, 1979; Willimczik, Boltz, Fröhlich, & Rother, 1976). The effects of MP are interesting not only from an applied point of view (e.g., for the learning of sport skills or the rehabilitation of movement disorders) but also from a theoretical perspective, as an understanding of how MP functions could provide further insights into motor and cognitive processes involved in motor skill learning (Heuer, 1985).

The most influential hypotheses to explain the effects of MP are the cognitive hypothesis (Sackett, 1934), the ideomotor (or psychoneuromuscular) hypothesis (Allers & Scheminzky, 1926; Jacobson, 1932), and the programming hypothesis (Heuer, 1985, 1989). Although these hypotheses provide more or less plausible and empirically supported explanations for the effects of MP (for a review, see Heuer, 1985, 1989), neither hypothesis provides an explanation for the finding that a combination of physical and mental practice can be even more effective than physical practice alone. For example, Willimczik et al. (1976) had female high school students practice volleyball skills (serve, set) either just physically or both physically and mentally (with the total practice time being constant). They found that combined physical and mental practice led to more effective learning of these skills than physical practice alone did. As none of the previously mentioned hypotheses seem to be able to answer the question of why the mere imagination of a movement—at least when it is combined with physical practice—would be more effective than physical practice, additional assumptions are needed to explain these benefits of combined physical and mental practice.

One possibility is that MP trials function like physical practice trials without information feedback[1] (IF; Kohl et al., 1992; Wulf & Vogt, 1994). Several recent studies have shown that reducing the relative frequency of augmented feedback, or knowledge of results (KR; i.e., withdrawing it on a portion of trials), can enhance motor learning as compared to practice with KR after every trial (e.g., Winstein & Schmidt, 1990; Wulf & Schmidt, 1989; see also Schmidt, 1991, for a review). These findings have been explained in terms of the guidance hypothesis (Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991). According to this hypothesis, KR has positive functions, such as guiding the learner to the correct response. However, KR is also argued to have several negative effects that degrade learning. For example, by providing frequent KR, the learner might become too dependent on this information and neglect the processing of intrinsic feedback. Withdrawing KR on a portion of trials, on the other hand, forces the learner to pay more attention to her or his own feedback, thus promoting the development of a subjective error-detection-and-correction mechanism. In addition, every-trial KR has been shown to make movement production quite variable because the learner constantly tries to correct even minor deviations from the goal (e.g., Wulf & Schmidt, 1994; Wulf, Schmidt, & Deubel, 1993). These "maladaptive short-term corrections" (Schmidt, 1991) presumably prevent the learner from developing a stable movement repre-

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sentation or motor program. A reduced relative KR frequency, on the other hand, reduces these short-term corrections and facilitates the development of a stable motor program.

As MP also does not involve augmented or sensory feedback about the movement outcome (i.e., IF), it is possible that MP functions like physical practice without IF. Some support for the notion that alternating physical and mental practice trials has similar effects as alternating physical practice trials with and without IF comes from a study by Kohl, Fisicaro, and Erbaugh (1993). These authors showed that imagining a certain percentage of a maximum voluntary contraction produced aftereffects that were functionally equivalent to those of a physical response without IF.

In the present study, we wanted to examine possible similarities in the effects of MP and physical practice without IF on the learning of a motor skill. We used a golf-putting task that required participants to putt golf balls to targets at different distances. If MP functions like physical practice without IF, practice conditions interspersed with MP or with no visual feedback or augmented IF trials should have similar effects on learning; that is, both conditions should produce more effective learning than practice with IF after every trial should. Learning was measured by a delayed retention test without IF. In addition, we wanted to determine the generalizability of the results to retention conditions with IF.

Method

Participants

Thirty-six students from the University of Munich participated in the experiment. All participants had normal or corrected vision. They were paid DM 15 (about $9) for their participation. Participants were not informed about the purpose of the experiment, and none had prior experience with the task. Informed consent was obtained from all participants prior to inclusion in the study.

Apparatus and Task

The task required participants to putt golf balls with a standard length right-handed putter (Lamkin OPTIC-VII, Precision II) into target zones marked on the floor. These target zones were 10-cm wide and were drawn with a red marker on a gray carpet (560 x 155 cm) concentrically around a red dot, located near one end of the carpet, from which the putt was executed. The target zones were 185, 285, and 385 cm away from the red dot (measured from the middle of each zone). The nearest target was labeled as 1, the middle target as 2, and the most distant target as 3. Between the target zones were eight black lines, 10-cm apart from each other, that divided the space between the targets into nine zones. These zones were numbered to help the experimenter assess the distance off target.

Experimental Design and Procedure

Participants were randomly assigned to one of three groups: the 100% IF group, the 50% IF group, and the 50% MP group. All participants were instructed to propel the golf ball along the putting surface into the target zones by striking the ball with the putter. The experimenter first showed the participant the correct grip and stance and then demonstrated the putting action. Participants, however, were not given any practice trials at this point. They were told that the sequence of targets would always be 1, 2, 3; 1, 2, 3; and so forth. Participants were then given six golf balls and were asked to perform the first six trials. After each trial, the experimenter gave KR (e.g., "hit" for putting the golf ball into the target zone or "minus 7" for a stroke seven zones short of the target), recorded the deviation from the target to the nearest 10-cm zone, and collected the golf balls. After the first six trials, participants were given further instructions depending on the practice condition that they had been assigned to.

In the 100% IF group, participants completed 14 blocks of 6 trials, resulting in a total of 84 practice trials. The procedure described earlier was used and in addition to their visual feedback, participants were given augmented IF in the form of verbal KR after every trial. The 50% IF group received no visual or augmented IF on every other 6-trial block. (Note that in the remainder of this article, when referring to experimental conditions, the term no IF refers to no visual or augmented IF.) To prevent participants from seeing where the golf ball stopped in relation to the target, they wore a baseball hat with a piece of cloth (about 25 x 25 cm) attached to its left side. This prevented participants from viewing the path of the golf ball for more than about 30 cm, but allowed them to see the ball when striking it. Participants were also allowed to look at the target before each strike. They alternately performed 6-trial blocks with and without IF until they had completed all 84 practice trials.

Participants in the 50% MP group were asked to just imagine putting the golf ball to the target on every other 6-trial block. They were instructed to image the movement not only visually but to try to "feel" striking the ball and to "watch" the path of the ball and where it came to a stop. Participants were allowed to see the target during MP trials, but they were not allowed to move the putter. They were asked to imagine putting the six golf balls in the same order as before. Similar to the

50% IF condition, participants in the 50% MP group alternately performed 6 physical trials (with IF) and 6 mental trials until they had completed 84 trials. The total time of the practice phase was about 30 min for all participants.

One day after practice, participants returned to the laboratory to perform two retention tests. Retention 1 consisted of 18 trials without IF, with the order of targets being the same as during practice. During the first retention test, participants wore the baseball hat that prevented them from seeing the results of their actions. Retention 2 consisted of 18 trials with IF (in the same order as before); that is, in addition to their visual feedback, participants were given verbal KR by the experimenter after each trial.

Data Analysis

Dependent measures were absolute error (AE), indicating the participants' overall success in hitting the targets; absolute constant error (|CE|), as a measure of bias; and variable error (VE), as a measure of intra-individual consistency in responding. These error scores were first calculated for each target separately and then averaged across targets. As no data were available for the 50% MP group on every other 6-trial block during practice (Blocks 2, 4, 6, 8, 10, 12, and 14), only those practice blocks were analyzed for which data were available for all groups (Blocks 1, 3, 5, 7, 9, 11, and 13). Thus, the practice data were analyzed in 3 x 7 (Group x Block) univariate analyses of variance (ANOVAs) with repeated measures on the last factor. For both retention tests, the 18 trials were collapsed into one block and analyzed in univariate one-way ANOVAs (i.e., group as the independent variable). To eliminate potential problems associated with the sphericity assumption, probability levels were computed using the Greenhouse-Geisser degrees-of-freedom adjustment. Post hoc comparisons of means were performed using the Student-Newman-Keuls ($p < .05$) procedure. The strength of association (ω^2) was also reported for significant group effects.

Results

Practice

All three groups consistently reduced their AE scores across the practice phase (see Figure 1, left side), with all groups demonstrating similar performances. Thus, the interspersed no-IF blocks in the 50% IF condition and the physical and mental practice blocks in the 50% MP condition obviously had no degrading (or facilitating) effects on practice performance (at least on the IF blocks that are shown in the graph in Figure 1) as compared to the 100% IF condition. The main effect for block was significant, $F(6, 198) = 21.67$, $p < .001$, whereas the main effect for group and the Group x Block interaction were not significant. The |CE| data (see Table 1) show that all groups became more accurate in hitting the target over the course of practice, $F(6, 198) = 12.01$, $p < .001$. Similar to AE,

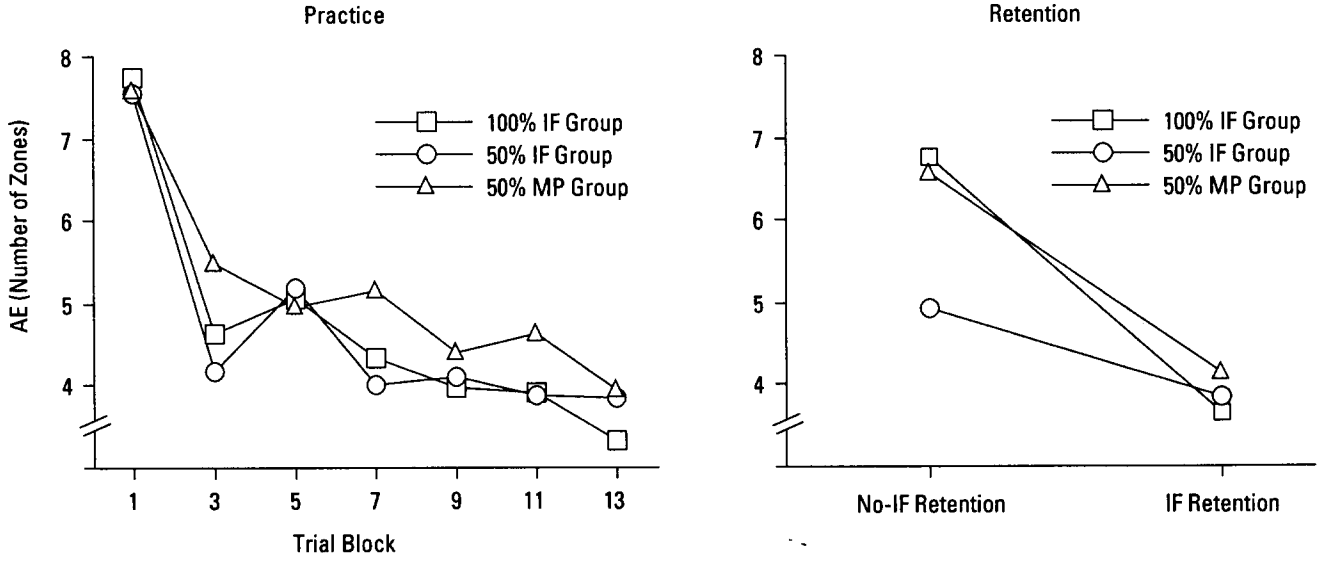

Figure 1. Absolute error (AE) in practice and in the 24-hr retention tests without information feedback (no-IF retention) and with IF (IF retention). MP = mental practice.

there was no significant difference between groups and no interaction of group and block. Participants not only became more accurate but also generally more consistent in responding from the beginning to the end of practice (see VE data in Table 1). Only the block effect was significant, $F(6, 198) = 16.83$, $p < .001$.

Retention Without IF

Mean AE scores in the no-IF retention test are shown on the right side of Figure 1. The 50% IF group had clearly lower AE scores than the 100% IF group and the 50% MP group. The group effect was significant, $F(2, 33) = 5.95$, $p < .05$, $\omega^2 = .29$. Post hoc tests indicated that the 50% IF group had significantly lower AE scores than both the 100% IF group and the 50% MP group. The 50% IF group also demonstrated lower |CE| scores than the 100% IF group and the 50% MP group (see Table 1). The group effect was also significant for |CE|, $F(2, 33) = 5.48$, $p < .05$, $\omega^2 = .17$. Post hoc tests revealed that only the difference between the 50% IF group and the 100% IF group was significant. The 50% IF group was not only more accurate but also more consistent in putting the golf balls than the 50% MP group, whereas the 100% IF group showed intermediate performance (see VE data in Table 1). The main effect for group was significant, $F(2, 33) = 3.94$, $p < .05$, $\omega^2 = .20$. Post hoc tests indicated that the 50% IF group had significantly lower VE scores than the 50% MP group.

Retention With IF

In the IF retention test, all groups had considerably lower errors than in the no-IF test. There were no significant differences between groups with regard to either AE (see Figure 1, far right), |CE|, or VE.

Discussion

Even though there were no significant performance differences between groups during practice, the 50% IF condition produced more effective learning than both the 100% IF and 50% MP conditions in the no-IF retention test (as measured by AE). The beneficial effects of the reduced IF frequency, relative to IF after every trial, are in-line with previous studies examining IF relative frequency effects on motor learning (e.g., Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). Combined physical and mental practice (50% MP condition), however, did not lead to more effective learning than physical practice with 100% IF did, as has been demonstrated before (e.g., Kohl et al., 1992, Experiment 2; McBride & Rothstein, 1979; Ulich, 1967; White et al., 1979; Willimczik et al., 1976). Yet the 50% MP group did not demonstrate poorer retention performance than the 100% IF group, even though they had only half the number of physical practice trials.

More important, MP trials did *not* have the same effects on learning as physical practice trials without visual or augmented IF. Even though during practice there were no differences between the 50% IF group and the 50% MP group, withdrawing IF on 50% of the trials clearly produced more effective learning than did MP on 50% of the trials. In the no-IF retention test, the 50% IF group had significantly lower AE and VE and also tended to be more accurate (|CE|) than the 50% MP group. Thus, there seems to be a clear benefit to actually executing a movement, even if, or especially if, no visual or augmented IF is available, as compared to just imagining the movement. Perhaps reducing the relative IF frequency encourages learners to pay more attention to their intrinsic feedback (e.g., kinesthetic feedback), which is probably not possible to the same degree under MP conditions (and not necessary under physical practice conditions with 100% IF), leading to a stronger error-detection-and-correction mechanism (Salmoni et al., 1984; Schmidt, 1991). Also, the 50% IF group demonstrated a greater stability in movement production than did the 50% MP group in the no-IF retention test, suggesting that executing a movement without IF, and not just imagining it, enhances movement stability. The results, therefore, do not support the notion that MP has the same effect on learning as

Table 1. Absolute constant error (|CE|) and variable error (VE) in practice and in the no-information feedback (IF) and IF retention tests

Dependent variable	Group	Practice blocks 1	2	3	4	5	6	7	No-IF retention	IF retention
|CE|	100% IF	4.5	4.7	4.1	3.1	2.4	2.6	2.2	5.3	1.8
	50% IF	4.5	3.8	3.8	3.0	3.1	2.8	2.7	2.9	1.9
	50% MP	6.2	3.6	3.1	4.2	3.5	2.3	2.5	4.7	1.9
VE	100% IF	6.9	6.3	4.4	4.0	4.3	4.2	3.2	5.5	4.3
	50% IF	7.2	5.9	4.4	3.5	4.0	3.8	3.4	4.7	4.5
	50% MP	7.3	5.9	5.3	4.2	4.3	5.9	4.2	6.0	4.8

Note. MP = mental practice.

physical practice without IF. Withdrawing IF on a portion of trials seems to clearly produce more effective learning than practicing movements mentally for the same number of trials.

Contrary to the no-IF retention test (Retention 1), there were no significant differences between groups in the IF retention test (Retention 2). Based on the present results, the possibility cannot be excluded that the 50% IF group demonstrated more effective performance on the no-IF retention test because these participants, contrary to those of the 100% IF and 50% MP groups, were used to performing without IF (i.e., because their practice conditions were more similar to the no-IF retention conditions). However, in other studies, such a specificity-of-learning interpretation (e.g., Henry, 1968; Tulving & Thomson, 1973) has been shown not to be a viable explanation for the learning advantages of a reduced IF frequency. For example, Winstein and Schmidt (1990, Experiment 3) and Schmidt, Lange, and Young (1990, Experiment 2) provided convincing evidence against the specificity hypothesis by showing that a reduced IF frequency can produce more effective performance even in IF retention tests. Most likely, in the present experiment, the effects of IF in Retention 2 were so powerful that they overshadowed the differential learning effects that were seen in the no-IF retention test and produced performances that were comparable to those reached toward the end of practice.

The present results indicate that reducing the frequency of visual or augmented IF during MP is probably not the only reason for the effectiveness of combined physical and mental practice. Rather, there seems to be an advantage to actually executing a movement (without IF) as compared to just imagining it. Thus, it still remains unclear why combined physical and mental practice can enhance learning relative to physical practice alone. Determining what are the exact underlying mechanisms of MP remains a challenge for future research.

References

Allers, R., & Scheminzky, F. (1926). Über Aktionsströme der Muskeln bei motorischen Vorstellungen und verwandten Vorgängen [About action potentials of the muscles during motor imagery and related processes]. *Pflügers Archiv für die gesamte Physiologie, 212,* 169–182.

Feltz, D. L., Landers, D. M., & Becker, B. J. (1988). A revised meta-analysis of the mental practice literature on motor skill learning. In D. Druckman & J. Swets (Eds.), *Enhancing human performance: Issues, theories, and techniques* (pp. 61–101). Washington, DC: National Academy Press.

Grouios, G. (1992). Mental practice: A review. *Journal of Sport Behavior, 15,* 42–59.

Henry, F. M. (1968). Specificity vs. generality in learning motor skills. In R. C. Brown & G. S. Kenyon (Eds.), *Classical studies on physical activity* (pp. 328–331). Englewood Cliffs, NJ: Prentice-Hall.

Heuer, H. (1985). Wie wirkt mentale Übung? [How does mental practice work?] *Psychologische Rundschau, 36,* 191–200.

Heuer, H. (1989). A multiple-representations' approach to mental practice of motor skills. In B. Kirkcaldy (Ed.), *Normalities and abnormalities in human movement* (pp. 36–57). Basel: Karger.

Hinshaw, K. E. (1991). The effects of mental practice on motor skill performance: Critical evaluation and meta-analysis. *Imagination, Cognition, and Personality, 11,* 3–35.

Jacobson, E. (1932). Electrophysiology of mental activities. *American Journal of Psychology, 44,* 677–694.

Kohl, R. M., Ellis, S. D., & Roenker, D. L. (1992). Alternating actual and imagery practice: Preliminary theoretical considerations. *Research Quarterly for Exercise and Sport, 63,* 162–170.

Kohl, R. M., Fisicaro, S. A., & Erbaugh, S. J. (1993). Motor response variations: Peripheral and central sources of error. *Journal of Motor Behavior, 25,* 67–74.

McBride, E. R., & Rothstein, A. L. (1979). Mental and physical practice and the learning and retention of open and closed skills. *Perceptual and Motor Skills, 49,* 359–365.

Sackett, R. S. (1934). The influence of symbolic rehearsal upon the retention of a maze habit. *Journal of General Psychology, 10,* 376–395.

Salmoni, A. W., Schmidt, R. A, & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical appraisal. *Psychological Bulletin, 95,* 355–386.

Schmidt, R. A. (1991). Frequent augmented feedback can degrade learning: Evidence and interpretations. In J. Requin & G. E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 59–75). Dordrecht, The Netherlands: Kluwer Academic.

Schmidt, R. A., Lange, C., & Young, D. E. (1990). Optimizing summary knowledge of results for skill learning. *Human Movement Science, 9,* 325–348.

Stebbins, J. A. (1968). A comparison of the effects of physical and mental practice on learning a motor skill. *Research Quarterly, 39,* 714–720.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 352–373.

Ulich, E. (1967). Some experiments on the function of mental training in the acquisition of motor skills. *Ergonomics, 10,* 411–419.

White, K. D., Ashton, R., & Lewis, S. (1979). Learning a complex skill: Effects of mental practice, physical practice, and imagery. *International Journal of Sport Psychology, 10,* 71–78.

Willimczik, K., Boltz, M., Fröhlich, H., & Rother, R. (1976). Zur Effektivität des mentalen Trainings im Schulsport [On the effectiveness of mental practice in physical education]. In M. Letzelter & N. Müller (Eds.), *Sport und Sportwissenschaften.* Berlin, Germany.

Winstein, C. J., & Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 677–691.

Wulf, G., & Schmidt, R. A. (1989). The learning of generalized motor programs: Reducing the relative frequency of knowledge of results enhances memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 748–757.

Wulf, G., & Schmidt, R. A. (1994). Feedback-induced variability and the learning of generalized motor programs. *Journal of Motor Behavior, 26,* 348–361.

Wulf, G., Schmidt, R. A., & Deubel, H. (1993). Reduced feedback frequency enhances generalized motor program learning but not parameterization learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1134–1150.

Wulf, G., & Vogt, S. (1994). How does mental practice work? Some evidence for the KR frequency hypothesis. Unpublished manuscript, Max-Planck-Institute for Psychological Research, Munich, Germany.

Note

1. The term *information feedback* (IF) is preferred in this context to *knowledge of results* (KR) because IF includes augmented feedback (KR in this experiment) as well as visual and proprioceptive sensory feedback. In this experiment, KR and visual sensory feedback are withdrawn, thereby making it not possible to consider the role of KR alone. (Thanks to Dick Magill and Tim Lee for pointing this out.)

Authors' Notes

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