THE EFFECTIVENESS OF MENTAL PRACTICE USED IN CONJUNCTION WITH AUDIO - VISUAL AND VISUAL PRACTICE IN THE DEVELOPMENT OF THE FOREHAND DRIVE IN TENNIS

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By

Charlotte Graham Knox

AN ABSTRACT OF A THESIS

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ABSTRACT

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The Problem

The purpose of this study was to determine the relative effectiveness of mental practice used in conjunction with audio and audio-visual instruction employing matched pairs of subjects in the performance of the forehand drive in tennis.

Conclusions

Results indicated that experimental group A (the audio-visual mental practice group) improved 6.5 percent from the initial test to the final test and experimental group B (the audio mental practice group) declined -6.5 percent. Only one test indicated that significant results occurred during the six week experimental period. A Paired t-Test indicated that at the 95 percent level of confidence the mean change in experimental group B was signifcantly less (t=-2.06) than the mean change in experimental group A. It was concluded that audio-visual practice used in conjunction with mental practice was superior to audio used in conjunction with mental practice under the conditions of the experiment.

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CHAPTER I

INTRODUCTION

Man's ability for acquiring new skills has a definite relationship to his effectiveness in establishing control over his environment. It is this unique ability which has enabled him to adapt to the demands of a changing environment. Investigations related to the development of more efficient techniques for acquiring new skills have become increasingly important as levels of achievement rise. In recent years a number of investigations including those of Eggleston (44), Perry (15), Rubin-Rabson (19), Beattie (42), Waterland (58), Clark (4), Kelsey (13), Smith and Harrison (28), Whiteley (51), Egstrom (7), and Steel (34) have shown the value of mental practice in the learning process.

Purpose of the Study

It is the purpose of this study to determine the relative effectiveness of mental practice used in conjunction with audio and audio-visual instruction employing matched pairs of subjects in the performance of the forehand drive in tennis.

Need for the Study

Investigators have studied the various aspects of mental practice, including the effectiveness of different combinations of mental and physical practice, the role of mental practice in retention, the effect of mental practice on the body, and many other variables which might facilitate or inhibit the amount of improvement to be gained from mental

practice. An important initial step, however, has received little of the investigators' attention. Only one study has been conducted to determine the type of instruction that would be most productive in developing a motor skill, prior to the conceptualization session. Paul Surburg (36) investigated the effectiveness of mental practice combined with three variables of instruction: audio, visual, and audio-visual presentations of the forehand tennis drive. Among the variables of instruction, audio, used in conjunction with mental practice proved to be the most effective method for the development of the forehand drive.

Another important step has also received little of the investigators' attention. Research has been undertaken to discover the relation of individual difference variables to improvement under mental practice conditions. Although investigators have probed into the effects of abstract reasoning (Wilson, 52), games ability (Start, 31, Whiteley, 51), imagery (Whiteley, 51, Start and Richardson, 33), intelligence (Perry, 15, Clark, 4, Start, 29, 32, and Whiteley, 51), mechanical reasoning (Wilson, 52), motor ability (Whiteley, 51), sex (Perry, 15), and spatial relations (Wilson, 52), only games ability, imaging ability and selective attention have shown a significant relation to the amount of gain from mental practice. In spite of the significance of these variables and the subsequent need to equate groups in order to make a valid comparison, no previous attempt has been made to match subjects on any of these variables prior to participation in mental practice.

Definition of Terms

Mental practice refers to "the symbolic rehearsal of a physical activity in the absence of any gross muscular movements" (16, p.97). As defined by Perry, mental practice is ". . . the repetition or

rehearsal of the task 'in the mind's eye'" (15, p.6). Therefore when a gymnast stands with his eyes closed and "thinks" his way through the movement he is about to perform he is engaged in mental practice.

Limitations of the Study

Sample. This study is confined to ten matched pairs of subjects selected from 106 women at Michigan State University.

Techniques and Procedures. There was no feasible way, other than limiting the study to a brief training period which was not practical in this investigation, of controlling mental practice outside of the training sessions.

It is recognized that the effectiveness of the coordinator of the testing and practice sessions and her attitude toward the experimental procedure may have an influence on the achievement and attitudes of the students.

The questionnaire developed for this study was used without being tested previously.

This is a one-term study with no provision for retention testing. The study is of necessity limited by the validity and the inherent limitations of the tests used for matching purposes and the testing procedures employed.

CHAPTER II

REVIEW OF LITERATURE

Comparison of Mental and Physical Practice

Many investigators have compared the effectiveness of physical and mental practice in the acquisition or development of a motor skill. The first investigation concerned with mental practice was conducted in 1899 by W. G. Anderson (2). Anderson conducted several investigations in which gymnastic movements were thought of instead of practiced. He reported that gymnastic movements could be learned if the mind only was trained, without actual use of the muscles (2, p.278). Confirming statistical analysis was not presented.

More recently Perry (15) utilizing elementary school children, attempted to determine the relative efficiency of mental practice and physical practice in tapping, card sorting, a peg board task, mirror drawing, and digit substitution. He found significant improvement with either method and reported that the relative effectiveness varied with the task used. In the peg board task the mental practice method seemed to be more effective than actual practice.

A basketball skill has often been utilized in investigations comparing mental and physical practice. In 1943, Vandell, Davis, and Clugston (39) reported on the learning of basketball throwing and dart throwing in a three week study including high school and college groups. Although the number of subjects was small, the consistency of the results prompted the investigators to conclude that mental practice was about as

effective as physical practice under the conditions of the experiment. This investigation was verified by D. M. Beattie (42) with a larger number of subjects. Beattie not only obtained confirmation of the earlier study, but also found bilateral transfer from the preferred to the non-preferred hand.

Clark (4) made a comprehensive study of basketball free throwing as affected by mental practice and other selected variables, including arm strength and intelligence. The fifteen day study revealed that while both physical and mental practice led to significant improvements in performance in varsity, junior varsity, and novice groups, the novice groups were most successful in utilizing physical practice. Intelligence as measured by the Short Form of the California Mental Maturity Test was found to have no significant relationship. Start (32) in another basketball study, investigated the role of intelligence and mental practice in the development of the underarm free throw for groups of varying ability. He found that significant improvement in shooting free throws was not significantly related to the initial score or to individual intelligence.

Another avenue of investigation for comparing the two methods of practice has been throwing skills. Twining (38) presented 36 college men with a ring toss experiment. The group that received no practice over a three week period showed no significant learning, whereas the physical practice group improved 137 percent and the mental practice group improved 36 percent. Whiteley (51) used a tennis ball throwing task involving school age boys to determine the relative value of mental and physical practice. Neither method proved superior. A study by Burns (43) employing 250 girls with ages ranging from junior high

through college, used the skill of dart throwing. This study reported that physical practice and a combination of both types were superior to mental practice alone under the conditions of the experiment.

Combinations of Mental and Physical Practice

In addition to Burns (43) many other investigators have studied the effects of combinations of physical and mental practice periods. Trussell (49) using a two hand-three ball juggling task found no significant gains in learning to juggle when a comparison was made between physical and mental practice. The greatest improvement, however, occurred with five minutes of mental practice for six days followed by fourteen days of physical practice. The group which had only physical practice was the second best, followed by the group which had five minutes of mental practice for fourteen days and then six days of physical practice. The all mental practice group came in fourth place and the no practice group last. In a study by Riley and Riley and Start (18) four groups of fourteen and fifteen year old girls practiced quoit throwing for twelve days. The group which alternated days of mental and physical practice improved the most. The group which received six days of physical practice followed by six days of mental practice was second, followed by the group which received six days of mental practice then six days of physical practice.

As a sidelight of his main investigation, Whiteley (51) studied the improvement of four groups of twenty-three boys each, on a complex gymnastic skill. The groups practiced for twenty minutes each for twelve days. The group which alternated five minutes physical practice with five minutes mental practice improved the most. Next came the group which

alternated ten minutes physical practice with ten minutes mental practice. The all physical practice group was in third place and the all mental practice group was fourth. Ergstrom (7) gave physical performance tests to six groups of twenty male university students each, on the first, seventh, and thirteenth day of his investigation. The group which alternated mental and physical practice gained the most but was not significantly better than the all physical practice group which came in second.

Mental Practice and Retention

Another effect of mental practice that has been investigated is its role in retention of motor learning. In a study of keyboard trials in piano, Rubin-Rabson (19) used three groups with three skilled pianists in each group. The group employing five physical practice trials followed by a four minute mental practice period and then physical practice until the piece could be played with only one error, had significantly better retention one week later than either of the other two groups. While one of the other groups employed physical practice until the piece could be played once with only one error, followed by four minutes of mental practice, the other group employed only physical practice. Sackett (22) also found that thinking through in verbal terms once a day in the interval between learning and relearning a maze habit was beneficial to the retention of a maze habit after one week.

Mental Practice and Endurance

Kelsey (13) investigated the value of mental practice for increasing endurance, which he defined as "the ability to continue repeated muscular activity" (13, p.47). Thirty-six college men conceptualized sit-ups for five minutes per day for twenty days. Although the muscular

endurance of the abdominal and thigh flexor muscles increased significantly, the improvement was relatively slight when compared with the results of the physical practice group. Another study on the effect of mental practice on muscular endurance was conducted by Steel (34) using four groups of randomly selected school boys on a bench press task. This study also investigated the effect of combinations of physical and mental practice. One group had mental practice, another no practice, another physical practice followed by five minutes of mental practice, and the fourth physical practice. Though the physical and mental practice combination group gained 12.66 percent it was not significantly superior to the physical practice group which gained 8.54 percent.

Mental Practice and Smoothness of Performance

Still other investigators have investigated the effect of mental practice on smoothness of performance. Waterland (50) compared a physical practice and a mental practice group on a ten pin bowling skill. The physical practice group was coached under standard conditions of instruction, while the mental practice group was instructed to close their eyes and imagine the kinesthetic "feel" of the bowling action before delivering each ball down the alley. Under these conditions the mental practice group had a smoother performance, as well as increased velocity and mean score.

Another study which could be included in this category was conducted by Abelskay and Surkov (1). Using two groups with only two jumpers in each group they found that high jumpers who imagined the detailed movements of their jump before take-off showed superior improvement to those who did not employ this procedure.

Effects of Mental Practice on the Body

Mental practice has also been shown to have several effects on the body. For example, it increases muscular tension as shown by the electromyographical evidence of Jacobson (12) and Shaw (24, 25, and 26). Jacobson has shown that an imagined movement (e.g. bending one arm), results in measurable action currents generated in the flexor muscle of the same arm. These minimal muscular contractions occur always in the limb which is imagined as being moved and are not observable in the other limbs, or in the trunk, providing the subject has learned to relax completely. Shaw (25) reported an increase in muscular potentials in all muscle groups tested during the imaging of such tasks as squeezing a hand dynamometer, typing, singing, and playing a wind instrument. In another study, Shaw (26) had his subjects imagine lifting bars of varying weight. He found that when the mental activity was increased by varying the size or the task or the amount of difficulty, muscular activity also increased. The evidence of Shaw (24) and Jacobson (12) differs slightly in that Jacobson reported that his subjects, trained to relax, demonstrated action current potentials only in the muscles involved in the particular imagined activity, while Shaw noted that localization of the action current potentials was not obtained in his study. Shaw theorized that "the distribution of these action current potentials seems to indicate that during the revival of vestigal responses, one can expect to be present any muscular activity that accompanied that original response" (25, p. 216).

An earlier article by Freeman (8) on the spread of neuromuscular activity during mental work described a method for studying the activity of five muscle groups in the human body and presented certain patterns of neuro-muscular "spread" which were found to occur under a number of

experimental conditions.

In addition to increasing muscular tension in the body, mental practice has also been reported to have caused actual body movement. Schultz (47) asked his subjects to imagine that a string held in one hand and weighted on the other end would swing from left to right or forward and backward. Every subject who consistently thought of these movements actually produced them. The more vivid the imagination process, the more pronounced was the actual overt movements. A study by Arnold (3) on the effectiveness of waking suggestion on body sway also showed the influence of mental practice on body movement. Arnold (3) found that the amount of sway increased with the vividness of the subject's imagery. A combination of visual and kinesthetic imagery was found to be more effective than visual imagery alone.

Investigations have also demonstrated that mental practice affects respiration, and the cortex. Short (27) found that during actual visualization, visual imagers breathed regularly and showed frequent blocking of Alpha rhythm. Verbal imagers, on the other hand, breathed irregularly with the Alpha rhythm persistent during the period of verbal imagery.

Visual Aspect of Mental Practice

Several investigators have emphasized the visual aspect of instruction in mental practice. Harby (41) utilized motion pictures to stimulate mental activity in his mental practice technique of a free throw skill. He varied the time span of his mental practice periods from seven to twenty-one days and found no gains in the four groups involved in the conceptualizing technique. Garber (45) utilized a loop film of the under hand free throw, shown three times a session, to stimulate conceptulization of the skill for college men. An improvement was shown in skill

execution after fourteen days of mental practice.

Supola (35) employed a some what different method and found that previous observation of mirror drawing without actual motor performance facilitated later execution of the task. In his study the experimental group had ten trials with the right hand on a mirror drawing task followed by observation of a partner carrying out ten trials. This arrangement resulted in superior performance on the test trial compared with the control group which had ten trials with the right hand only with no later opportunity for observation. Gagne (9) investigated the transfer of training to a motor task following varying amounts of preliminary practice on a pictured representation. Although no significant differences between the response scores of the different groups were found on the first ten trials of practice on the motor task, significant differences did appear between these learning scores as the learning continued. In general, the amount of transfer on the thirtieth trial of final learning increased directly with the number of trials of preliminary practice.

Smith and Harrison (28) investigated the effects of motor, visual, reversed visual, mental and guided practice upon speed and accuracy of preformance of a three hole punch board task. The subjects of the groups practiced according to their particular procedures for six periods of ten seconds, after an initial one minute trial. After each of the ten second practice periods, the subjects were required to read for ten seconds making a total time of two minutes. It was concluded that the most significant over-all improvement occurred under the mental practice and visual conditions. Surburg (36) investigated the effects of mental practice in conjunction with audio, visual, and audio-visual instruction in the performance of the forehand drive in tennis. The group engaged in

mental practice showed significant improvement while those with just audio, visual, or audio-visual practice showed no significant improvement. Among the variables of instruction, audio in conjunction with mental practice proved to be the most effective under the conditions of the experiment.

CHAPTER III

METHOD OF PROCEDURE

Selection of Subjects

Subjects for the study were female college students enrolled in physical education at Michigan State University. From 106 volunteers, ten matched pairs of subjects were selected on the basis of their scores on the Surburg adaptation of the Broer-Miller Tennis Test (36), the Iowa-Brace Test of Motor Educability (40), and a modified version of the Gordon Test for Autonomy of Imagery (10).

General Procedure

The subjects were matched on the basis of their scores on the Ioaw-Brace Test of Motor Educability, a modified version of the Gordon Test for Autonomy of Imagery, and the Surburg adaptation of the Broer-Miller Tennis Test which was administered to the subjects on two consecutive days. One member of each pair of subjects was randomly assigned to the experimental group A. Experimental group A was designated as the audio-visual mental practice group while experimental group B was designated as the audio mental practice group. The experimental groups trained according to their particular designation three times a week for a period of six weeks. Following the six week training program the Surburg adaptation of the Broer-Miller Tennis Test was again administered to both groups. A questionnaire was also administered to gain the opinions of the subjects.

Training Program

Following the initial tests for matching purposes, the training program consisted of three practice sessions each week for a period of six weeks. Each group had the practice session divided into two parts: instructional and conceptual. During the instructional phase experimental group A (the audio-visual mental practice group) watched and listened to the forehand drive segment of a sound film on tennis (40). Experimental group B (the audio mental practice group) listened to the sound portion of the film but did not actually view the film during the instructional phase of their practice sessions. During the second portion of each practice session the subjects in both experimental groups closed their eyes and conceptualized twenty-five times all of the movements involved in the execution of the forehand drive. To formalize the actual procedure the following instructions were read each group just prior to their conceptual practice:

> I want you to close your eyes and imagine yourself on a tennis court standing just behind the base line. When you have done this as well as you are able, try to mentally rehearse the routine of bouncing the ball, and then contacting it with the racket on your forehand side. Besides trying to see yourself also try to feel yourself going through the routine. Try to see and feel yourself having your racket back, with your wrist firm and the head of the racket up. Try to see yourself stepping forward as you contact the ball so that your left foot is at the one o'clock position if you were standing in the middle of a large clock. Continue the forward movement with your whole body. Watch the ball as it clears the net and see where it lands on the court. Give the area near the opposite base line your careful attention and in your next drive try to make any adjustments in your actions which you feel will cause the ball to just clear the net and land in that area. Count to yourself each time that you contact the ball mentally until you have completed the entire movement 25 times. Now close your eyes and quietly concentrate.

The subjects were instructed not to think about or to participate in tennis outside of the study. Immediately following the last training session the subjects in both groups were administered the Surburg adaptation

of the Broer-Miller Tennis Test and a questionnaire (See Appendix A).

Analysis of Data

A comparison of the initial and final scores of both experimental groups on the Surburg adaptation of the Broer-Miller Tennis Test was made by a t-Test, a Sign Test, a Chi Square Contigency Test and a Paired t-Test with a two-sided alternative and a level of significance of 0.05. A questionnaire was also administered to obtain the opinions of the subjects on the teaching method used and to provide other pertinent information.

CHAPTER IV

RESULTS

Analysis of Data

A paired t-Test (See Appendix C) indicated that at the 95 percent level of confidence the mean change in experimental group B (the audio mental practice group) was significantly less (t=-2.06) than the mean change in experimental group A (the audio-visual mental practice group). Neither experimental group, however, had a significant difference between means at the .05 level between initial and final tests (See Appendix D and E). Experimental group A had a t score of t=.25 and experimental group B had a t score of 0.00.

Changes in the performance level from the initial test to the final test were as follows: experimental group A +6.5 percent and experimental group B -6.5 percent.

A Chi Square Contigency Test indicated that during the six week experimental period no change occurred which was significant at the .05 level (See Appendix F).

Questionnaire Analysis

Results of a questionnaire (See Appendix A and B) administered to both experimental groups just after their final test, indicated that five of the twenty subjects felt that they were more successful when performing mentally than when performing physically. Seventeen

reported confidence in mental practice as a factor in improving the forehand drive. No one indicated having problems with extraneous practice either mental or physical outside of the regular practice sessions.

Four students, however, indicated that they found problems in practicing mentally. Three of these four were in experimental group B (the audio mental practice group) and they also indicated that they found it difficult to concentrate on the type of presentation which their group received prior to mental practice.

Discussion of Findings

These findings were not statistically significant because of the small sampling and various methodological problems. It is interesting to note, however, the negative results found in experimental group B between initial and final tests. In the research available concerning mental practice, only two other studies have indicated negative results. Trussell (37) first cited an instance when mental practice did not effect an improvement in performance. The fact that her juggling task was not familiar to the subjects was thought to be a variable. In 1965, Corbin (5) conducted a unique study using a wand juggling skill as the criterion task. On the basis of his results he suggested that ". . . mental practice can only be effective if subjects have experience in the task prior to their exposure in practicing mentally (5, p.149). It may have been advantageous, therefore, to have established a minimum skill level as a criterion for selection previous to matching.

Another aspect which must be considered is the fact that the subjects in experimental group B did not have a clear concept of the task to benefit adequately from audio presentation alone. This is emphasized by Cratty (53) who stated that "Although verbal instruction seems most important

during the initial stage of learning, its complexity should not exceed the comprehension limits of the learner. It seems best to keep verbal training to a minimum, especially in learning tasks containing rapid movements. . . A verbal demonstration may be copied. . . only to the extent to which the learner is able to identify with the presentation and see himself in the role of the performer" (53, p.49).

Another factor which could have aided in producing negative results was suggested by Cratty (53). He suggested that "Mental rehearsal may be more facilitating in a task which remains in a stable visual field than one that does not" (53, p.216). They found no difference between groups whose time was occupied in simple noninterfering mental and motor tasks and a group that was permitted to mentally practice a locomotor maze performed while blindfolded.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to compare the effectiveness of mental practice used in conjunction with audio and audio-visual instruction, employing ten matched pairs of subjects, in the performance of the forehand tennis drive. The subjects, 106 volunteer female college students enrolled in Physical Education classes at Michigan State University, were matched on the basis of their scores on the Surburg adaptation of the Broer-Miller Tennis, the Iowa Brace Test of Motor Educability, and the Betts Test of Visual Autonomy. Experimental group A was designated as the audio-visual mental practice group while experimental group B was designated as the audio mental practice group. The experimental groups trained according to their particular designation three times a week for a period of six weeks. Each group had the practice session divided into two parts: instructional and conceptual. Following the six week training program the Surburg adaptation of the Broer-Miller Tennis Test and a questionnaire was administered to both groups.

Results indicated that experimental group A (the audio-visual mental practice group) improved 6.5 percent from the initial test to the final test and experimental group B (the audio mental practice group) declined -6.5 percent. Only one test indicated significant results. A Paired t-Test indicated that at the 95 percent level of confidence the

mean change in experimental group B was significantly less (t=-2.06) than the mean change in experimental group A.

Conclusions

The conclusions which may be drawn from this study are of course limited to the specific task which was undertaken and to the nature and conditions of the the subjects and procedure. Within these limitations the statistical analysis of the experimental groups supports the presentation of the following conclusions:

1. Audio-visual practice used in conjunction with mental practice was superior to audio used in conjunction with mental practice under the conditions of the experiment.

2. Audio used in conjunction with mental practice did seem to cause a decline in performance between initial and final tests.

3. Further research seems warranted in the area of the type of instruction that would be most productive in developing a motor skill prior to the conceptualization session.

Recommendations for Further Research

It is clear that better controlled investigations are needed to confirm or refute the findings already obtained and to extend the knowledge of the type of instruction which is necessary prior to mental practice. For example, additional research could be done in the following areas:

1. Studies are needed which establish optimal mental practice procedures.

2. Further studies are required which establish individual difference factors which may facilitate or inhibit the amount of improvement to be gained from mental practice.

3. The immediate and long range effect of different types of experience prior to mental practice should be explored.

4. Studies are required which establish the nature of the task which can be acquired through mental practice.

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APPENDICES

APPENDIX A

RESULTS OF QUESTIONNAIRE

Experimental Group A
(Audio-visual Mental Practice)

Please read the following questions carefully and place a check in the appropriate column.

		Yes	No
1.	Did you find any problems in practicing mentally?	1	9
2.	Did you practice physically outside of the regular practice sessions?	-	10
3.	Did you practice mentally outside of the regular practice sessions?	-	10
4.	Do you have confidence in mental practice as a factor in improving the forehand drive?	9	1
5.	Do you feel you were more successful when performing mentally than when performing physically?	3	7
6.	Did you find it difficult to concentrate on the presentation which your group received prior to mental practice?	-	10

APPENDIX B

RESULTS OF QUESTIONNAIRE

Experimental Group B
(Visual Mental Practice)

Please read the following questions carefully and place a check in the appropriate column.

		Yes	No
1.	Did you find any problems in practicing mentally?	3	7
2.	Did you practice physically outside of the regular practice sessions?	-	10
3.	Did you practice mentally outside of the regular practice sessions?	-	10
4.	Do you have confidence in mental practice as a factor in improving the forehand drive?	8	2
5.	Do you feel you were more successful when performing mentally than when performing physically?	2	8
6.	Did you find it difficult to concentrate on the presentation which your group received prior to to mental practice?	3	7

APPENDIX C

PAIRED t-TEST

The t-test of the hypothesis that the difference between the mean changes in two normal, dependent subpopulations is equal to, not greater than, or not less than some specified value (δ_o) when nothing is known about the variance of the changes in the two subpopulations.

Assume: One bivariate normal population produced by matching prior to experimental period, having bivariate normal subpopulations produced by testing before (b) and retesting after (a) the experimental period.

To Test: $H_0: \bar{\Delta}_2 - \bar{\Delta}_1 \geq \delta_o = 0$

$H_1: \bar{\Delta}_2 - \bar{\Delta}_1 < \delta_o = 0$

Test Statistic: $$t = \frac{\bar{D}_2 - \bar{D}_1 - \delta_o}{\sqrt{\frac{n\Sigma D_1^2 - (\Sigma D_1)^2 + n\Sigma D_2^2 - (\Sigma D_2)^2 - 2n\Sigma D_1 D_2 + 2\Sigma D_1 \Sigma D_2}{n^2(n-1)}}}$$

Set: $\alpha = .05$ and β and δ such that n=20 is necessary and sufficient.

Draw: A bivariate random sample of n=20, i.e. 20 matched pairs of subjects.

Obtain: $\Sigma D_1 = 3.5 \quad \Sigma D_2 = 0 \quad \Sigma D_1^2 = 362.75 \quad \Sigma D_2^2 = 288$

$\bar{D}_1 = .35 \qquad \bar{D}_2 = 0$

RSD: t with df=n-1=20-1=19

CHR: Reject H_0 for t=2.0930

Compute: $$t = \frac{0 - .35 - 0}{\sqrt{\frac{10(362.75) - 12.25 + 10(288) - 0}{100(9)}}}$$

$$= \frac{-.35}{\sqrt{\frac{3.02}{900}}} = \frac{-.35}{1.7} = -206$$

Conclude: Accept H_o at the .05 level of significance. At the 95 percent level of confidence the mean change in group B was less than the mean change in group A.

APPENDIX D

t-Test

The t-test of the hypothesis that the difference between the means ($\delta = \mu_2 - \mu_1$) of two normal, dependent subpopulations is equal to, not greater than, or not less than some specified value (δ_0) when nothing is known about the variance (σ_1^2 and σ_2^2) of the two subpopulations.

Assums: One bivariate normal subpopulation produced by retesting.
X_1 and X_2 both $\stackrel{d}{=} N(\mu_1, \mu_2, \sigma_1^2, \sigma_2^2, \rho_{12})$
The bivariate sample is random

To Test: $H_0: \mu_2 - \mu_1 \leq \delta_0 = 0$

$H_1: \mu_2 - \mu_1 > \delta_0 = 0$

Test Statistic: $$t = \frac{\bar{X}_2 - \bar{X}_1 - \delta_0}{\sqrt{\frac{n\Sigma D^2 - (\Sigma D)^2}{n^2(n-1)}}}$$

Set: $\alpha = .05$ and β and δ such that $n=10$ is necessary and sufficient.

Draw: A bivariate random sample of $n=10$.

Obtain: $\bar{X}_1 = 17.5 \quad \bar{X}_2 = 18 \quad \Sigma D^2 = 362.75$
$\Sigma D = 3.5$

RSD: t with df=n-1=10-1=9

CRR: Reject H_0 for $t=2.26$

Compute: $$t = \frac{18 - 17.5 - 0}{\sqrt{\frac{10(362.75) - (12.25)}{100(9)}}} = \frac{.5}{\sqrt{\frac{3627.5 - 12.25}{900}}} = \frac{.5}{\sqrt{\frac{3615.25}{900}}} = \frac{.5}{\sqrt{4.01}} = \frac{.5}{2.0} = .25$$

Conclude: Accept H_0 at the 95 percent level of confidence. The difference between means is not significant at the .05 level.

APPENDIX E

t-TEST

The t-test of the hypothesis that the difference between the means ($\delta = \mu_2 - \mu_1$) of two normal, dependent subpopulations is equal to, not greater than, or not less than some specified value (δ_0) when nothing is known about the variance of the two subpopulations.

Assums: One bivariate normal subpopulation produced by retesting.
X_1 and X_2 both $\stackrel{d}{=} N(\mu_1, \mu_2, \sigma_1^2, \sigma_2^2, \rho_{12})$
The bivariate sample is random

To Test: $H_0: \mu_2 - \mu_1 \leq \delta_0 = 0$

$H_1: \mu_2 - \mu_1 > \delta_0 = 0$

Test Statistic: $t = \dfrac{\bar{X}_2 - \bar{X}_1 - \delta_0}{\sqrt{\dfrac{n\Sigma D^2 - (\Sigma D)^2}{n^2(n-1)}}}$

Set: $\alpha = .05$ and β and δ such that n=10 is necessary and sufficient.

Draw: A bivariate random sample of n=10

Obtain: $\bar{X}_1 = 11.8 \quad \bar{X}_2 = 11.8 \quad \Sigma D^2 = 288$
$\Sigma D = 0$

RSD: t with df=n-1=10-1=9

CRR: Reject H_0 for t=2.26

Compute: $\dfrac{11.8 - 11.8 - 0}{\sqrt{\dfrac{10(288) - 0}{100(9)}}} = \dfrac{0}{\sqrt{\dfrac{288}{900}}} = 0$

Conclude: Accept H_0 at the 95 percent level of confidence. The difference between means is not significant at the .05 level.

APPENDIX F

CHI SQUARE CONTIGENCY TEST

The approximate χ^2 test of the hypothesis that the difference between the proportions of "successes" ($\delta = \pi_2 - \pi_1$) in two dependent bimonial subpopulations is equal to, not greater than, or not less than the specified value (δ_0) when $\delta_0 = 0$.

Assume: One bivariate binomial population produced by matching

$X_1 \sim [\pi_1 + (1-\pi_1)]^n$; where $P["success"] = \pi_1$, $P["failure"] = 1-\pi_1$

$X_2 \sim [\pi_2 + (1-\pi_2)]^n$; where $P["success"] = \pi_2$, $P["failure"] = 1-\pi_2$

The bivariate binomial sample is random

To Test: $H_0: \pi_2 - \pi_1 = \delta_0 = 0$

$H_1: \pi_2 - \pi_1 \neq \delta_0 = 0$

Test Statistic: $\chi^2 = \dfrac{(n_{21} - n_{12})^2}{n_{21} + n_{12}}$

Set: $\alpha = .05$ and β and δ such that n=20 is necessary and sufficient.

Draw: A bivariate binomial random sample of n=20

Obtain: $p_1 = .03$ $p_2 = .04$ $n_{11} = 2$ $n_{21} = 1$ $n_{12} = 1$ $n_{22} = 3$

RSD: χ^2 with df=1

CRR: Reject H_0 for $\chi^2 \geq 2.86$

Compute:

Group B \ Group A	Suc.	Fail	Total	P
Suc.	2	1	3	.03
Fail	1	3	4	.04
Total	3	4	7	
P	.03	.04		

$$\chi^2 = \frac{(1-1)^2}{1+1} = \frac{0}{2} = 0$$

Conclude: Accept H_0 at the 95 percent level of confidence. During the six week experimental period no change occurred which was significant at the .05 level.