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A STUDY OF THE EFFECTS OF PACED AUDIO-RHYTHM ON REPETITIVE MOTION

by

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ENGINEERING REPRINT SERIES NO. 75

A Study of the Effects of Paced Audio-Rhythm on Repetitive Motion*

by John A. Conte
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ABSTRACT ■ *The study described was propounded to determine if it is possible to provide a bio-physical driving force that will stimulate the operator in repetitive tasks to work at a rhythm that is comfortable, yet more productive than the rhythm he would normally set for himself. Results of tests revealed that the use of paced audio-rhythm can decrease the average cycle time for repetitive tasks and decrease the variance of the cycle times. The writer concludes that the development of actual applications of paced audio-rhythm in the modern industrial work plant may prove a powerful tool for increased productivity for the operators performing highly repetitive tasks.*

■ The question of how to extract the greatest output from the work plant and worker shall always be present. Answers to this question range from the field of industrial psychology to theories of capital investment. Studies of the interaction of the worker with his physical environment have also provided many answers. The effects of audio sounds upon the worker and his output have been the subject of numerous published articles. Most authors agree with Broadbent and Little (4), "That the rate of work is not improved by noise reduction, except perhaps by a general morale factor, but that at times noise interacted with other job features such as low illumination to reduce the rate of work." As to the matter of music and worker reaction, Roberts (9) concluded that, "When programmed scientifically, music reduces boredom and worker tension" and "For groups, the increase in efficiency has been found to average from five to 20 percent." But, upon extensive search, this author has found few published papers that discuss the effects that a paced rhythm or paced audio-rhythm has upon a repetitive task.

Of the somewhat relevant articles found, only the abstracts are cited below since the complete articles were either unobtainable or of foreign sources.

Gemelli and Galli (6) conducted:

"Experiments on the comparative value of free labor and labor at the conveyor belt, such as used in the Ford factories. They found that there are two categories of working men, a smaller class who prefer free labor and give better results therewith; and a larger class who prefer forced labor. . . . The former become nervous when they have to adapt themselves to the rhythm of a machine; and the latter find automatic work with its enforced rhythm less fatiguing and affording them greater mental freedom."

Bills and Shapin (2) tested the hypothesis:

"Fatigue is usually more rapid in physical than in mental work. This is sometimes attributed to the usual fixed speed of the former, in contrast to the voluntary rate of mental work. To check this view, 30 subjects were tested on naming colors (5 to 15 minute periods) and geometrical forms (15 minute periods). Fatigue was found to be smaller when the pace was set by the apparatus than it was for the voluntary rate. These results are exactly opposite to the hypothesis tested."

Rebentisch (8) deduced:

"Work may be rhythmically regulated in two ways: (a) through continuous timing, as in the assembly belt; or (b), through temporarily given accents, as in rowing. The type and extent of the effect are dependent upon such factors as the nature of the task, magnitude of movements involved, length of work period, and personality and individual tempo of the worker. General conclusions are: (a) The more irregular a movement the greater the initial detrimental effect of rhythm and the greater the subsequential facilitory effect. (b) Rhythmical accent usually makes for poorer work at first, followed by improvement above the regular level. (c) With rhythm the extent of output is increased. (d) The magnitude of movements is in part dependent on the rhythm."

And Düker (5):

"Studied the effect of tempo on quality and amount of work in adding simple figures and doing a simple task consisting of making paper bows according to a definite pattern. Two conditions were used: a free one, where the subject worked according to his own rhythm, and one in which he performed the work to a definite tempo indicated by a sound hammer. Three subjects worked for 10 minutes daily during a period of 16 days. The results and conclusions given are as follows: (a) Rhythm increases efficiency both quantitatively and qualitatively. (b) Rhythm is beneficial, however, only if it is adjusted to an individual's own speed. Any tempo which is too slow or too fast for a particular person is detrimental to his efficiency. (c) A well-adjusted tempo

* *Editor's Note*—Mr. Conte was presented the 1965 AIIE Student Technical Paper Award for this paper. It is hoped that other undergraduate Industrial Engineering students will be encouraged by his success.

Figure 1. Overhead view of work station, showing peg boards, pegs in bin, drop disposal, board guides, and the audio-rhythm pacing device (a metronome). The author and timer are shown checking out the work place in the preparation of the actual testing of subjects.

gives the worker a pleasant feeling. (d) Rhythmic work takes less effort than free work. (e) The greater efficiency during rhythmic work is due to the saving of what Düker terms 'psychic energy'."

As a rule, these studies lack any quantitative statements as to how much productivity can be increased by the use of pacing. In all but one, they lacked the use of audio-rhythm as the pacing device. In the one investigation that did use paced audio-rhythm (5), only three subjects were tested for short (10 minute) working periods. These studies are inconclusive regarding the effects that paced audio-rhythm has upon productivity and thus this study was undertaken.

In repetitive work, the worker, through the learning process, develops a natural rhythm of his own for the specific task. The repeated motions of the entire work cycle aid in acquiring rhythm (7). Such a rhythm is essential to the smooth and automatic performance of such a task and enables the worker to achieve automatic performance without mental effort (1).

In certain work situations, the rhythm of the repetitive operation is paced or predetermined by mechanical considerations, and thus the worker is forced to work with a rhythm relative to his machine. An example might be a hand-fed printing press or a repeating forge. The operator in such a situation may produce more per day because the machine has taught him to work with a rhythm that is faster than the rhythm he might have learned on his own. The worker is still comfortable, working without mental effort, and producing more for the company and possibly earning more for himself, because the machine has taught him a rhythm of automatic performance that is faster and more efficient than the rhythm he would have normally set for himself.

But, is it possible to provide a biophysical driving force, in tasks that are not mechanically controlled, that will stimulate the operator to work at a rhythm that is comfortable, yet more productive than the rhythm he would normally set for himself?

The objective of this investigation is to answer this question in part, by testing the hypothesis that: Paced audio-rhythm has no effect upon the rate of production for highly repetitive tasks. This would imply that a worker's natural rhythm is just as productive as an outside induced audio-rhythm.

Procedure

To test the hypothesis, a very repetitive task was selected and cycle times were collected for each subject under two separate conditions—working without and with paced audio-rhythm.

The repetitive task used in making the test was the placing of wooden pegs in a peg board. The design of the pegs and boards, and the simultaneous symmetrical method used in filling the boards, were very similar to those used by Barnes (1), and are shown in Figure 1.

The work station, for the task, was set up in such a way that the task operated continuously. After the completion of one board, only one additional therblig, consistent with the rhythm, was needed to remove the completed board to the side and move another in place and continue with the task. Complete descriptions of the task method and the design of the work station, boards, and pegs are in Appendices A and C, respectively.

The paced audio-rhythm, used in this study was produced by a metronome. The worker, when working with the metronome, was instructed as follows:

1. While learning the rhythm, to count to himself rhythmically with the beats of the metronome.
2. To grasp a peg on one beat and to insert it in the board on the next.

In this way, the beats of the metronome accented the grasp and insert while the unaccented times were occupied with the elementary elements of reach, move, and position. When working without the paced audio-rhythm, the worker was discouraged from counting to himself.

For the test, 10 subjects were chosen. All were male students of the University of Missouri at Columbia.

Their age range was 18–26 years. They worked a total of two hours each, divided into one hour with and one hour without the paced audio-rhythm. A 10 minute break was taken between the two hours, with a five minute break halfway within each hour.

Since only one variable was to be tested, namely completion rate with and without audio-rhythm, the following variables were held constant.

Learning

The 10 subjects were divided into two equal groups. Those in Group I worked the first hour using their own natural pace and the second hour they worked using the paced audio-rhythm. With those in Group II, the order of the two tasks was reversed, the first hour they worked using the paced audio-rhythm and the second hour they worked using their own natural pace. Dividing of the subjects into these two groups was done in order to eliminate the effect of practice as the operator proceeded from one condition to the other.

By the "snap-back stop watch time study method," continuous recordings of each cycle time were collected. This was done to determine when the subject had effectively reached the stable level of his learning curve for each specific task.

Accuracy

The subjects were asked to insert the rounded end of the peg in the board. They were also instructed that if a mistake was made (that is, rounded-end up), they were to ignore it and proceed with the task. Most of the subjects completed the task with an average accuracy of 95–100 percent, although one or two were notoriously poor. But, no matter what the accuracy on the first hour of work, the subjects were instructed and corrected, when necessary, to achieve approximately the same accuracy the second hour as they had the first.

Effort

When working without the paced audio-rhythm, the subjects were asked to work "at a rate they would normally set for themselves," as if they were being paid on an incentive basis. When working with the paced audio-rhythm, a beat was selected within the first five minutes that was slightly difficult at first to master, but could be reasonably mastered within the first half hour. This beat normally ranged between 84 and 92 beats per minute for this specific task, and produced a rhythm which was approximately 10 percent faster than the natural rhythm used by most subjects.

Results

For each hour test, it was found that all learning effects were minimized within the first 30 minutes. The data upon which the results are based are the mean of the last 30 cycle times. In general, this was the last 15 minutes of each hour test. This gave each subject at least 45 minutes of practice on each task before data were collected to give his mean cycle time for working both without and with the paced audio-rhythm.

Table 1 (a). **Table 1 (b).**

Group I and Group II Taken as a Whole.

Mean time without (wo)	.416
Mean time with (w)	.358
Mean of difference ($wo-w$)	.056

Subject	$\overline{wo}$	$\overline{w}$	$\overline{wo}-\overline{w}$	Subject	$\overline{wo}$	$\overline{w}$	$\overline{wo}-\overline{w}$
Group I				Group II			
1	.421	.353	.068	3	.410	.354	.056
2	.408	.354	.054	4	.427	.380	.047
5	.383	.364	.019	6	.453	.359	.074
7	.377	.352	.025	8	.424	.364	.060
9	.408	.349	.059	10	.451	.354	.097
Mean of ($\overline{wo}-\overline{w}$) .045				Mean of ($\overline{wo}-\overline{w}$) .067			

In Tables 1 (a), and 1 (b), are given the mean cycle times for each subject working both without ($\overline{wo}$) and with ($\overline{w}$) the paced audio-rhythm, and the difference between the two means ($\overline{wo}-\overline{w}$). The subjects in Group I, who worked the first hour using their own natural incentive pace, are represented in Table 1(a), and the subjects of Group II, who worked the first hour using the paced audio-rhythm, are represented in Table 1(b).

Since all subjects had lower mean cycle times when working with the paced audio-rhythm, all differences ($\overline{wo}-\overline{w}$) were positive. Throughout the rest of the article, these differences in the means ($\overline{wo}-\overline{w}$) will be known as the "decreases."

Although the raw data show a mean decrease of .045 minutes for Group I, and .067 minutes for Group II, a statistical "t" test of the difference (see Appendix D) was not significant at the five percent level. Hence the sample population of the two groups can be considered as one. A confidence interval for the mean of these 10 decreases can be computed (see Appendix E), assuming that the 10 sample decreases were independent, normally distributed, random variables. Treated as a whole, the 10 decreases had a sample mean of .056 minutes. The computed 95 percent confidence interval for the decreases of the 10 subjects tested was $.056 \pm .016$ minutes. This represents a decrease in the mean cycle time of nine to 17 percent, when the paced audio-rhythm was used, and set approximately 10 percent faster than the subject's natural pace. The subjects expressed a decided preference for working with the paced audio-rhythm. Reasons given were:

1. "It seemed easier."
2. "It seemed less tiring."
3. "You did not have to concentrate on the task as much."
4. "You could think about other things when working."

One or two of the subjects, the same subjects who had the poorest accuracy, disliked the paced audio-rhythm, "because it was very frustrating." The most common comment of all was the expression of dislike for the

Table 2

Values of Variance Given in 10^{-4} Minutes

Subject	S_{wo}^2	S_w^2
1	4.53	.82
2	1.63	.38
3	.75	.25
4	1.06	.17
5	1.06	.25
6	4.16	.30
7	3.13	1.13
8	1.63	1.07
9	.81	.16
10	.65	.24
Pooled	1.94	.48

repetitive task under both conditions—"I would sure hate to do this for a living."

In Table 2 are listed the sample variances for each subject, computed from the same 30 cycle times which were used to compute the mean cycle times. Two sample variances for each subject are given, one for working without (S^2_{wo}) and one for working with (S^2_w) the paced audio-rhythm.

Since the paced audio-rhythm reduced the sample variance for each of the 10 individuals tested, a statistical "F" test was used (see Appendix F) to test the null hypothesis that there was no significant reduction in the pooled variance for each of the two conditions. This test resulted in the rejecting of the null hypothesis and the accepting of the alternative hypothesis that, at the five percent level of significance, there is a significant decrease in variance in cycle times when the subjects used the paced audio-rhythm.

Summary

This study was propounded in an effort to answer more fully the question: Is it possible to provide a biophysical driving force that will stimulate the operator, in repetitive tasks, to work at a rhythm that is comfortable, yet more productive than the rhythm he would normally set for himself? This was done by testing the hypothesis: Paced audio-rhythm has no effect upon the rate of production for highly repetitive tasks. This would imply that a worker's natural rhythm is just as productive as an outside induced audio-rhythm. The hypothesis was rejected.

The objective results of this study revealed, with 95 percent confidence, that use of paced audio-rhythm can:

1. Decrease the average cycle time by nine to 17 percent for such a repetitive task tested.
2. Decrease the variance of cycle times.

It was also found that most, but certainly not all, subjects expressed preference for working with the paced audio-rhythm because it afforded them greater mental freedom and seemed less fatiguing.

The author also found that he was able to agree subjectively with the conclusions expressed by those authors cited at the beginning of this study.

Based upon the results of this study and those cited, it appears that sufficient research has been performed to justify considering the extension of these results to the industrial environment, perhaps on a pilot-study basis initially. Ultimately, paced audio-rhythm may prove a powerful tool for increasing the productivity for operators of highly repetitive tasks.

Appendix A—Detailed Task Method

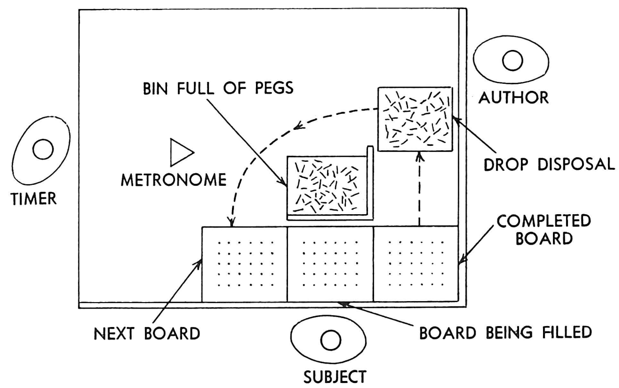
The subjects were instructed as follows: "Simultaneously grasp one peg in each hand from the bin and insert them in the top two center holes with the rounded ends down. In the same manner, continue to complete the center rows, then the next outer rows, and then finally the two most outer rows. Holes are always to be filled two at a time, from the bin toward yourself, center rows first and outermost rows last. After completion of the board, two more pegs are to be grasped and placed in the two top center holes in the next board, which is just to the left of the completed board. While still holding on to these two pegs, you are to move the board to the right and directly in front of you. All that will be needed to move this next board in place will be this move to the right, since the boards are restricted to only right and left movements by the guides. When this next board is moved directly in front of you, the completed board will also be moved to the right and out of the way. I will have the responsibility of removing the completed boards from your right and assuring that the next board is in its proper place to your left. You are to fill the boards in this continuous manner until you either wish to ask a question or are instructed to stop by either the timer or myself."

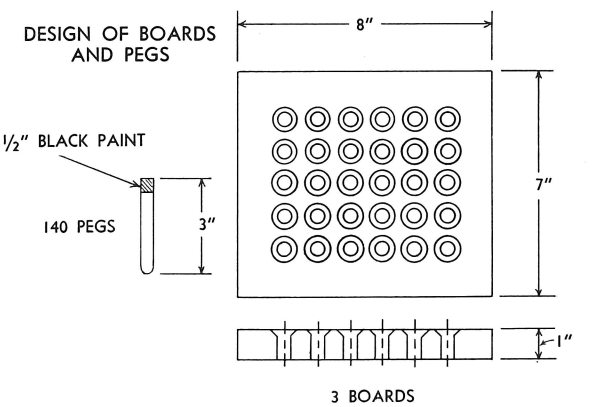
The timer was instructed as follows: "Record continuous readings of the time needed to complete each board by the subject. You will do this with a stop watch by the snap back time study method. You will also indicate to the subject when it is time for a rest period. To indicate when a cycle time is not representative, I will tell you when a cycle time should be starred. Such cycles will be those in which the subject runs out of pegs, uses an incorrect method, or is stopped for a correction. Those will usually occur within the first half hour, while the subject is learning the task."

The author was responsible for: Assuring that the next board was in place and that the completed board was removed, and emptied by use of the drop disposal; assuring that enough pegs were available in the bin by taking the pegs from the drop disposal, an open box whose bottom was less than six inches below the table top, and placing them in the bin when needed; and also for instructing and correcting the subject for errors in method or accuracy.

Appendix C

LAYOUT OF WORK STATION





Appendix D—"t" test for Equality of Means

A test of the hypothesis that the means of two normal distributions are equal.

Assumptions

1. The decreases $(\overline{wo}-\overline{w})$ of the subjects in both Groups I and II are normally distributed with means (μ_I and μ_{II} respectively) and a variance σ^2.
2. The sample means of the decreases for Groups I and II ($\overline{X}_I$ and $\overline{X}_{II}$ respectively) are estimates of the unknown population means, μ_I and μ_{II}.
3. The sample variances of the decreases for Groups I and II (S_I^2 and S_{II}^2 respectively) are each estimates of the unknown population variance σ^2.

H_0: $\mu_I = \mu_{II}$
H_A: $\mu_I \neq \mu_{II}$

Level of Significance

$$\alpha = .05$$

Test Statistic

$$t = \frac{|\overline{X}_I - \overline{X}_{II}|}{\hat{S}\sqrt{1/n_I + 1/n_{II}}}$$

Critical Region

Reject H_0: when $t_{cal} > t_{.025},\ n_I + n_{II} - 2$

$t_{cal} > t_{.025},\ 8$

$t_{cal} > 2.30$

Accept H_0: when $t_{cal} < 2.30$

Data Given

$$n_I = n_{II} = 5$$
$$S_I^2 = 4.50 \times 10^{-4}\ \text{min.}^2$$
$$S_{II}^2 = 3.85 \times 10^{-4}\ \text{min.}^2$$
$$\hat{S}^2 = \frac{(n_I - 1)S_I^2 + (n_{II} - 1)S_{II}^2}{n_I + n_{II} - 2}$$
$$\hat{S}^2 = 4.30 \times 10^{-4}, \qquad \hat{S} = 2.08 \times 10^{-2}$$
$$\overline{X}_I = 4.76 \times 10^{-2}, \qquad \overline{X}_{II} = 6.69 \times 10^{-2}$$
$$|\overline{X}_I - \overline{X}_{II}| = 2.19 \times 10^{-2}$$

Computation

$$t = \frac{2.19 \times 10^{-2}}{(2.08 \times 10^{-2})\sqrt{.4}} = 1.66$$

Therefore: Since $2.03 > 1.66$, accept $H_0: \mu_I = \mu_{II}$

Conclusion

Since the population means of the decreases of the two groups are the same, the five decreases in each group can be considered as coming from one homogenous sample.

Appendix E—"t" test for Confidence Interval

Computation of a confidence interval for the mean of a normal distribution when the population variance is unknown.

Assumptions

1. The decreases $(\overline{wo}-\overline{w})$ of the 10 subjects tested are normally distributed with a mean, μ, and a variance σ^2.
2. The mean $(\hat{\bar{x}})$ of the 10 decreases is an estimate of the unknown population mean (μ) of the decreases.
3. The sample variance (S^2) of the 10 decreases is an estimate of the population variance of the decreases.

Level of Significance

$$\alpha = .05$$

Statistic

$$CI = \overline{X} \pm (t_{.025},\ n - 1\ \text{d.f.})\sqrt{\frac{S^2}{n}}$$

Subject # 6 Mike Sarno　　　　Date 2/11/65

First Hour with metronome　　　　Second Hour without metronome

Time	Cycle Time	Time	Cycle Time	Time	Cycle Time	Time	Cycle Time
3:50	.46		.38		10 min rest	5:40	.48
	.48		.38	5:05	.46		.48
	.50		.38		.47		.47
	.45		.39		.46		.49
	.45		.38		.45		.43
	.42		.38		.46		.47
	.45		.38		.46		.45
	.42		.37		.47		.45
	.43		.38		.46		.46
	.43		.38		.45		.47
	.43		.37		.44		.39
	.43		.39		.44		.41
	.44		.38		.45		.43
	.43		.38		.45		30 .38
	.42		.37		.46		.43
	.43		.38		.45		.45
	.42		.38		.45		.41
	.40		.39		.45		.42
	.43		.38		.46		.44
	.42		30 .38		.45		.44
	.45		.38		.41		.46
	.42		.38		.46		.46
	.43		.38		.42		.45
	.42		.38		.41		.46
	.43		.38		.45		.44
	.43		.37		.46		.45
	.43		.38		.48		.44
	.40		.38		.45		.45
	.42		.37		.48		~~.51*~~
	.41		.37		.47		.47
	.42		.38		.48		.47
	.41		.38		.46		.46
	.41		.39		.46		.47
	.43		.38		.46		.46
	.40		.38		.47		.48
	.40		.38		.45		.48
	.40		.37		.45		.47
	.40		.37		.47		.46
	.39		.38		.46		.47
	.40		.38		.48		.46
	.41		.39		.48		.47
4:20	.43		.38		.48		.46
	5 min. rest		.37		.48		.47
4:25	.41		.38	5:35	.47	6:10	.46
	.40		.38		5 min rest		stop
	.40		.38				
	.39		.38				
	.38		.38				
	.38	4:55	.39				

almost 100% accuracy both hours
preferred working with metronome—
"more mental freedom"

Data Given

$\overline{X}$ = Mean of the 10 $(\bar{w}o - \bar{w}) = 5.60 \times 10^{-2}$ min.
S^2 = Variance of the 10 $(\bar{w}o - \bar{w}) = 5.16 \times 10^{-4}$ min.^{2}
$n = 10$

$$t_{.025}, n-1 \text{ d.f.} = t_{.025}, 9 \text{ d.f.} = 2.26$$

Computation

$$CI = \left(5.60 \pm 2.62\sqrt{\frac{5.16}{10}}\right) \times 10^{-2} \text{ min.}$$
$$= (5.60 \pm 1.62) \times 10^{-2} \text{ min.}$$

Therefore:

The 95 percent confidence interval of the unknown mean μ is equal to

$$.056 \pm .016 \text{ min.}$$

Conclusion

The 95 percent confidence interval of the mean decrease is $.056 \pm .016$ minutes. Comparing this interval with the mean of the 10 mean cycle times, collected when the subjects did not use the paced audio rhythm, (.416 minutes), results in a reduction of the mean cycle time by nine to 17 percent.

Appendix F—"F" test for Equality of Variance

A test of the hypothesis that the population variances of two normal distributions are equal.

Assumptions

1. The sample variances of the mean cycle times, $\overline{wo}$, are normally distributed and the population variance σ_{wo}^2, is estimated by, S_{wo}^2, the mean of the 10 sample variances of $\overline{wo}$.

2. The sample variances of the mean cycle times, $\bar{w}$, are normally distributed and the population variance, σ_w^2 is estimated by, S_w^2, the mean of the 10 sample variances of $\bar{w}$.

H_0: $\sigma_{wo}^2 = \sigma_w^2$
H_A: $\sigma_{wo}^2 > \sigma_w^2$

Level of Significance

$$\alpha = .05$$

Test Statistic

$$F = \frac{S_{wo}^2}{S_w^2}$$

Critical Region

Reject H_0: when $F_{\text{cal}} \geq F_{.05}, n_{wo} - 1, n_w - 1$
$F_{\text{cal}} \geq F_{.05}, 9, 9,$
$F_{\text{cal}} \geq 3.18$

Accept H_0: when $F_{\text{cal}} < 3.18$

Data Given

$$n_{wo} = 10 \qquad n_w = 10$$
$$S_{wo}^2 = 1.94 \times 10^{-4} \text{ min.}^2$$
$$S_w^2 = .48 \times 10^{-4} \text{ min.}^2$$

Computation

$$F = \frac{1.94 \times 10^{-4} \text{ min.}^2}{.48 \times 10^{-4} \text{ min.}^2} = 4.04$$

Therefore: Since $4.04 > 3.18$, reject H_0: and accept H_A: that $\sigma_{wo}^2 > \sigma_w^2$

Conclusion

The variance of cycle times is significantly reduced when the worker uses paced audio-rhythm.

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