THE EFFECTS OF COMBINED ENVIRONMENTAL FACTORS ON HUMAN PERFORMANCE OF A MANUAL TASK: NOISE AND TEMPERATURE

RESEARCH REPORT

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By

Robert P. Lewis

Approved by

Dr. Newton C. Ellis
Chairman

Dr. R. D. Huchingson

Dr. P. N. Hale, Jr.

Dr. J. M. Elliott

Texas A&M University
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This study was done while under contract with the U. S. Army Materiel Command. It is hoped that it will be useful in the the area of maintainability engineering and, in particular, in relation to the problems of maintainability analysis and prediction.

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In this paper, the effects of two environmental factors, noise and temperature, upon human performance of a simple, well-learned manual dexterity task were examined. The experimental design was a 2x2 factorial, using twelve subjects. The data obtained from scores on a Purdue Pegboard task were analyzed in a randomized block, by means of an analysis of variance. Results indicated that temperature had a significant effect on performance, while noise and the temperature x noise interaction did not.

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CHAPTER I

INTRODUCTION

Two areas of system design which have come under close consideration in the last decade or so are maintainability and human factors. Hardly considered before World War II, both of these areas now play an important part in the design of new systems and equipment, particularly in the field of defense. The United States Army now has extensive guidelines and requirements in both areas which are part of practically all the contracts it lets. Maintainability is a characteristic of system design and operation, which can be expressed as the probability that an item will be retained in, or restored to a specified operational state within a certain time period, when maintenance is performed according to specified procedures and resources. More commonly, however, it is easier to express maintainability in terms of the mean time to repair (MTTR) of a system or equipment, since a probability density function is not always obtainable. Human factors is the study of man's part in the system and must be considered in order to assure that the system does not exceed the capabilities of man to operate or maintain it, for no matter how capable or maintainable a system may seem on paper, it can perform no better, nor be repaired any faster than the men available allow. Unfortunately, there is no easy index for the human factors considerations of a system, therefore, additional care must be taken to assure that good human engineering principles are observed in the design of systems and equipment.

Obviously, the areas of human factors and maintainability overlap. Human factors engineers must be concerned with the maintenance as well as the operational aspects of a system and maintainability engineers must consider the maintenance man when designing for maintainability and must be familiar with human engineering problems and principles. A particularly significant example in which human factors and maintainability overlap is the problem of a maintenance man in the field attempting to effect either preventive maintenance or active repair on a piece of equipment in an environment which is somewhat less than optimal, either with respect to one factor, or a combination of factors. It is the purpose of this paper to consider such a problem, namely: what is the effect of environmental factors such as temperature and noise on the performance of a psychomotor task? What are the effects of these factors taken individually and what is their combined effect on human performance?

Two levels of temperature and noise were studied; these will be discussed in Chapter II. Chapter III will present the experimental design and procedure, and Chapters IV and

V will give a discussion of the results and some conclusions and recommendations.

CHAPTER II

LITERATURE SURVEY

The levels of temperature and noise selected for this study were 75°F. and 55°F. and 55 and 95 decibels* respectively. The following paragraphs provide the background and rationale for selecting these levels.

Noise

The experimental literature concerning the effects of noise on human performance is extensive although some research is somewhat contradictory. There are few experiments reported which were concerned with the interaction of noise with other environmental factors. Among the more notable reports considering noise alone is one by Schoenberger and Harris (18)** in which psychomotor performance was evaluated under four noise conditions ranging from quiet to 110 decibels. The general hypothesis of their study was that high noise levels produce decrements in learning performance. The results only partially supported the hypothesis and an

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*All intensity values are given in decibels of sound pressure, reference 0.0002 dynes/cm2.

**Numbers in parantheses refer to numbered references in the List of References.

interaction effect between noise levels and test sessions caused the authors to conclude that the phenomenon of performance decrement did not occur uniformly throughout the course of learning, and probably is of lesser importance for well-learned tasks. Another report on noise by Broadbent and Burns (2), states that "noise does not usually reduce the speed with which work is carried out, but rather increases the number of mistakes (p. 11)." Still another article by Chapanis (3) indicates that noise serves more as a fatiguing factor than as a detrimental influence on performance of simple, well-learned tasks. In other words, persons merely expend more energy in maintaining constant performance. From these references it can be seen that there is no universal effect of noise on performance. For one thing, it is difficult to control the factor of suggestion. Subjects may believe that when the work environment has been made quieter, they ought to be able to work faster and so do. This may or may not indicate any genuine effect on performance of a noisy environment. The opposite effect is also possible in which subjects perform better in a noisy environment, because they feel they should.

Perhaps the only conclusion one can reach from reading reviews of the effects of noise on human performance is that there are effects. Whether these effects are detrimental or facilitative (or both), how they are related to intensity or frequency, what changes occur over time, etc., remain largely undetermined.

The choice of type and level of noise to be used in this experiment was somewhat difficult. The first decision made was to use ambient noise as the normal level and a high intensity noise as the adverse level. Although it has been shown by Fornwalt (9) that noise of random periodicity and by Broadbent (1) that noise of high frequency are more detrimental in their effect on performance, it was decided to use constant, broadband random (white) noise to present a more uniform, more easily controllable noise environment. Schoenberger and Harris (18) used white noise in their experiment, as have several others (6), because noise of this type contains all frequencies up to a specified maximum (20,000 hz.) at a fairly constant intensity. White noise can thus be used as an easily reproducible, readily available noise source, without concern for periodicity or spectrum. The ambient noise level was around 55 decibels and the high noise level chosen was 95 decibels. This level was felt to be the highest allowable level for white noise with frequencies up to 20,000 hz. to insure no temporary or permanent threshold shifts which might interfere with test results.

It was mentioned earlier that only a few references were found to include investigation of a combination of noise with another environmental factor. Three of these reports by Dean (5), Lewis (12), and Loeb (13) were concerned with noise and vibration. In these, as in the references on noise alone, the results were inconsistent but it was found, generally, that noise had no effect other than as a fatiguing factor.

Two reports were found which considered noise and temperature. In both these reports white noise was used at several intensity levels ranging from 72 to 92 decibels by Viteles (21) and 70 to 110 decibels by Dean (4). Temperature was varied from 73°F. to 94°F. in Viteles' experiment and from 70°F. to 110°F. in Dean's. The results of these two investigations were conflicting in that Viteles reported an adverse effect on performance at high temperature, with no noise effect, while Dean reported no effect of temperature or noise on performance. This difference may be due to the fact that in the former experiment, the tasks were: discrimination tests, mental multiplication, number checking and code and location tests, while in the latter, the tasks were merely tracking and monitoring. This paper differs from both these reports in that low temperature, rather than high, was used as the adverse level, as will be seen in the next section on temperature.

Two additional references were found in which temperature, noise, and vibration and their combined effects were studied by Dean (6) and Loeb (15). Here again, results differed and, unlike the problem presented in this paper, high temperature effects were investigated rather than low temperature effects.

Temperature

A major decision which was encountered during the early stages of research was the question concerning which side of the so-called "comfort zone" should be used for the adverse temperature portion of the experiment. Would low or high temperatures be more effective in obtaining experimental results? An experimental constraint which influenced this decision was the capability of the Human Factors Environmental Chamber at Texas A&M University where the experiment was performed. The chamber had a practical temperature range from approximately 30°to 100°F. Thus, any temperature or range of temperature used in the experiment was required to lie within this constraint.

The results of an initial survey of previous experimentation indicated that the physiological and psychomotor responses were not significantly affected by exposure to seemingly intolerable hot environments. Forlando (8) found no decrement in reaction time of subjects after six hours of exposure at temperatures in the range of 120°F. dry bulb. Loeb and Jeantheau (14) observed no loss in performance on a task of monitoring twenty dials over a three hour period when exposed to temperatures from 110°F. to 125°F. dry bulb.

The bulk of the sources which were investigated seemed to substantiate the concept that the extremities of man are especially subject to the effects of a cold environment. Teichner and Wehrkamp (20) experimentally confirmed that subjects exposed to a temperature of 55°F. produced poorer visual-motor performance than when tested at 85°F. In general, experiments indicated that motor performance requiring manual dexterity in comparatively intricate manipulations suffers a marked loss in efficiency due to the effects of exposure to cold (19).

After consideration was given to such factors as degree of decrement, laboratory limitations, and subject inconvenience, the decision was made to perform the adverse temperature portion of the total experiment using chamber temperatures in the vicinity of 50°F. The ambient temperature of 75°F. was used for the remaining portions of the experiment. No attempt could be made to control the relative humidity of the experiment since precise humidity regulation was not available in the chamber.

Once the decision concerning the temperature level was made, some of the theories as to why decrements in dexterity occur were investigated. It was found that when a person's environment cools, and he needs to conserve heat, the blood vessels constrict in the extremities. In addition, if the cold becomes extreme, reflex shivering occurs which increases the basal metabolic rate (17). Stiffness of the fingers results due to the friction created by the increased viscosity of synovial fluid, the "lubricant" of the joints (11). These factors, plus the following responses formulated by Mills (16), give the probable causes of impaired performance as a direct result of cold temperatures:

1. Tactile sensitivity of the finger-tip decreases when exposed to cold.

2. Sensory information necessary for the accurate control of finger movements may not be available.

3. Where extreme cold is encountered, pain has a disruptive effect on sensor-motor coordination.

4. Detrimental changes in the strength of responses in the hand also result.

Thus it was felt that temperature levels of $75^{o}$and 50^{o}F. would be suitable for use in this experiment.

The design and procedure used in the experiment will be presented in the next chapter.

CHAPTER III

EXPERIMENTAL DESIGN AND PROCEDURE

Design of the Experiment

The experiment used for this problem was of a 2x2 (or 2^2) factorial design, that is, two factors were considered, each at two levels. The factors were noise, at levels of 55 and 95 decibels, and temperature, at levels of 75°and 50°F., as indicated in the previous chapter. Twelve subjects participated twice in each of the 4 factorial experimental conditions yielding 96 data points. Because of a restriction on the time required to change the temperature in the test environment, it was necessary to take all the data points for one temperature at a time, thus precluding complete randomization of the order in which the data was taken. Therefore, it was necessary to give each subject sufficient practice to insure that learning would not be confused with temperature effects in the results (7). Also, it was necessary to randomize the order in which the experiment was run within subjects, since otherwise each subject would have to have been present the entire time that the experiment was being run, which was impractical. This was taken into account in the model, how ever. The model for this experiment was as follows:

$$X_{ijkm} = u + T_i + N_j + TN_{ij} + S_k + TS_{ik} + NS_{jk} + TNS_{ijk} + e_{m(ijk)}.$$

Where:

X_{ijkm} is the measured variable

u is a common effect in all observations

T_i is the effect due to temperature, $i = 0,1$

N_j is the effect due to noise, $j = 0,1$

S_k is the subject effect, $k = 1,2...,12$

$e_{m(ijk)}$ is the error term, $m = 1,2$, which is assumed to be independent and normally distributed with zero mean and variance σ_e^2.

The other terms represent various interaction effects. The hypotheses being tested were:

H_1: $T_i = 0$ for $i = 0,1$.

H_2: $N_j = 0$ for $j = 0,1$.

H_3: $TN_{ij} = 0$ for $i = 0,1$ and $j = 0,1$.

If any of these hypotheses were rejected by an analysis of variance, it could be concluded that there was a significant effect due to temperature, noise, or an interaction of the two. The significance level used was five percent.

Equipment

A General Radio random noise generator (Type 1390-B) was used for the noise source. The output was fed into a McIntosh amplifier (Model 240) which drove a Knight loudspeaker in the test chamber. Sound level readings were made with a General Radio 1551-C Sound Level Meter.

Performance Measure

The task used to measure a subject's performance in this experiment consisted of arranging pegs, washers, and sleeves in a certain configuration on a standard Purdue Pegboard (see Figure 1). Subjects were allowed to use both hands and were given specific instructions on the method of assembly (7). The task was to place a peg in an appropriate hole, place a washer, then a sleeve, then another washer on the peg, then move on to another hole. The pattern of holes to be filled alternated from left to right, filling every other hole on the left and filling every third hole on the right (see Figure 2). The score was taken to be the number of correctly assembled parts within the experimental period of one minute. The number of errors made was not analyzed, since subjects either made no errors or corrected them.

Experimental Procedure

This experiment was performed in the Human Factors Environmental Chamber in the Industrial Engineering Department of Texas A&M University. The subject wearing short sleeves was seated in the chamber at a table on which were the Purdue Pegboard, the Knight loudspeaker, and a small red light (see Figure 3). The small red light, at the upper right hand corner of the pegboard, served as a start-stop

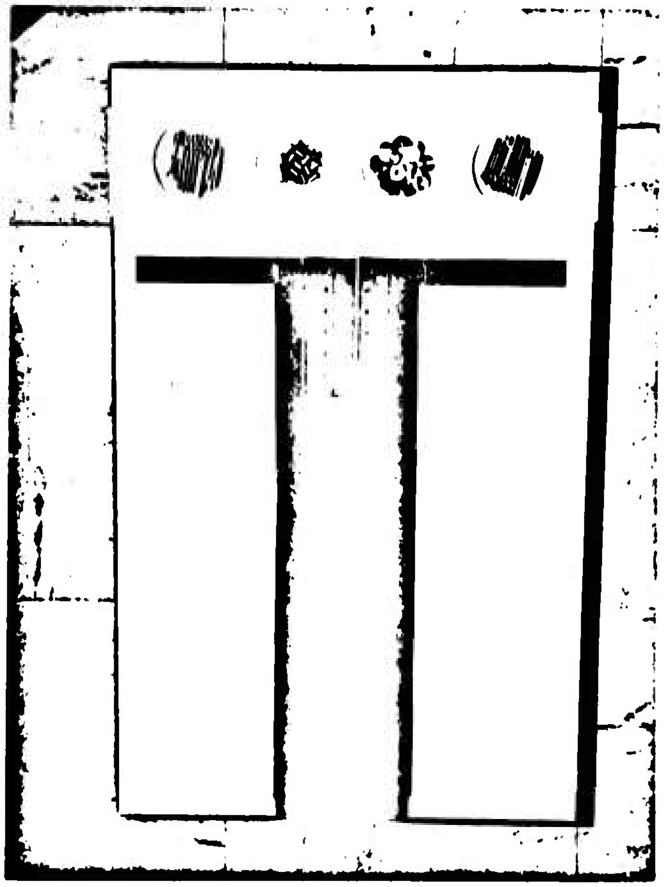

Figure 1

Purdue Pegboard

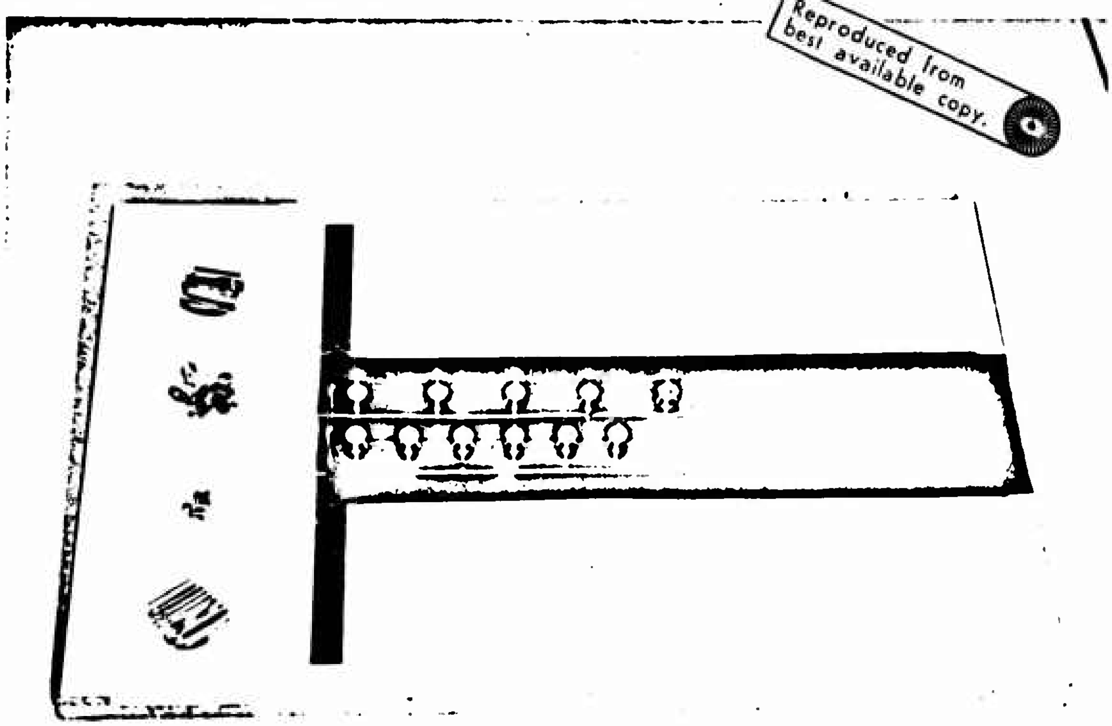

Figure 2

Proper Arrangement of Pegboard

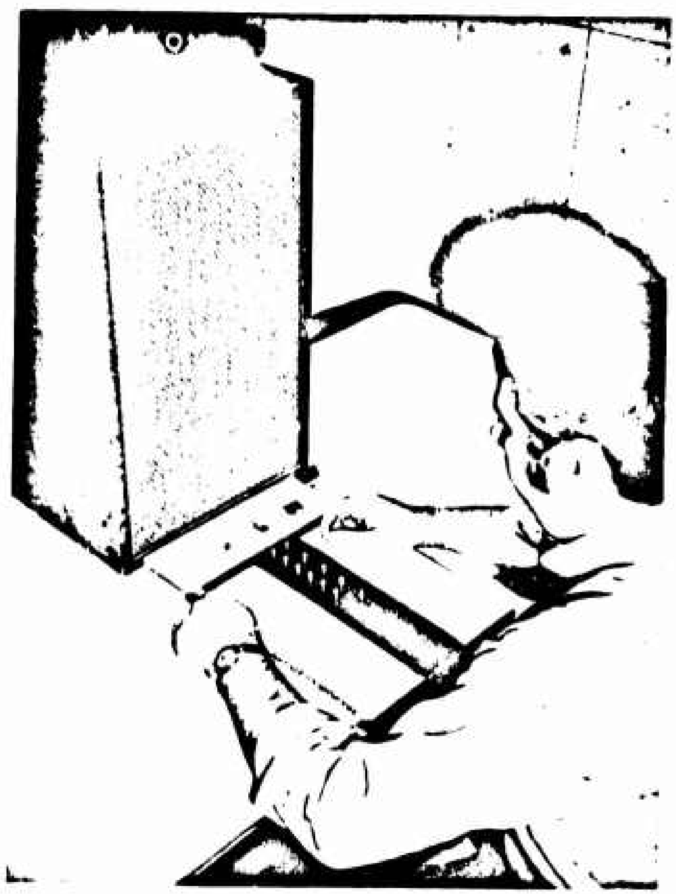

Figure 3

Equipment Configuration on Test Table

signal. The subject was instructed to start when the light flashed and stop when it came on again. The subject started with his bare arms resting on the table, on either side of the pegboard, and stopped immediately when the red light relit. After preliminary instructions, each subject was given nine trial runs, each one minute long, before data was recorded. The first session was the control temperature, 75°F. The subject was started and stopped one minute later by the signal, his score was taken, the pegboard disassembled, the subject rereadied, the noise level set appropriately, and the procedure repeated until all four runs were completed for each of the twelve subjects. The second session was the adverse temperature level, 50°F. Each subject was given one trial run and the procedure above repeated.

In the next chapter, the results derived from the data obtained will be presented, along with a discussion of the results.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the analysis of variance of the data obtained from the experiment is summarized in Table 1. The following paragraphs discuss these results and their implications.

Temperature

As can be seen from Table 1, the F value for the temperature effect is significant at the one percent level and therefore also at the five percent level. This implies that the hypothesis: H_1: $T_i = 0$ for $i = 0,1$ must be rejected, and it can be concluded that the temperature level did affect performance of the task. Figure 4, a plot of mean score versus noise level, shows that the mean score values were lower at 50^{o}F. than at 75^{o}F., so it can be stated that the lower level of temperature adversely affected performance. This is in agreement with the studies listed in Chapter II.

Noise

The F value for the noise effect was not found to be significant at the five percent level, and the hypothesis: H_2: $N_j = 0$ for $j = 0,1$ cannot be rejected. It therefore

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value
T	1	157.59	157.59	10.17*
N	1	1.76	1.76	< 1
TN	1	3.76	3.76	< 1
S	11	1557.78	141.62	9.14*
TS	11	107.03	9.73	< 1
NS	11	52.86	4.81	< 1
TNS	11	61.87	5.62	< 1
error(e)	48	743.50	15.49	
Total	95	2686.15		

* significant at $\alpha = 0.01$

T- Temperature

N- Noise

S- Subjects

Table 1

Analysis of Variance

(ANOVA) Table

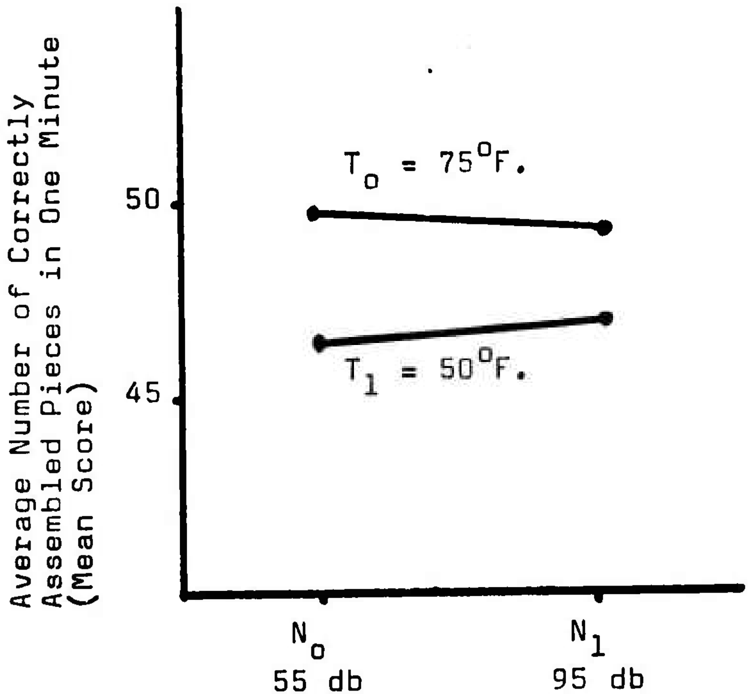

Figure 4

Mean Score Versus Noise Level

cannot be concluded that the noise level had an effect on performance.

Noise x Temperature

The noise x temperature term was also found to be insignificant at the five percent level, implying that the hypothesis: H_3: $TN_{ij} = 0$ for $i = 0,1$ and $j = 0,1$ cannot be rejected. Therefore, there was no interaction effect present. This can be seen in Figure 4, since the two lines are very nearly parallel.

Subjects

Table 1 indicates that the subject effect is significant, which is expected in experiments of this sort, but that none of the interaction effects is significant.

Chapter V will present the conclusions drawn from this experiment and some recommendations for further study.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In Chapter IV it was stated that the low temperature level of 50°F. had a detrimental effect on performance, compared to the normal level of 75°F. From this, it can be concluded that temperatures substaintially below the normal comfort zone adversely affect human performance of manual tasks when no protective clothing except short sleeves is worn. It is felt that temperatures even lower than that used would produce an additional decrement. Nothing can be said from this experiment about adversely high temperatures, however, as well as what temperature is optimum for tasks such as the one used.

The results showed that white noise, on the other hand, had no apparent effect on human performance nor any interaction effect with the temperature levels used. This conclusion is limited to white noise at 95 db, and nothing can be said about higher intensity levels of white noise, noises of a different type, or different temperature levels.

The direction of additional work on this problem should be the investigation of a broader temperature range, with more levels of temperature; and a broader noise intensity range, as well as different types of noise, including noise of random periodicity.

APPENDIX

Subject Number	T_0 (75°F.)		T_1 (50°F.)	
	N_o(55db)	N_1(95db)	N_o(55db)	N_1(95db)
1	46 46	45 50	40 48	42 44
2	45 53	45 49	52 44	47 50
3	59 67	54 66	56 62	56 57
4	39 50	43 45	43 42	51 44
5	46 59	48 53	47 47	45 47
6	49 46	45 46	44 45	48 44
7	53 49	55 45	40 51	44 50
8	48 48	46 52	41 46	45 50
9	41 42	47 44	42 48	41 42
10	48 47	48 50	42 42	46 44
11	48 51	50 51	43 46	45 44
12	48 54	46 56	50 50	48 53

Table 2

Data

Number of Correctly Assembled Pieces in One Minute

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