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Effect of Startle Stimuli on Performance

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The effect of auditory startle stimulus on the performance of 178 healthy men in various tasks has been studied. The tasks consisted of: mental activity, complex psychomotor activity, simple sensomotor activity, equilibrium in standing position on one leg, simple visual reaction time, and muscular force of a fatigued muscle. The strong sound of the klaxon-hoot or the sound of the pistol-shot were used as startle stimuli. Performance decreased in all tasks except the force of fatigued muscle, which showed improvement for a period of about 10 seconds. The quantity and quality of the efficiency in mental and complex sensomotor activity decreased very substantially for 20-30 seconds on the average. We suppose that the startle stimulus can cause mistakes in flying.

IN THE COURSE OF OUR WORK with pilots as well as study of aviation accidents we found that sudden, strong, surprise stimuli, e.g. the startle stimuli, can reduce the pilot's working efficiency. Under these circumstances the safety of the flight may be threatened. Despite the fact that there has been much work solving the problem of the startle stimuli (Strauss;[6] Landis and Hunt[3]; Sternbach[5]) little attention has yet been given to the changes in the pilot's efficiency. Having studied the effect of the startle stimuli Woodhead[7,8] and Culbert[1] proved convincingly that man's efficiency is being radically—though only temporarily—reduced under the effect of the stimuli mentioned above. Some information about the effect of steady continuous noise as well as of irregular noise was drawn from studies by Ford[2] and Plutchik.[4]

In this research we have undertaken to solve the following questions: What kind of human functions can be impaired by the startle stimuli most readily? How is the reduction of performance manifested? When does efficiency begin to resume normal level?

METHODS

One hundred seventy eight males, aged from 17 to 38 years, without auditory disturbances, were examined. In our experiments particular attention was given to the effect of startle stimuli on the following functions: (1) the mental activity (48 examinees), (2) the complex psychomotor activity (38 examinees), (3) the simple reaction time (30 examinees), (4) the sensomotor activity of the hand (15 examinees), (5) the standing stability (19 examinees), and (6) the muscular force of fatigued muscles (28 examinees).

The "7-test" was used as an index of the mental activity: the examinee was seated and subtracted 7 from 1000 in writing.

The complex psychomotor activity was evaluated by the following test. The examinee was directed to look at the nearest pair of different lights on a panel and react either with his right hand or with his right (left) leg in order to return the red light to its proper location. As soon as this was done correctly, the next array of lights automatically appeared on the panel.

The simple visual reaction time was measured to an accuracy of 0.01 seconds. The white light was turned out by a switch situated 30 cm distance from the examinee's hand. About 40 reactions were consecutively assessed; they followed one another in short irregular intervals of 3-5 second duration.

In the sensomotor test, the examinee was standing and extended his right hand and tried to trace the irregularly prescribed line on an 8 mm wide and 166 cm long belt. Every deviation from the prescribed line was estimated as a mistake.

The standing stability without visual control was investigated by means of registration of the titubative motions of the head; the curve was estimated either from the diameter of the circular line or from the diameter of the diagonals in their widest and narrowest parts.

The muscular force was estimated with the aid of the Mosso ergograph. The examinee picked up a weight of 2 kg with the middle finger of his right hand at a rate of 66 times per minute. The startle stimulus sounded as soon as the amplitude of the excursions decreased to half of their initial height.

Besides the changes in efficiency, we attempted to make a generalization concerning the overall effect of the motor startle reaction. The subjective feeling after the startle stimulus and the subjective disturbance in the work were examined. Discomfort in the muscles of the neck and limbs was considered to have been more stressful in the generalization.

The startle reaction was produced by a klaxon-hoot of 100 dB intensity at 1 m distance; the mean frequency was 300-400 Hz and 2000-3000 Hz. Besides the klaxon-hoot we used the pistol shot, the peak intensity of which was 130 dB at 1 m distance. The pistol shot, however, was used only with regard to its effect on muscular force.

In these studies, all subjects had been instructed before the experiments. They were informed that some

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stimulus would appear but they were not told the type it would be or when it would appear.

RESULTS

The results of studies with the first group of subjects using the "7-test" showed that depending upon the startle stimuli, the performance declined on the average from 10.3 to 7.4 correct subtractions during the first 30 seconds. This difference was statistically significant at the level $p < 0.001$ (t-test). Within the next 30 seconds the performance returned to the normal level. A clear-cut increase in the number of incorrect reactions was also noted after the startle stimuli (from 6.7 up to 12 per minute: $p < 0.01$). A significant decline was registered during the next minute.

In 4 out of 8 subjects mistakes were observed about 2 minutes before the provocation of the startle stimuli. The incorrect reactions had a clear tendency to increase in response to the strong disturb stimuli.

From the results of the above investigation it is apparent that the decline in performance was seen mainly during the first seconds after the startle stimuli: then it tended to resume its normal level. It was necessary to confirm these results on the basis of a more detailed examination.

Hence, another group of subjects was investigated with the "7-test". As is shown in Figure 1, the number of substractions decreased significantly during the first seconds after the startle stimuli (from 14 to 9.6 per minute; $p < 0.001$). During the next 15 seconds this amount was stabilized at 10.4 ($p < 0.01$) and the increase to 12.4 was noticed during the second half of a minute.. This difference however was statistically insignificant. The number of subtractions resumed its initial level only during the next minute. Hence, the greatest number of incorrect reactions was registered during the first minute after the klaxon-hoot. Within the first 15 seconds the majority of incorrect subtractions occurred. Most of the mistakes appeared in those subjects who made the largest number of incorrect subtractions during the first half of the test. In all subjects a decline in performance was noted during the first 15 seconds.

In 10 out of 48 subjects exposed to the startle stimuli a significant decrease of efficiency was observed as compared to that obtained before the stimuli (the difference exceeded 50 percent in the first 30 seconds). Two of these subjects were unable to work for 30 seconds, and one of them even for a whole minute. On the contrary, in the first 30 seconds, e.g. in the period of the strongest effect of the startle stimuli on the human body, the efficiency of 6 subjects increased in comparison with that attained before the stimuli.

Within the next 30 seconds an increase in performance either on the average or even above average was noted in 21 subjects. It was surprising that after the startle stimuli the efficiency of the subjects with performance above the average showed a significant decrease as compared to those with performance below average. The latter were more resistant to the startle stimuli. This relationship was statistically significant ($p < 0.05$).

It is evident in Figure 2 that in solving the complex sensomotor test the effect of the startle stimuli on the duration of the reaction time as well as on the number of correct reactions was observed. The reaction time to exposure after the startle stimuli showed an increase. (The duration of the reactions depended on the repeated incorrect reactions). Before the startle stimuli the average reaction time to the exposure amounted to 1.86 seconds: immediately after the startle stimuli it showed an increase to 4.01: the highest time was seen during the second exposure after the startle stimuli (4.25 seconds). The other tests were solved as rapidly as usual.

Immediately after the startle stimuli the reaction

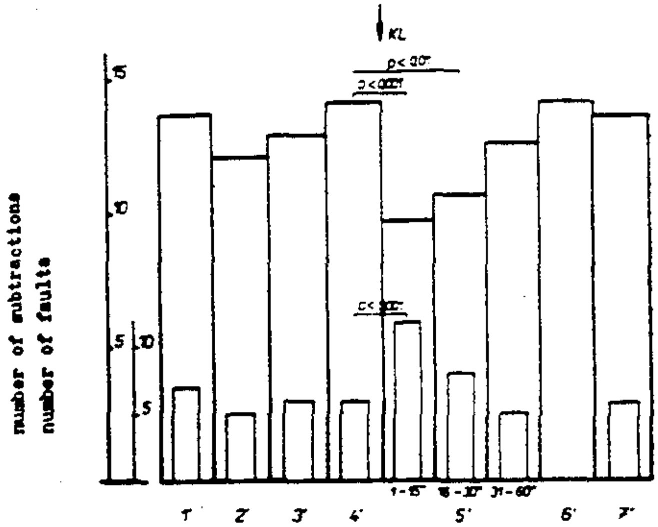

Fig. 1. The effect of the klaxon hoot on the performance in 7-test. N = 22.

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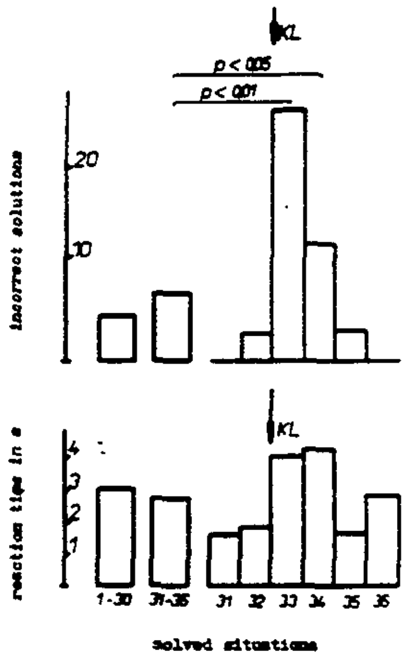

Fig. 2. The effect of startle stimulus on the complex sensometer activity. N = 38.

time increased in all subjects, except two. The next reaction time showed an increase in all subjects. The highest reaction times were to 13.0 seconds, 11.8 seconds and 10.0 seconds. These reactions were incorrect and had to be repeated. The highest reaction time after the startle stimuli and the greatest number of incorrect reactions were observed in the same subjects.

The effect of the startle stimuli proved to be most informative as far as the number of incorrect reactions was concerned. A great number of mistakes occurred in two exposures following the startle stimulus. The ratio of incorrect reactions in the six solved situations was as follows: 0; 3; 26; 12; 3; 0. The incorrect reaction was noticed in more than 2/3 of the subjects exposed to the sound of the klaxon-hoot. This difference was statistically significant at the level $p < 0.01$. The incorrect reactions decreased only in 1/3 of the examinees ($p < 0.05$). In 10 out of 12 subjects the incorrect reactions were noted during the previous situation as well.

In the first moment after the startle stimuli the incorrect reaction was repeated six times. In most cases these incorrect reactions occurred in the hand operation. A disorientation lasting over 15 seconds was observed in two subjects. The subjects with performance

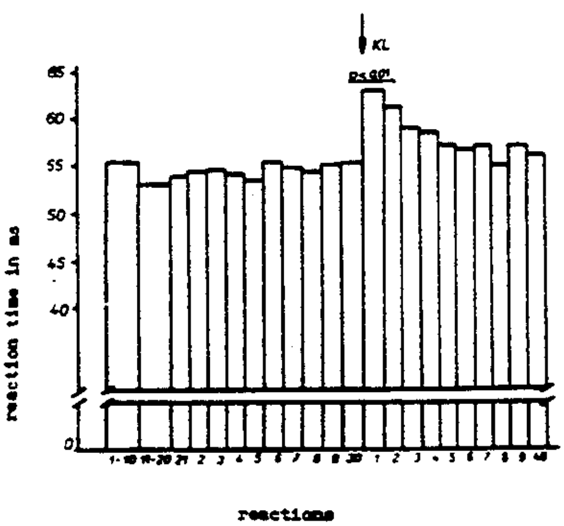

Fig. 3. The effect of the startle stimulus on the simple visual reaction time. N = 30.

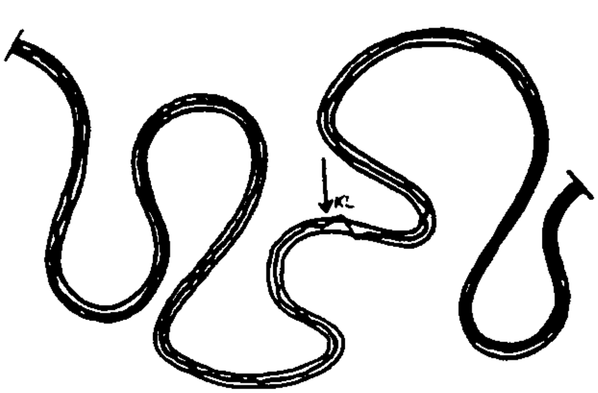

Fig. 4. The typical effect of the startle stimulus on the sensometer activity of the hand.

below the average made more mistakes after the startle stimuli ($p < 0.05$).

The effect of the startle stimulus on the simple visual reaction time can be seen in Figure 3. The total time of the 1.0 to 10.0 reaction averaged 0.55 seconds; the 11.0 to 20.0 reaction, 0.53 seconds; the 21.0 to 30.0 reaction amounted to 0.54 seconds; the 31.0 to 40.0 reaction came to 0.58 seconds on the average. Hence, between the 11th and the 20th reaction the shortest duration was noted. Between the 1st and 10th reaction a gradual shortening from the beginning was seen; during the 11th to 30th reaction the time was gradually normalized. The shortest average reaction was the 17th (0.52 seconds). Between the 1st and 10th reaction we noted 7 incorrect reactions; between the 11th and 20th, 6 incorrect reactions were seen; 13 incorrect reactions occurred between the 21st and 30th reactions; 5 incorrect reactions appeared between the 31st and 40 reactions. The klaxon-hoot resounded between the 30th and the 31st reactions. The average time of the 31st reaction lengthened from 0.55 to 0.63 seconds. Immediately after the startle stimuli the reaction time of 12 subjects showed an increase; in 18 subjects a decrease was seen. The average time of the second reaction after the startle stimuli was 0.61 seconds; this reaction had a tendency to get shorter only in 7 subjects; in 1 subject the reaction was on the initial level and in 22 subjects a lengthening was observed ($p < 0.01$). During the next reactions the reaction time was gradually and nearly regularly standardized but it resumed its initial level only in the 38th reaction (0.55 seconds). It was the shortest reaction after the stimuli. The average reaction time before the startle stimuli amounted to 0.45 seconds in the fastest responding subject, and the slowest responder achieved 0.79 seconds. Both extreme reactions were not under the effect of the startle stimulus.

The effect of the startle stimuli on sensomotor activity of the hand was estimated from the time necessary for the work and from the incorrect reactions. The average time of tracing the belt of 166 cm amounted to 26.2 seconds. The relative time in respect to the length of the line was nearly equal before and after the startle stimuli. Before the startle stimuli the length of the line was 56.4 percent; the relative time necessary for its tracing amounted to 57.7 percent. We concentrated especially on the part of the line of about 10 cm—traced immediately after the startle stimuli—corresponding to 1.6 seconds. As shown in Figure 4, the motor reaction immediately after the startle stimuli is represented by the incorrect line and by tracing above or below the line of the belt. Immediately after the startle stimuli incorrect reactions were seen in 11 out of 15 subjects. The majority of incorrect reactions were manifested as a tracing above the line of the belt. In two cases only this incorrect tracing appeared twice. The upper limit was damaged in eight instances; the lower one in three cases.

Comparing the part of the line traced immediately after the startle stimuli with that before and after (with approximately the same number of mistakes) it can be seen that the former comprises a sevenfold number of mistakes. The average amplitude of the curve after the startle stimulus was 4.6 mm at a dispersion of 1-11 mm. No mistakes were noted in 3 subjects with the lowest amplitude (neither after the startle stimulus nor during the experiment). The length of the incorrect marking of the curve averaged 4.5 cm (at a dispersion of 1-10 cm) e.g. of about 1 second. No correlation between the curve and the incorrect reactions was noted (before the startle stimulus).

After the startle stimulus a decrease of incorrect reactions was seen in 5 subjects and an increase was shown in 5 of them. The latter made the greatest number of mistakes during the whole experiment. In subjects with incorrect reactions before the startle stimulus (9 subjects) and after the stimulus (7 subjects) the mistakes were observed immediately after the startle stimulus as well. The higher the rate of tracing the greater the number of incorrect reactions ($p < 0.05$). The rate, however, was not correlated with the curve.

The changes of the titubate motions before and after the startle stimulu—when the examinee stood erect with his heels and toes touching or when he stood on his right leg—are illustrated in Figure 5. When standing on the right leg, the average magnitude of the titubate motions increased from 22 mm to 43.3 mm and after the startle stimulus, up to 50.2 mm (measured from the diameter of two diagonals). The changes between the above positions and those measured after the startle stimuli are statistically significant ($p < 0.005$). In 3 instances we noted even a better standing position after the startle stimulus. The decrease in the standing position was seen in other subjects. The greatest adverse change in subjects exposed to the startle stimulus was 81 percent and 55 percent compared to the initial values. It was noted that the most frequent reaction provoked by the startle stimulus was the wave of increased muscular tonus. This was manifested as a trembling and shaking of the whole body. The complete loss of equilibrium and the premature cessation of the experiments did not occur even in subjects suffering from the generalized motor startle reaction.

The effect of the startle stimulus on muscular force is shown in Figure 6. The first average length of the lifting of ergograph weight amounted to 44.3 mm with a range of 30 to 58 mm. The excursions gradually decreased. During their decrease to 50 percent and the resounding of the klaxon-hoot the time was very variable, about 129.8 seconds on the average at a dispersion of 62-385 seconds. This time represents an average of 138 liftngs of the weight. The average height of the last liftings before the startle stimulus was 23.1 mm, e.g. 52.1 percent of the initial height. The height of the next to the last liftings averaged 23.5 mm, e.g. 53.7 percent of the initial value. The liftings showed an increase in all subjects immediately after the startle stimuli. Relative values of the first, second, third, fourth and fifth reactions after the startle stimulus were: 27.1 mm (61.9 percent); 27.8 mm (63.7 percent); 26.5 mm (60.2 percent); 28.9 mm (66.1 percent) and 27.5 mm (62.0 percent). The muscular force increased progressively after the stimulus. The 4th lifting was the highest ($p < 0.01$). After this lifting the muscular force gradually decreased and approximately after 11.6 liftings (the dispersion 2-33), e.g. per 10.5 seconds it resumed its initial level. The maximum average increase of the muscular force amounted to 10 percent; the maximum individual increase was 94.7 percent. In 8 subjects the rhythm of the muscular reaction was disturbed as well.

DISCUSSION

Our results regarding the effect of startle stimuli on the performance of man do not differ essentially from those obtained by Woodhead[7,8] and by Culbert.[1] The functions requiring consideration and decision can be damaged most of all. The more difficult the problem to be solved the greater the decrease in efficiency. In solving a very complex psychomotor test the performance has a clear tendency to decrease in all subjects. The deterioration of work requiring accurate muscular coordination can be noted as well, but only for a short period. In other tests some individuals showed an in-

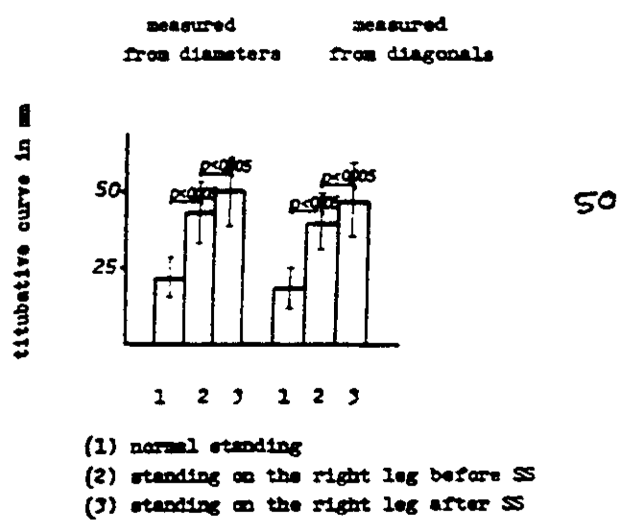

Fig. 5. The effect of the startle stimulus on the standing stability without visual control. N = 22.

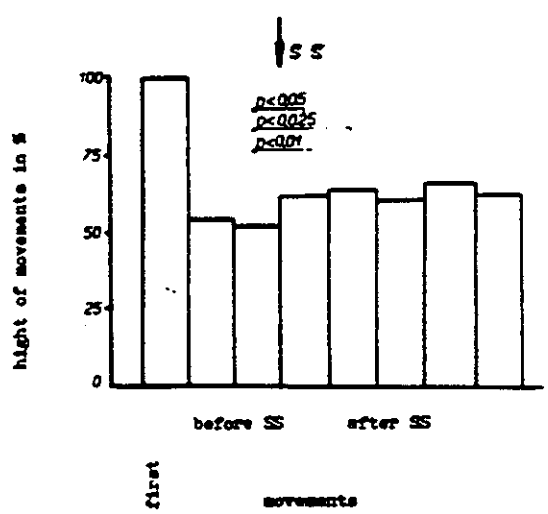

Fig. 6. The effect of the startle stimulus on the muscular force. N = 28.

crease in efficiency immediately after the startle stimuli. The increase, however, was not significant in any instance.

During work requiring participation of superior mental functions, decrease and deterioration in the quality of efficiency manifested itself in many mistakes. Of course, the most significant decline in efficiency was observed immediately after the startle stimuli; then the performance showed a gradual normalization. Within 30 seconds on the average its initial value was resumed. The simple motor functions have a clear tendency to normalize immediately after the cessation of the primary motor reaction (in most cases).

It was surprising for us to find that the simple reaction time lengthened too, despite the fact that quite the opposite had been expected. The muscular tone and force show an increase under the effect of the strong auditory stimulus for several seconds. It may appear when a pistol shot is used in starting athletes or a shout is used as a stimulus.

The significant and opposite differences in the endurance of the working efficiency response to the startle stimuli can be noted. This difference amounts to several hundred percent. The interruption of the work can be observed even when the subjects have been prepared for the stimulus and have tried not to yield to its effect.

We assume that the endurance of some people is especially dependent on the state of the nervous system and on their experience. The working efficiency decreases especially during non-automatic activity in which the durable skills have not been created. The greater endurance in respect of the startle stimuli is observed in those activities in which it has been necessary to watch the changes of the stimulus field and to react continually (e.g., in driving a car).

On the contrary—if it is necessary to grasp a great amount of information, some to be kept in the "short" memory and to react immediately—the performance showed a significant decrease. The strong stimuli break the train of thought and the subject has to start working again, and if he continues to work he makes many mistakes. No complete disintegration of thought under the effect of the startle stimulus has been noted in this respect since all subjects were able to continue and finish their work.

How does the interruption from activity occur? During the first moments the disturbance in performance appears as a result of the primary motor reaction which is generalized to a certain extent. Its cessation is followed by the secondary orienting reaction and the subject concentrates his attention on the test, tries to continue and as a matter of fact he starts working again.

The sudden strong noise penetrates into the CNS: through the reticular formation is spread over the various areas; the process arising in the cortex is interrupted and superseded.

It is evident that the startle reaction is of great importance in survival of the individual in the modern world. However, it is often purposeless and occurs in situations in which it is undesirable and ridiculous.

As to people with unbalanced superior nervous system, the hysterics, neurotics with anxieties, the startle stimulus will probably be much more significant.

CONCLUSIONS

Some conclusions may be made based upon results of this work. In mental, complex psychomotor and simple sensomotor activity the performance decreases in response to the startle stimulus significantly, but temporarily. The quantity and the quality of the efficiency declines and the incorrect reactions have a clear tendency to increase. The lengthening of the simple visual time is noted and the titubate motions during the standing position on one leg become worse.

In mental and complex psychomotor activity the time of the negative effect on performance represents 20-30 seconds on the average. The motor activity requiring accuracy of motion in the extremities and precise coordination of the motion is under the effect of the startle stimulus only for a short period of about 1-2 seconds. Hence, the activity connected with the complex synthetic-analytical activity of the central nervous system requiring consideration and rapid decision is under the strongest effect of the startle stimulus. The strongest effect of the stimulus is noticed after the stimulation; then a gradual decrease of the effect can be seen.

Only the force of a fatigued muscle showed an increase. This improvement lasted for a short period of about 10 seconds (on the average).

Significant individual differences of sensitivity were observed after the startle stimulation. In some subjects the immediate increase after the stimulation can be seen; in others, on the contrary, a panic reaction and "blocking" lasting about 1 minute may occur. No complete disintegration of thinking was noted in this respect.

Startle stimuli can cause mistakes in flying especially in a situation requiring rapid analysis, correct decision and sensitive reaction. As a consequence of this work it seems desirable to investigate the endurance of efficiency relative to the startle stimulus in all employees in which a short reduction of efficiency may threaten safety in flying.

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