Quantifying Cognitive impairment due to physical or mental stress

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ABSTRACT
In this paper, we study impairment caused by physical stress and impairment caused by alcohol consumption. We first base line the EEG waves in a meditation state. Then we measure the EEG waves during the physical activities such as walking, climbing stairs and doing sit-ups. We also measure the effect on brain as a person spins while sitting in a revolving chair (simulating a mental stress). Finally, we measure the EEG waves after consumption of alcohol. Our study shows that EEG waves do capture the physical activities that cause impairment. The magnitude of EEG waves increases with increased intensity of stress as measured by physical exercise or alcohol consumption. The magnitude is highest for sit-ups as compared to other activities and the magnitude for sit-ups after alcohol is even higher when compared with magnitude before alcohol consumption. A higher magnitude means lower level of alertness. The results could be used to improve the care of elderly and plan the intensity of their physical activity.

Categories and Subject Descriptors
J.3

General Terms
Measurement, Performance, Experimentation, and Human Factors.

Keywords
Cognitive impairment, EEG waves, physical stress, alcohol consumption.

1. INTRODUCTION
Cognitive impairment can occur for several reasons. Transient or short term impairment can be caused by physical or mental stress. Attempts have been made to study and model Cognition using EEG waves [1-2]. Cognitive state estimations have been done using EEG waves [3]. Neural signals are obtained by placing electrodes on the scalp and measuring small electrical signals called EEG brainwaves. These EEG waves record the electrical activity in the brain in terms of waves of various frequency bands. These bands have been divided into several categories.

- Delta Waves: These waves are associated with the deepest levels of sleep. They are in the frequency range of 0-4 Hz.
- Theta waves: These waves appear during the drowsy state or sleep state (not the deep sleep). These waves are in the frequency range of 4-7Hz.
- Alpha waves: These waves appear during the phase when a person is awake but the eyes are closed. The frequency range of these waves is 8-12 Hz.
- Beta waves: These waves are in the frequency range of 12-30 Hz. They are associated with the normal wakeful state of consciousness.

The effect of exercise on brain using EEG waves has been documented in several studies showing that exercise does cause enhanced brain activity and is captured by Alpha and Beta waves of EEG [4-7]. Studies have been done to document cognitive impairment due to daily physical and emotional stress and anxiety [8]. The caregivers of palliative patients experience a high level of emotional stress causing transient impairment in them [9]. Researchers have also used EEG to study how music cognition affects emotional aspects of the brain system [10-11]. Another interesting use of EEG is to study changes in EEG waves due to the driving distractions [12-13]. EEG waves are also used in several other applications such as its use to distinguish epileptic seizures [15], patients in coma [16], depth of anesthesia [17] and motion sickness [18]. In this paper we present the results of some experiments done to determine the mental impairment as measured by EEG waves. We have done experiments in physical exercise involving walking, climbing stairs and sit-ups. It is not possible to induce emotional stress, so we influence the brain by having a subject spin in a revolving chair to cause dizziness in the brain, similar to motion sickness. Finally, we studied the effect of alcohol on brain as measured by EEG waves.

2. Objectives and Paper Outline
The objective of this study is to determine the cognitive impairment of individuals during activities that influence the brain. The brain influence may be caused by emotional issues or by physical stress or by other actions. In these experiments we influence the brain activity by doing physical exercise of varied strenuousness. It is not possible to actually simulate emotional issues, but we influence brain by having a subject sit in a revolving chair and then rotate the chair. This causes dizziness in the brain, similar to motion sickness, causing transient

PETRA '13, May 29 - 31 2013, Island of Rhodes, Greece

http://dx.doi.org/10.1145/2504335.2504384

impairment. We also study the effect of alcohol on brain activity as measured by EEG waves. In the following sections we write about the various experiments we have done. In section 4.1 we plot a baseline of the EEG waves in a meditative state. The results of all other experiments are then compared with this baseline state. In section 4.2 we document an experiment where a subject is made to sit in a revolving chair and then the chair is spun. In Section 4.3 we show the results of the walking exercise. In section 4.4 we show the results of the sit-ups. In section 4.5 we show the results of climbing stairs. In section 4.6 we document the magnitude of EEG waves after alcohol consumption. We also did two additional variations in our experiments. In section 4.7 we write the results of comparing heart rate with EEG waves as a subject climbed stairs. In section 4.8 we document another variation in which a subject just imagines doing the physical exercise of walking or sit-ups while we record the EEG waves.

3. Experimental Setup

In this section we describe the equipment used to do these experiments. The device to measure the waves consists of:

- A Neurosky head band with a dry electrode to be placed on the forehead. The device is easy to place on the forehead without any discomfort.
- A second electrode on the head band to be placed on the ear lobe.
- Software that records the EEG waves sent from the head band. The communication between the computer and the head band uses blue-tooth protocol.
- The heart rate is measured using a hear rate monitor that is worn on the chest.

4. Experimental Results

In this section we present the results of the experiments to simulate impairment. In each experiment the Neurosky band is tied to the forehead such that the electrode touches the middle of the forehead. A second electrode is tied to the ear with a clip. The software uses Bluetooth to communicate between the Neurosky band on the head and the computer. We focus on the alpha and the beta waves as these waves are of interest during the wakeful state. All the plots from these experiments show the magnitude of EEG waves on the y-axis. The meditation state experiment is important to baseline the magnitude of EEG waves. A meditation experiment done on one day may not be valid on another day. The reason is that the state of mind is different on different days. *So it is important to do this baseline experiment before each impairment experiment.*

4.1 Meditation State

In this experiment, the subject sat still on the chair with the eyes closed for about 2 minutes. This is used to baseline the least impaired state of the mind, the meditative state. A total of 10 experiments were done for the meditation state. Figure 1 shows a plot of the Alpha waves.

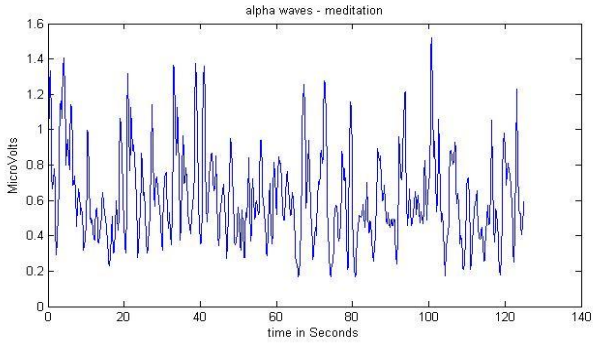

Figure 1: Alpha waves, meditation state while sitting. This state used to baseline the EEG waves for comparison with other experiments. High values on Y-axis indicate more activity and therefore less alertness.

The mean of the magnitude (y-axis) of the alpha wave is .62 and the range is from 0.17 to 1.52. The results for other meditation experiments showed similar results. A slight variation to the meditation state was done for the next experiment. Instead of sitting, the subject was made to stand still with eyes closed. The mean of the magnitude in the case of person standing is .94 and the range of the magnitude is from .26 to 2.8. A comparison with the statistical values of meditation while sitting shows that the max, min and mean values are higher for standing up as compared to meditation. This suggests that when a person is standing the concentration of his mind is less than compared to sitting.

4.2 Spinning in a chair

The meditation experiment provides a baseline data point to compare with the other exercises. In this experiment, we first simulate mental impairment by spinning a chair while a person is sitting in it. If a person sits in a revolving chair and the chair is spinning, he will feel dizziness similar to the motion sickness. The Neurosky band was attached to the head of a person sitting in the chair with his eyes closed. Another person pushed the chair repeatedly to spin the chair. Several experiments were done spinning the chair. The number of the spins varied from 1-5 between each experiment. We also varied the speed of spin during different experiments. For each variation we did 10 sets of experiments.

The plot for this experiment of 5 spins is shown in Figure 2. The statistical data for this plot shows the mean is 1.67 and the range is from .26 to 10.8. The values for 3 spins give a mean of 1.41 and the range is 6.44 for the high and approximately .27 for the low. Most of the peaks are between the magnitude of 4 and 6. Other graphs plotted for this experiment with different numbers of spins showed similar results. It was observed that if the number of spins increases, the mean value also increases and the max value also increases. Similarly the mean for the alpha waves during spinning increases to a magnitude of about 1.41 from the value of .62 for no spin. The magnitude of the raise varies depending on the number of spins and possibly on the state of mind of the subject. But the conclusion is that the mean and the high values of the range increases in value. The increase in value means that there is an increase in activity for the particular region of the brain as indicated by the alpha waves, leading to a decrease in alertness.

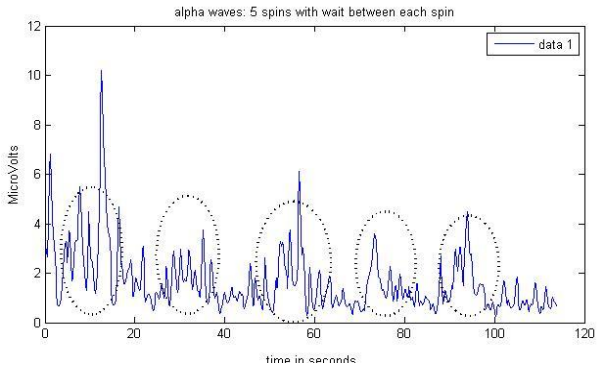

Figure 2: Alpha waves, 5 spins with eyes closed and wait of 10 seconds between each spin. Each spin is shown with an ellipse around the part of the plot. High values of peaks mean less alertness as compared to the meditation state.

The two sets of experiments do show the effect of mental impairment on the alpha waves. But there cannot be any conclusion made about the relationship between the number of spins and the level of cognitive impairment. The effect on the magnitude is still inconclusive. The goal is to find the relationship of magnitude with increased cognitive impairment. Another set of experiments was done to arrive at such a relationship. In this experiment the number of spins was increased after a brief rest. The experiment started with 1 spin and after a rest of 10 seconds, two spins were done and then after a rest of another 10 seconds, 3 spins were done. The hypothesis is that the x-axis should reflect that the time to get back to normal after 3 spins should be more than the time to get back to normal after 1 spin.

The result is shown in Figure 3. There are 3 sets of peaks. The first set shows one peak for one spin, the second set shows 2 peaks for 2 spins and the third set shows 3 peaks for 3 spins. The x-Axis shows the number of data points as also the time in seconds. It can be seen that after the first spin, it take 17 data points (157-140) to go back to the normal state, which corresponds to approximately 3 seconds.

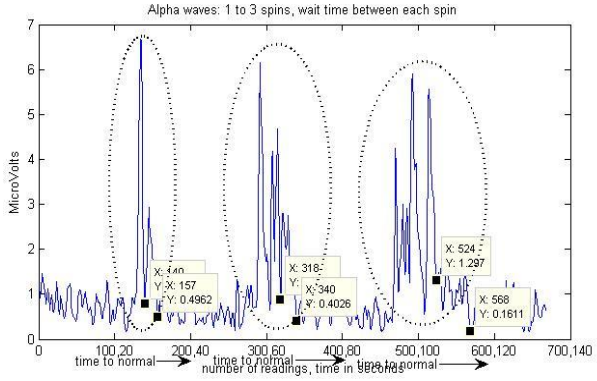

Figure 3: Alpha waves, 3 sets of spins - 1 spin, rest; 2 spins, rest; 3 spins and rest. The arrows along x-axis show the time it takes to go back to normal after the spins. High values at peaks mean less alertness.

After two spins it takes 22 data points (about 4 seconds) to go back to the normal state and after 3 spins it takes 44 data points (about 8 seconds) to go back to the normal state. This experiment does confirm that there is a relationship between the number of spins and the time it takes to go back to normal state. Another view of the same plot is generated using the smoothing function of Matlab. The result is shown in Figure 4.

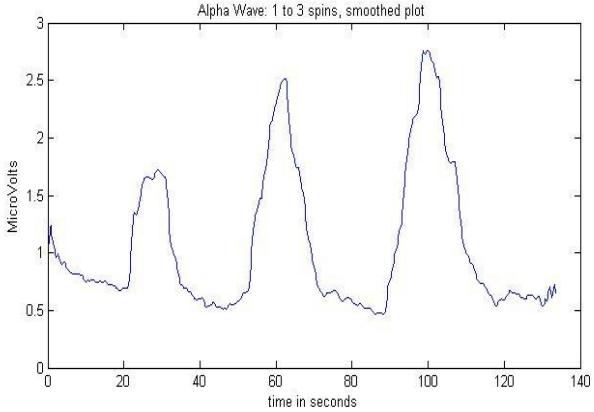

Figure 4: Alpha waves; 1 to 3 spins; smoothed plot.

In the next sections we describe some of the experiments done to cause impairment by doing physical exercises.

4.3 Walking Steps

In the previous experiment, there was no physical exercise, but the act of spinning does cause impairment in the brain. In this set of experiments the EEG waves were recorded as the subject walked several steps. The subject walked 10 steps in one set of experiments. These were repeated 10 times each. Figure 5 shows the plot for 10 steps.

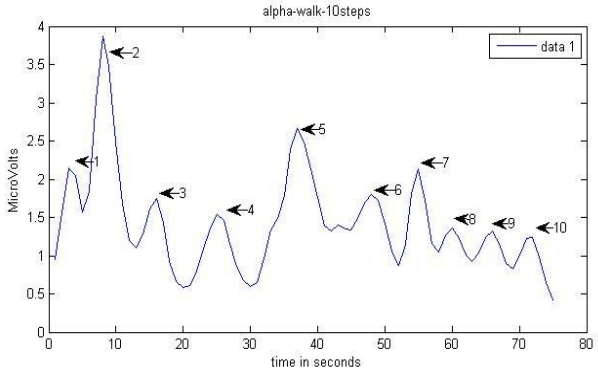

Figure 5: Alpha waves, eyes closed, walk 10 steps. The arrows show the peaks during each walking step.

For the 10 steps the mean is 1.42 and the range is between .41 and 3.87. The experiment was repeated for 15 steps and showed similar results. In both the cases it showed that the mean and the high range value is higher than the meditation state value.

We tried another variation of the walking experiment. In this experiment, the subject did 10 steps but stayed in the same place. This was to minimize any effect of actual movement. The mean in this case is 1.44 and the range is from .59 to 3.37. These results are consistent with the actual walking experiments.

4.4 Sit-Ups exercise

In this set of experiments, the EEG waves were measured as the subject did sit-ups. The subject did 10 repetitions of the experiments for 5 sit-ups and similarly repeated the experiments for 10 sit-ups and 15 sit-ups. The plot for 5 sit-ups is shown in figure 6. The mean of the Alpha waves magnitude is 7.32 and the range is from .98 to 18.2.

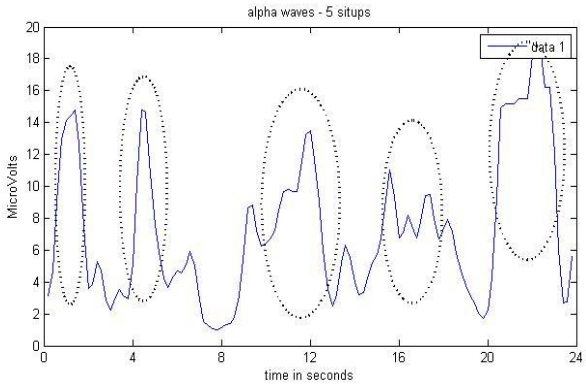

Figure 6: Alpha waves, eyes closed 5 sit-ups. Each sit-up peak is shown by the ellipse around the part of the plot. High value of y-axis magnitude means a low level of alertness. As compared to other plots, the sit-ups have a low alertness due to higher physical stress.

The magnitude for these experiments showed the highest values as compared to other experiments. Doing sit-ups is more strenuous than walking or spinning in the chair. This would suggest that the magnitude value of Alpha waves increases with higher physical stress, causing lower alertness. We repeated this experiment 10 times each for 10 sit-ups and 15-sit-ups and the results were consistent.

4.5 Climbing Stairs

In this experiment the subject climbed stairs while wearing the Neurosky band. The subject eyes are not closed but open. So we study the Beta waves of EEG for this set of experiments. The plots are also analyzed for any trends – linear or non-linear. An attempt is made to come up with a mathematical model of this trend.

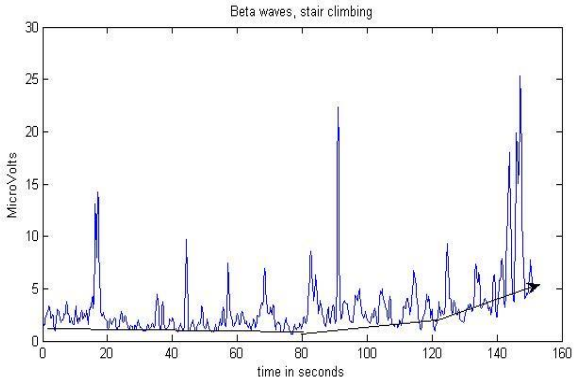

Figure 7: Beta Waves, Climbing stairs, eyes open. The arrow at the base of the plot show the increase over time is exponential.

Figure 7 shows the plot for stair climbing. The mean is 3.24 and the range is from .68 to 25.3. It may be observed that the trend of the waves is of increasing magnitude over time. The arrow line at the base shows the rise in the curve. It also shows that the increase is non-linear. The mathematical model for the increase in trend is plotted using three possible categories of equations, exponential, polynomial and power. We used Matlab toolkit to plot these curves. The fitting of exponential equation shows the best fit for the curve.

4.6 Experiments after Alcohol Consumption

Drinking alcohol also impairs mental capability. The type of impairment for all the categories is not same. For example, a person under stress due to life threatening emergency is under a different type of impairment as compared to the impairment after exercise or impairment after drinking alcohol. But our attempt is to see if we can observe the phenomenon of impairment using the EEG waves. The experiments were repeated after intake of alcohol. The meditation state experiments, the sit-ups and the stair climbing experiments were repeated after drinking various quantities of alcohol. The quantity was sufficient to cause impairment in the subject. The results in each case showed that the magnitude of the waves was higher as compared to the meditation state reading. Also in most cases the readings after the alcohol for similar exercise was higher than the readings before the alcohol intake which indicates a decrease in alertness. These experiments were repeated 10 times during each session of alcohol consumption and it was repeated over 3 sessions. These sets of experiments were done by the author himself and no other subject was involved in the consumption of alcohol.

Table 1: Alpha waves magnitudes after drinking of Alcohol, the high values as compared to non-alcohol consumption indicate lower alertness.

Experiment Type with Alcohol	Mean	Min	Max
Meditation moderate alcohol	.75	.25	2.25
Stairs climbing after alcohol	2.46	.22	13.39
Sit-ups after Alcohol	9.14	.7522	34.51

4.7 Correlation of Heart Rate and Beta waves during exercise

Alpha and Beta waves measure the brain activity when the person is awake. During these exercises the heart rate also changes, based on the duration and intensity of the exercise. The hypothesis is that there is a correlation between heart rate and the EEG waves. There have been very few studies to establish correlation between the EEG waves and heart rate. Abdallah et al [20] have done studies to establish correlation between EEG waves and heart rate during various sleeping patterns. Their focus is on the effects of sleep apnea, which is a sleep breathing disorder that brings about changes in heart rate neurological activity. The conclusion was that the EEG waves corresponding to Delta, Sigma and Theta bands had strong correlation with heart rate at different sleep stages. Derbali et al [21] did a study on the prediction of motivation of players in a serious game using the EEG waves and any correlation with heart rate. The conclusion of the study was that the theta waves were positively correlated with motivation. However the heart rate did not show any correlation with this activity. In this section we present the results of experiments done to study the correlation of Beta waves and the heart rate.

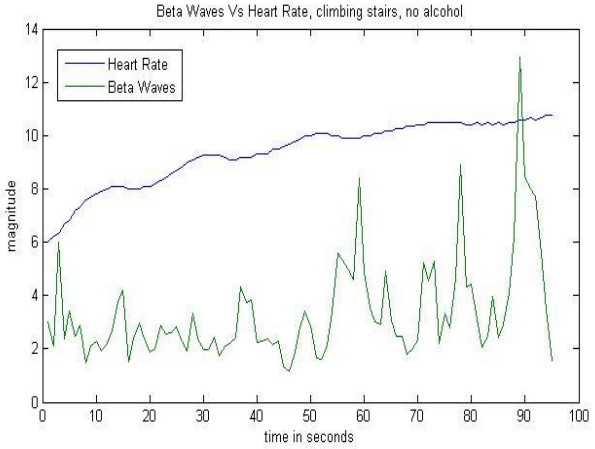

Figure 8: Beta waves and hear rate comparison, climbing stairs.

In this experiment the heart rate was also recorded simultaneously with the EEG waves. The plot is shown in Figure 8. The x-axis in this plot is modified to show time scale in seconds. This is done to have a correlation with the heart rate readings, which are recorded once per second. As mentioned earlier, the Beta wave magnitude is recorded 4-6 times every second. In this plot, the magnitude in each second is calculated by taking an average of all the Beta wave readings in each second. The y-axis shows the magnitude of Beta waves. The heart rate magnitude is normalized so that it is on a similar scale as the beta waves.

There does not seem to be a direct correlation between increase in heart rate and the increase in Beta waves. Heart rate increase starts as soon as exercise is started. But the Beta wave magnitude increase does not start immediately. Heart rate magnitude begins to flatten after a certain magnitude is reached, but the Beta wave magnitude starts to increase later in the exercise.

4.8 Thinking Exercise

We did some experiments where the subject does not actually do any physical exercise but only imagines it. We first asked the subject to imagine he was walking and take 10 steps. The plot for this experiment did not show any correlation with actual walking. We repeated this experiment for sit-ups. We asked the subject to imagine doing 10 sit-ups. Again the plot did not show any correlation with the plot of actual sit-ups. The main reason is that imagining does not cause real physical or emotional stress. So the EEG waves do not record any change. Also it is difficult to imagine walking or doing sit-ups in a consistent manner. The time interval between each walking step cannot be consistent without actually taking the steps. Similarly the time interval between each sit-up cannot be consistent.

5. DISCUSSION OF RESULTS

We can make the following conclusions from the set of experiments.

- The magnitude of the Alpha waves is affected by cognitive impairment. The magnitude of the median Alpha waves increases with cognitive impairment. The high value of Alpha waves range also increases with increased activity.
- The time it takes to reach normal state increases with increased cognitive impairment. This conclusion is reached with the experiment whose plot is shown in figure 3.
- As the intensity of exercise increases, the magnitude of alpha waves also increases. This was consistently shown when we compare the standing state with the meditation state and then progressively with the walking state and finally during the state of doing sit ups. The increased magnitude indicates a decrease in alertness.
- The Alpha waves do record the number of steps taken while walking. The subject walked with eyes closed (to avoid eye ball movement) and no movement in the head to avoid the effects of any artifacts causing these peaks. This experiment was repeated by making the subject take 10 and 15 steps staying at the same place physically (stationary walk). This was done to further limit the effect of moving.
- The Alpha waves do record the number of sit ups. In this case also the subject did sit ups with eyes closed and no movement of head.
- The mathematical modeling of the trend lines shows that the exponential equation is a better fit for the curve.
- In the study of Alpha waves, the magnitude of Alpha waves did show an increase in the magnitude of mean value and the high value of the range after alcohol consumption.
- There does not seem to be a direct correlation between increase in heart rate and the increase in Beta waves.

Table 2: Comparison of all results, higher values mean higher power levels of the waves, which implies higher brain activity indicating lower alertness.

Experiment Type	Mean	Min	Max
Meditation, Sitting	.62	.17	1.52
Meditation Standing	.94	.26	2.78
Spinning in a revolving chair - 3 spins	1.41	.27	6.44
Spinning in a revolving chair - 5 spins	1.67	.26	10.18
walking steps	1.42	.41	3.87
Sit-Ups	7.3	.98	18.2
Climbing Stairs	3.24	.68	25.3

Table 1 summarizes the results of the experiments. The main conclusion we have is that the value of Alpha waves magnitude is higher for exercises that are more strenuous and also higher as compared to stationary case. The higher value means less alertness. The results were consistently observed over several repetitions of the same experiments.

6. CONCLUSION AND FUTURE WORK

In this paper we attempted to simulate transient impairment by doing physical exercise, causing dizziness by spinning and by consumption of alcohol. The results consistently showed that the brain activity showed higher levels in Alpha and Beta waves. It also showed that more intense the exercise the higher the magnitude of power level of the waves. After the consumption of alcohol the EEG levels were higher as compared to the EEG levels before the consumption of alcohol. A patent has already been filed by one of the authors [22].

Further studies on different level of exercise can further confirm these conclusions. We used equipment manufactured by a company called Neurosky. Further experiments can be done by using a variety of head bands manufactured by other companies.

7. Acknowledgements

This work is partially supported by the National Science Foundation under grants CNS-0751205, CNS-0821736 and IIS-1329119.

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