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The Effects of Total Sleep Deprivation on Basic Vital Signs and Cognitive Function in Humans

Amy Martin
Christine Davis
Young-Mi Oh

Zoology Department
North Carolina State University
Raleigh, NC 27695

Almarti2@ncsu.edu

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Amy Martin, Christine Davis, Young-Mi Oh

Department of Zoology, North Carolina State University, Raleigh, NC 27606

Abstract

Sleep deprivation is a common problem in modern society. Because sleep is a time for the body to regenerate vital parts, especially neurons, it has been the subject of scientific studies for the past 30 plus years. Unfortunately, with lack of sleep come many unwanted side effects, including impaired thinking, memory, and the depression of some vital signs. This experiment was designed to test the effects sleep deprivation on blood pressure, pulse, body temperature, and some cognitive abilities in order to compare results with past studies.

Six human volunteers, 3 female and 3 male, ages of 18 and 30, were studied in a two-part experiment, which included one 24-hour study of each individual's normal body conditions, and one 24-hour study of reactions to sleep deprivation. Comparison of the two data sets suggested a correlation between sleep deprivation and a decrease in blood pressure, pulse, body temperature, and cognitive performance. Pulse was most significantly affected; both blood pressures and body temperatures mimicked circadian patterns, but both also showed a decrease in overall levels of pressure and temperature when compared to the normal body conditions. Drops in cognitive tests scores show a decrease in long and short-term memory, creative thinking, and the ability to think and solve problems within time constraints.

The results demonstrate differences between normal body/brain function and that of sleep-deprived individuals. Additional studies involving more subjects, a more controlled environment, and/or a different variety of cognitive tests are required in order to make conclusive assumptions about a larger population.

Introduction:

Sleep is essential to the body and its functions, promoting bodily rest and rejuvenation in the neurons and other cells that are replaced or repaired during times of sleep. Sleep has also been proposed to conserve energy, detoxify the brain, and control thermoregulation within the brain (Maquet 2001). Ultimately, since sleep is so essential to the human body, scientists recommend approximately eight hours of sleep a night to promote efficient performance and thinking. On the other hand, within this fast paced society, few people receive the sleep that the body needs, and ultimately sleep deprivation affects a significant portion of the population. Ranging from shift workers, military personnel, or college students, short periods of sleep deprivation often occur in meeting deadlines or performing exercises. Lack of adequate sleep not only reduces productivity at work, but personal well-being and safety. It is important in this respect to understand the effects of sleep deprivation on the body.

Total sleep deprivation (TSD) has been shown to negatively affect many physiological, cognitive, and behavioral measures within the body (Miro *et. al.* 2002). During regular sleep, the body's vital signs fluctuate throughout the night. Body temperature, for example, follows a circadian rhythm, but is also influenced by sleep. During rapid eye movement sleep (REM) the body reaches the deepest sleep possible, in which most of dreaming also occurs. During REM, the body's temperature is at its lowest level. However, if sleep deprivation occurs and REM sleep is never reached, the body's internal temperature would be affected. Also, during a normal course of a day-night cycle, the body's blood pressure and heart rate slow down while the person is asleep and rise steadily as the person awakens. It is to be expected that sleep deprivation would also affect these vital signs.

Since many students pull all-nighters to study for tests and finish project deadlines, it would be important to understand if sleep deprivation may have any effects on the person's cognitive and memory skills. While the body's vital signs are certainly affected, it is also important to consider the relationship between sleep and cognitive skills. The role of sleep in learning and memory is poorly understood and has yet to be determined and precisely characterized. What most researchers in the field believe is that sleep is primarily involved in consolidation of memory traces, and that such traces may be reactivated and incorporated into long term memory (Maquet 2001). However, it is not known if sleep is an absolute requirement for memory consolidation or if sleep only allows for more favorable conditions. Some available data suggest that sleeping during the night after a specific training session is critical to perceptual learning. Also, significant enhancement in learning is seen after being allowed to sleep the previous night. Subjects who were sleep deprived during the post-training night showed virtually no performance improvements the following days (Maquet 2001). But we are still unsure exactly how sleep and sleep-deprivation affects the overall memory and learning skills. Many researchers feel that tests performed in past studies to assess cognitive ability after total sleep deprivation were not accurate and precise enough to detect subtle discrepancies between the healthy and the sleep deprived mind (Siegel 2001).

The experiment reported here attempted to analyze the effects of sleep deprivation on human vital signs, including pulse, body temperature, and blood pressure, as well as on cognitive abilities based on several standard tests.

Materials and Methods:

To perform the sleep deprivation experiment, six human subjects were used (three females and three males). The subjects were 18-30 years old and were familiar to the college environment where sleep deprivation is prevalent. The subjects were all in good, normal health at the time of the experiment.

In the first part of the experiment the control data were produced during a 24-hour period without sleep deprivation. The data from these tests created a profile for each individual that was subsequently compared to the results of the sleep deprivation experiment. Each subject was tested over a 24-hour period under normal daily activity and patterns of sleeping, within their own personal environment. Each subject had his or her body temperature, blood pressure, and pulse rate taken every four hours over a 24-hour period. The subjects' pulse was taken with the "finger on the wrist" technique, with the pulse taken for 10 seconds and multiplied by 6 to get the total beats per minutes. Body temperature was taken with an oral thermometer. The blood pressure was done using a stethoscope and a sphygmomanometer cuff. In addition to these tests, the subjects underwent 5 different cognitive tests, which determined the impact of sleep deprivation on neurological functions. The first test consisted of a listening memory test based on word recognition and affiliation. The subjects were read 12 word pairs, 6-associated word pairs and 6 non-associated word pairs. After five minutes, the subjects were asked to recall the paired word when given the other word. The second test was the Hayling's test. Ten sentences were read. For example, "The girl went to the…" and the subjects were asked to fill in the blanks with a word that rendered the sentences meaningless. Verbal fluency was tested in the third cognitive test. The subjects were asked to name how many animals they could in one minute. Short-term and long-term memory of the subjects was tested using verbal recall where the subject was given a list of ten words and asked to repeat the words after 5 minutes and again after 20 minutes. The final cognitive exam tested the subjects' memory in relation to facial recognition. The subjects were shown 10 cards with faces on them at a rate of one face every five seconds. After 30 minutes, the subjects were shown 15 cards and were asked to pick out the 10 that were previously shown.

The treatment portion of the experiment tested the same parameters during a total of 36 hour of sleep deprivation. The subjects woke up at their regular times on the testing day, and the experiment began 12 hours after awakening. The subject's vital signs were taken every four hours throughout the next 24 consecutive hours. Also, the subjects were given similar cognitive tests during the 24-hour period to see if there was a difference in the reaction time and scoring of the subject due to the effects of total sleep deprivation.

Results:

The experiment tests the subjects' vital signs of blood pressure, heart rate, and body temperature every four hours starting from time 0, which is 12 hours after the subject first awoke, and consistently checks for 24 hours. The cognitive tests were performed at 4pm, which falls in the range of the peak cognitive ability, and the subjects were scored on the number they got correct in the time frame provided. Each of the tests was statistically evaluated using a paired t-test to determine if the control and treatment were significantly different (Ref. 7).

Blood pressure data, (Fig.1) on average, shows a slight decrease during the sleep deprivation treatment. The data were graphed using the formula [(SP-DP)/2]+DP where SP stands for systolic pressure and DP meaning diastolic pressure. The average was taken between all subjects and the mean was then graphed. The control line illustrates a dramatic drop at time 2, approximately around 3am, which was the time of the subjects' deepest sleep. This drop is common since the body is doing the least amount of work. The blood pressure, however, rose steadily from 90.6 at time 2 to 95.5 at time 3 as the subjects woke up and started working. The control blood pressure steadily rose throughout the day as the people went through their daily tasks. The treatment blood pressure shows a constant range approximately 95 throughout the entire experiment. Because the subjects received no sleep during the time when the control reached its lowest peak, the blood pressure seems higher; however, little change was evident. Statistically, there is no significant statistical difference (p value = 0.1277) between the control and the treatment at time 2. This lack of difference can be attributed to the fact that one subject may have had an abnormally high or low blood pressure at that time and disrupted the t-test. Because the treatment blood pressure had no place to rise, there was no significant increase is evident in the control. As the day continued the blood pressure raised slightly as more activity took place. Overall, the blood pressure during sleep deprivation decreased slightly, but the average for the whole data was not statistically different in the t-test with a p-value of 0.9937 and t = 0.0082.

Sleep deprivation has a significant effect on heart rate, which overall shows a great decrease in comparison to the control situation (Fig. 2). The subject's pulse was taken for 10 seconds and then multiplied by 6 to receive the heartbeats per minute. The average was taken between each individual at each time interval and that number graphed. The data, however, is deceptive because while the two lines look like they differ greatly, the difference could lie only between one or two heartbeats. The control line illustrates the normal pulse rate for a regular day. The pulse rate decreased significantly to 74 bpm at time 2, which was the time when the subjects were within the deepest sleep. The rate increased steadily to 80 bpm when the subjects were awakened and began their day. The pulse rate for the treatment of sleep deprivation decreased slowly throughout the trial, reaching a low point at approximately time 2 with 69 bpm. While the subjects were not at sleep, little physical activity was taking place throughout the night, which could account for the decrease at time 2. There is no significant difference between the control and the treatment at time 2 as the t-test valued p at 0.4341 and t = 0.85. The paired t-test, however, shows that there is an extremely significant statistical difference for the data as a whole with the p-value = 0.0006, therefore confirming that sleep deprivation leads to a decrease in the individual's heart rate.

Body temperature was affected by the sleep deprivation experiment (Fig. 3). The control data illustrates the common circadian rhythm and was influenced by the sleep. The body temperature drops between time 1 (36.7 C) and time 2 as the body enters sleep, and ultimately reaches the lowest peak at time 2 at approximately 36.3 C. This lowest point is occurred around 3am when the body enters the deepest REM sleep. From time 2 on the body temperature rose steadily to time 5 when it peaks with 37 C, and the data begins to slowly fall at the subjects settle down for the night. Sleep deprivation during the treatment section of the experiment prevented the body from following the common circadian rhythms and sleep interaction. The body temperature of the subjects decreases steadily reaching the lowest point (36.3 C) at time 4, which is around 4pm. There is a significant difference when the t-test was performed between the control and treatment at time 4 with the p-value = 0.0067 and t = 4.453. The treatment body temperature rose slightly from time 4 to time 6 (36.5 C), which could have been caused by more physical activity as the subject struggled to stay awake. While the data shows the lack of a circadian rhythm during sleep deprivation, overall, the data did not show a significant statistical difference that was expected in data as a whole with the p-value equaling 0.3497 and t = 1.014.

The performed cognitive tests were significantly affected by sleep deprivation, where the data shows a decrease in cognitive and memory ability when the scores of the control test are compared with the scores of the cognitive tests during total sleep deprivation. The first test, word association, shows a slight drop from 6.2 to 4.83 correct out of 10 paired words, but does not register significantly different during the t-test with the p-value = 0.2488 and t = 1.3047 (Fig. 4). The Hayling's test, however, does show significant statistical difference between the control, averaging 9.8 versus the treatment, which scored 7.12. The t-test provides the p-value of 0.0429 and t = 2.6968 (Fig. 5). During the verbal fluency test the subjects were able to name fewer animals during the treatment part of the experiment in comparison to the control. The average when the person had a full night's rest was 31.5, but the lack of sleep reflected in the scores of the verbal fluency test averaging only 24.5 on the treatment. These data reflect a significant statistical difference in the t-test with the p-value = 0.0218 and t = 3.2877 (Fig. 6). The verbal recall test proves to be the most constructive cognitive test and shows extreme statistical difference. Trial 1, which the subject was scored after five minutes, the control subjects scored an average of 6.3 out of 10, while the sleep deprived scored only 2.5 out of 10 (Fig.7). The t-test provides a result of significantly different because the p-value = 0.0020 and t = 5.8609. Trial 2 scored the subjects on the same ten words after twenty minutes with significant decreases. The control subjects remain the same with an average of 6.3, but the sleep deprived score decreases even more with an average of only 1.83 out of 10. The p-value = 0.0015 and t = 6.2605, which confirms an extreme statistical difference between the control and the treatment (Fig. 8). The last cognitive test consists of face recognition, in which the subjects are asked to identify faces after being previously shown 30 minutes before. The control subjects averaged 7 out of 10, but the sleep deprived scored 6.17. The t-test does not show a statistical difference with this cognitive test where the p-value = 0.4968 and t = 0.7324 (Fig. 9). Overall, the statistical tests show that the cognitive tests averaged lowered scores when the subjects were deprived of sleep when compared to the scores when sleep was allowed.

Discussion:

With a lack of sleep come many unwanted side effects, ultimately including depression of human vital signs, and impairment of thinking and memory. The experiment was designed to test the effects of total sleep deprivation on blood pressure, heart rate, and body temperature, and all vital signs displayed decreasing results during the treatment. Along with these tests, cognitive tests were performed to see if a correlation lies between sleep and memory skill. Overall, the results of the cognitive tests confirmed that sleep deprivation releases a negative effect on critical thinking, creativity, and memory.

The blood pressure results show a consistent pattern in comparison to the control, which demonstrated regular sleep oscillations. Though the blood pressure did not drop significantly enough to show results in the t-test because the subjects never slept, the body did not have time to rest, which would prevent the blood pressure from rising during the day. The t-test results did not show a statistical difference between the control and the treatment. This could be attributed to one or two people who had sudden increases or decreases of blood pressure within the time frame, thus upsetting the data. Experimental error could also play into the results of the blood pressure because the recorder could have read the sphygmomanometer wrong while taking the blood pressure since no computing software was used.

Heart rate was significantly affected by the total sleep deprivation because the rate dropped steadily throughout the 24-hour time frame (Fig. 2). Other performed experiments confirm that extended hours of wakefulness causes a reduction in heart rate, which is ultimately mediated by a decline in cardiac sympathetic activity (Holmes *et. al.* 2002). The statistical tests from this experiment confirm a significant difference between the overall averages of the control and the treatment, therefore correlating extended hours of wakefulness with a decline in cardiac activity and rate. One change could have been made to this section of the experiment to make the results more accurate, and that is taking the heart rate for a full minute instead of measuring for ten seconds and multiplying by six. While this should not significantly change the results, it would confirm the test's accuracy for a full minute of heartbeats.

The body's temperature drops greatly through the night during sleep and raises the following day as the body becomes more active, which is all related to circadian rhythms within the body. Literature confirms that sleep patterns alter the core body temperature and ultimately sleep deprivation leads to an overall decrease in body temperature (Holmes *et. al.* 2002). The lowest peak of body temperature occurs during REM sleep, which is the deepest part of a person's sleep and the point in which dreams occur. Since the subjects were not able to reach REM sleep during the treatment and the hypothermic effect of nighttime sleep, the body temperature was unable to drop significantly. This seems to be mediated by a reduction in heat production produced by cardiac sympathetic activity. Therefore, since cardiac activity decreased, leading to a depression of heart rate and blood pressure, the body did not produce enough heat during sleep deprivation, depressing the core body temperature.

Since many people struggle to get enough sleep, much concern has been raised over the correlation between sleep and memory and learning skills. This is one of the more common experiments explored in sleep deprivation and one of the most misunderstood. It is hypothesized that REM sleep has important role in memory consolidation, but the evidence is weak and contradictory (Siegel 2001). In that same article, Siegel continues to explain that many studies show that REM sleep deprivation does not affect learning of "intentional" tasks such as paired associate learning, verbal learning, and retention of anagrams, and thus scientists should focus on procedural learning tasks instead (Siegel 2001). However, in the cognitive tests performed with this experiment, many of which focused on such intentional tasks, positive test results show that sleep deprivation decreases a persons' ability for thinking critically, creativity, and within a reasonable time limit.

The word association test did not show statistical differences between the control and treatment. This could easily be attributed to the fact that it was the first test given and the person was more prepared. Also, the paired words may have been too difficult to remember even with a full night's rest. Next time the test should include paired words that are consistent, such as a verb and a noun put together. The Hayling's test, on the other hand, proved to be statistically different during the treatment, and illustrates that sleep deprivation does in fact affect the subject's ability to think creatively and logically. Total sleep deprivation affects the subject's ability to perform the verbal fluency test, which consisted of naming animals. It is shown that people who have had a lack of sleep cannot think fast enough and tend to repeat themselves or continue in circles, which ultimately affects the ability to recall information fast enough. This test, however, shows that total sleep deprivation does not affect long-term memory because the persons were still able to recall the names of animals. Other cognitive tests, however, correlate short-term memory loss with sleep deprivation. Because sleep deprivation affects short-term memory, the verbal recall test shows the most significant results of all the cognitive tests (Fig. 7-8). Short-term memory is established within seven minutes, and since the test asked the subject to recall the words after only five minutes, the lower scores illustrate that the lack of sleep affected the short-term memory. Ultimately, since the short-term memory was affected, the subjects were unable to process a long-term memory with the prepared words, thus resulting in an even sharper decrease in cognitive scores. The last cognitive test, face recognition, did not prove to be statistically different, which could be attributed to many different aspects (Fig. 9). It was the last test performed, which meant the subject may have been bored and uninterested in the pictures. Many of the names may have been uncommon or the pictures were not clear enough to distinguish in memory, resulting in the poor outcome. It would be better in future experiments to make sure the test is clear and understandable, and to test the subjects on the recollection of the names leading to a more effective test.

While the experiment proves to be successful in determining several effects of sleep deprivation on the human body, much is yet to be determined concerning total sleep deprivation. Scientists have been studying the brain's activity and functions during memory consolidation. The negative effects of sleep deprivation concerning alertness and cognitive performance suggests underlying alterations in brain physiology and function. Such a decrease seems to be found primarily in the thalamus, which is involved in alertness and attention, and also in the prefrontal cortex, which subserves alertness, attention, and other cognitive processes (Thomas *et. al.* 2000). These two cardinal features, alertness and cognitive performance, are greatly affected by lack of sleep. Thomas suggests that complex tasks performance is impaired as shown through tests of working memory, verbal fluency, logical reasoning, and creative thinking and planning. In a documented experiment testing cerebral response following sleep deprivation, the brain showed greater responsiveness to some cognitive demands during sleep deprivation (Drummond *et. al*. 2001). The results show that brain regions showing a significant response to total sleep deprivation include verbal learning regions as well as regions associated with attention (Drummond *et. al*. 2001). Ultimately, these studies have revealed a diminishing performance in divided tasks impairing the subject's ability to switch attention between tasks or improving attention to a new task.

While these studies seems to show significant results and effects of total sleep deprivation on the human body and thinking, the data do not fully answer the questions that have been raised, leading to an increasing number of discrepancies within this field. Siegel presents many cases in which scientists try to prove or disprove the correlation between total sleep deprivation, REM sleep, and memory consolidation (Siegel 2001). While we know that sleep is clearly important for optimum performance of learned tasks, the major role in memory consolidation and sleep deprivation is unproven. Much more research and experiments need to be done before any conclusive theory can be stated about such correlation involving sleep deprivation. Information must be obtained relating the amount of REM sleep with learning, the extent or depth of REM sleep, and the absence of REM sleep in memory consolidation before a conclusion can be made (Siegel 2001).

Ultimately, this experiment was successful in testing the effects of total sleep deprivation on human vital signs and cognitive abilities. Future experiments concerning this subject should be performed under a more controlled environment and include more subjects. This would hopefully account for more accurate results and data. Also, the cognitive tests should be given with more variety as discussed earlier, including mathematical tests, which seem to have a different effect upon cerebral activity (Drummond *et. al.* 2001). Overall, total sleep deprivation does affect the human body as illustrated with this experiment's data. Scientists have yet to conclude the actual effects upon cognitive and memory consolidation, but they know that sleep disruption occurring before learning will affect performance, along with disruptions in sleep patterns. Just as nutritional status, stress levels, and other variables affect the ability to concentrate and learn, adequate sleep is vital for the optimum performance in memory and learning. Understanding the effects of sleep deprivation will not only help scientists and doctors with their research, it will ultimately help the general public survive on lack of sleep in this fast-paced society.

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Figure Legends:

Figure 1: Blood Pressure

This figure illustrates the 6 subjects' blood pressure over the 24-hour testing period, in which the blood pressure was taken every four hours. The blood pressure was graphed using the formula [(SP-DP)/2]+DP, and the average of the entire data was then placed on the graph. The graph displays an overall decrease of the blood pressure in during the sleep deprivation part in comparison to the control blood pressure. The paired t-test issued the p-value at 0.9937 and $t = 0.0082$, which rates the overall data as not significantly different.

Figure 2: Pulse

This graph displays the average heart rate for 6 subjects during a 24-hour period. The vital sign was taken very four hours, and shows extreme statistical difference. The control line follows along a normal path, especially during sleep, in which the subjects' heart rates decreased greatly, and rose steadily when being awakened. Sleep deprivation has significant effects at lowering the body's heart rate steadily throughout the 24 hour testing time. The p-value given from the paired t-test was 0.0006 and $t = 4.6018$, illustrates overall an extreme significant difference.

Figure 3: Body Temperature

The average body temperature for the 6 subjects' is displayed in this graph. The temperature was watched over a 24-hour period and taken every 4 hours. The control line illustrates the circadian rhythm, in which sleep is affected. The body temperature drops steadily the subjects reach REM sleep, the deepest sleep, and then rises steadily throughout the day. On the other hand, the sleep-deprived subjects during the treatment part did not follow the circadian rhythm and shows a steady drop in body temperature, which was expected. However, the paired t-test results did not show a significant difference in the data with a p-value = 0.3497 and $t = 1.014$.

Figure 4: Cognitive Test 1: Word Association

The subjects were asked at 4 p.m. to repeat ten pairs of words, 5 associated and 5 non-associated, and the average scores out of 10 are listed in the graph. During the control, the subjects' scores were higher than the treatment scores, in which the persons had been sleep deprived for almost 24 hours. While there was a slight drop as illustrated in the graph, the t-tests did not show a statistical difference and $p = 0.2488$ and $t = 1.3047$.

Figure 5: Cognitive Test 2: Hayling's Test

The graph illustrates the difference in scores of the control and sleep deprived when asked to perform the Hayling's Test. The subject was asked to complete the sentence with a word that rendered the sentence meaningless. The graph shows the decrease in scores in the treatment in comparison to the control. The t-tests depicted a significant statistical difference with $p = 0.0429$ and $t = 2.6968$.

Figure 6: Cognitive Test 3: Verbal Fluency

This figure displays the results of the verbal fluency tests in which the 6 subjects were asked to name how many animals they could in one minute. The average of the control and the treatment were recorded and are listed in the graph. The sleep deprived subjects scored lower and were unable to name as many animals as the time when the subjects had a full night's rest. The t-test shows significant statistical difference between the control and the treatment with the p-value at 0.0218 and $t = 3.2877$.

Figure 7: Cognitive Test 4: Verbal Recall (Trial 1 @ 5 mins.)

The subjects were given a list of ten words and asked to repeat as many words as possible after five minutes. The average score of the 6 subjects were placed in the graph, which illustrates an extreme statistical difference between the control and the sleep deprived, who were unable to recall many of the words. The paired t-test issues the data a p-value of 0.0020 and $t = 5.8609$, which is a significant result.

Figure 8: Cognitive Test 4: Verbal Recall (Trial 2 @ 20 mins.)

As described in Figure 7, the 6 subjects were then asked to recall the same ten words after twenty minutes, which is to test their long-term memory. The average of both the control and the treatment were graphed and the t-test proved that there was a significant statistical difference between the two with the value of $p = 0.0015$ and $t = 6.2605$.

Figure 9: Cognitive Test 5: Face Recognition

This graph shows the result of the memory game in which the 6 subjects were shown 10 faces and asked to correctly identify those faces after 30 minutes. The average data reveals that the sleep deprived were less able to correctly recognize the face after 30 minutes when compared to the control. However, the paired t-test did not show a significant statistical difference between the control and the treatment with the p-value at 0.4968 and $t = 0.7324$.

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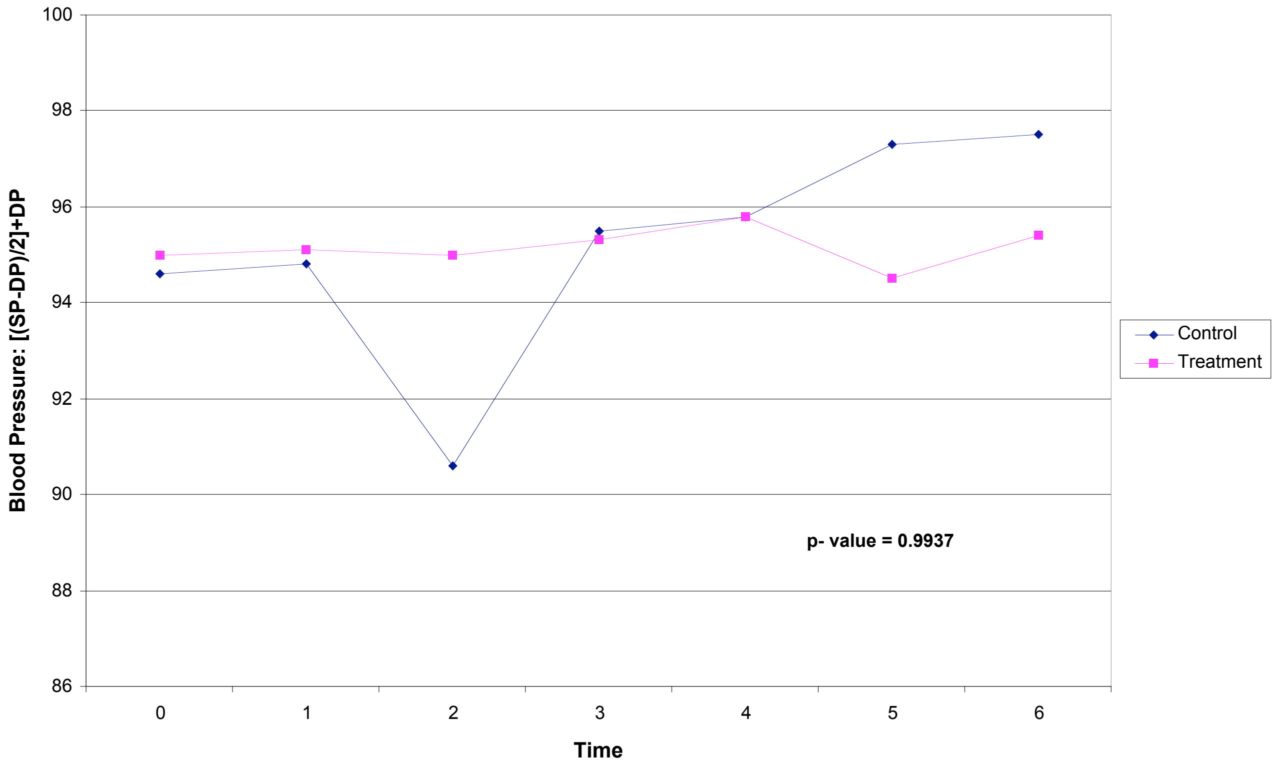

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