Assessing the Precision and Accuracy in a Small Sample of Actical Devices

Peter Sherick
Utah State University

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ASSESSING THE PRECISION AND ACCURACY IN A SMALL SAMPLE OF ACTICAL DEVICES

by

Peter Sherick

A report submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Statistics

UTAH STATE UNIVERSITY
Logan, Utah
2010
ABSTRACT

Assessing the Precision and Accuracy in a Small Sample of Actical Devices

by

Peter Sherick, Master of Science
Utah State University, 2010

Major Professor: Dr. Jürgen Symanzik
Department: Mathematics and Statistics

Abstract

Actigraphy is an increasingly popular approach in medicine to assess patient activity levels in a variety of scenarios. The devices are essentially accelerometers encased in a wrist-watch type assembly. This project sought to determine the device precision and accuracy for the Actical model. In a sample of four Acticals, it was found that intra-device variability was minimal. However, one device was found to be statistically biased in comparison to the other three. This bias could have adverse effects on aggregated or magnitude dependent data analysis. Also, inter-device comparisons may be problematic.
ACKNOWLEDGMENTS

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1. Introduction

For many years, the positive effect of exercise and activity on health and well-being has been known to medical doctors, if not explicitly demonstrated. For one, measurements on health and well-being are usually only implicitly related to these attributes. Heart rate and blood pressure are useful health measures, but may be confounded with other factors such as diet and family history. Patient responses are not easily quantified, questionnaires are the common (though problematic) approach. It is likewise difficult to assess the level of a patient’s activity. Again, self-reported data is helpful, but may also be incomplete or misleading. Reliable measurements of energy expenditure can be made in a laboratory setting. However, these procedures may be time-consuming, invasive or inconvenient. Additionally, they may fail to capture an individual’s true active nature.

A relatively new and popular approach is to measure physical activity via actigraph devices. Essentially, an actigraph is an accelerometer that records movement frequency and is encased in a wrist-watch type assembly. Labyak and Bourguignon (2002) discussed the application and issues of actigraphy technology in elderly women, including those recovering from illness and injury. They concluded that, along with self-reports, actigraphy can provide a useful representation of physical activity. An actigraph can be worn by an individual over an extended period of time, continuously recording data. In conjunction with patient information, a detailed picture of the exercise pattern and physical lifestyle can be constructed. Sleep patterns and restlessness can also be closely monitored.

With any measurement device, there is a concern regarding the reliability of the measurements. While activity is an abstract quantity, it is desirable that like devices give similar readings when exposed to the same conditions or movements. If a particular device was to systematically record imprecise or biased measurements, the
overall picture of the patient’s activity level might be obscured. Resulting conclusions could also be affected. Therefore, appropriate action should be taken to ensure that reasonable results are obtained.

Previous research has shown complications with measurements from various accelerometer instruments. One of the earlier models, the RT3, has been subjected to several experiments to assess quality. Powell, Jones, and Rowlands (2003) conducted reliability tests on the RT3 using a vibration and jig assembly. The devices were mounted so variability could be assessed in three directions of movement. While inter-device reliability was not a concern, orientation had a significant impact on readings. In a later study, Powell and Rowlands (2004) investigated eight RT3s simultaneously on a human subject. Typical movements were analyzed including: rest, walking, running, sitting and standing. Here, inter-device bias was a prominent complication particularly for high activity movement. The researchers recommended caution be exercised, especially when comparing among multiple devices.

The uniaxial RT3 has subsequently been displaced by triaxial (accelerometers able to measure in three dimensions) models. The Actical (Mini Mitter Company Incorporated, 2005) and ActiGraph (Actigraph Incorporated, 2010) are the most prominent in the literature. Esliger and Tremblay (2006) investigated a relatively large sample of 39 Acticals and 48 ActiGraphs. They found seven Acticals in the batch were too biased for use and advocated for field calibration equipment and frequent checking. These opinions were echoed in a follow up by Colley, Gorber, and Tremblay (2010).

There is considerable evidence to suggest calibration and reliability checks should be conducted in actigraphy research. As part of a larger study, an experiment and analysis was conducted on a small sample of representative Actical devices using a shaker table setup. In particular, device accuracy and precision are assessed. Accu-
racy is the agreement of measurements with the true, but unknown, value. Precision is the agreement of multiple measurements with one another. The setup of the experiment to compare the Actical devices is discussed in Section 2. In Section 3, the results are presented in both graphical and tabular forms. Finally, in Section 4, the implications of the experiment and analysis are discussed along with recommendations for future actigraphy research.
2. Methods

An initial experiment consisted of placing a bag containing a set of four Acticals in a backpack during a day hike. The Acticals were not secured or fastened in any specific manner within the bag. They were set to record at one-minute epochs, that is, the activity accumulated over one minute intervals. Once downloaded, plots of the data were generated. It was decided (see Results) than an in-depth analysis of the data would most likely not be productive due to the rudimentary experimental design. Consequently, a controlled experiment was constructed to compare the measurements of the Acticals.

To assess the reliability and default calibration of the Actical devices, the same four devices were used as in the backpack study. The entire experiment was completed over three hours on September 11, 2009. After first clearing the device memories, the Acticals were attached to a shaker table. The Actical devices were set to record at 15-second epochs. The table was set to Speed 3 for a period of four minutes and then turned off. After two minutes, the table was turned on at approximately the same speed. Due to the dial setup, it was not possible to achieve the exact same speed settings. The table was then turned off for another two minutes and the same procedure was repeated, for two periods each, at Speeds 6 and 8. The entire process was repeated twice. In total, three runs of two phases at Speeds 3, 6, and 8 were completed. After each run, the device memories were downloaded and then cleared. For each of the four Actical devices, there were six four-minute measurement series for each speed.

The raw downloaded data were saved as .awc files by the Actical software. These files were converted into .csv files in the R Statistical Software environment (R Development Core Team 2010). In order to effectively compare measurements from devices, it was necessary to subset the data. The first step involved locating the experimental
observations. However, it was beyond the control of the experimenters to start the shaker at exactly the same time as the time intervals studied. As a result, it was decided to use only the inner 14 observations of each four minute series of 16 observations. In this manner, observations over intervals where the shaker was turned on or off were eliminated. At Speed 3, all four Acticals consistently recorded activities of exactly zero for all of their 54 observations (14 inner measurements × 6 series). These measurements were excluded from any further analysis. Thus, for each Actical device there were six series of 14 observations at Speeds 6 (low) and 8 (high). The total of 672 observations (14 measurements × 6 series × 2 speeds × 4 Acticals) were used for the remainder of the analysis.

As a preliminary investigation, scatterplots of the data are constructed. Summary statistics are then computed for each series of observations including the mean, standard deviation and coefficient of variation. The deviations (Eq. 2) are also calculated for use in the variance analysis. These are the observed activity less the mean activity of all four Acticals (Eq. 3) at each of the 14 measurements. Histograms, Normal-Quantile plots and Boxplots of the deviations are generated. Additionally, the sample autocorrelation functions (ACF) are plotted for each series along with approximate 95% confidence bounds to assess time dependency. ACF plots measure the linear association of a series at various lags or time separations (i.e., significance at lag 1 indicates some dependency between consecutive observations).

Methods exist for production testing of electronic device in a quality control setting, see Engler, Souders, and Stenbakken (1998). Assessing in-field devices based on their measurements requires a different approach. The analysis of bias and precision of measuring devices can be accomplished in a manner of ways. Hahn and Nelson (1970) discussed comparing two devices using t-tests for the bias and F-tests for the precision. Grubbs (1973) constructed tests to compare three devices after finding
differences between the readings. Jaech (1976) advanced Grubbs’ work to include comparisons of more than three devices. Working with Grubbs’ model, Christensen and Blackwood (1993) proposed a multivariate regression setting that is comparatively straightforward to implement for any number of devices.

Accuracy and precision must be addressed separately. Two methods are used to assess these quantities for the Actical devices. The first method is the multivariate regression technique for assessment of device precision. To determine device accuracy a traditional ANOVA approach is taken.

2.1 Analysis of Precision

Twelve multivariate regressions are performed, in six phases \((l)\) for each of the low \((k = 1)\) and high \((k = 2)\) speeds. The means over all four devices \((j)\) are calculated at each of the 14 measurements \((i)\) in a series (Eq. 3). The deviations (Eq. 2) are then regressed on the means (Eq. 1). Due to the repositioning of the Acticals on the shaker table for the three runs, the residuals of each Actical are assumed to be uncorrelated. Note that only three regressions are used for the four Actical devices to avoid dependency with the mean. Namely:

\[
\begin{align*}
(1) \quad \bar{y}_{ijkl} &= \delta_{jkl} + \gamma_{jkl} \bar{y}_{i.kl} + \epsilon_{ijkl} ; \quad i = 1, \ldots, 14 ; \quad j = 1, 2, 3 ; \quad k = 1, 2 ; \quad l = 1, \ldots, 6 \\
(2) \quad \bar{y}_{ijkl} &= \bar{y}_{ijkl} - \bar{y}_{i.kl} ; \quad j = 1, \ldots, 4 \\
(3) \quad \bar{y}_{i.kl} &= \frac{1}{4} \sum_{j=1}^{4} y_{ijkl}
\end{align*}
\]

where

\[
\begin{align*}
(2) \quad \bar{y}_{ijkl} &= \bar{y}_{ijkl} - \bar{y}_{i.kl} ; \quad j = 1, \ldots, 4 \\
(3) \quad \bar{y}_{i.kl} &= \frac{1}{4} \sum_{j=1}^{4} y_{ijkl}
\end{align*}
\]
To test for the equality of variances, the full model (Eq. 1) is tested against the reduced model (Eq. 4):

\[ \tilde{y}_{ijkl} = \delta_{jkl} + \epsilon_{ijkl} \quad ; \quad j = 1, 2, 3 \]

That is, a test that all the regression slopes are zero is conducted (i.e., \( H_0 : \gamma_{1kl} = \gamma_{2kl} = \gamma_{3kl} \) vs. \( H_a : \gamma_{ikl} \neq 0 \) for at least one \( i \)). A standard multivariate test statistic, Pillai’s Trace, is computed. This test assumes the residuals are multivariate normally distributed, the statistics are approximately F-distributed. For a general description see Appendix B1, further information can be found in Khattree and Naik (1999). The tests are conducted at the \( \alpha = 0.05/12 = 0.00416 \) significance level, using a Bonferroni correction for the twelve tests to account for multiple comparisons. A rejection of the null hypothesis indicates there is a difference amongst the variances, or the precision, of the Acticals. Groupings (represented by A, B, C, up to D, if applicable) are consequently determined by running the same analysis on the measurements series of two Acticals at a time. For example, consider pairwise comparison of the variances of Actical 1 and 2 in a phase. The mean is found at each index of the two 14-measurement series. Thereafter, the deviations for Actical 1 (or Actical 2) would be calculated and regressed on the mean. Testing the slope (\( \gamma = 0 \)) as before determines whether the variances (precision) of Actical 1 and 2 are equal. It is not possible to perform this analysis if a series consists of 14 identical measurements, as this series would have no variability. As such, these Actical series are treated as distinct from any series that consists of at least two different measurements. The analysis is altered to test the variances of the remaining non-constant series. In testing the subsets, the Actical with the maximum variance is tested against the Actical with the minimum non-zero variance. If these are statistically different, the next pair of Actical variances
is considered. If the variances are not statistically different, then all the non-zero Actical variances (that are consequently between the maximum and minimum), are likewise not statistically different. Therefore, the Acticals are not distinct in precision. As such, the Acticals are assigned the same letter in the grouping.

Additionally, one can test the equality of both means and variances of the measurement series at once by computing the test statistic for the full model (Eq. 1) versus the residual model (Eq. 5):

\[
\bar{y}_{ijkl} = \epsilon_{ijkl} \quad ; \quad j = 1, 2, 3
\]

SAS Software (SAS Institute Inc. 2010) is used for this analysis. Note the analysis can also be performed in R using the `lm()`, `manova()` and `anova.mlm()` functions. Code for the R and SAS analyses is included in Appendices F and G.

### 2.2 Analysis of Accuracy

In comparison of the device biases, while the test above (Eq. 1 vs. Eq. 5) is useful, it does not allow direct comparisons on the means alone. Provided the variances are not unequal, a relatively simple Analysis of Variance (ANOVA) can be used. Graphical checks are used to assess model assumptions i.e., the residuals are independent, normally distributed with constant variance (Oehlert 2000). The observed Activity of the shaker \( \bar{y}_{ijkl} \) is modeled as follows (Eq. 6). Twelve ANOVAs in total are calculated using SAS Software and presented in Appendix E. Each has been indexed by the two speeds \( k \) and six phases \( l \). Here \( \mu_{kl} \) is the true unknown activity of the shaker and the effect of Actical \( j \) is accounted for by \( \eta_{jkl} \), a factor with four levels. The residual is expressed as \( \epsilon_{ijkl} \).

\[
y_{ijkl} = \mu_{kl} + \eta_{jkl} + \epsilon_{ijkl} \quad ; \quad i = 1, \ldots, 14 \quad ; \quad j = 1, \ldots, 4 \quad ; \quad k = 1, 2 \quad ; \quad l = 1, \ldots, 6
\]
The mean groupings are determined using Tukey’s Honest Significant Difference (HSD). For an explanation of this method, see Appendix B2 or Christensen (1987). To account for the multiple comparisons of the twelve ANOVAs, a Bonferroni correction is applied to the significance level: $\alpha = 0.05/12 = 0.00416$. Acticals are grouped together (same letter) if their means are not statistically different. An Actical could be placed into two groupings if it is not statistically different from two Acticals that are different. This could happen if the mean activity is between the other two Acticals’ mean activities that are different. The grouping of the intermediate Actical would then be represented with two letters.

In addition to the twelve analyses by phase, the six phases of low speed measurements are used within a separate ANOVA. The six low speeds are treated as distinct levels of the factor $\beta_{kl}$ in this analysis. The observed activity of the shaker $(y_{ijkl})$ is modeled in the two-way ANOVA with interaction (Eq. 7). The effects of the Actical, the speed, and the interaction of the two are accounted for by $\eta_{jk}$, $\beta_{kl}$, and $\eta\beta_{jkl}$; respectively. The residual is expressed as $\epsilon_{ijkl}$. The same analysis is repeated for the six high speed phases. Hence, $k = 1, 2$ represent the separate ANOVA models (presented in Appendix E) for low and high speeds:

$$y_{ijkl} = \mu_k + \eta_{jk} + \beta_{kl} + \eta\beta_{jkl} + \epsilon_{ijkl} ; i = 1, \ldots, 14 ; j = 1, \ldots, 4 ; k = 1, 2 ; l = 1, \ldots, 6$$

Mean groupings are again determined using Tukey’s HSD. The SAS code for the ANOVA analyses is available in Appendix G2. Though, an equivalent analysis can be performed in R, it is more complicated and many pieces must be done “by hand.”
3. Results

As positioning of the Acticals can have a pronounced effect on the measurements, it was concluded the data from the day hike experiment were not reliable enough to make definitive statistical inference. However, it is somewhat useful to compare plots of these data (Fig. 1). While the same general pattern of activity is captured by each device, the magnitude is often quite different. There is also aggregation of data as a result of the one-minute epochs. From this experiment it was decided that the maximum resolution of data should be obtained for analysis purposes. Thus, the Acticals were set to record at 15-second epochs for the following shaker experiment.

![Fig. 1: Plots of Activity During Preliminary Experiment](image)

[Activity recorded during a day hike by four Actical devices simultaneously. Due to the nature of the experiment, it is difficult to assess differences between the devices.]
The data recorded during the shaker experiment consisted of three runs of two phases at three speeds (3, 6, and 8). However, all the data recorded at Speed 3 are zero. These data are not utilized for the subsequent analysis. The condensed dataset used in the analysis can be found in Appendix A. The analysis consists of only the two low (Speed 6) and two high (Speed 8) series of the 14 inner observations. For example: L1, L2, H1, H2 stand for Low 1, Low 2, High 1, and High 2, respectively. These denote the four phases of the first run (the zero phases have been dropped). Scatterplots of the data over the experiment, separated by run and speed, are shown in Figure 2. Relevant summary statistics including the coefficient of variation (CV), standard deviation (SD), and mean are presented in Tables 1, 2, and 3, respectively. Of particular note is the consistent trend of Actical 1 recording the greatest mean activity count through all phases of the experiment.

Deviations from the mean of the four Acticals are determined at each of the 14 observations in the same phase and speed. Histograms, Boxplots, and Normal-Quantile plots of the deviations are generated to address model assumptions. A sample of the plots for the H1 series are shown in Figure 3 on top (Histogram and Normal-Quantile plot only). The complete collection, including Boxplots, is presented in Appendix C, Figures 4-6. The Normal-Quantile plots and Histograms show normality may not be satisfied. Many of the Boxplots are long-tailed or skewed.

In addition, plots of the sample autocorrelation function (ACF) are constructed for each series with 95% confidence bounds to detect time dependency. As an example, the ACF plots for each Actical's series in H1 shown in Figure 3 (middle and bottom). A lag is the distance between observations. For instance, the first and fifth observations would be separated by 4 lags, as would the third and seventh. The ACF at Lag 0 represents the correlation of each observation with itself and is equal to one.
unless the series is constant, in which case it is undefined. ACF plots for the other phases and speeds are presented in Appendix C, Figures 7-10. There is no consistent trend of time dependency in terms of the lags.
[The activity recorded by four Actical devices during a multi-part shaker table experiment. The table was set to a low speed twice (four minutes each) followed by a higher speed twice to make up one run. Between each four minute phase the shaker was turned off for two minutes. This sequence was repeated for three runs.]
[Using the deviations (Eq. 2), Histograms and Normal-Quantile plots are constructed to assess multivariate normality. It is difficult to determine if this assumption is satisfied due to low variability in the series. Plots of the autocorrelation functions (ACFs) are also created to address time dependency. These demonstrate the dependency of all observations separated by some lag. The dashed lines represent approximate 95% confidence bounds. There is no consistent trend in significant lags.]
No Actical records more than three different values in the series of 14 as shown in Table 2. At most, ten values were unique out of the 56 total observations in each phase. Regression models cannot be fit if all 14 observations are the same for an Actical (i.e., no variability). To address this issue, a reduced model is fit using the series that had at least two different observations. Multivariate normality of the residuals is a necessary precondition to make use of multivariate tests such as Pillai's Trace. For the purpose of this analysis, it was assumed this requirement held. The variance groupings for each phase as determined by Pillai's Trace statistic are presented in Table 2. For the corresponding p-values, see the Regression Results in Appendix D. The number of distinct measurements of the 14 are indicated in parenthesis after the standard deviations (SDs) in Table 2.

The results of the preceding analysis suggest there are no systematic differences between the Actical variances. The ACF plots (Figures 7 to 10 in Appendix C) show no consistent trend in terms of significant lags indicating there does not seem to be time trends. Though not produced, it was assumed plots of the Partial Autocorrelation Function (PACF) would likewise show no time trend. This analysis assumes the other conditions for ANOVA (Eq. 6) held. The mean groupings are determined using Tukey's HSD. These groupings are presented (using letters A, B, C, up to D if necessary) in Table 3. The full ANOVAs and the results from Tukey's HSD (including p-values) can be found in Appendix E. The mean activity recorded for Actical 1 is statistically different (and larger) throughout the experiment.

Two additional ANOVA models (Eq. 7) are also constructed to compare means. These are presented in Appendix E. The first makes use of all the low speed measurements, the second makes use of all those at the high speed. Speed is treated as a separate factor with levels for each phase, six levels of low speed and six of high speed. Due to the assembly of the shaker's speed dial it appears reasonable to treat
the six speeds as distinct. Consulting the data scatterplots (Fig. 2), this assumption seems justified. The corresponding groupings are determined through Tukey's HSD (Appendix B2). The groupings are presented in Table 4. The mean activity for Actical 1 remains statistically different (greater) at both low and high speeds as determined by Tukey's HSD (supporting p-values can be found in Appendix E).
### Table 1: Coefficients of Variation

[The calculated coefficients of variation \((\times 10^{-3})\) for the four Acticals in each phase of the shaker experiment. The maximum CV is indicated in bold face.]

<table>
<thead>
<tr>
<th>Low Speed</th>
<th>CV L1</th>
<th>CV L2</th>
<th>CV L3</th>
<th>CV L4</th>
<th>CV L5</th>
<th>CV L6</th>
</tr>
</thead>
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<tr>
<td>Actical 1</td>
<td>0.00</td>
<td><strong>9.62</strong></td>
<td>8.17</td>
<td>7.22</td>
<td>5.00</td>
<td>5.20</td>
</tr>
<tr>
<td>Actical 2</td>
<td>9.01</td>
<td>4.81</td>
<td>6.45</td>
<td>6.37</td>
<td>6.55</td>
<td><strong>6.89</strong></td>
</tr>
<tr>
<td>Actical 3</td>
<td><strong>9.27</strong></td>
<td>0.00</td>
<td>8.43</td>
<td>5.22</td>
<td>8.02</td>
<td>0.00</td>
</tr>
<tr>
<td>Actical 4</td>
<td>0.00</td>
<td>0.00</td>
<td><strong>8.59</strong></td>
<td><strong>8.88</strong></td>
<td><strong>9.01</strong></td>
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<th>CV H3</th>
<th>CV H4</th>
<th>CV H5</th>
<th>CV H6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actical 1</td>
<td><strong>9.06</strong></td>
<td><strong>7.47</strong></td>
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<td><strong>9.13</strong></td>
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### Table 2: Standard Deviation and Groupings

[The observed standard deviations of the four Acticals in each phase of the shaker experiment. The number of distinct observations in the 14 measurement series are indicated in parenthesis. The corresponding groupings are determined using Pillai’s Trace statistic. The maximum SD is indicated in bold face.]

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### Table 3: Mean Activity and Groupings by Phase

The observed mean activities recorded by the four Acticals in each phase of the shaker experiment. An AB signifies an Actical is not statistically different from those with an A nor those with a B. The maximum mean is indicated in bold face.

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### Table 4: Mean Activity and Groupings by Speed

The observed mean activities of the four Acticals for the low and high speed shaker levels. Actical 4 is neither statistically different from Actical 2 nor Actical 3, hence the BC grouping. It is statistically different than Actical 1. The maximum mean is indicated in bold face.

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4. Discussion

The results of the variability assessment show no pattern of imprecision by Actical device (Table 2). In fact, for twelve of the 48 series, there is no variability in the 14 measurements. That is, identical activity was recorded throughout a phase for an Actical. In H4 (see Table 2) for instance, only Actical 1 recorded more than one distinct value in the 14 measurements; it recorded two different values. At most, three different values were recorded in a 14-measurement series. Assuming the speed of the shaker and resulting output activity was constant, there is strong statistical evidence these Acticals are very precise.

The preceding regression analysis (using Pillai’s Trace statistic) suggests the variability of the Acticals is consistent between devices. The ACF plots also indicate there is no consistent time dependency. It was assumed the PACF plots would confirm the absence of time trends. The ANOVA analyses of bias is therefore justified if multivariate normality of the residuals is satisfied. Due to the structure of the data, it is difficult to verify this assumption. While each phase of the experiment contains 14 observations for each of the four Acticals, most of these are identical. As a result, the residuals are somewhat stratified and normality may not be satisfied. A non-parametric approach such as the Kruskal-Wallis ANOVA might be advantageous in future analysis, as multivariate normality is not required. Nevertheless, it was assumed the robustness of the ANOVA parametric model would allow for the mean comparisons. In all phases of the experiment, across low and high speeds, Actical 1 recorded the largest mean activity count as shown in Tables 3 and 4. The Tukey’s HSD indicates this bias was significantly different from the other three devices both at each phase and at low and high speeds overall (results are found in Appendix F). It is concluded that Actical 1’s measurements were biased.

Additionally, none of the Acticals recorded non-zero measurements during the
shaker experiment at Speed 3. The data from Speeds 6 and 8 are used for the analysis as low and high speeds, respectively. However, the implications of this unanticipated result are noteworthy. There is a threshold that is either a factory setting or a physical limitation of the accelerometer below which activity is not measured. Whether this threshold is below that of the corresponding human activity level of interest warrants further investigation. Powell and Rowlands (2004) demonstrated a similar issue on another model (RT3) of actigraphy device. The instrument was unable to differentiate running speeds above 8km/h. A similar study on the Actical on both very low level activity and high level activity would certainly be of interest.

It should be noted that this was a small scale experiment on a set of only four Actical devices. The fact that one in four devices was statistically biased is insufficient to infer the exact frequency of biased Acticals in a batch. However, Esliger and Tremblay (2006) showed that seven of 39 Acticals were problematic in a similar study. Researchers should use caution as problematic devices may be commonplace. Certainly, when comparing a biased against an unbiased device, issues could arise due to inter-monitor differences. This experiment suggests the variability of a single Actical device is minimal. So, intra-monitor comparisons seem to be fairly stable. However, any aggregative or magnitude dependent conclusions from Actical data should be met with appropriate skepticism.

One issue with the experiment itself was the omission of the position of the Actical device on the shaker table. This information was not recorded so position effects may confound the results. However, the Acticals were removed from the shaker and replaced for the three repetitions to download the data and clear the memory. It seems to be unlikely that the biased Actical would be placed in the same position for all three runs; however, these location data were not recorded.
Another more fundamental issue is the type of movement analyzed. The laboratory shaker experiment is certainly very different from human subject research. Can conclusions from the sterilized mechanical oscillations of the apparatus be applied to actual human movements? Again, a study like that of Powell and Rowlands (2004), where the RT3 was tested on human subjects and common movements, is called for on the Actical device.

Finally, this experiment did not investigate the effect of different angular orientations of the Actical on the shaker. A slight variation may or may not have an impact on the measurements. Orientation as well as placement position (hip or wrist) are additional factors to consider in terms of reliable and reproducible results on test subjects.

In conclusion, the results of the experiment tend to agree with previous work in the field. That is, the calibration and reliability of devices should not be assumed. Depending on the application of the data, it may be necessary to verify device accuracy. Unfortunately, at this point, reliable field-level calibration equipment does not seem to be available. Shaker tables have been a reasonable approach, but fail to account for human movement. Robotic arms also exist but may be cost prohibitive. Indeed, effective testing of actigraphy devices is a time consuming (and therefore costly) undertaking. Researchers should weigh the pros and cons regarding quality control monitoring. However, the developer of the Actical devices recommends periodically returning the devices to the factory for recalibration, Mini Mitter (2005, Section 1-4). In any case, if inter-subject comparisons are to be made, a suggestion would be to use multiple devices on each subject over the course of examination. Doing so will mitigate device differences in the long run. Data analysts should also be made aware of potential device calibration issues, particularly if their methods rely on cumulative or magnitude measures.
Actigraphy is an increasingly popular and useful technology to assess human activity levels in various medical contexts. Though not without concerns, actigraphy can provide a convenient and practical framework to assess activity and exercise patterns in respect to any number of health concerns. Convenience and relatively minimal discomfort are other desirable features. Of course, any measurement device is only as useful as its accuracy and precision. While concerns have been raised, other methods of assessing activity have their own complications. Self reports are often incomplete or inaccurate for instance. Actigraphy is best used as a supplement to current methods and not as a replacement for them. With complementary data, prognosis and management of a multitude of medical conditions are all the more effective. The value of actigraphy research extends to serious illness, recovery, depression and sleep science to name only a few applications. The more reliable the data, the better these problems can be addressed.
REFERENCES


APPENDIX A

DATA

This Appendix presents the experimental data used in the analysis.
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<tr>
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Table 7: Data for Run 3

[The Data extracted for use in the analysis from the third run of the Experiment]
APPENDIX B
TEST DETAILS

This Appendix presents the test statistics used in the analysis.
B.1 Pillai’s Trace Statistic

A multivariate linear model can be represented in matrix notation as

$$Y = XB + \bar{\epsilon}.$$ 

Each $y_i, x_i, \epsilon_i$ is an $n$ by 1 vector in the following:

$$Y_{nxp} = (y_1, y_2, \ldots, y_p)$$

$$X_{nx(k+1)} = (1_n, x_1, x_2, \ldots, x_k)$$

$$B = \begin{bmatrix} \beta_{01} & \beta_{02} & \cdots & \beta_{0p} \\ \beta_{11} & \beta_{12} & \cdots & \beta_{1p} \\ \vdots & \vdots & \ddots & \vdots \\ \beta_{k1} & \beta_{k2} & \cdots & \beta_{kp} \end{bmatrix}$$

$$\bar{\epsilon} = (\epsilon_1, \epsilon_2, \ldots, \epsilon_p)$$

Provided the regression matrix $X$ is of full column rank, one can obtain an estimate of the coefficient matrix $B$ using least squares estimation to minimize the residuals: $\sum_{i=1}^{p} \epsilon_i' \epsilon_i$. This yields the estimates

$$\hat{B} = (X'X)^{-1}X'Y$$

and

$$\hat{Y} = X\hat{B}.$$
Linear hypotheses of the type: $H_0 : \mathbf{LB} = 0 \text{ vs. } H_A : \mathbf{LB} \neq 0$ can be tested by defining the matrix $\mathbf{L}$. To test that all the slopes are 0, $\mathbf{L}$ is chosen as a $p \times p$ identity matrix except for $L_{11} = 0$. This tests that all the coefficients, but not the intercept, are 0. This is the comparison of Equations 1 and 4. To test Equations 1 and 5, choose $\mathbf{L} = \mathbf{I}$. The previous matrices are used to define two new matrices, the Hypothesis Matrix $\mathbf{H}$ and the Error Matrix $\mathbf{E}$ from which the test statistics are computed. These are defined as

$$\mathbf{E} = \mathbf{Y}'\mathbf{Y} - \mathbf{Y}'\hat{\mathbf{X}}\hat{\mathbf{B}} = (\mathbf{Y} - \hat{\mathbf{Y}})'(\mathbf{Y} - \hat{\mathbf{Y}})$$

and

$$\mathbf{H} = \hat{\mathbf{B}}'\mathbf{L}'[\mathbf{L}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{L}']^{-1}\mathbf{L}\hat{\mathbf{B}}.$$  

Pillai’s Trace Criterion is then defined as:

$$V = tr[(\mathbf{H} + \mathbf{E})^{-1}\mathbf{H}] = \sum_{i=1}^{p} \frac{\lambda_i}{(1 + \lambda_i)}.$$  

The $\lambda_i$ are the eigenvalues of $\mathbf{E}^{-1}\mathbf{H}$. The trace ($tr$) of a matrix is the sum of the elements on the main diagonal. Pillai’s Trace statistic follows an approximate F-Distribution. For further details see Khattree and Naik (1999).
B.2 Tukey's Honest Significant Difference

One approach to pairwise mean comparison is Tukey’s method, the Honest Significant Difference (HSD). Let \( y_i \sim N(\mu_i, \sigma^2) \); \( i = 1, \ldots, n \). Then take \( S^2 \) as an estimate of \( \sigma^2 \) that is independent of the \( y_i \)'s so that

\[
\frac{vS^2}{\sigma^2} \sim \chi^2(v)
\]

where \( v \) is the degrees of freedom of \( S^2 \). Then, the quantity

\[
\frac{\max_i y_i - \min_i y_i}{S} = Q \sim Q(n, v)
\]

follows the Studentized Range distribution. For the null hypothesis \( H_0: \mu_i = \mu_j \), one rejects at the corresponding \( \alpha \) level if

\[
\frac{|y_i - y_j|}{S} > Q(1 - \alpha, n, v).
\]

In the situation of the Actical ANOVAs, the \( \bar{y}_{jik} \)'s (the means for each Actical ‘treatment’ over the 14 observations) as in Equation 6 were assumed to be independent and \( S^2 \) was a function of the Mean-Squared Error (MSE) of the ANOVA. The mean groupings were then determined using all pairwise comparisons. A similar approach was taken for the two-factor ANOVA for the low and high speeds. For further information see Christensen (1987), Lattin et al. (2003), and Oehlert (2000).
APPENDIX C

ADDITIONAL GRAPHICS

This Appendix presents the Histograms, Boxplots, Normal-Quantile plots, and ACF plots of the deviations as a diagnostic to address model assumptions.
Fig. 4: Histograms of Deviations

[For each phase of the shaker experiment the deviations were calculated and a Histogram was created to assess normality.]
Fig. 5: Boxplots of Deviations

[For each phase of the shaker experiment the deviations were calculated and a Boxplot was created to assess normality.]
Fig. 6: Normal-Quantile Plots of Deviations

[For each phase of the shaker experiment the deviations were calculated and a Normal-Quantile plot was created to assess normality.]
Fig. 7: Autocorrelations Plots (Actical 1)

[For each phase of the shaker experiment the Autocorrelation plot of each series for Actical 1 were produced to assess time dependency. Series with no variability have undefined autocorrelation.]
Fig. 8: Autocorrelations Plots (Actical 2)

[For each phase of the shaker experiment the Autocorrelation plot of each series for Actical 2 were produced to assess time dependency. Series with no variability have undefined autocorrelation.]
[For each phase of the shaker experiment the Autocorrelation plot of each series for Actical 3 were produced to assess time dependency. Series with no variability have undefined autocorrelation.]
[For each phase of the shaker experiment the Autocorrelation plot of each series for Actical 4 were produced to assess time dependency. Series with no variability have undefined autocorrelation.]
APPENDIX D
REGRESSION RESULTS

This Appendix presents the Regression results and Pillai's Trace Statistic.
L1 Regression Analysis

Actical 2 vs. 3

The REG Procedure
Model: MODEL1
Multivariate Test: EqualVar

Error Matrix (E)
550.89507863

Hypothesis Matrix (H)
0.6049213677

Multivariate Statistics and Exact F Statistics

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L2 Regression Analysis

Actical 1 vs. 2

The REG Procedure
Model: MODEL1
Multivariate Test: EqualVar

Error Matrix (E)
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Hypothesis Matrix (H)
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<td>0.63982028</td>
<td>7.68</td>
<td>1</td>
<td>12</td>
<td>0.0169</td>
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<tr>
<td>Roy's Greatest Root</td>
<td>0.63982028</td>
<td>7.68</td>
<td>1</td>
<td>12</td>
<td>0.0169</td>
</tr>
</tbody>
</table>
L3 Regression Analysis  
**Actical 2 vs. 4**

The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar

Error Matrix (E)  
510.53076589

Hypothesis Matrix (H)  
42.826376968

**Multivariate Statistics and Exact F Statistics**

<table>
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<tr>
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<td>1.01</td>
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L4 Regression Analysis  
**Actical 3 vs. 4**

The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar

Error Matrix (E)  
295.75177485

Hypothesis Matrix (H)  
95.1767968

**Multivariate Statistics and Exact F Statistics**

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<td>12</td>
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### L6 Regression Analysis

#### Actical 1 vs. 4

The REG Procedure
Model: MODEL1
Multivariate Test: EqualVar

Error Matrix (E)
303.74707121

Hypothesis Matrix (H)
117.62792879

Multivariate Statistics and Exact F Statistics

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<td>4.65</td>
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### L6 Regression Analysis

#### Actical 1 vs. 2

The REG Procedure
Model: MODEL1
Multivariate Test: EqualVar

Error Matrix (E)
342.02392374

Hypothesis Matrix (H)
24.351076264

Multivariate Statistics and Exact F Statistics

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### H1 Regression Analysis

**Actical 1 vs. 3**

The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar  

Error Matrix (E)

\[ 840.55263158 \]

Hypothesis Matrix (H)

\[ 463.16166414 \]

#### Multivariate Statistics and Exact F Statistics

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### H2 Regression Analysis

**Actical 1 vs. 2**

The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar  

Error Matrix (E)

\[ 2096.7594735 \]

Hypothesis Matrix (H)

\[ 14.54407954 \]

#### Multivariate Statistics and Exact F Statistics

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</table>
### H3 Regression Analysis

**Actical 3 vs. 4**

The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar

**Error Matrix (E)**  
1921.8011761

**Hypothesis Matrix (H)**  
0.5023962874

**Multivariate Statistics and Exact F Statistics**

<table>
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<td>12</td>
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</tr>
</tbody>
</table>

### H4 Regression Analysis

Acticals 2, 3, and 4 have zero variances. Pillai's Trace cannot be calculated.  
Actical 1 is assumed to have distinct precision in the phase (H4).
H5 Regression Analysis  
Actical 1 vs. 2  
The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar  

Error Matrix (E)  
1892.7207027  

Hypothesis Matrix (H)  
216.77929732  

Multivariate Statistics and Exact F Statistics  
S=1  M=-0.5  N=5  

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<td>0.2638</td>
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<tr>
<td>Roy's Greatest Root</td>
<td>0.11453317</td>
<td>1.37</td>
<td>1</td>
<td>12</td>
<td>0.2638</td>
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H6 Regression Analysis  
Actical 1 vs. 3  
The REG Procedure  
Model: MODEL1  
Multivariate Test: EqualVar  

Error Matrix (E)  
910.20124048  

Hypothesis Matrix (H)  
362.88804523  

Multivariate Statistics and Exact F Statistics  
S=1  M=-0.5  N=5  

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<td>1</td>
<td>12</td>
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<tr>
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APPENDIX E
ANOVA RESULTS

This Appendix presents the ANOVA results and the Tukey HSD test.
LI ANOVA Results

Dependent Variable: activity

<table>
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<tr>
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<th>Mean Square</th>
<th>F Value</th>
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<tbody>
<tr>
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<td>1695.690476</td>
<td>30.11</td>
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<tr>
<td>Error</td>
<td>52</td>
<td>2928.867143</td>
<td>56.324176</td>
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<tr>
<td>Corrected Total</td>
<td>55</td>
<td>8016.928671</td>
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</tbody>
</table>

R-Square: 0.634620

Coeff Var: 0.644181

Root MSE: 7.504943

activity Mean: 1165.036

Source: actical

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<th>F Value</th>
<th>Pr &gt; F</th>
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<tr>
<td>3</td>
<td>5087.071429</td>
<td>1695.690476</td>
<td>30.11</td>
<td>&lt;.0001</td>
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</table>

Least Squares Means for effect actical

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: activity

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<td>&lt;.0001</td>
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Tukey’s Studentized Range (HSD) Test for activity

Alpha: 0.004167

Error Degrees of Freedom: 52

Error Mean Square: 56.32418

Critical Value of Studentized Range: 5.05260

Minimum Significant Difference: 10.134

Means with the same letter are not significantly different.

Tukey Grouping

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<thead>
<tr>
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<tr>
<td>A</td>
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<tr>
<td>B</td>
</tr>
<tr>
<td>B</td>
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<tr>
<td>B</td>
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### ANOVA Results

**Dependent Variable: activity**

<table>
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<th>Mean Square</th>
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**R-Square Coeff Var Root MSE activity Mean**

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<th>Mean Square</th>
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Least Squares Means for effect actical

Pr > |t| for HO: LSMean(i)=LSMean(j)

<table>
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<th>1</th>
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<th>3</th>
<th>4</th>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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Tukey's Studentized Range (HSD) Test for activity

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Means with the same letter are not significantly different.

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<td>1226.000</td>
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### L3 ANOVA Results

**Dependent Variable: activity**

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**R-Square**

- 0.678511

**Coeff Var**

- 0.795388

**Root MSE**

- Activity Mean

- 1180.857

**Least Squares Means for effect actual**

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L4 ANOVA Results

Dependent Variable: activity

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R-Square Coeff Var Root MSE activity Mean
0.647416 0.702876 8.380544 1192.321

Source actical

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<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6706.07143</td>
<td>2235.35714</td>
<td>31.83</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Least Squares Means for effect actical
Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0094</td>
<td>&lt;.0001</td>
<td>0.0088</td>
<td></td>
</tr>
<tr>
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<td>&lt;.0001</td>
<td>0.0609</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>0.0088</td>
<td>0.0609</td>
<td></td>
</tr>
</tbody>
</table>

Tukey's Studentized Range (HSD) Test for activity

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.004167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>52</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>70.23352</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>5.08260</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>11.317</td>
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</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N actical</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1207.429</td>
<td>14</td>
</tr>
<tr>
<td>B A</td>
<td>1197.000</td>
<td>14</td>
</tr>
<tr>
<td>B C</td>
<td>1186.500</td>
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<tr>
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L5 ANOVA Results

The GLM Procedure

Dependent Variable: activity

<table>
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<tr>
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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>1768.142857</td>
<td>589.380952</td>
<td>7.43</td>
<td>0.0003</td>
</tr>
<tr>
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<td>52</td>
<td>4123.571429</td>
<td>79.299451</td>
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<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>5891.714286</td>
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<td></td>
</tr>
</tbody>
</table>

R-Square  Coeff Var  Root MSE  activity  Mean
0.300107  0.729365  8.905024  1220.929

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>actual</td>
<td>3</td>
<td>1768.142857</td>
<td>589.380952</td>
<td>7.43</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

Least Squares Means for effect actual

Pr > |t| for HO: LSTaien(i)=LSTaien(j)

Dependent Variable: activity

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
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<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.120</td>
<td>0.0644</td>
<td>0.0002</td>
</tr>
<tr>
<td>2</td>
<td>0.0120</td>
<td></td>
<td>0.9123</td>
<td>0.5047</td>
</tr>
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<tr>
<td>4</td>
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<td>0.5047</td>
<td>0.1804</td>
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Tukey's Studentized Range (HSD) Test for activity

Alpha  0.004167
Error Degrees of Freedom  52
Error Mean Square  79.29945
Critical Value of Studentized Range  5.08260
Minimum Significant Difference  12.025

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N</th>
<th>actual</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>1229.643</td>
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<td>1</td>
</tr>
<tr>
<td>B A</td>
<td>1221.071</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>B A</td>
<td>1218.857</td>
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<td>2</td>
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<tr>
<td>B</td>
<td>1214.143</td>
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</table>
ANOVA Results

**Dependent Variable: activity**

<table>
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<th>Source</th>
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<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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R-Square Coeff Var Root MSE activity Mean

<table>
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<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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</thead>
<tbody>
<tr>
<td>actual</td>
<td>3</td>
<td>5914.339286</td>
<td>1971.446429</td>
<td>47.67</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Least Squares Means for effect actual

| i/j | 1   | 2 | 3   | 4 | Pr > |t| for H0: LSMean(i)=LSMean(j) |
|-----|-----|---|-----|---|------|----------------------------|
|     |     |   |     |   |      |                             |
| 1   |     | <.0001 |     | <.0001 |      | <.0001                     |
| 2   |     | <.0001 |   | 0.5715 | 1.0000 | 0.5715                     |
| 3   |     | <.0001 |   | 0.5715 | 1.0000 | 0.5715                     |
| 4   |     | <.0001 |   | 1.0000 | 0.5715 |                 |

Tukey's Studentized Range (HSD) Test for activity

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.004167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>52</td>
</tr>
<tr>
<td>Error Mean Square</td>
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</tr>
<tr>
<td>Critical Value of Studentized Range</td>
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<tr>
<td>Minimum Significant Difference</td>
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</table>

Means with the same letter are not significantly different.

**Tukey Grouping**

<table>
<thead>
<tr>
<th>Mean</th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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</tr>
<tr>
<td>B</td>
<td>1160.143</td>
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</tbody>
</table>
### HI ANOVA Results

**Dependent Variable: activity**

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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
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<td>14578.52381</td>
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<td>&lt;.0001</td>
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<tr>
<td>Error</td>
<td>52</td>
<td>13123.28571</td>
<td>252.37088</td>
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<tr>
<td>Corrected Total</td>
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<td>56858.85714</td>
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R-Square: 0.769195

**Type I SS**

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<th>Mean Square</th>
<th>F Value</th>
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<tbody>
<tr>
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<td>43735.57143</td>
<td>14578.52381</td>
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<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Least Squares Means for effect *practical*

<table>
<thead>
<tr>
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<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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Tukey's Studentized Range (HSD) Test for activity

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.004167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>52</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>252.37088</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>5.05260</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>21.452</td>
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</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N</th>
<th><em>practical</em></th>
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<tbody>
<tr>
<td>A</td>
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<td>B</td>
<td>2211.786</td>
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</tr>
<tr>
<td>C</td>
<td>2180.143</td>
<td>14</td>
<td>2</td>
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<tr>
<td>C</td>
<td>2162.143</td>
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</table>
### H2 ANOVA Results

**Dependent Variable: activity**

<table>
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<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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<tbody>
<tr>
<td><strong>Model</strong></td>
<td>3</td>
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<td><strong>Error</strong></td>
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<td>6640.07143</td>
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</tr>
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<td><strong>Corrected Total</strong></td>
<td>55</td>
<td>51345.98214</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**R-Square** = 0.870680

**Coeff Var** = 0.516339

**Root MSE** = 11.30016

**activity Mean** = 2188.518

#### Least Squares Means for effect actical

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>&lt;.0001</td>
<td></td>
<td>0.2821</td>
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<tr>
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<td>0.0077</td>
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<td>&lt;.0001</td>
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<tr>
<td>4</td>
<td></td>
<td>0.2821</td>
<td></td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

#### Tukey's Studentized Range (HSD) Test for activity

**Alpha** = 0.004167

**Error Degrees of Freedom** = 52

**Error Mean Square** = 127.6937

**Critical Value of Studentized Range** = 5.05260

**Minimum Significant Difference** = 15.259

Means with the same letter are not significantly different.

#### Tukey Grouping

<table>
<thead>
<tr>
<th>actical</th>
<th>Mean</th>
<th>N</th>
</tr>
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<tbody>
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<td>2209.000</td>
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<tr>
<td>B</td>
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</tbody>
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H3 ANOVA Results

Dependent Variable: activity

<table>
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<tr>
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<th>F Value</th>
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<tr>
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<td>49443.98214</td>
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<td></td>
</tr>
</tbody>
</table>

R-Square: 0.852599
Coef Var: 0.535260
Root MSE: 11.83872
activity Mean: 2211.768

Least Squares Means for effect actical

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>&lt;.0001</td>
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</tr>
<tr>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<tr>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<tr>
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<td>&lt;.0001</td>
<td>0.1115</td>
<td>&lt;.0001</td>
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</tr>
</tbody>
</table>

Tukey's Studentized Range (HSD) Test for activity

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.004167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>52</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>140.1552</td>
</tr>
<tr>
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<tr>
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Means with the same letter are not significantly different.

Tukey Grouping

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### H4 ANOVA Results

#### The GLM Procedure

**Dependent Variable: activity**

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<tr>
<th>Source</th>
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<th>Type I SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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</thead>
<tbody>
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<td>&lt;.0001</td>
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<td>100.28571</td>
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</tr>
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<td>Corrected Total</td>
<td>55</td>
<td>44416.21429</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **R-Square**: 0.882691
- **Coeff Var**: 0.463586
- **Root MSE**: 10.01428
- **activity Mean**: 2160.179

#### Least Squares Means for effect actical

**Pr > |t| for H0: LSmear(i)=LSmear(j)**

**Dependent Variable: activity**

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
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#### Tukey's Studentized Range (HSD) Test for activity

<table>
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<tr>
<th>Alpha</th>
<th>0.004167</th>
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</thead>
<tbody>
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<td>Error Degrees of Freedom</td>
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</tr>
<tr>
<td>Error Mean Square</td>
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<tr>
<td>Critical Value of Studentized Range</td>
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</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>13.523</td>
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</table>

Means with the same letter are not significantly different.

**Tukey Grouping**

<table>
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<tr>
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<td>2171.000</td>
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<td>2157.000</td>
<td>14 2</td>
</tr>
<tr>
<td>2120.000</td>
<td>14 4</td>
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H5 ANOVA Results

Dependent Variable: activity

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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>65967.91071</td>
<td>21989.30357</td>
<td>51.83</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>52</td>
<td>22080.21429</td>
<td>424.23489</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>55</td>
<td>88028.12500</td>
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<td></td>
</tr>
</tbody>
</table>

R-Square  Coeff Var  Root MSE  activity Mean
0.749396   0.920278   20.59696   2238.125

Source | DF | Type I SS | Mean Square | F Value | Pr > F |
actical | 3  | 65967.91071 | 21989.30357 | 51.83   | <.0001 |

Least Squares Means for effect actical
Pr > |t| for HO: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
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<td>0.0024</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<td>0.7070</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Tukey’s Studentized Range (HSD) Test for activity

Alpha  0.004167
Error Degrees of Freedom  52
Error Mean Square  424.2349
Critical Value of Studentized Range  5.05260
Minimum Significant Difference  27.813

Means with the same letter are not significantly different.

Tukey Grouping  Mean   N  actical
A   2285.357  14  1
B   2256.071  14  3
C   2209.714  14  4
C   2201.357  14  2
H6 ANOVA Results

The GLM Procedure

Dependent Variable: activity

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<tr>
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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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<td>52</td>
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<td>Corrected Total</td>
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<td>77007.56357</td>
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R-Square Coeff Var Root MSE activity Mean
0.864595 0.637410 14.18063 2221.589

Least Squares Means for effect actical

Dependent Variable: activity

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<th>3</th>
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</thead>
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<td>&lt;.0001</td>
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Tukey's Studentized Range (HSD) Test for activity

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<tbody>
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<td>Error Degrees of Freedom</td>
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<tr>
<td>Error Mean Square</td>
<td>200.5234</td>
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<td>Critical Value of Studentized Range</td>
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<td>Minimum Significant Difference</td>
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Means with the same letter are not significantly different.

Tukey Grouping

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<tr>
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<td>A</td>
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</tr>
<tr>
<td>B</td>
<td>2246.214</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>2187.857</td>
<td>14</td>
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<tr>
<td>C</td>
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</table>
### ANOVA Results - Low Speeds

**The GLM Procedure**

Dependent Variable: activity

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<th>Pr &gt; F</th>
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<td>236253.1310</td>
<td>10271.8753</td>
<td>162.32</td>
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<tr>
<td>Error</td>
<td>312</td>
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R-Square Coeff Var Root MSE activity Mean
0.922876 0.667440 7.954887 1191.851

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<th>F Value</th>
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<td>203939.8810</td>
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<td>3</td>
<td>25184.2024</td>
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Least Squares Means

Adjustment for Multiple Comparisons: Tukey

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<tr>
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<td>1184.66476</td>
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<tr>
<td>4</td>
<td>1186.70238</td>
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Least Squares Means for effect actical
Pr > |t| for HO: LSMEAN(i)=LSMEAN(j)

Dependent Variable: activity

<table>
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<tr>
<th>i/j</th>
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ANOVA Results - High Speeds

Dependent Variable: activity

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<td>actical</td>
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<td>286243.2024</td>
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<tr>
<td>actical*speed</td>
<td>15</td>
<td>17103.7976</td>
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Least Squares Means

<table>
<thead>
<tr>
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</table>
APPENDIX F

R CODE

This Appendix presents the R Code used to analyze the data.
### Read in Data, make sure .csv files are in working directory####

```
act1.1=read.csv('act11.csv')  # Actual 1 Run 1
act1.2=read.csv('act12.csv')  # Actual 1 Run 2
act1.3=read.csv('act13.csv')  # Actual 1 Run 3
act2.1=read.csv('act21.csv')  # Actual 2 Run 1
act2.2=read.csv('act22.csv')  # Actual 2 Run 2
act2.3=read.csv('act23.csv')  # Actual 2 Run 3
act3.1=read.csv('act31.csv')  # Actual 3 Run 1
act3.2=read.csv('act32.csv')  # Actual 3 Run 2
act3.3=read.csv('act33.csv')  # Actual 3 Run 3
act4.1=read.csv('act41.csv')  # Actual 4 Run 1
act4.2=read.csv('act42.csv')  # Actual 4 Run 2
act4.3=read.csv('act43.csv')  # Actual 4 Run 3

#### Create Subsets of 14 relevant observations, compute statistics####
```

```
act11.1=act1.1$activity[3236:3249]
act11.2=act1.1$activity[3264:3277]
act11.3=act1.1$activity[3289:3302]
act11.4=act1.1$activity[3313:3326]
summary(act11.1)
summary(act11.2)
summary(act11.3)
summary(act11.4)
a11=c(mean(act11.1),mean(act11.2),mean(act11.3),mean(act11.4))
sd11=c(sd(act11.1),sd(act11.2),sd(act11.3),sd(act11.4))
cv11=sd11/a11

act12.1=act1.2$activity[3450:3463]
act12.2=act1.2$activity[3474:3487]
act12.3=act1.2$activity[3498:3511]
act12.4=act1.2$activity[3522:3535]
summary(act12.1)
summary(act12.2)
summary(act12.3)
summary(act12.4)
a12=c(mean(act12.1),mean(act12.2),mean(act12.3),mean(act12.4))
sd12=c(sd(act12.1),sd(act12.2),sd(act12.3),sd(act12.4))
cv12=sd12/a12

act13.1=act1.3$activity[3642:3655]
act13.2=act1.3$activity[3666:3679]
act13.3=act1.3$activity[3690:3703]
act13.4=act1.3$activity[3714:3727]
summary(act13.1)
summary(act13.2)
summary(act13.3)
summary(act13.4)
a13=c(mean(act13.1),mean(act13.2),mean(act13.3),mean(act13.4))
sd13=c(sd(act13.1),sd(act13.2),sd(act13.3),sd(act13.4))
cv13=sd13/a13

act21.1=act2.1$activity[3236:3249]
act21.2=act2.1$activity[3264:3277]
act21.3=act2.1$activity[3289:3302]
act21.4=act2.1$activity[3313:3326]
summary(act21.1)
summary(act21.2)
summary(act21.3)
summary(act21.4)
a21=c(mean(act21.1),mean(act21.2),mean(act21.3),mean(act21.4))
```
sd21 = c(sd(act21.1), sd(act21.2), sd(act21.3), sd(act21.4))
cv21 = sd21 / a21

act22.1 = act2.2$activity[3450:3463]
act22.2 = act2.2$activity[3474:3487]
act22.3 = act2.2$activity[3498:3511]
act22.4 = act2.2$activity[3522:3535]
summary(act22.1)
summary(act22.2)
summary(act22.3)
summary(act22.4)
a22 = c(mean(act22.1), mean(act22.2), mean(act22.3), mean(act22.4))
sd22 = c(sd(act22.1), sd(act22.2), sd(act22.3), sd(act22.4))
cv22 = sd22 / a22

act23.1 = act2.3$activity[3642:3655]
act23.2 = act2.3$activity[3666:3679]
act23.3 = act2.3$activity[3690:3703]
act23.4 = act2.3$activity[3714:3727]
summary(act23.1)
summary(act23.2)
summary(act23.3)
summary(act23.4)
a23 = c(mean(act23.1), mean(act23.2), mean(act23.3), mean(act23.4))
sd23 = c(sd(act23.1), sd(act23.2), sd(act23.3), sd(act23.4))
cv23 = sd23 / a23

act31.1 = act3.1$activity[3236:3249]
act31.2 = act3.1$activity[3264:3277]
act31.3 = act3.1$activity[3289:3302]
act31.4 = act3.1$activity[3313:3326]
summary(act31.1)
summary(act31.2)
summary(act31.3)
summary(act31.4)
a31 = c(mean(act31.1), mean(act31.2), mean(act31.3), mean(act31.4))
sd31 = c(sd(act31.1), sd(act31.2), sd(act31.3), sd(act31.4))
cv31 = sd31 / a31

act32.1 = act3.2$activity[3450:3463]
act32.2 = act3.2$activity[3474:3487]
act32.3 = act3.2$activity[3498:3511]
act32.4 = act3.2$activity[3522:3535]
summary(act32.1)
summary(act32.2)
summary(act32.3)
summary(act32.4)
a32 = c(mean(act32.1), mean(act32.2), mean(act32.3), mean(act32.4))
sd32 = c(sd(act32.1), sd(act32.2), sd(act32.3), sd(act32.4))
cv32 = sd32 / a32

act33.1 = act3.3$activity[3642:3655]
act33.2 = act3.3$activity[3666:3679]
act33.3 = act3.3$activity[3690:3703]
act33.4 = act3.3$activity[3714:3727]
summary(act33.1)
summary(act33.2)
summary(act33.3)
summary(act33.4)
a33 = c(mean(act33.1), mean(act33.2), mean(act33.3), mean(act33.4))
sd33 = c(sd(act33.1), sd(act33.2), sd(act33.3), sd(act33.4))
cv33 = sd33 / a33

act41.1 = act4.1$activity[3236:3249]
act41.2 = act4.1$activity[3264:3277]
act41.3=act4.1$activity[3289:3302]
act41.4=act4.1$activity[3313:3326]
summary(act41.1)
summary(act41.2)
summary(act41.3)
summary(act41.4)
a41=c(mean(act41.1),mean(act41.2),mean(act41.3),mean(act41.4))
sd41=c(sd(act41.1),sd(act41.2),sd(act41.3),sd(act41.4))
cv41=sd41/a41

act42.1=act4.2$activity[3450:3463]
act42.2=act4.2$activity[3474:3487]
act42.3=act4.2$activity[3498:3511]
act42.4=act4.2$activity[3522:3535]
summary(act42.1)
summary(act42.2)
summary(act42.3)
summary(act42.4)
a42=c(mean(act42.1),mean(act42.2),mean(act42.3),mean(act42.4))
sd42=c(sd(act42.1),sd(act42.2),sd(act42.3),sd(act42.4))
cv42=sd42/a42

act43.1=act4.3$activity[3642:3655]
act43.2=act4.3$activity[3666:3679]
act43.3=act4.3$activity[3690:3703]
act43.4=act4.3$activity[3714:3727]
summary(act43.1)
summary(act43.2)
summary(act43.3)
summary(act43.4)
a43=c(mean(act43.1),mean(act43.2),mean(act43.3),mean(act43.4))
sd43=c(sd(act43.1),sd(act43.2),sd(act43.3),sd(act43.4))
cv43=sd43/a43

########################################################################
####Plots by Run : Low and High Speed Separate###########################
########################################################################

colors=c(1,2,3,4)
chars=c(1,2,3,4)
x11()
par(mfrow=c(3,2))

# L1,L2
plot(act11$epoch,act11$activity,xlim=c(3230,3280),ylim=c(1100,1300),
xlab="Epoch",ylab="Activity",main="First Run Low Speed (L1,L2)",pch=1)
points(act21$epoch,act21$activity,col=2,pch=2)
points(act31$epoch,act31$activity,col=3,pch=3)
points(act41$epoch,act41$activity,col=4,pch=4)
legend(3230,1300, c("Actical 1", "Actical 2", "Actical 3", "Actical 4"),
text.col=colors,pch=chars,col=colors)

# H1,H2
plot(act11$epoch,act11$activity,xlim=c(3280,3330),ylim=c(2150,2350),
xlab="Epoch",ylab="Activity",main="First Run High Speed (H1,H2)",pch=1)
points(act21$epoch,act21$activity,col=2,pch=2)
points(act31$epoch,act31$activity,col=3,pch=3)
points(act41$epoch,act41$activity,col=4,pch=4)

# L3,L4
plot(act12$epoch,act12$activity,xlim=c(3440,3490),ylim=c(1100,1300),
xlab="Epoch",ylab="Activity",main="Second Run Low Speed (L3,L4)",pch=1)
points(act22$epoch,act22$activity,col=2,pch=2)
points(act32$epoch,act32$activity,col=3,pch=3)
points(act42$epoch,act42$activity,col=4,pch=4)

# H3,H4
plot(act12$epoch,act12$activity,xlim=c(3490,3540),ylim=c(2150,2350),
xlab="Epoch",ylab="Activity",main="Second Run High Speed (H3,H4)",pch=1)
points(act22$epoch, act22$activity, col=2, pch=2)
points(act32$epoch, act32$activity, col=3, pch=3)
points(act42$epoch, act42$activity, col=4, pch=4)
# L5, L6
plot(act13$epoch, act13$activity, xlim=c(3640, 3690), ylim=c(1100, 1300),
     xlab="Epoch", ylab="Activity", main="Third Run Low Speed (L5, L6)" , pch=1)
points(act23$epoch, act23$activity, col=2, pch=2)
points(act33$epoch, act33$activity, col=3, pch=3)
points(act43$epoch, act43$activity, col=4, pch=4)
# H5, H6
plot(act13$epoch, act13$activity, xlim=c(3690, 3740), ylim=c(2150, 2350),
     xlab="Epoch", ylab="Activity", main="Third Run High Speed (H5, H6)", pch=1)
points(act23$epoch, act23$activity, col=2, pch=2)
points(act33$epoch, act33$activity, col=3, pch=3)
points(act43$epoch, act43$activity, col=4, pch=4)
########################################################################
#### ACF Plots ###########################################################
########################################################################

dev.new(width=7, height=6.5)
par(mfrow=c(4,3), mar=c(2.1, 2, 4, 0.5), oma=c(2, 2, 0, 0))
#### Actical 1#######################################################
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 1 L1')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act1.1, main=' Actical 1 L2'); acf(act1.2, main=' Actical 1 L3');
acf(act1.3, main=' Actical 1 L4'); acf(act1.4, main=' Actical 1 L5');
acf(act1.5, main=' Actical 1 L6');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 1 H1')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act2.1, main='Actical 1 H2'); acf(act2.2, main='Actical 1 H3');
acf(act2.3, main='Actical 1 H4'); acf(act2.4, main='Actical 1 H5');
acf(act2.5, main='Actical 1 H6');
text("Lag", side=1, line=0.2, cex=1, font=2, outer=TRUE)
text("Autocorrelation", side=2, line=0.2, cex=1, font=2, outer=TRUE)
#### Actical 2#######################################################
acf(act3.1, main='Actical 2 L1'); acf(act3.2, main='Actical 2 L2');
acf(act3.3, main='Actical 2 L3'); acf(act3.4, main='Actical 2 L4');
acf(act3.5, main='Actical 2 L5'); acf(act3.6, main='Actical 2 L6');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 2 H1')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 2 H2')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 2 H3')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act4.1, main='Actical 2 H4'); acf(act4.2, main='Actical 2 H5');
acf(act4.3, main='Actical 2 H6');
text("Lag", side=1, line=0.2, cex=1, font=2, outer=TRUE)
text("Autocorrelation", side=2, line=0.2, cex=1, font=2, outer=TRUE)
#### Actical 3#######################################################
acf(act4.1, main='Actical 3 L1');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 3 L2')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act4.2, main='Actical 3 L3'); acf(act4.3, main='Actical 3 L4');
acf(act4.4, main='Actical 3 L5');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 3 L6')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act4.5, main='Actical 3 H1');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 3 H2')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act4.6, main='Actical 3 H3');
plot(2, xlim=c(0, 10), ylim=c(-0.5, 1), main='Actical 3 H4')
abline(h=0); abline(h=2/sqrt(14), col=4, lty=2); abline(h=-2/sqrt(14), col=4, lty=2)
acf(act4.7, main='Actical 3 H5'); acf(act4.8, main='Actical 3 H6');
text("Lag", side=1, line=0.2, cex=1, font=2, outer=TRUE)
text("Autocorrelation", side=2, line=0.2, cex=1, font=2, outer=TRUE)
plot(2, xlim=c(0,10), ylim=c(-0.5,1.0), main='Actual 4 L1')
abline(h=0);abline(h=2/sqrt(14),col=4,lty=2);abline(h=-2/sqrt(14),col=4,lty=2)
plot(2, xlim=c(0,10), ylim=c(-0.5,1.0), main='Actual 4 L2')
abline(h=0);abline(h=2/sqrt(14),col=4,lty=2);abline(h=-2/sqrt(14),col=4,lty=2)
acf(act42.1,main='Actual 4 L3');acf(act42.2,main='Actual 4 L4');
acf(act43.1,main='Actual 4 L5');acf(act43.2,main='Actual 4 L6');
acf(act41.3,main='Actual 4 H1');
plot(2, xlim=c(0,10), ylim=c(-0.5,1.0), main='Actual 4 H2')
abline(h=0);abline(h=2/sqrt(14),col=4,lty=2);abline(h=-2/sqrt(14),col=4,lty=2)
acf(act42.3,main='Actual 4 H3');
plot(2, xlim=c(0,10), ylim=c(-0.5,1.0), main='Actual 4 H4')
abline(h=0);abline(h=2/sqrt(14),col=4,lty=2);abline(h=-2/sqrt(14),col=4,lty=2)
acf(act43.3,main='Actual 4 H5');acf(act43.4,main='Actual 4 H6');
mtext("Lag", side=1, line=0.2, cex=1, font=2, outer=TRUE)
mtext("Autocorrelation", side=2, line=0.2, cex=1, font=2, outer=TRUE)

########################################################################
####Compute Deviations from Actual Mean Each Observation###############
########################################################################
ml1=(act11.1+act21.1+act31.1+act41.1)/4
ml2=(act11.2+act21.2+act31.2+act41.2)/4
ml3=(act12.1+act22.1+act32.1+act42.1)/4
ml4=(act12.2+act22.2+act32.2+act42.2)/4
ml5=(act13.1+act23.1+act33.1+act43.1)/4
ml6=(act13.2+act23.2+act33.2+act43.2)/4
mh1=(act11.3+act21.3+act31.3+act41.3)/4
mh2=(act11.4+act21.4+act31.4+act41.4)/4
mh3=(act12.3+act22.3+act32.3+act42.3)/4
mh4=(act12.4+act22.4+act32.4+act42.4)/4
mh5=(act13.3+act23.3+act33.3+act43.3)/4
mh6=(act13.4+act23.4+act33.4+act43.4)/4

l1d=c(act11.1-ml1,act21.1-ml1,act31.1-ml1,act41.1-ml1)
l2d=c(act11.2-ml2,act21.2-ml2,act31.2-ml2,act41.2-ml2)
h1d=c(act11.3-mh1,act21.3-mh1,act31.3-mh1,act41.3-mh1)
h2d=c(act11.4-mh2,act21.4-mh2,act31.4-mh2,act41.4-mh2)
l3d=c(act12.1-mh3,act22.1-mh3,act32.1-mh3,act42.1-mh3)
l4d=c(act12.2-mh3,act22.2-mh3,act32.2-mh3,act42.2-mh3)
l5d=c(act12.3-mh3,act22.3-mh3,act32.3-mh3,act42.3-mh3)
l6d=c(act12.4-mh3,act22.4-mh3,act32.4-mh3,act42.4-mh3)
h3d=c(act13.1-mh5,act23.1-mh5,act33.1-mh5,act43.1-mh5)
h4d=c(act13.2-mh5,act23.2-mh5,act33.2-mh5,act43.2-mh5)
h5d=c(act13.3-mh5,act23.3-mh5,act33.3-mh5,act43.3-mh5)
h6d=c(act13.4-mh5,act23.4-mh5,act33.4-mh5,act43.3-mh5)

########################################################################
###Histograms###########################################################
########################################################################
x11()
par(mfrow=c(4,3))
hist(l1d,main='L1 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(l2d,main='L2 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(l3d,main='L3 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(l4d,main='L4 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(l5d,main='L5 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(l6d,main='L6 Deviations',xlab='',xlim=c(-40,40),ylim=c(0,35))
hist(h1d,main='H1 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))
hist(h2d,main='H2 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))
hist(h3d,main='H3 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))
hist(h4d,main='H4 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))
hist(h5d,main='H5 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))
hist(h6d,main='H6 Deviations',xlab='',xlim=c(-100,100),ylim=c(0,35))

########################################################################
###Boxplots##############################################################
########################################################################


par(mfrow=c(1,2))
boxplot(l1d,12d,13d,14d,15d,16d,main="Low Speed Deviations",
    names=c("L1", "L2", "L3", "L4", "L5", "L6"), ylim=c(-40,40))
boxplot(h1d,h2d,h3d,h4d,h5d,h6d,main="High Speed Deviations",
    names=c("H1", "H2", "H3", "H4", "H5", "H6"), ylim=c(-100,100))

###Quantile Plots###
par(mfrow=c(4,3))
qqnorm(Ud,main="NQ Plot L1",ylim=c(-30,30))
qqnorm(l2d,main="NQ Plot L2",ylim=c(-30,30))
qqnorm(l3d,main="NQ Plot L3",ylim=c(-30,30))
qqnorm(l4d,main="NQ Plot L4",ylim=c(-30,30))
qqnorm(l5d,main="NQ Plot L5",ylim=c(-30,30))
qqnorm(l6d,main="NQ Plot L6",ylim=c(-30,30))
qqnorm(h1d,main="NQ Plot H1",ylim=c(-60,60))
qqnorm(h2d,main="NQ Plot H2",ylim=c(-60,60))
qqnorm(h3d,main="NQ Plot H3",ylim=c(-60,60))
qqnorm(h4d,main="NQ Plot H4",ylim=c(-60,60))
qqnorm(h5d,main="NQ Plot H5",ylim=c(-60,60))
qqnorm(h6d,main="NQ Plot H6",ylim=c(-60,60))

########################################################################
###REGRESSION ANALYSIS###
########################################################################
##Run 1 Phase 1 L1####
rl1bar=(act11.1+act21.1+act31.1+act41.1)/4
y111=act11.1-rl1bar;y211=act21.1-rl1bar;y311=act31.1-rl1bar;y411=act41.1-rl1bar;
rl1mat=cbind(y211,y311,y411)
rl1.fit=lm(y111~rl1mat)
summary(rl1.fit)
rl1.man=aoov(rl1mat~"11bar")
summary(manova(rl1mat~"11bar"))#error 'residuals have rank 1 < 3'
summary(anova.m1m(rl1.fit))#error 'residuals have rank 1 < 3'
rl1.fit0=lm(rl1mat~0)
anova.m1m(rl1.fit,rl1.fit0)#error 'residuals have rank 1 < 3'

##Run 1 Phase 2 L2####
rl2bar=(act11.2+act21.2+act31.2+act41.2)/4
y121=act11.2-rl2bar;y212=act21.2-rl2bar;y312=act31.2-rl2bar;y412=act41.2-rl2bar;
rl2mat=cbind(y212,y312,y412)
rl2.fit=lm(y121~rl2mat)
rl2.fit0=lm(rl2mat~0)
summary(rl2.fit)
summary(manova(rl2mat~"12bar"),test='Pillai')#error 'residuals have rank 1 < 3'
anova.m1m(rl2.fit,rl2.fit0)

##Run 1 Phase 3 H1####
rl3bar=(act11.3+act21.3+act31.3+act41.3)/4
y131=act11.3-rl3bar;y213=act21.3-rl3bar;y313=act31.3-rl3bar;y413=act41.3-rl3bar;
rl3mat=cbind(y213,y313,y413)
rl3.fit=lm(y131~rl3mat)
rl3.fit0=lm(rl3mat~0)
summary(rl3.fit)
summary(manova(rl3mat~"13bar"))
anova.m1m(rl3.fit,rl3.fit0)

##Run 1 Phase 4 H2####
rl4bar=(act11.4+act21.4+act31.4+act41.4)/4
y141=act11.4-rl4bar;y214=act21.4-rl4bar;y314=act31.4-rl4bar;y414=act41.4-rl4bar;
rl4mat=cbind(y214,y314,y414)
rl4.fit=lm(rl4mat~"14bar")
rl4.fit0=lm(rl4mat~0)
summary(r14.fit)
summary(manova(r14mat-r14bar)) #error 'residuals have rank 1 < 3'
anova.mlm(r14.fit,r14.fit0) #error 'residuals have rank 1 < 3'

##Run 2 Phase 1 L3####
r21bar=(act12.1+act22.1+act32.1+act42.1)/4
y121=act12.1-r21bar;y221=act22.1-r21bar;y321=act32.1-r21bar;y421=act42.1-r21bar;
r21mat=cbind(y221,y321,y421)
r21.fit=lm(r21mat~r21bar)
r21.fit0=lm(r21mat~0)
summary(r21.fit)
summary(manova(r21mat-r21bar),test='Pillai')
anova.mlm(r21.fit,r21.fit0)

##Run 2 Phase 2 L4####
r22bar=(act12.2+act22.2+act32.2+act42.2)/4
y122=act12.2-r22bar;y222=act22.2-r22bar;y322=act32.2-r22bar;y422=act42.2-r22bar;
r22mat=cbind(y222,y322,y422)
r22.fit=lm(r22mat~r22bar)
r22.fit0=lm(r22mat~0)
summary(r22.fit)
summary(manova(r22mat-r22bar),test='Pillai')
anova.mlm(r22.fit,r22.fit0)

##Run 2 Phase 3 H3####
r23bar=(act12.3+act22.3+act32.3+act42.3)/4
y123=act12.3-r23bar;y223=act22.3-r23bar;y323=act32.3-r23bar;y423=act42.3-r23bar;
r23mat=cbind(y223,y323,y423)
r23.fit=lm(r23mat~r23bar)
r23.fit0=lm(r23mat~0)
summary(r23.fit)
summary(manova(r23mat-r23bar))
anova.mlm(r23.fit,r23.fit0)

##Run 2 Phase 4 H4####
r24bar=(act12.4+act22.4+act32.4+act42.4)/4
y124=act12.4-r24bar;y224=act22.4-r24bar;y324=act32.4-r24bar;y424=act42.4-r24bar;
r24mat=cbind(y224,y324,y424)
r24.fit=lm(r24mat~r24bar)
r24.fit0=lm(r24mat~0)
summary(r24.fit)
summary(manova(r24mat-r24bar))
anova.mlm(r24.fit,r24.fit0)

##Run 3 Phase 1 L5####
r31bar=(act13.1+act23.1+act33.1+act43.1)/4
y131=act13.1-r31bar;y231=act23.1-r31bar;y331=act33.1-r31bar;y431=act43.1-r31bar;
r31mat=cbind(y231,y331,y431)
r31.fit=lm(r31mat~r31bar)
r31.fit0=lm(r31mat~0)
summary(r31.fit)
summary(manova(r31mat-r31bar),test='Pillai')
anova.mlm(r31.fit,r31.fit0)

##Run 3 Phase 2 L6####
r32bar=(act13.2+act23.2+act33.2+act43.2)/4
y132=act13.2-r32bar;y232=act23.2-r32bar;y332=act33.2-r32bar;y432=act43.2-r32bar;
r32mat=cbind(y232,y332,y432)
r32.fit=lm(r32mat~r32bar)
r32.fit0=lm(r32mat~0)
summary(r32.fit)
summary(manova(r32mat-r32bar),test='Pillai')
anova.mlm(r32.fit,r32.fit0)

##Run 3 Phase 3 H5####
r33bar=(act13.3+act23.3+act33.3+act43.3)/4
y133=act13.3-r33bar;y233=act23.3-r33bar;y333=act33.3-r33bar;y433=act43.3-r33bar;

r33mat=cbind(y233,y333,y433)
r33.fit=lm(r33mat~r33bar)
r33.fit0=lm(r33mat~0)

summary(r33.fit)
summary(manova(r33mat~r33bar))
anova.mlm(r33.fit,r33.fit0)

##Run 3 Phase 4 H6###

r34bar=(act13.4+act23.4+act33.4+act43.4)/4
y134=act13.4-r34bar;y234=act23.4-r34bar;y334=act33.4-r34bar;y434=act43.4-r34bar;

r34mat=cbind(y234,y334,y434)
r34.fit=lm(r34mat~r34bar)
r34.fit0=lm(r34mat~0)

summary(r34.fit)
summary(manova(r34mat~r34bar))
anova.mlm(r34.fit,r34.fit0)
APPENDIX G
SAS CODE

This Appendix presents the SAS Code used to analyze the data.
G.1 Regression Analysis

title1 'L1 Regression Analysis':

data run11;
  infile 'C:\actical\run11.DAT' obs=14;
  input i i1 ac1 i2 ac2 i3 ac3 i4 ac4 @ @;
  acbar = (ac1+ac2+ac3+ac4)/4;
  y1tilda = ac1 - acbar;
  y2tilda = ac2 - acbar;
  y3tilda = ac3 - acbar;
  y4tilda = ac4 - acbar;
run;

proc reg data = run11;
  model y2tilda y3tilda y4tilda = acbar;
  EqualVar:mtest acbar/print;
  Bias_Var:mtest intercept, acbar/print;
run;

data run11a;
  set run11;
  sacbar=(ac2 + ac3)/2;
  sy2tilda = ac2 - sacbar;
run;

title2 'Actical 2 vs. 3';
proc reg data = run11a;
  model sy2tilda = sacbar;
  EqualVar:mtest sacbar/print;
run;

/*******************************************************************************/

title1 'L2 Regression Analysis';

data run12;
  infile 'C:\actical\run12.DAT' obs=14;
  input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @ @;
  acbar = (ac1+ac2+ac3+ac4)/4;
  y1tilda = ac1 - acbar;
  y2tilda = ac2 - acbar;
  y3tilda = ac3 - acbar;
  y4tilda = ac4 - acbar;
run;

proc reg data = run12;
  model y2tilda y3tilda y4tilda = acbar;
  EqualVar:mtest acbar/print;
  Bias_Var:mtest intercept, acbar/print;
run;

data run12a;
  set run12;
  sacbar=(ac1 + ac2)/2;
  sy2tilda = ac2 - sacbar;
run;

title2 'Actical 1 vs. 2';
proc reg data = run12a;
  model sy2tilda = sacbar;
  EqualVar:mtest sacbar/print;
run;
title1 'L3 Regression Analysis';

data run21;
infile 'C:\actical\run21.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@;
acbar = (ac1+ac2+ac3+ac4)/4;
y1tilda = ac1 - acbar;
y2tilda = ac2 - acbar;
y3tilda = ac3 - acbar;
y4tilda = ac4 - acbar;
run;

proc reg data = run21;
model y1tilda y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run21a;
set run21;
sacbar=(ac1 + ac2)/2;
sy2tilda = ac2 - sacbar;
run;

title2 'Actical 1 vs. 2';
proc reg data = run21a;
model sy2tilda=sacbar;
EqualVar:mtest sacbar/print;
run;

/title1 'L4 Regression Analysis';

data run22;
infile 'C:\actical\run22.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@;
acbar = (ac1+ac2+ac3+ac4)/4;
y1tilda = ac1 - acbar;
y2tilda = ac2 - acbar;
y3tilda = ac3 - acbar;
y4tilda = ac4 - acbar;
run;

proc reg data = run22;
model y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run22a;
set run22;
sacbar=(ac3 + ac4)/2;
sy3tilda = ac3 - sacbar;
run;

title2 'Actical 3 vs. 4';
proc reg data = run22a;
model sy3tilda=sacbar;
EqualVar:mtest sacbar/print;
run;

/title1 'L5 Regression Analysis';
data run31;
infile 'C:\actical\run31.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@
acbar = (ac1+ac2+ac3+ac4)/4
y1tilda = ac1 - acbar
y2tilda = ac2 - acbar
y3tilda = ac3 - acbar
y4tilda = ac4 - acbar;
run;

proc reg data = run31;
model y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run31a;
set run31;
sacbar=(ac1 + ac4)/2;
sy1tilda = ac1 - sacbar;
run;
title2 'Actical 1 vs. 4';
proc reg data = run31a;
model sy1tilda=sacbar;
EqualVar:mtest sacbar/print;
run;
/**************************************************************************/

/title1 'H1 Regression Analysis';

data run32;
infile 'C:\actical\run32.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@
acbar = (ac1+ac2+ac3+ac4)/4
y1tilda = ac1 - acbar
y2tilda = ac2 - acbar
y3tilda = ac3 - acbar
y4tilda = ac4 - acbar;
run;

proc reg data = run32;
model y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run32a;
set run32;
sacbar=(ac1 + ac2)/2;
sy1tilda = ac1 - sacbar;
run;
title2 'Actical 1 vs. 2';
proc reg data = run32a;
model sy1tilda=sacbar;
EqualVar:mtest sacbar/print;
run;
/**************************************************************************/

/title1 'H1 Regression Analysis';

data run13;
infile 'C:\actical\run13.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@ ;
acbar = (ac1+ac2+ac3+ac4)/4 ;
y1tilda = ac1 - acbar ;
y2tilda = ac2 - acbar ;
y3tilda = ac3 - acbar ;
y4tilda = ac4 - acbar ;
run;
proc reg data = run13 ;
model y2tilda y3tilda y4tilda = acbar ;
EqualVar:mtest acbar/print ;
Bias_Var:mtest intercept , acbar/print ;
run ;
data run13a ;
set run13 ;
sacbar=(ac1 + ac3)/2 ;
sytilda = ac1 - sacbar ;
run ;
title2 'Actical 1 vs. 3' ;
proc reg data = run13a ;
model sytilda=sacbar ;
EqualVar:mtest sacbar/print ;
run ;
/ ************************************************************************
title1 'H2 Regression Analysis' ;
data run14 ;
infile 'C:\actical\run14.DAT' obs=14 ;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@ ;
acbar = (ac1+ac2+ac3+ac4)/4 ;
y1tilda = ac1 - acbar ;
y2tilda = ac2 - acbar ;
y3tilda = ac3 - acbar ;
y4tilda = ac4 - acbar ;
run ;
proc reg data = run14 ;
model y2tilda y3tilda y4tilda = acbar ;
EqualVar:mtest acbar/print ;
Bias_Var:mtest intercept , acbar/print ;
run ;
data run14a ;
set run14 ;
sacbar=(ac1 + ac2)/2 ;
sytilda = ac1 - sacbar ;
run ;
title2 'Actical 1 vs. 2' ;
proc reg data = run14a ;
model sytilda=sacbar ;
EqualVar:mtest sacbar/print ;
run ;
/************************************************************************
title1 'H3 Regression Analysis' ;
data run23 ;
infile 'C:\actical\run23.DAT' obs=14 ;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@ ;
acbar = (ac1+ac2+ac3+ac4)/4 ;
y1tilda = ac1 - acbar ;
y2tilda = ac2 - acbar;
y3tilda = ac3 - acbar;
y4tilda = ac4 - acbar;
run;

proc reg data = run23;
model y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run23a;
set run23;
sacbar=(ac3 + ac4)/2;
sy3tilda = ac3 - sacbar;
run;

title2 'Actical 3 vs. 4';
proc reg data = run23a;
model sy3tilda = sacbar;
EqualVar:mtest sacbar/print;
run;

/**************************************************************************/
title1 'H4 Regression Analysis';
data run24;
infile 'C:\actical\run24.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@;
acbar = (ac1+ac2+ac3+ac4)/4;
y1tilda = ac1 - acbar;
y2tilda = ac2 - acbar;
y3tilda = ac3 - acbar;
y4tilda = ac4 - acbar;
run;

title2 'Actical 1 vs. Others';
proc reg data = run24;
model y2tilda y3tilda yltilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

/**************************************************************************/
title1 'H5 Regression Analysis';
data run33;
infile 'C:\actical\run33.DAT' obs=14;
input i1 ac1 i2 ac2 i3 ac3 i4 ac4 @@;
acbar = (ac1+ac2+ac3+ac4)/4;
y1tilda = ac1 - acbar;
y2tilda = ac2 - acbar;
y3tilda = ac3 - acbar;
y4tilda = ac4 - acbar;
run;

proc reg data = run33;
model y2tilda y3tilda y4tilda = acbar;
EqualVar:mtest acbar/print;
Bias_Var:mtest intercept, acbar/print;
run;

data run33a;
set run33;
sacbar=(ac1 + ac2)/2;
syltilde = ac1 - sacbar;
run;

/*--- Actical 1 vs. 2 ---*/
title2 'Actical 1 vs. 2';
proc reg data = run33a;
model sytilde = sacbar;
EqualVar: mtest sacbar/print;
run;

/*--- Actical 1 vs. 3 ---*/
title2 'Actical 1 vs. 3';
proc reg data = run33a;
model sytilde = sacbar;
EqualVar: mtest sacbar/print;
run;

title1 'H6 Regression Analysis';

data run34;
  infile 'C:\actical\run34.DAT' obs=14;
  input i1 acl i2 ac2 i3 ac3 i4 ac4 @@
  acbar = (acl+ac2+ac3+ac4)/4
  y1tilde = acl - acbar
  y2tilde = ac2 - acbar
  y3tilde = ac3 - acbar
  y4tilde = ac4 - acbar
run;

proc reg data = run34;
model y2tilde y3tilde y4tilde = acbar;
EqualVar: mtest acbar/print;
Bias_Var: mtest intercept, acbar/print;
run;

data run34a;
set run34;
  sacbar=(ac1 + ac3)/2;
syltilde = ac1 - sacbar;
run;

/*--- Actical 1 vs. 3 ---*/
title2 'Actical 1 vs. 3';
proc reg data = run34a;
model sytilde = sacbar;
EqualVar: mtest sacbar/print;
run;
G.2 ANOVA Analysis

title 'L1 ANOVA';
data run11;
infile 'C:\actical\run11.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run11;
    class actical;
    model activity = actical;
    means actical / Tukey alpha=0.00416666;
    lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
    output out = residuals p=pred r=resid;
run;
/*--------------------------------------------------------------------------------*/

title 'L2 ANOVA';
data run12;
infile 'C:\actical\run12.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run12;
    class actical;
    model activity = actical;
    means actical / Tukey alpha=0.00416666;
    lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
    output out = residuals p=pred r=resid;
run;
/*--------------------------------------------------------------------------------*/

title 'L3 ANOVA';
data run21;
infile 'C:\actical\run21.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run21;
    class actical;
    model activity = actical;
    means actical / Tukey alpha=0.00416666;
    lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
    output out = residuals p=pred r=resid;
run;
/*--------------------------------------------------------------------------------*/

title 'L4 ANOVA';
data run22;
infile 'C:\actical\run22.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run22;
    class actical;
    model activity = actical;
    means actical / Tukey alpha=0.00416666;
    lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
    output out = residuals p=pred r=resid;
run;
/*--------------------------------------------------------------------------------*/

title 'L5 ANOVA';
data run31;
infile 'C:\actical\run31.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run31;
   class actical;
   model activity = actical;
   means actical / Tukey alpha=0.004166666;
   lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
   output out = residuals p=pred r=resid;
run;
/************************************************************/

title1 'L6 ANOVA';
data run32;
   infile 'C:\actical\run32.DAT' obs=14;
   input actical activity @@;
   run;
proc glm data=run32;
   class actical;
   model activity = actical;
   means actical / Tukey alpha=0.004166666;
   lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
   output out = residuals p=pred r=resid;
run;
/************************************************************/

title1 'H1 ANOVA';
data run13;
   infile 'C:\actical\run13.DAT' obs=14;
   input actical activity @@;
   run;
proc glm data=run13;
   class actical;
   model activity = actical;
   means actical / Tukey alpha=0.004166666;
   lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
   output out = residuals p=pred r=resid;
run;
/************************************************************/

title1 'H2 ANOVA';
data run14;
   infile 'C:\actical\run14.DAT' obs=14;
   input actical activity @@;
   run;
proc glm data=run14;
   class actical;
   model activity = actical;
   means actical / Tukey alpha=0.004166666;
   lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
   output out = residuals p=pred r=resid;
run;
/************************************************************/

title1 'H3 ANOVA';
data run23;
   infile 'C:\actical\run23.DAT' obs=14;
   input actical activity @@;
   run;
proc glm data=run23;
   class actical;
   model activity = actical;
   means actical / Tukey alpha=0.004166666;
   lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
   output out = residuals p=pred r=resid;
run;
/*******************************************************************************************/

title 'H4 ANOVA';
data run24;
infile 'C:\actical\run24.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run24;
class actical;
model activity = actical;
means actical / Tukey alpha=0.00416666;
lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
output out = residuals p=pred r=resid;
run;
*******************************************************************************************/

pageTitle 'H5 ANOVA';
data run33;
infile 'C:\actical\run33.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run33;
class actical;
model activity = actical;
means actical / Tukey alpha=0.00416666;
lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
output out = residuals p=pred r=resid;
run;
*******************************************************************************************/

pageTitle 'H6 ANOVA';
data run34;
infile 'C:\actical\run34.DAT' obs=14;
input actical activity @@;
run;
proc glm data=run34;
class actical;
model activity = actical;
means actical / Tukey alpha=0.00416666;
lsmeans actical / pdiff=all adjust=Tukey alpha=0.00416666;
output out = residuals p=pred r=resid;
run;
*******************************************************************************************/

pageTitle "Diagnostics-Plots of Residuals against Predicted Values";
proc plot data=residuals;
plot resid*(actical pred);
run;

pageTitle "Diagnostics-Summary Statistics for the Residuals";
proc univariate normal plots data=residuals;
var resid;
histogram resid / normal noframe;
probplot resid / noframe;
run;
*******************************************************************************************/

pageTitle 'ANOVA Low Speeds';
data actdata;
infile 'C:\actical\actdat.DAT';
input run speed actical activity @@;
run;
data actdata1;
set actdata;
if 1 <= speed <= 6;
keep run actical speed activity;
*activity = sqrt(activity);
run;

proc glm data=actdatal;
class actical speed;
model activity = speed\actical;
lsmeans actical / pdiff=all adjust=Tukey alpha=0.025;
output out = residuals p=pred r=resid;
run;

/********************************************
titlel "Diagnostics-Plots of Residuals against Predicted Values";
proc plot data=residuals;
plot resid=(run actical pred);
run;

titlel "Diagnostics-Summary Statistics for the Residuals";
proc univariate normal plots data=residuals;
var resid;
histogram resid / normal noframe;
probplot resid / noframe;
run;

/********************************************
titlel 'ANOVA High Speeds';
data actdata;
infile 'C:\actical\actdat.DAT';
input run speed actical activity;
run;
data actdata2;
set actdata;
if 7 <= speed <= 12;
keep run actical speed activity;
*activity = sqrt(activity);
run;

proc glm data=actdata2;
class actical speed;
model activity = speed\actical;
lsmeans actical / pdiff=all adjust=Tukey alpha=0.025;
output out = residuals p=pred r=resid;
run;

/********************************************

**********************************************************************************