LONGITUDINAL ANALYSIS OF BODY MEASUREMENTS (WHtR, BMI, BFI) CHARACTERIZING THE EFFECTIVENESS OF ph360
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Data collected between 5/1/2014 and 3/16/2018

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Executive Summary

The objective of this study was to characterize the effectiveness of ph360 Personalized Health and Wellness Program, in reducing 3 body measure- indices: waist-to-height ratio (WHtR), body mass index (BMI) and body fat index (BFI). Keeping the ranges of these indices within healthy limits have been shown to be important to individual wellbeing, and reduce risk factors for a variety of diseases including cardiovascular disease (CVD) and diabetes, and yet many individuals struggle greatly to get within and/or stay within the healthy ranges. Healthy ranges for these indices vary based on age and gender, but for the purposes of this analysis the healthy range of WHtR was set at 0.49 or less as per the latest research in anthropometric indicators of cardiometabolic risk\textsuperscript{1-5}, and the healthy range for BFI was based on the table in Appendix B.

The improvements (changes in body measurements) were tracked at the subject level, by spacing self-reported body measurement check-ins throughout the individual's engagement in ph360 Personalized Health and Wellness Program. In total there were 4133 individual data points, each logged by one of 1334 individual subjects at different check-in points. Subject ages and genders were also recorded to determine if there were significant differences in body measurement changes based on these factors.

The statistical analysis consisted of a sequence of 4 basic parts: Part I Descriptive Statistics, Part II Exploratory Data Analysis (EDA), Part III ANOVA, and Part IV Modeling. The conclusions of the analysis were as follows:

- The ph360 Personalized Health and Wellness Program was effective in significantly decreasing individual body measurement indices. Of the 1334 subjects in the study, nearly all showed at least some improvement/reduction in their body measurement indices. For most subjects the effects are nearly immediate, with a significant proportion of the improvement realized within the first 100 days of participation in the program.

- The ph360 Personalized Health and Wellness Program was effective in improving the studied anthropometric indices for both males and females. However, there were some slight differences between males and females. Female subjects comprised 88% of the sample studied, and they had more rapid reductions in baseline body measurement indices than males. This difference was most pronounced in WHtR and BFI.
• The ph360 Personalized Health and Wellness Program was also effective across all ages in the study. There were however some differences observed between the age groups. Typically, younger individuals achieved more rapid decreases in the 3 body measurement indices than their older counterparts. Also, a higher percentage of the younger age groups achieved their healthy WHtR target of less than 0.49. However, having a lower percentage of their age group in the healthy WHtR range to begin with, the older age groups actually made larger proportional gains in the overall percentage of their age group attaining the healthy WHtR range.

• Of the body measurements tracked in this study, there was a very high level of correlation within change-from-baseline (CFB) measurements and untransformed measurements. The negative correlation between overall time and the body measurements shows that the longer someone participated in the program the more the body measurements decreased towards the desirable healthy ranges.

• This study confirms that the ph360 Health and Wellness Program was effective in reducing WHtR, BMI and BFI for males and females across all age groups.
Methods

After the initial data cleaning that included results from participants who remained in the program at least 3 months and provided updated measurement information, were not pregnant, hospitalized or seriously ill/injured during their time with the program, and did not have missing or erroneous data, results from 1334 participants remained.

The cleaned data set in this analysis consisted of results from 4133 body measurement check-ins (self-reported), each check-in was logged by one of 1334 individual subjects. Each subject completed at least 2 check-ins, all of which at different time points within the course of ph360 Personalized Health and Wellness Program. The check-ins consisted of logging their own anthropometric measurements (height, weight, neck circumference, waist circumference, hip circumference). Imperial measurements (feet, inches, pounds) were converted into metric (centimeters and kilograms). From the self-reported check-in measurements, 3 new indices were calculated, waist-to-height ratio (WHtR), body mass index (BMI), and body fat index (BFI).

\[
\text{WHtR} = \frac{\text{Waist}}{\text{Height}}
\]

\[
\text{BMI} = \frac{\text{Weight}}{(\text{Height}/100)^2}
\]

\[
\text{BFI for men} = 86.010 \times \log_{10}(\text{Waist - Neck}) - 70.041 \times \log_{10}(\text{Height}) + 36.76
\]

\[
\text{BFI for women} = 163.205 \times \log_{10}(\text{Waist + Hip + Neck}) - 97.684 \times \log_{10}(\text{Height}) - 78.387
\]

These 3 indices were the primary response variables of interest in this study. The first check-in for a given subject was taken to be that subject’s baseline measurement. Based on the baseline measurements, subjects that were classified as “standard plus”, “overfat” or “obese” were retained in this analysis (as these were the subjects in most need of body measurement improvements). The rules for subjects to be classified into those 3 categories and qualify for the study were as follows:

<table>
<thead>
<tr>
<th>Ages</th>
<th>Male</th>
<th>Female</th>
</tr>
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<tbody>
<tr>
<td>18-39</td>
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</tr>
<tr>
<td>40-59</td>
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<td>29+</td>
</tr>
<tr>
<td>60+</td>
<td>20+</td>
<td>30+</td>
</tr>
</tbody>
</table>

www.ph360.me
Also, there were 4 independent predictor variables that characterized the check-ins: subject, date, gender and age. As previously mentioned, there were 1334 subjects, of these subjects 1170 (~88%) were female and 164 (~12%) were male. The subject ages varied from 18 to 99 years old, with a mean age of ~51 years old (~48 for males and ~52 for females). The body measurement data consisted of check-ins logged between May of 2014 and March of 2018.

The next step in preparing the data was to calculate several new variables. These variables were defined as follows:

1 Age Group; Age was rounded to the nearest decade and converted from numeric to factor for grouping purposes.

1 Day; Day of check-in from baseline check-in. For each subject, check-in date minus the date of their first check-in. This is the day number, since the subject first engaged in ph360 Personalized Health and Wellness Program.

1 Day Group; Days grouped (Day 0, Day 1-50, Day 51-100, Day 101-250, Day 251-500, Day 500+)

1 Response CFBs; 6 response change-from-baseline (CFB) values were calculated from the 6 original response variables (waist, height, weight, WHtR, BMI, and BFI). Each of the response CFB values was calculated within subject by subtracting the baseline response (first check-in response) from the other check-in responses for that subject.

The responses expressed as change-from-baseline (CFB) were intended to more concisely answer questions of overall improvement, at the subject level (i.e. within subject), while controlling for the initial subject-to-subject variability in baseline body measurement indices.
Statistical Analysis

The statistical analysis consisted of a sequence of 4 basic parts: Part I Descriptive Statistics, Part II Exploratory Data Analysis (EDA), Part III ANOVA, and Part IV Modeling. The objectives of each part of the analysis are as follows:

Part I, Descriptive Statistics; This portion of the analysis was intended to give us a general sense of the data at a very high level, and to guide the Exploratory Data Analysis.

Part II, Exploratory Data Analysis; This portion of the analysis was intended to uncover and highlight interesting features in the data in more detail, and this information was then used to guide subsequent analyses. Specifically, interesting features found during the EDA, were subjected to more formal statistical testing in the ANOVA and Modeling parts of the analysis.

Part III, ANOVA; This portion of the analysis examined in detail the effect of independent variables (as grouping factors) on the dependent response variables. One-way and Two-way ANOVA were investigated.

Part IV, Modeling; This portion of the analysis was the most formal and was intended to quantify specific effects observed less formally during previous parts of the analysis.

The analyses were all conducted in R using a variety of packages detailed in Appendix A.
Results

Descriptive results

Table 1 below summarizes grouped means of the responses grouped by independent factors: gender, age group, and day group. Age groups 20 (less than 25 years old), 80 (75 to 85 years old), 90 (85 to 95 years old), and 100 (greater than 95 years old) were removed from the summary table as the data was too sparse and its variability too large to make means reliable with any level of confidence. The most important thing that this table shows is that there are very consistent decreases in the 3 indices (WHtR, BMI and BFI) over time (as summarized by day group), for both males and females. The table also shows that the 3 change-from-baseline (CFB) indices, which control for subject-to-subject variability by measuring relative change within each subject, are even more consistently decreasing with time. Finally, this table shows that females achieve even greater reductions in these key body measurement indices than do males. This means that the ph360 Personalized Health and Wellness Program is effective in reducing measurement indices for all age groups for both males and females, and that overall females exhibit even greater decreases than males in these indices.

Table 1. Summary of body composition data separated by age and gender.
Figure 1 below summarizes the 4133 measurement check-ins by subject age and gender. The histogram clearly shows that there was a non-uniform distribution of the ages of subjects, with more subjects at higher ages. The average age of subjects was 51 years old, with over 80% of the check-ins logged by subjects over the age of 40. Histogram 1 shows that there were also differences in the gender distribution, with 3672 surveys taken by female subjects (mean age ~52 years old) and only 461 surveys taken by male subjects (mean age ~48 years old).

Figure 1.Histogram of check-ins by age and gender.
Body composition change over time

Figure 2 below shows that all 3 original and change-from-baseline body measurement indices decrease with increasing time in ph360 Personalized Health and Wellness Program. Also, the slopes of these trends for gender, while close, appear to show that females make more rapid decreases in their body measurements than males. Later in the analysis, ANOVA and modeling will test this potential gender difference more formally.

Figure 2. Body Measurement Indices vs. Time, Grouped by Gender.
Figure 3 below shows that all 3 original and change-from-baseline body measurement indices decrease with increasing time in ph360 Personalized Health and Wellness Program. Also, the slopes of these trends for age group are very close. The only visual differences may be in the change-from-baseline measurements of WHtR and BFI, where younger subjects appear to make more rapid decreases in their body measurements than their older counterparts. Later in the analysis, ANOVA and modeling will test this potential age group difference more formally.

Figure 3. Body Measurement Indices vs. Time, Grouped by Age.
Figure 4 below shows the relationship between body fat index (BFI) and waist measurement based on gender. Since women naturally have more fat than men, it is of no surprise to see the higher BFI values. But what is noticeable and worth future investigation is that there seems to be a greater proportion of men with seemingly low BFI but high WHtR, justifying the inclusion of multiple anthropometric measures in the assessment of obesity-related health risks.

![BFI vs. Waist Measurement](image-url)

Figure 4. Plot of Body Fat Index versus Waistline Measurement.
Figure 5 below helps to answer a key question from this study, “Does ph360 Personalized Health and Wellness Program help individuals transition away from unhealthy waist-to-height ratios (WHtRs)”. Specifically, a WHtR value greater than 0.51 is considered a health concern, and a risk factor for cardiovascular disease and diabetes. Success, with respect to WHtR was defined as reaching and maintaining a value below 0.49. The bar chart below shows the percentage of subjects meeting the success criteria of WHtR < 0.49. For all age groups, the percentage of subjects achieving WHtR success more than doubles in under a year. The improvements are greater for younger age groups. However, the proportional improvements are actually greater for older age groups. For example, at day zero only 7% of the 70-year-old age group meet the healthy WHtR criteria, but within 100 days this percentage has quadrupled to 28%. This means that ph360 Personalized Health and Wellness Program is effective in reducing WHtR for all age groups, even those above 50, who often have a harder time shrinking their waistlines due to hormonal changes.
Figure 6 below shows the overall shift in distributions of the 3 critical body measure indices with increasing time engaged in ph360 Personalized Health and Wellness Program. In the top two plots, the center of mass of the waist-to-height ratio (WHtR) shifts from above 0.51 to below 0.49 in less than 100 days. Also, the whole distribution compresses towards WHtR = 0.45, and the heavy tail towards high WHtR values nearly disappears. The same basic observations also hold for the body mass index (BMI) and body fat index (BFI). This is very clear visual evidence that the ph360 Personalized Health and Wellness Program impacts the critical body measurement indices as intended.
Figure 7 below shows all correlation coefficients (Pearson's R's) for each pair of response variables. Also, included in the correlations analysis were the age and day grouping factors. The table shows a very high level of correlation within change-from-baseline (CFB) measurements and untransformed measurements. Height was uncorrelated, but that is not surprising, as height is not expected to change much compared to the other body measures. The table also shows that day was negatively correlated to the body measurements. So as days in ph360 Personalized Health and Wellness Program increases, body measurements decrease. This association confirms that the ph360 Health and Wellness Program was effective in reducing body measurements overall.

Figure 7. Correlations Matrix of Response Variables.
Table 3 below summarizes group-wise differences observed in one-way ANOVA, treating the 3 body measurement indices as response variables and gender, age group, and day group as grouping factors. Key findings from the ANOVA performed on the anthropometric variables were:

1. Males naturally exhibit higher WHtR and BMI but much lower BFI than females, as is to be expected. But participating males also exhibit less decrease in their change-from-baseline measurements than females, across all 3 body measurement indices, indicating a stronger positive effect in women.

2. Older subjects exhibit higher WHtR and BFI measurements than their younger counterparts, a naturally occurring phenomenon associated with aging. But what is interesting is that for certain age group pairs older subjects exhibit greater decreases in their change-from-baseline measurements than their younger counterparts.

3. There were numerous significant differences in day group comparisons across all 3 measurements and change-from-baseline measurements. The largest decreases were in BFI, but all indices dropped consistently as observed by the negative “DIFF” values for all significant differences.

Table 3. Significant Effects from One-Way ANOVA.
Table 4 below summarizes the significant effects observed in two-way ANOVA, treating the 3 body measurement indices as response variables and gender and age group as combined grouping factors. Post-hoc analysis of the coefficients for age group and gender shows that there were relatively few significant effects of age group and gender in the interaction model. This means that when age groupings and gender groupings are included in the same analysis, as combined grouping variables, there are less statistically significant differences and interactions between the resultant groups. What this means is the ph360 Personalized Health and Wellness Program was effective for all ages and both genders, and combining these groups doesn't reveal any additional significant differences.

Table 4. Table of Significant Effects from Two-Way ANOVA.
Effects on body composition

Table 7 below is a summary of all models used to fit the 3 body measurement indices and change-from-baseline indices. The best model for this data was found to be a mixed effects model with time as a continuous main effect. The model also included fixed main effects for age and gender, and a random effect for subject. This model performed basically the same as the equivalent model including all two-way interactions, thus during model selection, the simpler model was retained as it was more parsimonious (with lower AIC and BIC). The model specification for the best model, the linear mixed main effects model was as follows:

Response = Intercept + Age + Gender + Day + (1|Subject) + Error

Significant coefficients are color-coded green to teal (min to max) in the bottom half of table 4. The model indicates that gender and time (day) were the terms that had the greatest influence on the body measurement indices. The model also revealed some significance of the age term. However, the coefficient*age magnitude was lower than the coefficient*time and coefficient*gender magnitudes. Essentially, this model corroborates and reinforces the overall finding that changes in body measurements were most dependent on the amount of time someone participated in ph360 Personalized Health and Wellness Program.
Table 4. Interactions of age, gender and body composition variables.

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Conclusions

The ph360 Personalized Health and Wellness Program was effective in significantly decreasing individual body measurement indices. Of the 1334 subjects in the study, nearly all showed at least some improvement/reduction in their body measurement indices. For most subjects the effects are nearly immediate, with a significant proportion of the improvement realized within the first 100 days of ph360 Personalized Health and Wellness Program.

The ph360 Personalized Health and Wellness Program was effective in improving wellness scores for both males and females. However, there were some slight differences between male and female subjects. Female subjects comprised 88% of the sample studied, and they had more rapid reductions in baseline body measurement indices than males. This difference was most pronounced in 2 indices, waist-to-height ratio and BFI.

The ph360 Personalized Health and Wellness Program was also effective across all ages in the study. There were however some differences observed between the age groups. Typically, younger individuals achieved more rapid decreases in the 3 body measurement indices than their older counterparts. Also, a higher percentage of the younger age groups achieved their healthy WHtR target of less than 0.49. However, having a lower percentage of their age group in the healthy WHtR range to begin with, the older age groups actually made larger proportional gains in the overall percentage of their age group attaining the healthy WHtR range.

Of the body measurements tracked in this study, there was a very high level of correlation within change-from-baseline (CFB) measurements and untransformed measurements, while height changes were uncorrelated. Also, overall time engaged in the ph360 Personalized Health and Wellness Program was negatively correlated to the body measurements. As days participating in the program increased, body measurements decreased, and this association confirms that the ph360 Health and Wellness Program was effective in reducing body measurements overall and helping maintain the healthier anthropometric measures over time.

In conclusion, participation in the ph360 personalised health and wellness program results in short term and sustained decrease in important anthropometric indices that relate to CVD risk.
APPENDIX A: Body Fat Ranges

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References


