A USABILITY STUDY OF SEATBELT BUCKLE ACCESSIBILITY FOR ELDERLY OCCUPANTS

Niharika Bandaru
Christopher Sarros
Aaron Latour
TRQSS, Inc.
Canada

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ABSTRACT

Elderly occupants form a sub-group in the population spectrum that is often categorized as "vulnerable" in the automotive industry. By 2050, the segment of the population aged 60+ is expected to approximate 26%, which reinforces the importance of developing more adaptable safety technologies that provide optimal and accessible restraint. Following previous research where we analyzed the performance of motorized adjustable buckles in increasing the ease of access to recessed belt buckles for children in booster seats, we extended the examination to study their applicability to elderly occupant comfort and safety.
Thereby, the objectives were:

1. Perform a series of usability studies to prove that the current industry trend of recessed buckles is causing accessibility issues.
2. Attempt to confirm if motorized adjustable buckles improve latching performance while maintaining the intended geometry, given the previous objective was proven true.

A series of studies were conducted with a fixture that simulated the rear right side seat of a mid-sized sedan. The fixture was equipped with a motorized adjustable buckle which replicated two buckle modes – recessed and elevated. Occupants were asked to latch themselves with the buckle in both positions. Observations were made of the number of latch attempts, latching times, occupant preferences, and difficulty levels. The data shows a statistically significant difference for the mean latching attempts and durations between the two buckle modes (recessed and elevated). Objective feedback collected from the occupants shows that a majority of the sample population preferred the elevated mode. However, a strong explanation by the predictor variables (age, sex, weight, standing height, sitting height, arm length, arm to buckle length, and location) of response variables (latch attempts and durations, and buckle preferences) could not be established, unlike our previous study where strong correlations were found. This study's results indicate that elderly occupants are influenced by categorically different factors than children, as variables like age, weight, height, and sex had a limited influence on the outcome of the study. Observations and analyses conducted during the trials point towards more subjective factors that may have had a greater impact on the outcomes; predominantly general health, which can be arbitrary and indifferent to the predictors that were considered in this study. Furthermore, a singular seating configuration was used in this study. More permutations of seat sizes and buckle mounting types will aid in confirming this study's hypotheses.

INTRODUCTION

Elderly occupants are a sizeable and growing segment of the world population. The populations of U.S., Japan, and many other countries are "aging" at historically rapid rates, in the sense that the percentage of the population exceeding 60, 70, and 80 years is larger than at any previous time, and projected to continue to increase for the next few decades[1]. Elderly occupants often face challenges in daily activities due to a myriad of possible physical challenges, and seatbelt latching falls in that umbrella.

In view of this, it becomes pertinent that the automotive safety industry prioritizes elderly occupant restraint. Geometrical configurations of seatbelts are important in providing optimal seatbelt accessibility and comfort, along with restraint performance. Therefore, following previous research where the performance of motorized adjustable buckles in increasing the ease of access to recessed belt buckles for children in booster seats was studied, the analysis was extended to study their applicability to elderly occupant comfort and safety.

Buckle configuration is one issue, where certain car manufacturers have chosen to recede buckles of rear seats further into the seat, possibly to maintain a low Lap-Shoulder point and improve lap belt restraint. This was studied with respect to children in booster seats previously, where it was found that lower buckle heights were indeed causing challenges for buckle accessibility [2]. Following that, the first objective of this paper was to conduct a series of usability studies to examine if a recessed or a relatively more elevated belt buckle configuration was favourable to elderly occupants in terms of accessibility when latching a seatbelt. The second, based on the outcome of the first objective, was to study the effectiveness of a motorized adjustable buckle as a possible solution to increasing accessibility and providing a more comfortable seatbelt configuration to a vulnerable and increasing elderly occupant demographic while simultaneously maintaining the manufacturer's intended buckle position.

METHOD

The method for this study can be divided into three segments: buckle surveying, wherein outboard rear seat buckles of various makes and models were surveyed; usability studies, wherein elderly volunteers meeting pre-determined constraints participated in a series of buckle use trials; and data analysis, where data collected from the usability studies was examined to determine if the posited hypotheses were true.

Buckle Survey

A buckle survey was conducted in the previous study establishing a database of buckle positions and geometries from various vehicles [2]. The data from the surveys was used to help determine the need for a motorized adjustable buckle as postulated in the hypotheses, and to establish buckle configuration for the fixture used in the study. The chosen buckle was to be of a sturdy, inflexible mounting structure that was consistent with the sturdiness of the motorized adjustable buckle (see Figure A1 in Appendix for different buckle mounting types) [2]. Metal anchor strap type buckles and buckles with stiff boots of various vehicle makes and models were measured (refer to Table A1 in Appendix), and a buckle configuration from MY2016 was chosen for the fixture, which was maintained for this study. The previous buckle survey database was expanded to include vehicles of MY 2017-2019 to study further receding trends in buckle configurations.

The chosen seat position was the outboard 1st rear row passenger seat. The chosen seat position was based on buckle survey results where recessed belt buckles were more frequently found in the rear seats than in the front seats, as well as to maintain testing continuity consistent with the previous study where the outboard rear seat was the position of choice for the study. The following buckle configuration data of outboard 1st rear row buckles in vehicles was collected (Figures 1a, 1b):

1. Exposed buckle height (H)
2. Distance from seat back to face 1 of buckle (L')
3. Distance from seat back to face 2 of buckle (L)
4. Maximum seat base width (B)
5. Center of seat to buckle (C)[2]

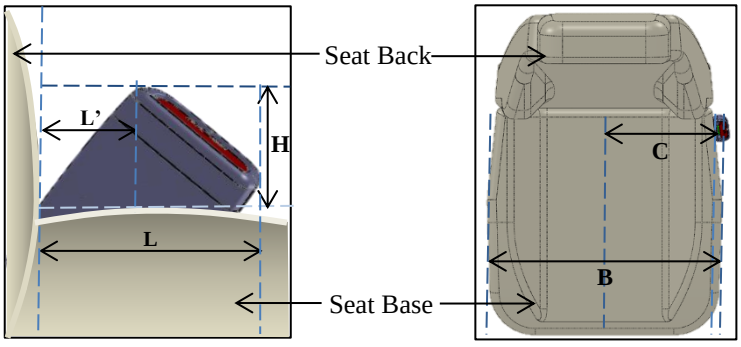

Figure 1a *Figure 1b, Top View of Seat*

Figure 1: Buckle Measurements (Figure 1a), Seat Measurements (Figure 1b).

Usability Study:

The intentions of this activity were to address the following questions:

(a) Do recessed buckles pose accessibility issues for elderly occupants in rear seats?

(b) How do they fare in comparison to elevated buckles?
(c) How does the data vary between occupants of various age groups, heights, weights, genders etc.?
(d) Are motorized adjustable buckles a viable solution?

Following the buckle surveys, volunteers were invited to participate in usability studies conducted across Windsor-Essex County, Canada, at retirement residences and seniors clubs. The details of the studies are as enumerated below:

Mounting Fixture A mounting fixture emulating the outboard rear row seating position of an average mid-sized sedan (Toyota Camry), which was used in previous research that sets precedent to this study [2], was used as shown in Figure 2. An informal survey of popular online automotive websites [3, 4] helped inform the choice of vehicle that the fixture was modelled after. The chosen seat was determined by a seat survey conducted among various vehicles in MYs 2010-2016 (refer to Table A1 in Appendix). A shelf-mount seatbelt retractor assembly was placed over the right shoulder of the car seat. The WSIR (Webbing Sensitive Inertial Response), VSIR (Vehicle Sensitive Inertial Response), and Automatic Locking Retractor (ALR) features were disabled to avoid interference due to locking during the study [2].
An electronically driven motorized belt buckle that replicated two buckle modes – recessed and elevated – was positioned to the left of the vehicle seat (Figures 3a, 3b). In the recessed mode (Figure 3a), the buckle was positioned at L' = 1cm, L = 5cm, H = 1 cm, and C = 22.5cm, which was based on the motorized adjustable buckle geometry, vehicle seat geometry, and buckle survey results for MY 2016. In its elevated mode (Figure 3b) the buckle extends outwards and diagonally upwards by 50mm and 13 degrees. The buckle was connected to a power supply and a switch that allowed the researcher to switch the buckle positions between trials [2].
The right side of the fixture was required to be completely adjacent to a wall (or any planar surface). This was to simulate the vehicle door, so as to recreate the vehicular environment for the test subjects and ensure test fidelity [2].

Figure 2: Mounting fixture used for the usability study.

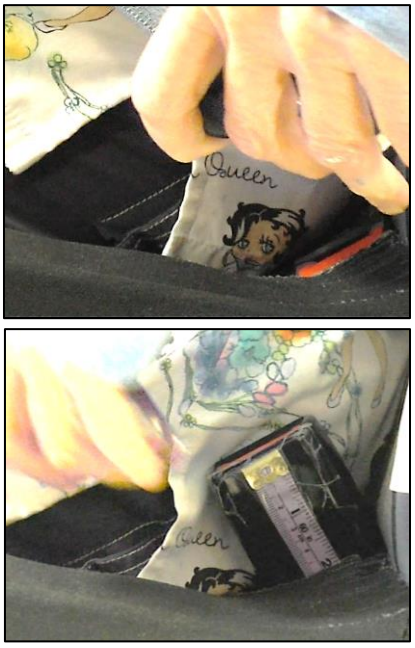

Figure 3: Buckle in recessed mode (3a), and buckle in elevated mode (3b).

Study Constraints The selection process involved picking consenting participants from local retirement residences and seniors clubs. All research ethics guidelines as defined in the Tri-Council Policy Statement by the Panel on Research Ethics [5] were adhered to in this process. Qualifications for candidates participating in the usability study were deemed as follows:

- Age: The occupant was to be 65 years old or above (residents and members at the surveyed locations were 65 or older)

- Height, weight: No restrictions on height or weight were enforced.

It was also required that the participant was able to independently latch themselves with a seatbelt, without the need for assistance.

Study Apparatus The following tools were employed:

- Two video recording devices, one with slow motion and frame by frame recording capabilities (60 fps), were used for this study. The slow motion device was placed directly in line with the buckle, on the left side of the fixture. The slow motion video recordings were used to analyze latch attempts, latch duration, and hand movements. The second recording device was placed diagonally opposite and across from the fixture. These recordings were used to study the overall behaviour of the participants during the trials as well as any other observational data.

- An electronic weighing scale

- Two 60-in soft tape measures; one was taped to a wall for height measurements and the second was used for arm length measurements.

- Two 3ft retractable metal tape measures; these tape measures were inserted into slots created in the roof of the mounting fixture and used to take "Sitting Height" and "Shoulder to Buckle" measurements [2].

Study Procedure The study procedure was replicated from previous research on seatbelt compatibility for occupants in booster seats, and was largely unchanged [2]. The participant was first asked to state their name, age, gender and whether they were currently using a belt extender.

Next, they were weighed and their arm length (straight line distance from the edge of their shoulder to the tip of their longest finger, (A)) and standing height (h) measurement/s were recorded (Figure 4).

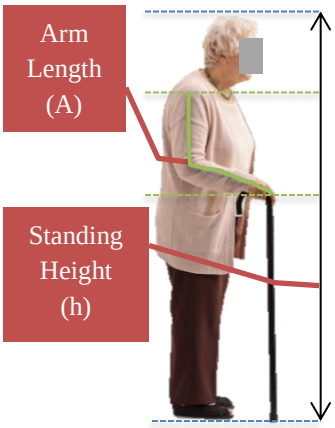

Figure 4: Standing Height and Arm Length Measurements.

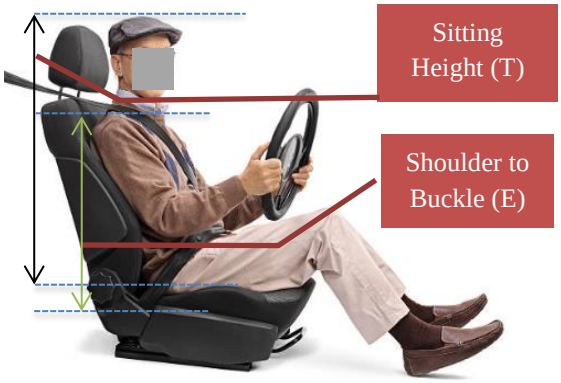

Figure 5: Sitting Height and Shoulder to Buckle Measurements.

The participant was then asked to seat themselves in the fixture while "Sitting Height" (distance from the top of the head to the center of the seat base, (T)) and "Shoulder to Buckle" (straight line distance from the edge of their shoulder to the top surface of the buckle, (E)) measurements were taken (Figure 5). Two slots were cut out in the roof of the fixture to incorporate one tape measure each. One would be used to measure "Roof to Head length" (R) and the other to measure "Roof to Shoulder" (S). These measurements were subtracted from the "Roof to Seat Base" (93cm) and "Roof to Buckle" (92cm) measurements, which were measured beforehand, to obtain T and E measurements. Next, inquiries pertaining to the participant's seatbelt wearing habits were made – if they could use the seatbelt themselves, or if assistance was needed owing to physical or medical restrictions. This was done to obtain an informal awareness of the participant's latching routine and to determine whether they were qualified to participate in the study. Data pertaining to the use of belt extenders was also collected, to establish if buckle accessibility was a common problem which would in turn help determine the need for a more effective solution. In

the cases where the participant independently latched themselves occasionally, they would be encouraged to repeat that for the study, but if the participant always requires assistance and repeatedly struggled with extracting the webbing, maintaining their grip on the slip tongue and/or with the general logistics of using a seatbelt during the trials, they were ultimately disqualified [2].
The protocol for the trials was as follows:

1. Each participant was asked to familiarize themselves with the setup and practice extracting the webbing before the commencement of the trials.
2. There were two trials for each participant – Trial A and Trial B, one for each buckle mode (recessed and elevated).
3. The participants were asked to latch the seatbelt, first for Trial A. After Trial A, the researcher would switch the position of the buckle unbeknownst to the occupant, and ask them to repeat Step 3 for Trial B. They were not informed of the changing buckle modes between the trials (the change point of the study) so as to prevent any presumptive biases.
4. Trials A & B were recorded separately on both recording devices for each participant.
5. Any unique behaviour was observed and recorded [2].

It is important to note that the order of the buckle modes was alternated between participants, as shown in the following example trial matrix:

Table 1.
Usability Study Trial Matrix

Participant #	Trial A	Trial B
1	1	2
2	2	1
3	1	2
4	2	1
5	1	2

1	Recessed
2	Elevated

This was done in order to eliminate any influence a consistent order may have had over the latch attempts and latch durations.
The data collected from the study can be found in the Appendix in Table A2. Figure A3 in the Appendix shows images taken during the course of the study.

Analysis
Data assessment was performed in three phases:

Paired t Tests The buckle video recordings from the usability study were evaluated to obtain the number of latch attempts, total latch duration, and a third parameter of buckle find time, for Trial A & Trial B of each individual participant. The statistical software Minitab [6] was used for the purpose of conducting Paired t Tests for the following groups:

- Latch Attempts (Recessed) vs Latch Attempts (Elevated)
- Latch Duration (Recessed) vs Latch Duration (Elevated)
- Buckle Find Time (Recessed) vs Buckle Find Time (Elevated)

The definition of Latch Attempts is consistent with previous research [2]. Latch Attempts were defined as follows:
One Latch Attempt:

- A single, deliberate, and continuous downward movement of the slip tongue resulting in a singular interaction with ANY buckle surface (buckle top, PRESS button, buckle sides, buckle slot etc.). This downward movement would be followed by a distinctive upward/retracting movement in the case of an unsuccessful latch attempt.

- A single, deliberate, and continuous movement in the buckle region outside of the buckle, below reference line 1 for the recessed mode and reference line 2 for the elevated mode (Figure 6a, 6b). The slip tongue would interact with a single non-buckle surface (seat base, seat back).
- A single, deliberate, and continuous movement in the buckle region outside of the buckle, below reference line 1 for the recessed mode and reference line 2 for the elevated mode, with zero interactions with any surfaces [2].

For the purpose of distinguishing between a continuous and an irregular latch attempt, it was decided that certain motions would be counted as "Half latch attempts".
Half Latch Attempt:

- A deliberate and continuous downward movement of the slip tongue resulting in insertion into the buckle slot after a brief, unintended interaction with the PRESS button or the buckle cover. The insertion would be 1 latch attempt and the brief interaction with the PRESS button or the buckle cover, a half attempt.
- A deliberate but interrupted downward movement of the slip tongue into the buckle slot where the movement of the slip tongue involves brief hesitation but no visible retraction [2].

In exceptional cases, latch attempt analysis was subjective where an attempt stretched outside the definition of a full or half latch attempt.

Latch Duration was defined as the difference between the start time and end time during the course of attempting to latch into the buckle. Latch start and end times for each mode were defined as follows:
Recessed mode: The start time of the event was defined as the instance when any surface of the slip tongue would coincide with the top edge of reference line 1 (Figure 6a) and the end time of the event was defined as the moment when the PRESS button on the buckle reemerged after a successful latch (±1 frame).
Elevated mode: The start time of the event was defined as the moment when any surface of the slip tongue would coincide with the top edge of reference line 2 (Figure 6b) and the end time of the event was defined as the moment when the PRESS button on the buckle re-emerged after a successful latch (±1 frame). There were cases wherein the participant retracted the seatbelt or removed the slip tongue from the video recording frame to adjust their grip on the slip tongue. In these cases the time during which the slip tongue was out of the frame was subtracted from the overall duration. Cases where the tongue or buckle views were obstructed by the participant's hand were disqualified [2].

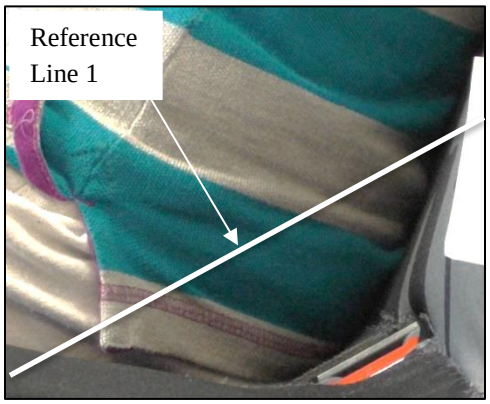

Figure 6a: Buckle in recessed mode and Reference Line 1.

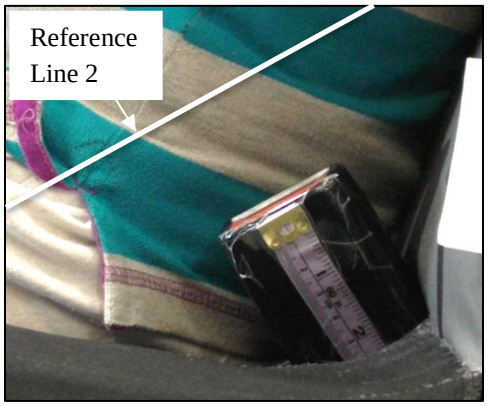

Figure 6b: Buckle in elevated mode and Reference Line 2.

Buckle Find Time: An additional third component was added to the analysis which was not a significant factor in the previous research with child occupants – buckle find time. It was observed that some elderly occupants tended to actively locate the buckle, with the slip tongue outside the buckle area and/or use their hands without a slip tongue. This tendency manifested at the start of the trials and/or during the course of latch attempts, and could not be counted into the latch duration factor owing to the fact that the occupants were trying to locate the buckle and not attempting to latch (Figure 7).

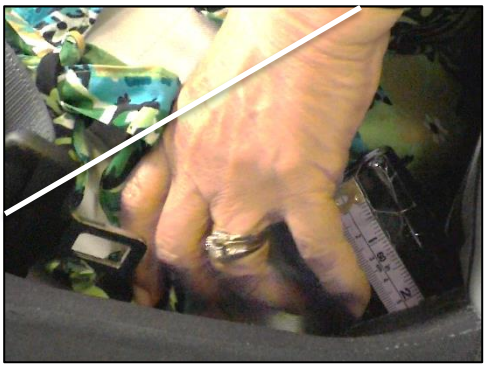

Figure 7: Occupant trying to locate buckle (Buckle Find Time).

Buckle Find Time was the difference between the start and end times of attempting to locate the buckle.

Recessed mode: The start time was the moment when the occupant introduced their hand or the slip tongue below reference line 1 and used either to visibly "find" the buckle without attempting to latch and the end time of the event was defined as the moment when the hand was raised above said reference line or when the slip tongue was used for latching attempts.
Elevated mode: The start time was the moment when the occupant introduced their hand or the slip tongue below reference line 2 and used either to visibly "find" the buckle without attempting to latch and the end time of the event was defined as the moment when the hand was raised above said reference line or when the slip tongue was used for latching attempts.

Reference lines: Reference line 1 was placed 50mm above the top edge of the buckle in recessed mode. Reference line 2 was placed 50mm above the top edge of the buckle in elevated mode. 50mm is the length by which the buckle extends from the recessed mode.

Regression Latch Attempts, latch durations, buckle find times, and individual preferences (recorded retrospectively for each participant) for each buckle mode were regressed against various predictor variables to understand which of these had the strongest influence on the outcomes, and how.
The predictor variables, along with the nature of each predictor that were considered for the regressions were:

- Age (years) - Continuous
- Weight (kg) - Continuous
- Sex (M/F) - Categorical
- Standing Height (cm) - Continuous
- Sitting Height (cm) - Continuous
- Arm Length (cm) - Continuous
- Shoulder to Buckle (cm) - Continuous
- Location - Categorical

Participant buckle preferences were noted after the trials. Responses were categorized into four groups:

- No preference
- Recessed mode
- Elevated mode

- Either

Factors like Standing Height and Sitting Height, that are expected to show a fair degree of correlation between one another, showed only a 50.1% regression value, which meant only about half of the variation in Standing Height was explained by Sitting Height in a linear model. The factor of regression showed that Sitting Height did not pose a strong enough threat as a repeating or confounding factor to Standing Height, and was therefore retained as an explanatory variable (refer to Figure A7a in Appendix). A similar explanation can be attributed to when comparing Arm Length and Shoulder to Buckle measurements. While a small positive correlation was achieved, very little of the variation in Arm Length was explained by Shoulder to Buckle length, and both factors had to be retained as possible explanatory factors (refer to Figure A7b in Appendix).
Weight is an independent variable, which unlike in preceding research with children in booster seats, proved to be a stronger explanatory factor, and was therefore also retained as a predictor variable for regression assessments.

Observational Analysis Video recordings of the test subjects during the trials were studied to identify any behavioral differences between the trials for each subject. Specifics are:
1. The test subject being Out of Position while attempting to latch
2. The extent to which test subjects may have to rotate their bodies to visually access the buckle
3. Any other idiosyncrasies or struggles associated with performing a latch

These observations would further assist in gauging the relative ease or difficulty for the test subjects in latching themselves in the different modes.

RESULTS

Total count of participants from all of the locations was 123. The total sample size for overall analysis was 112, after removing participants that did not meet the study requirements (as enumerated in Table A2 of Appendix) and occupants who failed to independently perform a latch during the trials. Latch Attempts, Latch Duration, and Buckle Find Time were evaluated separately due to different sample sizes, attributed to the following reasons:

1. At the time of latching, the re-emergence of the PRESS button on the buckle was blocked by a participant's hand/s, making it difficult to determine the Start and End times for Latch Duration assessment. However, distinct visible hand movements made it viable to count latch attempts, which were not affected when the buckle view was blocked.
2. Conversely, instances where hand movements for latch attempts were too incoherent, but Latch Duration Start and End times were still decipherable were disqualified for Latch Attempt analysis only.
3. The total sample population that met the study requirements qualified for Buckle Find Time analysis, unless the occupant failed to perform a latch independently and external support was required to do so.

Therefore, participants not meeting the individual requirements of a certain dependent variable were excluded from that dataset only, and considered in the other datasets given that they satisfied their respective conditions. Table A3 in the Appendix shows the final results for Latch Attempt, Latch Duration, and Buckle Find Time datasets. Figures A8-A24 in the Appendix show charted results. Paired t Test evaluations were performed on these data groups using the statistical software Minitab [6].

Paired t Tests:

Outlier fences for Latch Attempt and Latch Duration datasets were calculated using the 1.5*IQR rule, as follows:

Table 2.
Outlier Fences for Latch Attempts in Various Categories.

Group	Sub-group	Latch Attempt Difference	
		LL	UL
Overall	-	-11.3	17.2
Age	65-69	-13.6	21.9
	70-79	-10.6	15.4
	80-89	-9.4	13.6
	90-98	-14	22
Sex	Male	-10	17
	Female	-11.2	16.3
Trials	Rec. first	-10.1	15.4
	Elv. first	-12.8	19.3
Location	Study Site 1	-1	3
	Study Site 2	-11.9	28.6
	Study Site 3	-27.4	22.1
	Study Site 4	-8.8	14.3
	Study Site 5	-11	17

Note: LL – Lower Limit, UL – Upper Limit

Table 3.
Outlier Fences for Latch Duration in Various Categories.

Group	Sub-group	Latch Duration Difference	
		LL	UL
Overall	-	-12.6	17.5
Age	65-69	-14.1	41.9
	70-79	-8.6	24.8
	80-89	-1.5	10.3
	90-98	-3.7	13.3
Sex	Male	-3.9	15.4
	Female	-4.4	14.4
Trials	Rec. first	-5.3	16.7
	Elv. first	-1.8	12.3
Location	Study Site 1	-3.2	7.7
	Study Site 2	-32.2	51.2
	Study Site 3	-90.3	62.2
	Study Site 4	-7.7	13.9
	Study Site 5	-14.9	21.6

Note: LL – Lower Limit, UL – Upper Limit

All negative lower fences are a result of the outlier calculation process. The Latch Attempts and Latch Duration variables are positive counts that start at zero. Therefore all negative lower outlier fences can effectively be rounded up to a "0". All outliers from this evaluation were excluded and Paired t Test analyses were performed using the resulting data. It is vital to note that only the initial outliers were removed and any subsequent outliers calculated by Minitab were not excluded.

The 1.5*IQR rule based outlier fences were not applied to the Buckle Find Time dataset, as the number of cases where the Buckle Find Time was zero superseded the number of cases with recorded times > 0s. This resulted in the latter set of cases resulting as outliers, which is misleading. Excluding all of the 0s Buckle Find Time cases, resulted in the remainder 26 cases with recorded times >0s showing no outliers. This scenario was ideal, but not truly representative of the population. Therefore, a decision was made to analyze the combined results of both scenarios, but without the application of outlier fences.

Table 4.
Paired t Test Results for Mean Latch Attempts in Various Categories.

Latch Attempts					
Group	Sub-group	Sample Size	Paired Diff μ	% Diff	P-value
Overall	-	100	2.9	29.2	<0.001
Age	65-69	12	4.25	49.3	0.008
	70-79	37	2.3	29	0.002
	80-89	29	2.14	20.7	0.005
	90-98	23	4.9	34.5	0.001
Gender	M	27	2.8	26.1	0.005
	F	73	2.9	30.5	<0.001
Trials	Rec. first	54	2.5	27.6	<0.001
	Elv. first	47	3.7	32.9	<0.001
Location	Study Site 1	5	1.4	14	0.404
	Study Site 2	13	6.3	45.9	0.005
	Study Site 3	15	-3.3	-27.2	0.815
	Study Site 4	46	2.7	34.6	0.001
	Study Site 5	27	2.8	23.6	0.005

Note: Alpha risk level for P-values: 0.05

Table 5.
Paired t Test Results for Mean Latch Duration in Various Categories.

Latch Duration (s)					
Group	Sub-group	Sample Size	Paired Diff μ	% Diff	P-value
Overall	-	97	2.5	21.9	<0.001
Age	65-69	12	4.4	46.2	0.013
	70-79	37	1.6	19.3	0.067
	80-89	29	2.3	17.6	0.030
	90-98	22	4.7	25.9	0.013
Gender	M	27	4.3	31.8	0.002
	F	70	1.9	17.5	0.003
Trials	Rec. first	53	3	26.9	<0.001
	Elv. first	45	1.5	13.3	0.033
Location	Study Site 1	5	11.1	57.5	0.2
	Study Site 2	15	11.2	43.2	0.021
	Study Site 3	16	-16.5	-117	0.970
	Study Site 4	44	2.6	33	<0.001
	Study Site 5	26	2.3	15.6	0.060

Note: Alpha risk level for P-values: 0.05

All P-values > 0.05 were determined insignificant for the analysis of study trial results. Result examples for the aforementioned categories can be found in the Appendix on Pages xii-xxi. Sample sizes were large enough for most categories, and normality was not an issue; however for categories where the sample size < 20 (highlighted in red under Sample Size column in Tables 4, 5), normality could not be established, and more data would provide greater significance to the results.
Paired Difference μ for Latch Attempts is the difference between Mean of Latch Attempts (Recessed) and Mean of Latch Attempts (Elevated). Paired Difference μ for Latch Duration is the difference between Mean of Latch Duration (Recessed) and Mean of Latch Duration (Elevated). P-values remain largely under the alpha risk level of 0.05, other than a few exceptions (as highlighted in red under P-value column in Tables 4, 5).

The following outcomes were obtained from data analysis:

Latch Attempts

- The mean latch attempts for the recessed mode would be greater than mean latch attempts for the elevated mode in a population with a 99.99% significance.
- For the study sample size, there was a 29.2% decrease in mean latch attempts in the elevated mode in comparison to the recessed mode.
- The data shows a 95% confidence in the mean latch attempts in the recessed mode being greater than 2.09 attempts in comparison to the mean latch attempts in the elevated mode.
- Percentage differences between recessed and elevated mode latch attempts for the age sub-group ranged from 20.7-49.3%. However, the increase in percentage difference was not proportional to rise in age, and normality could not be established in the case of 65-69YO occupants, with a sample size of only 12 participants.
- A small percentage difference in latch attempts was observed in the female occupant sub-group (30.5%) in comparison to their male counterparts (26.1%). However, the sample size for females was over twice that

of males. This large difference in participation accounts for a more representative average value in the case of the females, and more comparative variance in the case of the males.

- A small percentage difference in latch attempts was observed between "Recessed Mode first" versus "Elevated Mode first" categories, with the latter showing a slightly higher percentage difference. This means that on average, participants that had the order "2, 1" (refer to Table 1) showed a slightly greater improvement between latch attempts in comparison to those who performed according to the order "1, 2".
- Location based results varied from -27.2 – 45.9%, which is a fairly large range. However, sample sizes from trials at *Study Site 1, 2, and 3* were too small to establish normality, which means the P-values are less accurate than required to determine significance in a population.
  However, trials from *Study Site 4*, and *5* showed a percentage difference of 34.6% and 23.6% respectively, with significant P-values.

Latch Duration

- The mean latch duration for the recessed mode would be greater than mean latch duration for the elevated mode in a population with a 99.99% significance.
- For the study sample size, there was a 21.9% decrease in mean latch duration in the elevated mode in comparison to the recessed mode.
- The data shows a 95% confidence in the mean latch duration in the recessed mode being greater than 1.51s in comparison to the mean latch duration in the elevated mode.
- Percentage differences between recessed and elevated mode latch durations for the age sub-groups ranged from 17.6-46.2%. However, the increase in percentage difference was not proportional to rise in age, and normality could not be established in the case of 65-69YO occupants, with a sample size of only 12 participants. The P-value was slightly outside of the established alpha risk level of 0.05 in the case of the 70-79YO category, owing to a single unusual outlier (refer to Page xviii in Appendix) which was a subsequent outlier after the first round of outlier eliminations. Owing to this explanation, the Paired μ result for this category was still considered as significant.
- A large percentage difference in mean latch duration was observed between the female occupant category (17.5%) and the male occupant category (31.8%). However, the sample size for females was over twice that of males, and such a large difference needs to be accounted for. The female category result is a more representative average owing to the large sample size, and the male result is less normalized than its female counterpart.
- A difference of 6% was observed between the "Recessed Mode first" and "Elevated Mode first" categories, with the former showing a higher percentage difference (53%). Both categories had comparable sample sizes. This means that on average, participants that had the order "1, 2" (refer to Table 1) showed a slightly greater improvement in latch duration in comparison to those who performed according to the order "2, 1".
- Location based results varied from -117 – 57.5%. This unusual range can be attributed to the small sample sizes at *Study Site 1, 2, and 3*, which resulted in extreme and insignificant data.
  However, trials from *Study Site 4*, and *5* showed a percentage difference of 33% and 15.6% respectively. The P-value for *Study Site 5* is slightly greater than the established alpha risk level of 0.05, owing to a single unusual outlier (refer to Page xx in Appendix) which resulted after the first round of outlier eliminations. Owing to this, the Paired μ result for this category was still deemed significant.

Buckle Find Time Only two Paired t Tests were performed for Buckle Find Time (BFT) calculations: 1) Entire sample size, and 2) Sample size where either buckle mode trial had a result >0s. The results for these calculations are as shown below:

1. Entire sample size

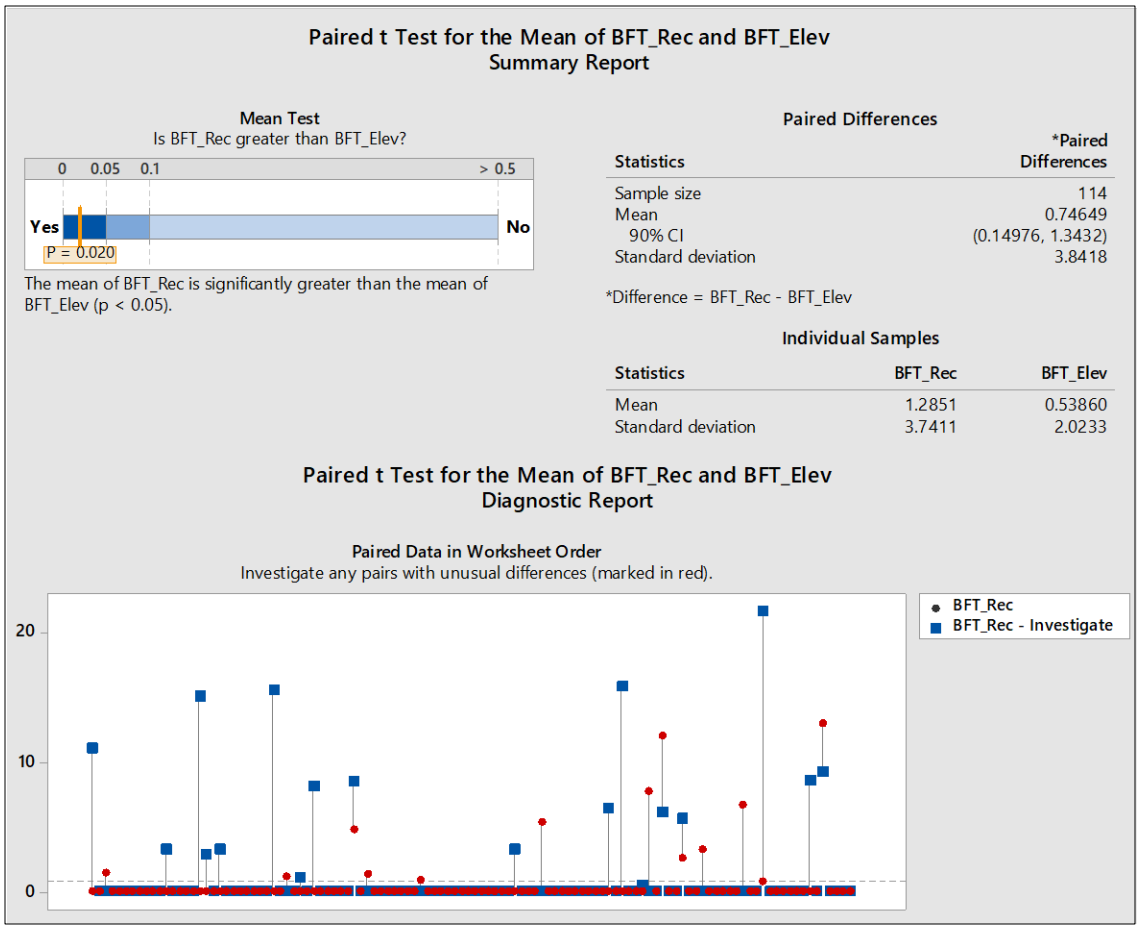

Figure 8: Paired t Test results of Buckle Find Time (Recessed) vs Buckle Find Time (Elevated) for the entire sample size.

As seen above, almost all of the pairs where BFT = 0s for both recessed and elevated mode (here forth referred to as "No Result Data") trials have been determined as outliers, with the addition of some pairs where either trial (recessed or elevated) with measurements >0s. The Paired μ difference is marginal at 0.75s. This data is significantly representative of a population as the P-value is <0.05, but the result is insignificant in terms of representing a study sample that did spend time locating the buckle.

2. Sample size = 26 (Pairs where either trial (recessed or elevated) > 0s)

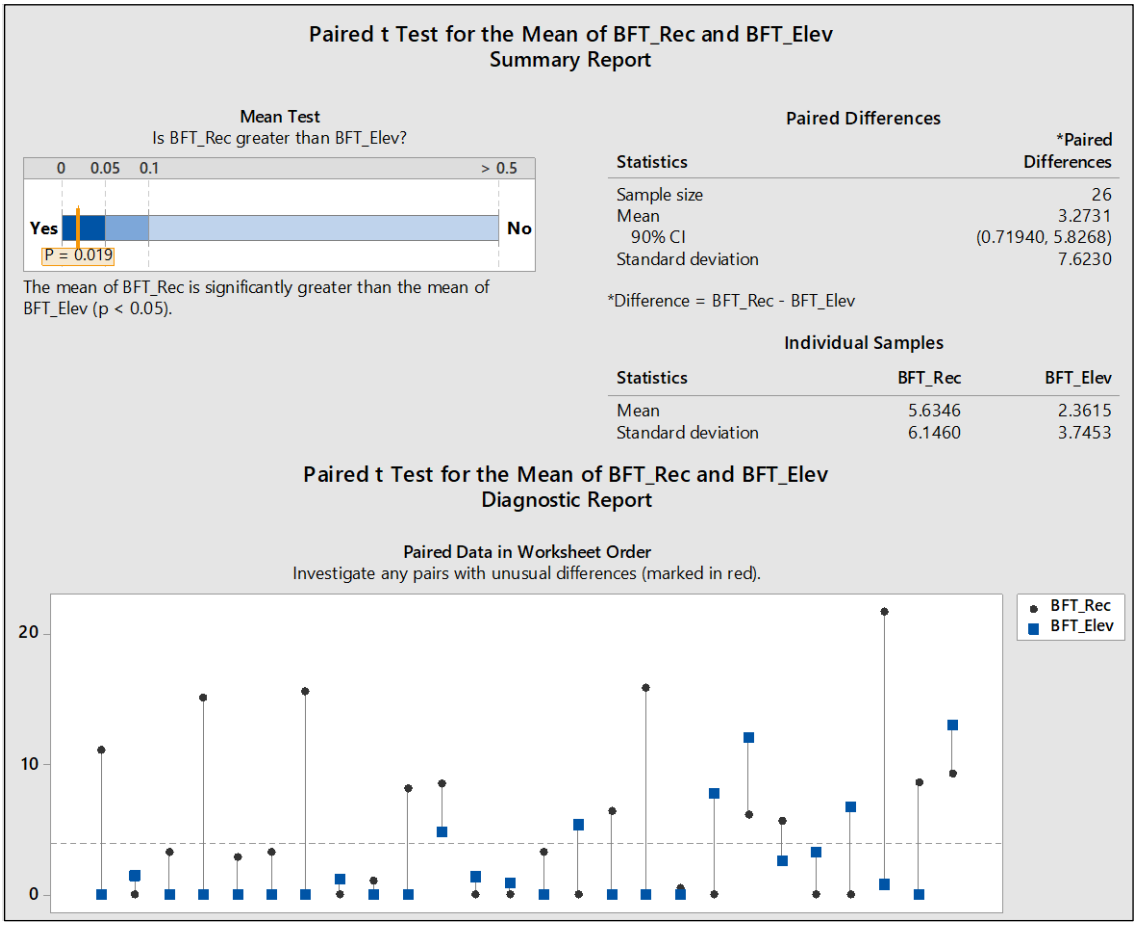

Figure 9: Paired t Test results for Buckle Find Time (Recessed) vs Buckle Find Time (Elevated) for sample size = 26.

Upon the removal of No Result Data, the sample size is reduced to 26 and the Paired μ difference between recessed mode and elevated mode BFTs = 3.27s, where the mean BFT for the recessed mode was higher. A P-value of 0.019 establishes this result as significant in a population. With the removal of No Result Data, the outlier fences readjust themselves, and no outliers are found. The percentage difference of 58.1% between recessed and elevated mode BFTs is significant for the sub-group in a population that spends time finding the buckle prior to attempting to latch. Further evaluations based on age, gender, buckle mode order, and location were not performed for BFT owing to the small, insignificant sample size that would be generated for each category.

Regression

Multiple variable regressions, were performed between the various predictor and dependent variables to determine which factors explained the variance in the data. Only the initial set of residuals calculated by Minitab was removed and any subsequent residuals were not excluded. Examples of individual response variable regressions can be found on Pages xxii-xxviii of the Appendix.

The dependent variables were Latch Attempts, Latch Duration, Buckle Find Time, and Preference.

The following were the results of the regression analysis:

Table 6.
Results of Regression Analysis.

Response Var.	Predictor Var. in Model	r^2 (%)	P-value
LA Rec.	Age, Weight, Shoulder to Buckle, Location	27.44	0.002
LA Elv.	Age, Weight, Sitting Height	16.89	<0.001
LD Rec.	Age, Weight, Sitting Height, Location	33.87	<0.001
LD Elv.	Age, Weight, Sitting Height, Location	44.58	<0.001
BFT Rec	Arm Length, Location	21.65	0.002
BFT Elv	Standing Height, Location	67.73	0.011
Preference	Location	29.19	<0.001

Note: LA - Latch Attempts, LD – Latch Durations, BFT – Buckle Find Times

The predictor variables in the model for each multiple regression of each individual response variable vary. In each case, the regression model included the predictor variables that explained the variance in the output values the most, without overfitting. P-values in each case are < 0.05, which means all of the models are significant in a population. The following were the results of the regressions:

- Age, Weight, and Location are the predominant predictor variables. Location is the most consistent among all the predictor variables, contributing the most new information to explain the models (refer to Figures A18-A24 in Appendix).
- The predictors are able to explain variance to only a certain extent, reaching a peak r^2 of 67.73% in the case of BFT Elevated. Latch Attempt Elevated is the least explained model for the given predictors with an r^2 of 16.89%.
- Gender does not explain or contribute to the results of the study discussed within the scope of this research paper.
- Location supersedes the other predictors in explaining almost all the models (refer to Figures A18-A24 in Appendix).
- This data will help analyze what factors play the most influence in determining whether an elderly occupant benefits from a motorized adjustable buckle or not.
- Parameters outside of the scope of this study were responsible for the unexplained variance in the models.
- This data will help examine other factors not included in the regression models that may have been responsible for the recorded outcomes. It will also help analyze if adjusting these factors would increase or decrease Latch Attempts, Latch Durations, Buckle Find Times and change Buckle Preferences in future studies.

Buckle Preferences:

Buckle preference data that was collected from each participating individual revealed information that supports the results of the Paired t Tests.

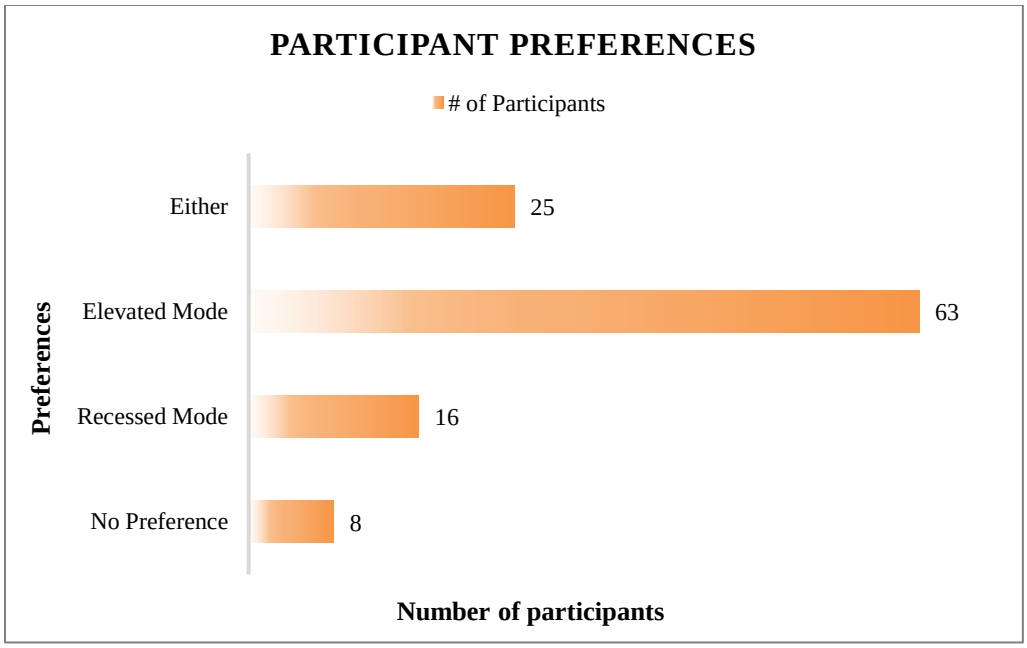

Figure 10: Participant buckle preference results, sorted by preference type.

Occupants were not informed of the changing buckle mode nor the trial order, which removes a considerable amount of bias from the preference results. Some occupants preferred neither buckle mode ("No Preference"), which means that both buckle modes were disliked, and others preferred either buckle mode ("Either"), which means that both buckle modes were equally liked. Of note is that the number of participants whose preference was either buckle mode was greater in number than those who exclusively preferred the recessed buckle mode. Participants overwhelmingly preferred the elevated mode over the recessed mode.

Other Observations:

Supplementary observations recorded during the study trials provide some insight into participant idiosyncrasies and latching patterns, those which have not or cannot be accounted for in statistical analyses.

- It was observed that overweight or obese occupants (BMI >25, Table A2 in Appendix) tended to prefer the elevated buckle mode, owing to a wider spanning lap.
- Most participants did not use a belt extender in their daily lives (refer to Table A2 in Appendix).
- There was a much higher participation from females than males.

DISCUSSION

A notable observation from the trials and analyses is the comparative performance of the elderly population versus the children in booster seats. While the overall latch attempt performance was relatively similar (as seen in Table 7 below), there was a noticeable increase in latch duration percentage difference in the case of the elderly sample population. Paired Difference µs were also relatively higher for multiple sub-categories in the case of the elderly cohort, as seen in the table below, where Paired Difference µ results of the two studies have been conditionally formatted separately for Latch Attempts and Latch Duration (separation of variables indicated by black boxes in table below), with a green to red gradient (green being the lowest and red being the highest value). Graphs comparing the results of both studies can be found in the Appendix.

Table 7.
Comparative analysis of children (in booster seats) versus elderly cohort performances (Latch Attempts and Latch Duration).

		Latch Attempts (Children)		Latch Attempts (Elderly)		Latch Duration (Children)		Latch Duration (Elderly)	
Group	**Sub-group**	**Sample Size**	**Paired Diff μ**	**Sample Size**	**Paired Diff μ**	**Sample Size**	**Paired Diff μ**	**Sample Size**	**Paired Diff μ**
Overall	-	112	1.83	100	2.9	96	1.21	97	2.5
Gender	M	67	1.3	27	2.8	57	0.67	27	4.3
	F	45	2.42	73	2.9	38	1.77	70	1.9
Trials	Rec. First	57	1.97	54	2.5	46	1.54	53	3
	Elv.First	55	1.69	47	3.7	50	0.91	45	1.5
		Latch Attempts				**Latch Duration**			
		Sample Size		**Paired Diff μ**		**Sample Size**		**Paired Diff μ**	
	Children								
Age	4	23		2.97		22		3.55	
	5	23		2.78		18		4.43	
	6	24		1.38		22		0.63	
	7	25		0.8		22		0.62	
	8	19		1.18		17		0.64	
	Elderly								
	(65-69)	12		4.25		12		4.4	
	(70-79)	37		2.3		37		1.6	
	(80-89)	29		2.14		29		2.3	
	(90-98)	23		4.9		22		4.7	

Location played an important role in explaining the variance in various regression models. This can be explained by different underlying factors that govern the participants at each location, like:

1. Whether the location was a retirement residence (which was 4 out of the 5 locations surveyed) or seniors' activity club.
2. The level of fitness or daily physical activity that participants from each location were accustomed to.
3. Average health of participants at any given location.

It was noticed that the seniors' activity club (Study Site 4) generated the most participants out of all the surveyed locations (Tables 4, 5). Participants at this location seemed more agile and active, in comparison to the long term residents of the retirement residences whose mobility and cognition seemed to be more compromised due to various health reasons (possibly Parkinson's disease, Alzheimer's disease, early stages of cataract, etc.). As location dominated age as a stronger predictor variable in most of the regression results, it draws into attention the fact that the overall health for elderly participants is a possibly stronger factor in latching performance than how old they may be. There is no singular, straightforward measure for "Health", as participants could suffer from a variety of medical afflictions of various degrees, with multiple issues affecting the same individual sometimes, compounding the degree of their inflexibility and immobility. Therefore, direct correlations could not be established between "Health" and Latch Attempts, Latch Duration, or Buckle Find Time.

Another observation that needs to be addressed is the ratio of female to male participants in the study. A total of 90 females participated as opposed to 33 males, a very high and disproportionate ratio. This can be appropriated to the established fact that females enjoy a lower mortality rate than men [7-9], which increases in significance with increase in age. Females are also more robust than their male counterparts at all ages [7], which justifies a relatively higher level of enthusiasm in partaking in activities. However, in order to obtain a more balanced comparison of results with respect to the study conducted, a bigger sample size of male participants would have been favourable.

It was also observed that the 65-69YO age category had the lowest number of participants among all the age groups. This can be attributed to a lower number of residents and members pertaining to that age group at the locations that were surveyed.

Similar to the previous study, the input variables (Latch Attempts, Latch Duration, and Buckle Find Time) had to be individually examined, as they had a low P-value, little co-relation, or insufficiently explained for variance when regressed against one another (Figures A25-A29 in the Appendix). The plausible reasons for this could be:

- Multiple latch attempts can be performed in a short span of time, as demonstrated by some older occupants.
- A single latch attempt can be performed over a relatively long time span, as demonstrated by some younger occupants.
- Not all the participants spent time finding the buckle prior to attempting to latch, which meant Buckle Find Time is a separate measurement from Latch Duration.

As discussed via regression analysis, other variables outside the scope of this study need to be examined to justify the unexplained variance in the data. Other potential predictors could be:

1. Vehicle make
2. Buckle anchor type
3. Seat back angle
4. Seating position (FR RH, RR CTR etc.)
5. Latch force
6. Medical conditions

LIMITATIONS

Certain aspects of data collection used in this analysis may have introduced unintended variability to the estimates. Due to a need for further assessments using more configurations, the results cannot be considered universally representative of the randomly sampled test subjects.
The limitations associated with this study are as follows:

- Only one buckle configuration in the recessed mode was studied. Further studies using the best and worst case buckle benchmarking data would provide insight into latching tendencies.
- Only one buckle configuration in the elevated mode was studied (50mm height increase). Further studies into higher buckle lengths would help analyze the optimum buckle height for latching.
- One seating configuration was used - midsize right hand rear row sedan seat. Varying combinations of seat sizes and buckle types would have to be studied.
- Only eight predictor variables were taken into account. Changing the seating configuration, seat position, and other factors outside the scope of this study may influence the results of future evaluations.
- In the cases of some occupants, assistance was provided with the webbing feed, as they visibly struggled to completely extract the webbing themselves. The amount of webbing provided was not measured in each case, and this randomness could have introduced some variability.
- Some occupants' communicated preference for buckle mode was in direct contradiction to their performance during the trials. This bias was typically because of the type of buckle the occupant was accustomed to in their daily lives.
- Any medical issues limiting the performance of participants was a significant factor in this study, as discussed in the Discussions segment of this paper.

CONCLUSION

The analysis in this paper justifies the first hypothesis posed in this paper: the recessed buckle position is more difficult to use than the elevated buckle position for elderly occupants in a population, as demonstrated by the differences in Latch Attempt, Latch Duration, and Buckle Find Time results, under similar circumstances as adopted by this study.
It was also observed that an increase or decrease in percentage differences in performances were not directly proportionate to an increase in age. Females showed a greater percentage difference in latch duration than males, but similar performances in the latch attempt category; however, a larger male participant sample size is imperative to establish comparative and significant results. Trial mode order saw that participants that had the order "2, 1" in the Latch Attempt category showed little difference in performance than the ones that had the order "1, 2". This was the opposite case with respect to the Latch Duration category, where percentage difference in performance spikes, with participants that had the order "1, 2" showing more improvement than the ones who had the order "2, 1".
Occupants that spent time finding the buckle prior to latching, showed an improvement when switched over from the recessed mode to the elevated mode. However, only a small percentage of individuals in the population displayed the tendency to visibly locate the buckle prior to attempting to latch.
Elderly occupants showed a greater improvement when switched from recessed to elevated mode than children in booster seats in the Latch Attempt and Latch Duration categories, for comparable sample sizes.

However, elderly occupants were governed by different predictors than their younger counterparts. Age played a prominent role in dictating the latching patterns of children in booster seats, whereas it played a meandering role in case of the elderly, who were influenced more by the location of the study, which was an indirect measure of their fitness levels.
The chosen predictors played a comparatively smaller role overall in influencing the latching performances and preferences of the participants, relative to the results of the previous study. Factors outside of the scope of this study need to be examined to elucidate the unexplained variance in the regression models.

The data from this analysis shows that the usage of a motorized adjustable buckle demonstrations a clear benefit to improving accessibility for the elderly while maintaining the manufacturer's intended buckle position. These findings confirm the second hypothesis proposed in this study for the conditions that participants were examined under. A further examination including different configurations and variable factors is required to advance a universal confirmation of the hypotheses.

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APPENDIX

Table A1.
Buckle and Seat Width Measurements

				Seat		Buckle		
#	**Year**	**Make**	**Model**	**B (cm)**	**C (cm)**	**H (cm)**	**L (cm)**	**L' (cm)**
1	2019	Toyota	C-HR	51	18	3	4.5	1
2	2019	Nissan	Kicks	46	15.5	0	9	4.5
3	2019	Mazda	CX-5	53	20.5	1.25	7	3
4	2019	Mazda	CX-3	40.5	17	2	7.5	4
5	2019	Mazda	CX-9	55	19	2.5	5.5	1
6	2019	Mazda	6	55	21	3	6.5	2.5
7	2018	Chevrolet	Silverado	51	21	3	11	6.5
8	2018	Chevrolet	Silverado LT	51	23	4	6	1
9	2018	Ford	F150-Ext. Cab	49	19.5	7	7	2.3
10	2018	Mazda	3	54	18.7	1.2	6.5	2
11	2018	Mazda	CX-5	46	19	2	7	3
12	2017	Chevrolet	Silverado	51	21	3	11	6.5
13	2017	Nissan	Maxima	52	17	6	7.5	3
14	2017	Nissan	Pathfinder	51	22.5	1.75	14.5	10
15	2017	Hyundai	Elantra	56	21	2	5	1
16	2017	Buick	Encore	48.5	17	6	13	9
17	2017	Chrysler	Pacifica	46.5	23.25	2.6	6	2.6
18	2017	Ford	Fusion	50	22.5	6	4.5	0
19	2017	Toyota	Sienna	59	24	4.5	7.5	3.5
20	2017	Honda	Accord	51	18	8	11	7
21	2017	Honda	CR-V	51	19	2	6.5	1.5
22	2017	Ford	Escape	46	16.5	4	8	3.5
23	2016	Dodge	Caravan	52	21	5	9.5	5.5
24	2016	Dodge	Dart	54	22.5	0.5	8	4
25	2016	Ford	Escape	46	16	5	8.5	4.5
26	2016	Ford	Focus	50	22	4.5	6	2
27	2016	Ford	Fusion	55	23	6.5	5	1.5
28	2016	Hyundai	Sonata	49	20	4.5	7	3
29	2016	Jeep	Cherokee	52	20	3	8	4
30	2016	Jeep	Grand Cherokee	50.5	20	1	8.5	4.7
31	2016	Mazda	3	49.5	24.25	3.5	7	2
32	2016	Mazda	CX-5	53	22.5	4	6	1.5
33	2016	Nissan	Rogue	52.5	22.25	3.8	12.5	8.5
34	2016	Chrysler	200	48	20	6	6	2.5
35	2016	Nissan	Maxima	38.5	19.25	6.5	5.2	1.8
36	2016	Chrysler	Town & Country	50	20	4.5	6	3
37	2016	Kia	Optima	39.5	N/A	7.8	7	3
38	2016	Mazda	CX-3	48	18	2	11.5	7
39	2016	Volvo	XC90	51.8	N/A	10	7	3
40	2016	Honda	HR-V	51.8	15.54	10	7	3
41	2016	Mercedes	GLC	46.5	19.5	4.5	9	5
42	2016	Toyota	RAV4	52.5	19	6	10.5	4.5

43	2015	Dodge	Caravan	47.0	21.5	5.0	5.0	0.0
44	2015	Ford	Escape	46.0	16.2	3.0	8.0	3.0
45	2015	Mazda	3	51.0	18.5	1.5	6.5	2.0
46	2015	Jeep	Cherokee	52.0	20.0	4.0	8.0	5.0
47	2015	Fiat	500L	41.0	15.0	5.0	18.0	13.0
48	2015	Ford	Fusion	48.5	18.0	5.5	5.5	1.0
49	2015	Toyota	Sienna	58.5	24	7.5	11	4
50	2015	Ford	Focus	50.0	22.3	4.5	5.3	1.5
51	2015	Chrysler	200	51.2	22.8	2.0	7.0	2.5
52	2015	Toyota	RAV4	52.0	19.5	4.4	10.8	5.8
53	2015	Chrysler	Town & Country	52.4	21.0	5.0	8.0	4.0
54	2015	Ford	Edge	50.0	20.0	-3.0	2.1	-2.7
55	2014	Chevrolet	Cruz	50.0	17.0	3.5	12.0	6.0
56	2014	Jeep	Cherokee	54.0	21.0	3.4	10.0	6.0
57	2014	Jeep	Grand Cherokee	50.5	19.0	0.0	11.0	7.5
58	2014	Ford	Fusion	47.0	18.0	5.0	5.0	0.0
59	2014	Dodge	Caravan	51.0	23.2	5.0	8.5	4.5
60	2014	Ford	Focus	51.0	23.5	5.3	5.1	1.5
61	2014	Ford	Escape	47.0	19.0	3.8	7.4	3.0
62	2014	Mazda	3	55.0	20.5	0.0	6.5	2.0
63	2013	Ford	Escape	46.0	17.0	3.0	7.5	3.0
64	2013	Ford	Focus	50.0	16.0	4.0	6.0	1.0
65	2013	Chevrolet	Cruz	49.0	17.5	4.0	12.0	6.0
66	2013	Chrysler	Town & Country	52.4	21.0	5.0	8.0	4.0
67	2013	Hyundai	Elantra	50.0	25.0	4.0	5.0	1.0
68	2013	Dodge	Dart	51.5	19.0	2.3	6.0	2.0
69	2013	Chevrolet	Malibu	51.5	23.0	4.0	12.2	7.7
70	2013	Ford	Fusion	50.0	22.0	5.5	4.3	0.7
71	2012	Dodge	Caravan	51.0	22.8	5.0	7.5	3.5
72	2012	Dodge	Dart	51.0	20.0	1.5	7.0	3.0
73	2012	Chrysler	300	50.0	17.0	5.5	5.0	0.0
74	2012	Jeep	Cherokee	49.0	17.0	0.0	9.0	4.5
75	2012	Ford	Focus	50.0	18.0	3.5	5.7	1.0
76	2012	Chevrolet	Cruz	49.5	17.0	5.0	12.0	8.5
77	2012	Dodge	Caravan	51.0	22.8	5.0	7.5	3.5
78	2011	Jeep	Cherokee	49.0	18.0	0.0	9.0	5.0
79	2011	Dodge	Caravan	52.0	21.0	4.0	7.6	4.0
80	2010	Dodge	Caravan	51.5	21.5	4.1	8.5	4.5

Note: All measurements based on in house benchmarking and are not reflective of vehicle design conditions.

Figure A1a

Figure A1b

Figure A1c

Figure A1: Metal anchor strap type buckle mount (Figure A1a), Cable type buckle mount [12]; Figure A1b), Webbing type mount (Figure A1c).

Figure A2a

Figure A2b

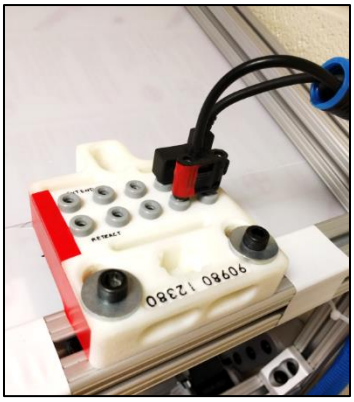


Figure A2c

Figure A2: Mounting fixture and study setup (Figure A2a), Rear view of mounting fixture (Figure A2b), Buckle switch (Figure A2c).

Figure A3: Participants of the usability study.

Table A2.
Data Collected from Usability Study

#	Age	Sex	Belt Extender	Weight (kg)	h (cm)	BMI	A (cm)	R (cm)	T (cm)	E (cm)
1	77	F	N/A	55.84	155	23.24	74.93	17.5	75.5	49.5
2	65	F	N/A	76.18	173	25.45	76.2	5	88	63
3	85	F	N/A	65.83	113	51.55	68.58	18	75	49.5
4	72.9	M	N/A	105.78	186	30.58	81.28	4.5	88.5	62.5
5	72	F	N/A	76.73	118	55.10	62.23	14	79	53
6	77	F	N/A	69.46	163	26.14	71.12	12	81	52.5
7	71	M	N/A	59.02	178	18.63	74.93	9.5	83.5	55.5
8	77	F	N/A	60.38	172	20.41	71.12	10	83	55
9	87	M	N/A	77.18	178	24.36	66.04	7	86	56.5
10	70	F	N/A	69.46	164	25.83	71.12	7.5	85.5	57
11	72	M	N/A	84.90	188	24.02	69.85	3.5	89.5	61
12	72	F	N/A	80.36	155	33.45	66.04	13	80	57.5
13	84	M	N/A	65.38	165	24.01	71	12.5	80.5	52.5
14	74	F	N/A	74.00	165	27.18	71.12	10.5	82.5	58.3
15	80	F	N/A	54.48	154	22.97	66.04	13.5	79.5	53
16	82	F	N/A	52.66	169	18.44	72.39	13.5	79.5	50.5
17	75	F	N/A	66.74	163	25.12	71.12	11.5	81.5	56
18	76	F	N/A	68.55	163	25.80	66.04	12	81	56
19	75	F	N/A	95.34	176	30.78	74.93	12.5	80.5	54
20	70	F	N/A	78.09	164	29.03	69.85	6	87	60.5
21	69	F	N/A	73.55	160	28.73	64.77	13.5	79.5	56
22	77	F	N/A	68.55	152	29.67	62.23	14	79	53
23	66	F	N/A	80.81	177	25.79	71.12	6.2	86.8	59
24	83	F	N/A	89.44	147	41.39	63.5	19.6	73.4	49.5
25	79	F	N/A	75.36	165	27.68	59.69	8	85	58
26	71	F	N/A	80.36	165	29.52	69.85	12	81	55
27	68	M	N/A	85.81	193	23.04	76.2	0	93	62.5
28	70	M	N/A	81.27	175	26.54	68.58	6	87	59
29	72	F	N/A	65.38	153	27.93	66.04	17	76	49.7
30	76	F	N/A	67.19	152	29.08	64.77	18	75	48
31	69	M	N/A	65.83	166	23.89	67.31	9	84	58.5
32	68	F	N	57.84	158	23.17	63	15	78	53.6
33	75	F	N	49.21	154	20.75	60	16	77	50
34	75	F	N	61.93	163	23.31	65	14.5	78.5	49
35	68	F	N	67.92	168	24.06	67	11	82	54.5
36	86	F	N	62.74	165	23.05	73	15	78	51.8
37	80	F	N	65.47	155	27.25	66	17	76	51.6
38	82	F	N	69.92	169	24.48	72	10	83	58
39	82	F	N	97.97	169	34.30	77	14.2	78.8	51

40	71	F	N	81.08	167	29.07	68	9.5	83.5	57
41	68	F	Y	74.82	163	28.16	71	22	71	47
42	90	F	N	60.84	164	22.62	67	15.6	77.4	51.8
43	77	F	N	62.83	160	24.54	65	13	80	54.5
44	78	F	N	76.91	167	27.58	64	9.5	83.5	54.5
45	74	M	N	75.18	174	24.83	74	8.2	84.8	57
46	72	F	N	65.56	175	21.41	76	6.5	86.5	57.5
47	73	F	N	74.91	159	29.63	64	11.5	81.5	56
48	75	F	N	74.55	172	25.20	67	6.5	86.5	60
49	73	F	N	72.82	159	28.80	65.5	12	81	53
50	71	F	N	86.44	152	37.41	69	16	77	50.7
51	72	M	N	75.45	171	25.80	71	10.5	82.5	52
52	88	F	N	66.28	175.5	21.52	77.5	10.4	82.6	54.8
53	92	F	N	50.39	158	20.19	74	18.5	74.5	50
54	96	F	Y	48.94	150	21.75	70	21	72	46.5
55	69	F	N	94.52	164	35.14	74	7	86	59
56	81	M	N	67.01	170	23.19	75	9	84	58
57	70	F	N	59.93	159	23.70	71.5	14.2	78.8	51.5
58	66	F	N	74.55	167	26.73	74	13	80	54
59	81	F	N	69.01	157	28.00	67	17.5	75.5	51.9
60	75	F	N	82.81	164	30.79	71	10	83	54.5
61	88	F	N	82.36	173	27.52	77	13	80	54
62	84	M	N	82.17	170	28.43	78	10.5	82.5	55
63	90	M	N	84.17	180	25.98	78	7.5	85.5	62
64	96	F	N	60.11	150	26.72	68	18.5	74.5	48.5
65	83	F	N	66.47	148	30.34	62	19.4	73.6	50
66	65	F	N	65.83	157.5	26.54	74	13.5	79.5	51
67	94	M	N	70.64	169	24.73	77	7	86	55
68	65	F	N	66.10	168	23.42	68	11	82	50
69	85	F	N	59.20	156	24.33	75	20.5	72.5	44.8
70	84	M	N	66.37	182	20.04	75	6.5	86.5	59
71	83	M	N	102.33	178	32.30	77	7.5	85.5	59.5
72	93	F	N	54.84	152	23.74	70	21	72	47.5
73	91	M	N	76.18	176	24.59	75	8.5	84.5	57.5
74	89	M	N	72.64	166	26.36	69	8.5	84.5	56
75	92	F	N	49.58	152	21.46	69	18.5	74.5	49.5
76	87	F	N	62.02	156	25.48	67	18	75	48
77	90	M	N	70.10	170	24.26	76	10	83	55.5
78	93	F	N	78.27	157	31.75	65	18.5	74.5	48
79	88	F	N	63.74	164	23.70	70	14	79	52
80	88	F	N	70.55	164	26.23	75	15.5	77.5	50.5
81	80	F	N	45.58	155	18.97	64	16	77	50
82	71	F	N	51.21	150	22.76	58	21	72	46

83	90	F	N	62.92	151	27.60	68	21	72	49.5
84	98	M	N	84.72	163	31.89	74.5	20	73	52
85	77	F	N	64.65	156	26.57	72	19.5	73.5	47.5
86	73	M	N/A	88.17	164	32.78	70	15.5	77.5	50
87	84	M	N	66.74	247	10.94	76	0	93	63
88	83	M	N	74.37	175.5	24.14	75	10	83	53
89	79	F	N	51.30	167	18.40	71.5	15	78	50.5
90	91	F	N	67.92	164	25.25	63	10	83	52
91	80	F	N	46.76	152	20.24	61	20	73	48
92	83	F	N	55.48	163	20.88	68	14	79	53
93	85	F	N	91.53	158	36.66	65	12	81	52
94	90	F	N	42.68	161	16.46	68.5	13.2	79.8	52
95	90	M	N	61.29	169	21.46	73.5	15	78	48
96	94	F	N	47.13	156	19.36	63	16	77	50
97	92	M	N	85.90	172	29.03	70.5	9.5	83.5	55
98	84	M	N	94.25	168	33.39	66.5	10	83	56
99	95	M	N	60.11	168	21.30	71	15	78	54
100	91	F	N	98.06	165	36.02	65.5	13	80	56
101	92	F	N	44.58	161	17.20	65	12	81	54
102	90	F	N	43.40	162.5	16.44	64.5	19	74	48.5
103	96	F	N	63.20	159	25.00	67.5	20	73	47.5
104	90	F	N	63.02	165	23.15	74	13.5	79.5	53
105	72	F	N	69.46	167.5	24.76	70.5	12.5	80.5	54
106	82	M	N	71.10	175	23.22	73	11	82	53
107	82	M	N	128.03	175	41.81	71	10	83	58
108	97	F	N	72.55	159	28.70	67	18.5	74.5	51
109	88	F	N	78.36	157	31.79	61	18.5	74.5	48
110	85	M	N	81.90	168	29.02	66	16	77	57
111	76	F	N	57.48	158	23.02	63.5	18.5	74.5	48.5
112	87	F	N	62.20	161	24.00	64	15	78	51

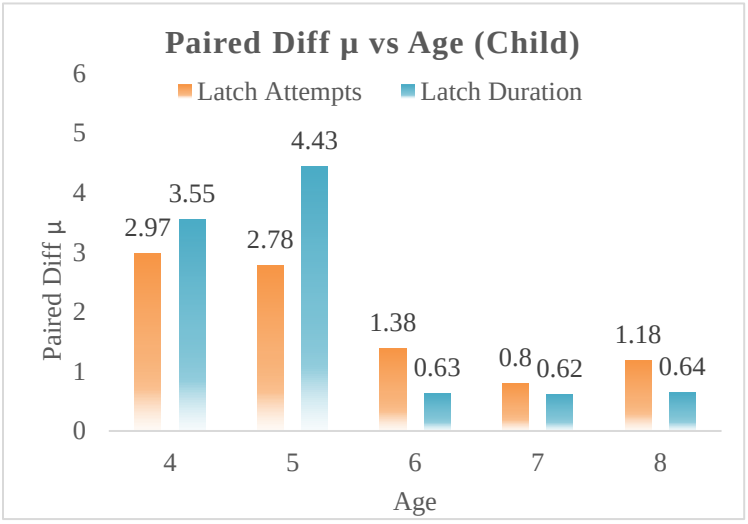
Table A3.
Trial Latch Attempts and Latch Duration Results

#	Trial A	Trial B	Preference	# of LA(Rec.)	# of LA(LUB)	LA Diff	LD (Rec)	LD (LUB)	LD Diff	BFT (Rec.)	BFT (LUB)	BFT Diff
1	2	1	1	8.5	3	5.5	00:07.5	00:03.5	00:04.0	00:00.0	00:00.0	00:00.0
2	1	2	2	3	4	-1	00:04.6	00:05.8	-00:01.2	00:11.1	00:00.0	00:11.1
3	1	2	2	6	6.5	-0.5	00:06.1	00:04.7	00:01.4	00:00.0	00:00.0	00:00.0
4	2	1	1	4	12	-8	00:04.0	00:12.7	-00:08.7	00:00.0	00:01.2	-00:01.2
5	1	2	2	9	5	4	00:08.0	00:02.6	00:05.5	00:00.0	00:00.0	00:00.0
6	2	1	1	3	3	0	00:03.1	00:02.7	00:00.4	00:00.0	00:00.0	00:00.0
7	2	1	2	10	5.5	4.5	00:11.6	00:05.1	00:06.4	00:02.9	00:00.0	00:02.9

8	1	2	2	7.5	1.5	6	00:04.2	00:01.9	00:02.3	00:00.0	00:00.0	00:00.0
9	1	2	2	13	10.5	2.5	00:12.5	00:08.1	00:04.4	00:00.0	00:00.0	00:00.0
10	2	1	2	6	3	3	00:02.7	00:04.2	-00:01.5	00:00.0	00:00.0	00:00.0
11	2	1	1	3.5	5.5	-2	00:08.8	00:03.0	00:05.9	00:00.0	00:00.0	00:00.0
12	1	2	2	11	4	7	00:10.6	00:04.5	00:06.1	00:00.0	00:00.0	00:00.0
13	2	1	2	19	12.5	6.5	00:21.1	00:12.7	00:08.3	00:00.0	00:05.4	-00:05.4
14	1	2	2	12	6	6	00:09.7	00:03.9	00:05.8	00:00.0	00:00.0	00:00.0
15	1	2	1	2.5	3	-0.5	00:02.4	00:02.3	00:00.1	00:00.0	00:00.0	00:00.0
16	2	1	3	2.5	3.5	-1	00:03.7	00:03.1	00:00.6	00:00.0	00:00.0	00:00.0
17	2	1	1	4.5	21	-16.5	00:05.3	00:32.1	-00:26.8	00:00.0	00:00.0	00:00.0
18	2	1	2	8	1.5	6.5	00:06.8	00:02.5	00:04.3	00:00.0	00:00.0	00:00.0
19	1	2	2	9	5.5	3.5	00:06.8	00:03.9	00:02.9	00:00.0	00:00.0	00:00.0
20	1	2	2	6.5	3.5	3	00:09.2	00:03.2	00:06.0	00:00.0	00:00.0	00:00.0
21	1	2	1	4	2.5	1.5	00:06.3	00:03.0	00:03.3	00:00.0	00:00.0	00:00.0
22	2	1	2	6.5	3	3.5	00:07.8	00:03.4	00:04.3	00:00.0	00:00.0	00:00.0
23	1	2	2	2.5	4	-1.5	00:03.9	00:03.3	00:00.7	00:00.0	00:00.0	00:00.0
24	2	1	3	4	4	0	00:03.3	00:04.9	-00:01.6	00:00.0	00:00.0	00:00.0
25	1	2	2	3.5	4	-0.5	00:05.8	00:04.0	00:01.8	00:00.0	00:00.0	00:00.0
26	1	2	2	25	5.5	19.5	00:38.7	00:06.7	00:32.0	00:00.0	00:00.0	00:00.0
27	2	1	2	8	3	5	00:05.8	00:04.4	00:01.4	00:00.0	00:00.0	00:00.0
28	1	2	2	6	4	2	00:04.3	00:03.6	00:00.7	00:00.0	00:00.0	00:00.0
29	2	1	2	13.5	10	3.5	00:13.3	00:07.5	00:05.8	00:00.0	00:00.0	00:00.0
30	1	2	1	15	9	6	00:10.7	00:13.8	-00:03.0	00:00.0	00:01.4	-00:01.4
31	2	1	2	4	4	0	00:05.8	00:04.5	00:01.3	00:03.3	00:00.0	00:03.3
32	1	2	2	12	3.5	8.5	00:12.9	00:03.1	00:09.8	00:00.0	00:00.0	00:00.0
33	2	1	3	16	5.5	10.5	00:10.8	00:05.8	00:05.0	00:00.0	00:00.0	00:00.0
34	1	2	2	4	9	-5	00:05.4	00:10.7	-00:05.3	00:00.0	00:00.0	00:00.0
35	2	1	2	12	3	9	00:15.3	00:05.7	00:09.5	00:00.0	00:00.0	00:00.0
36	1	2	2	6	3.5	2.5	00:07.6	00:04.1	00:03.5	00:00.0	00:00.0	00:00.0
37	2	1	2	2.5	2	0.5	00:02.7	00:02.3	00:00.4	00:00.0	00:00.0	00:00.0
38	1	2	2	14	2.5	11.5	00:10.8	00:03.7	00:07.1	00:00.0	00:00.0	00:00.0
39	2	1	3	11.5	10	1.5	00:10.3	00:10.3	00:00.0	00:00.0	00:00.0	00:00.0
40	1	2	1	7	9	-2	00:06.2	00:12.9	-00:06.6	00:03.3	00:00.0	00:03.3
41	1	2	3	6.5	8.5	-2	00:05.0	00:06.3	-00:01.3	00:00.0	00:00.0	00:00.0
42	2	1	3	5	5	0	00:03.5	00:06.2	-00:02.7	00:00.0	00:00.0	00:00.0
43	1	2	2	7	6	1	00:14.1	00:08.1	00:06.0	00:00.0	00:00.0	00:00.0
44	2	1	2	7	3	4	00:06.8	00:04.4	00:02.4	00:00.0	00:00.9	-00:00.9
45	1	2	3	15	6.5	8.5	00:20.8	00:05.1	00:15.7	00:08.1	00:00.0	00:08.1
46	1	2	2	4	2	2	00:04.0	00:01.5	00:02.5	00:00.0	00:00.0	00:00.0
47	2	1	3	9	6	3	00:19.1	00:12.9	00:06.2	00:02.9	N/A	N/A
48	2	1	2	6	1	5	00:03.2	00:02.6	00:00.7	00:00.0	00:00.0	00:00.0
49	1	2	2	11	8.5	2.5	00:15.1	00:22.7	-00:07.6	00:00.0	00:00.0	00:00.0
50	2	1	3	4	6	-2	00:03.0	00:06.1	-00:03.1	00:00.0	00:00.0	00:00.0

51	1	2	2	7	9	-2	00:07.7	00:11.0	-00:03.3	00:15.6	00:00.0	00:15.6
52	1	2	2	4	5	-1	00:08.1	00:03.5	00:04.6	00:00.5	00:00.0	00:00.5
53	2	1	2	5.5	11.5	-6	00:06.3	00:12.4	-00:06.1	N/A	00:00.0	N/A
54	2	1	3	2	23	-21	00:02.9	01:13.0	-01:10.1	00:09.3	00:13.0	-00:03.8
55	1	2	2	24	11.5	12.5	00:30.2	00:13.2	00:17.1	00:00.0	00:00.0	00:00.0
56	2	1	2	12.5	52	-39.5	00:18.7	01:20.3	-01:01.6	00:00.0	00:00.0	00:00.0
57	1	2	2	4.5	4	0.5	00:03.0	00:02.4	00:00.6	00:15.1	00:00.0	00:15.1
58	2	1	3	17.5	5.5	12	00:16.8	00:06.5	00:10.3	00:00.0	00:00.0	00:00.0
59	1	2	2	40	46.5	-6.5	N/A	N/A	N/A	N/A	00:00.0	N/A
60	1	2	1	12.5	58.5	-46	00:25.9	01:27.0	-01:01.2	00:08.5	00:04.8	00:03.7
61	2	1	3	13.5	29.5	-16	00:23.9	00:47.7	-00:23.7	00:07.8	N/A	N/A
62	2	1	3	9.5	7	2.5	00:08.4	00:06.8	00:01.5	00:00.0	00:00.0	00:00.0
63	1	2	2	13.5	5	8.5	00:13.8	00:07.4	00:06.4	00:00.0	00:00.0	00:00.0
64	1	2	3	11.5	5	6.5	00:15.6	00:03.8	00:11.8	00:00.0	00:00.0	00:00.0
65	2	1	2	47	7.5	39.5	01:00.8	00:06.0	00:54.8	00:03.3	00:00.0	00:03.3
66	1	2	2	6	2	4	00:03.0	00:01.9	00:01.2	00:00.0	00:00.0	00:00.0
67	2	1	2	21	6.5	14.5	00:28.1	00:05.9	00:22.2	00:00.0	00:00.0	00:00.0
68	1	2	2	4	1	3	00:03.4	00:03.1	00:00.3	00:00.0	00:01.5	-00:01.5
69	1	2	2	14	5.5	8.5	00:21.1	00:03.4	00:17.6	00:00.0	00:00.0	00:00.0
70	2	1	1	15	5	10	00:16.3	00:07.7	00:08.6	00:00.0	00:00.0	00:00.0
71	1	2	3	10.5	6	4.5	00:10.8	00:09.8	00:01.0	00:00.0	00:00.0	00:00.0
72	1	2	2	8.5	4.5	4	00:14.6	00:03.0	00:11.7	00:00.0	00:00.0	00:00.0
73	2	1	3	11.5	18.5	-7	00:08.9	00:16.7	-00:07.8	00:00.0	00:06.7	-00:06.7
74	1	2	3	5.5	4.5	1	00:02.9	00:05.0	-00:02.2	00:00.0	00:00.0	00:00.0
75	2	1	2	21.5	14	7.5	00:46.6	00:17.6	00:29.0	00:21.7	00:00.8	00:20.9
76	2	1	1	5	7.5	-2.5	00:06.1	00:10.2	-00:04.1	00:00.0	00:00.0	00:00.0
77	1	2	2	27	7	20	00:54.1	00:10.2	00:43.9	00:00.0	00:00.0	00:00.0
78	2	1	1	29	14.5	14.5	00:22.1	00:20.6	00:01.5	00:00.0	00:00.0	00:00.0
79	1	2	0	7.5	7	0.5	00:10.0	00:06.5	00:03.6	00:00.0	00:00.0	00:00.0
80	2	1	0	25.0	6	19	01:06.4	00:09.0	00:57.4	00:06.1	00:12.0	-00:05.9
81	1	2	0	5.5	4	1.5	00:04.7	00:03.1	00:01.7	00:00.0	00:00.0	00:00.0
82	1	2	0	6	5	1	00:06.0	00:05.0	00:00.9	00:00.0	00:00.0	00:00.0
83	2	1	0	6	21	-15	00:09.3	00:17.4	-00:08.1	00:00.0	00:03.3	-00:03.3
84	2	1	0	27.5	17.5	10	00:57.2	00:45.6	00:11.6	00:00.0	00:00.0	00:00.0
85	2	1	1	3	6	-3	00:02.0	00:17.3	-00:15.3	00:00.0	00:00.0	00:00.0
86	1	2	2	12	5	7	00:16.3	00:03.8	00:12.5	00:01.1	00:00.0	00:01.1
87	2	1	2	12.5	12	0.5	00:13.9	00:11.4	00:02.5	00:00.0	00:00.0	00:00.0
88	1	2	2	7	5	2	00:13.8	00:05.3	00:08.4	00:00.0	00:00.0	00:00.0
89	2	1	3	3	2	1	00:02.9	00:01.9	00:01.0	00:00.0	00:00.0	00:00.0
90	1	2	2	10	4.5	5.5	00:12.3	00:03.6	00:08.7	00:00.0	00:00.0	00:00.0
91	2	1	2	9	7	2	00:05.7	00:03.3	00:02.4	00:00.0	00:00.0	00:00.0
92	1	2	3	9	14	-5	00:08.4	00:20.6	-00:12.2	00:00.0	00:00.0	00:00.0

93	2	1	2	15	10	5	00:15.4	00:12.9	00:02.5	00:00.0	00:00.0	00:00.0
94	1	2	3	2	3	-1	00:03.3	00:04.8	-00:01.5	00:00.0	00:00.0	00:00.0
95	2	1	0	6	10	-4	00:08.6	00:09.8	-00:01.2	00:00.0	00:00.0	00:00.0
96	1	2	2	18	4.5	13.5	00:46.0	00:04.5	00:41.5	00:00.0	00:00.0	00:00.0
97	2	1	2	8	5.5	2.5	00:07.7	00:06.9	00:00.8	00:00.0	00:00.0	00:00.0
98	1	2	2	12.5	7.5	5	00:21.4	00:05.7	00:15.7	00:00.0	00:00.0	00:00.0
99	2	1	3	8	7.5	0.5	00:15.0	00:10.0	00:04.9	00:00.0	00:00.0	00:00.0
100	1	2	2	10	5.5	4.5	00:08.0	00:04.9	00:03.1	00:00.0	00:00.0	00:00.0
101	2	1	0	11	4.5	6.5	00:12.9	00:05.1	00:07.9	00:00.0	00:00.0	00:00.0
102	1	2	2	5.5	4.5	1	00:08.1	00:03.5	00:04.6	00:00.0	00:00.0	00:00.0
103	1	2	1	9	9.5	-0.5	00:21.7	00:16.6	00:05.2	00:00.0	00:00.0	00:00.0
104	1	2	2	11.5	8	3.5	00:10.7	00:04.4	00:06.2	00:00.0	00:00.0	00:00.0
105	2	1	2	13	5	8	00:11.4	00:04.7	00:06.7	00:00.0	00:00.0	00:00.0
106	2	1	2	32	8.5	23.5	00:34.4	00:08.1	00:26.3	00:00.0	00:00.0	00:00.0
107	1	2	1	10.5	11.5	-1	00:09.6	00:13.8	-00:04.2	00:00.0	00:00.0	00:00.0
108	2	1	3	48.5	39.5	9	01:04.6	01:09.4	-00:04.8	00:00.0	00:00.0	00:00.0
109	1	2	3	12	42	-30	00:30.3	01:30.6	-01:00.3	N/A	N/A	N/A
110	2	1	2	9	7	2	00:11.9	00:08.4	00:03.5	00:00.0	00:00.0	00:00.0
111	1	2	3	7	17	-10	00:06.0	00:16.3	-00:10.3	00:00.0	00:00.0	00:00.0
112	2	1	3	18	8	10	00:16.8	00:15.5	00:01.3	00:00.0	00:00.0	00:00.0



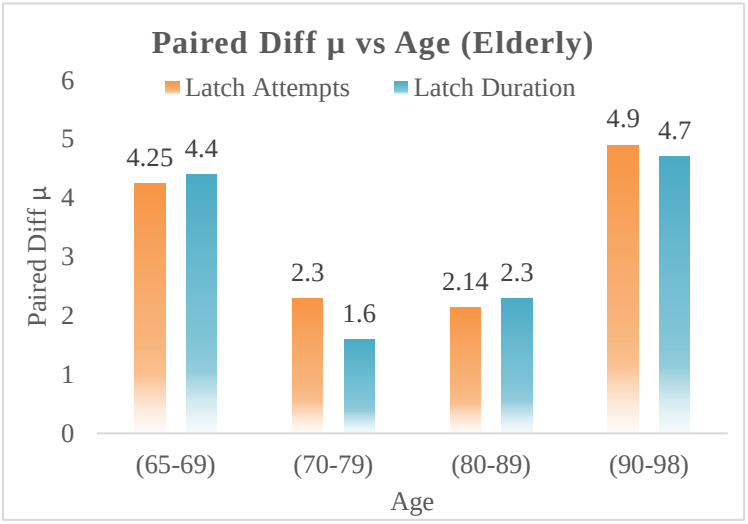


Figure A4: Graphs comparing Paired Diff μ vs Age for Latch Attempts and Latch Duration for Children and Elderly Cohorts.

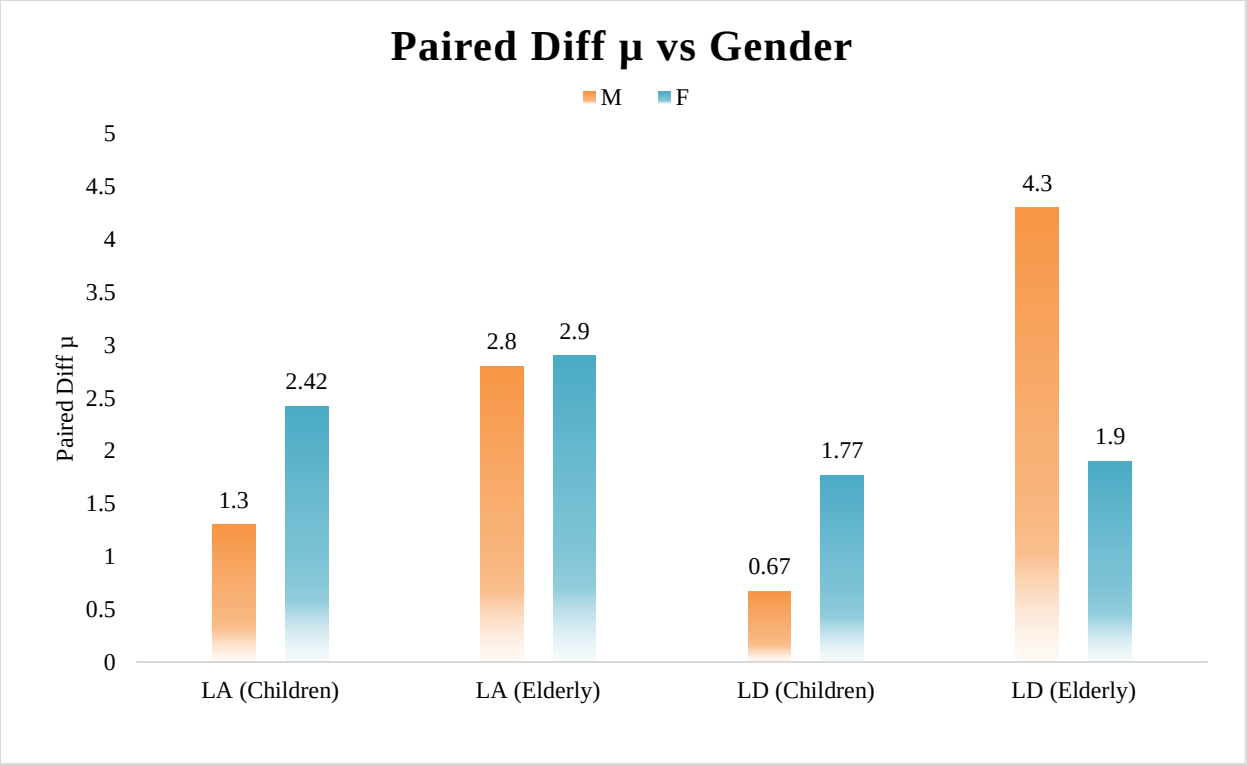


Figure A5: Graph showing Paired Diff μ vs Gender for Latch Attempts and Latch Duration for Child and Elderly Cohorts.

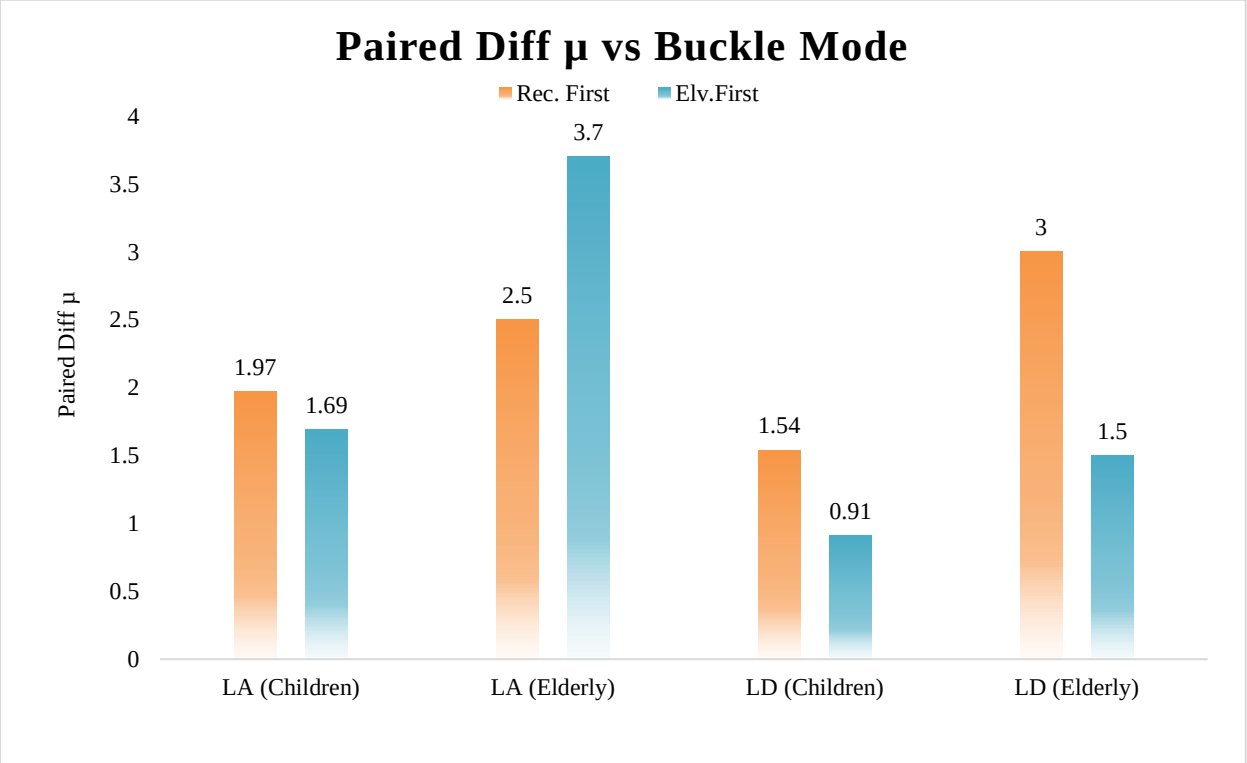


Figure A6: Graph showing Paired Diff μ vs Buckle Mode for Latch Attempts and Latch Duration for Child and Elderly Cohorts.

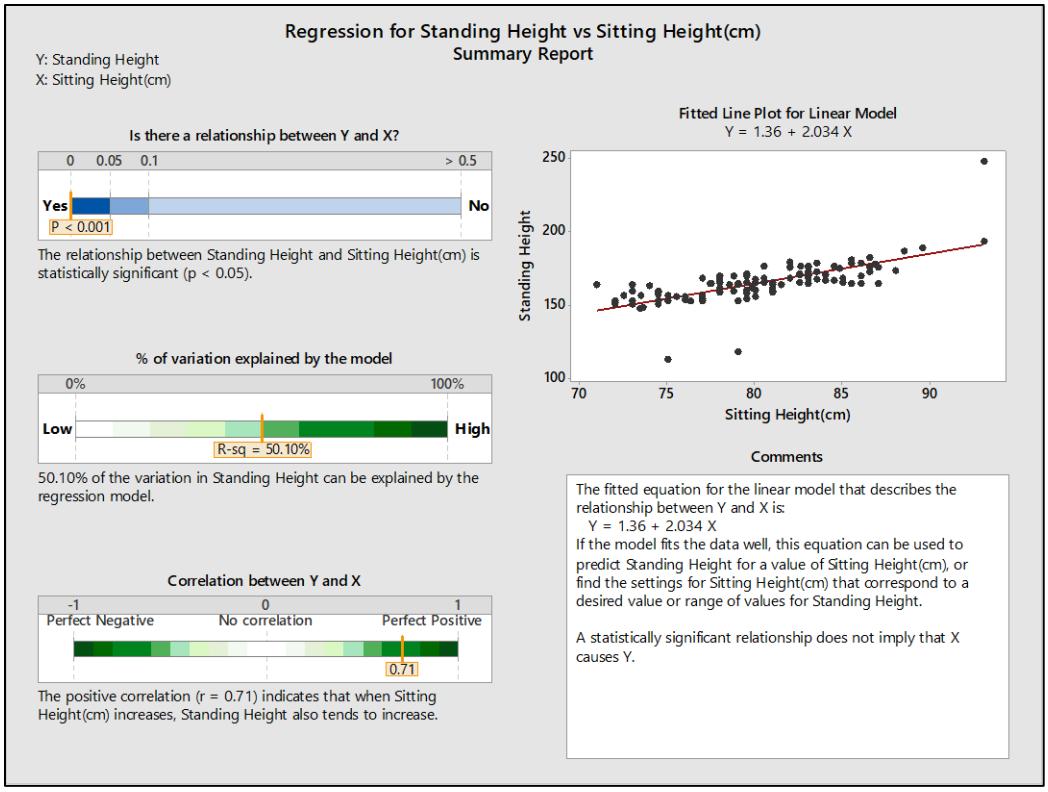


Figure A7a

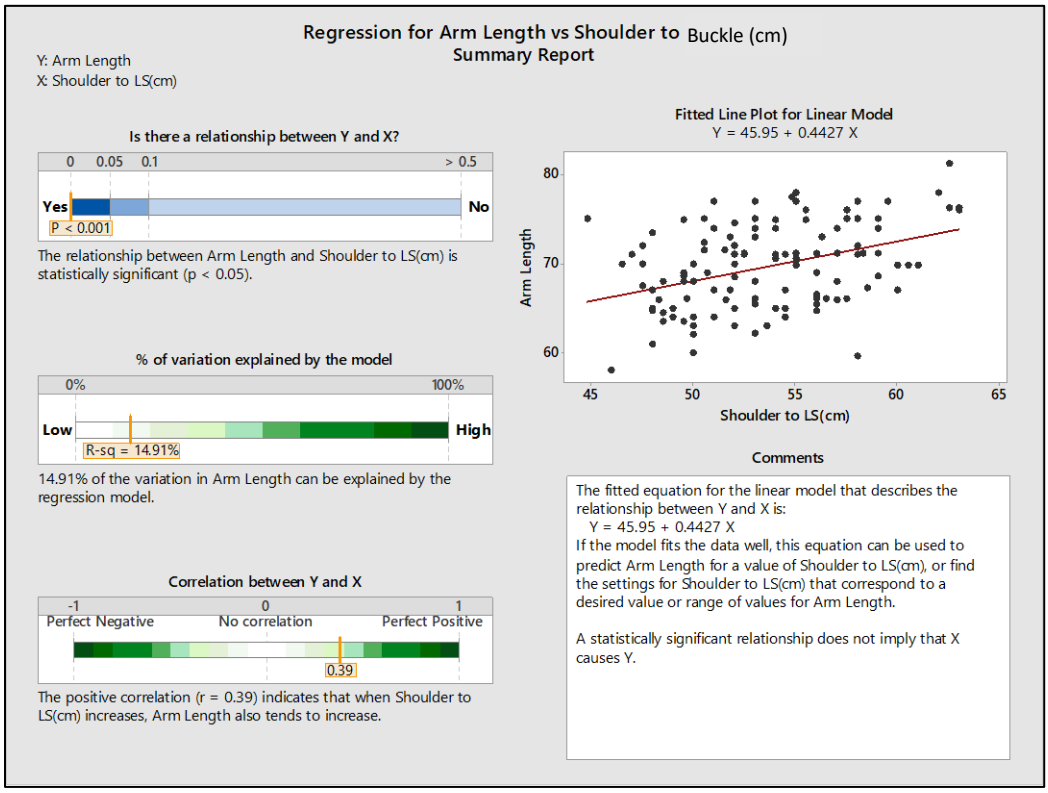


Figure A7b

Figure A7: Simple Regressions; Standing Height vs Sitting Height (Figure A7a), Arm Length vs Shoulder to Buckle (Figure A7b).

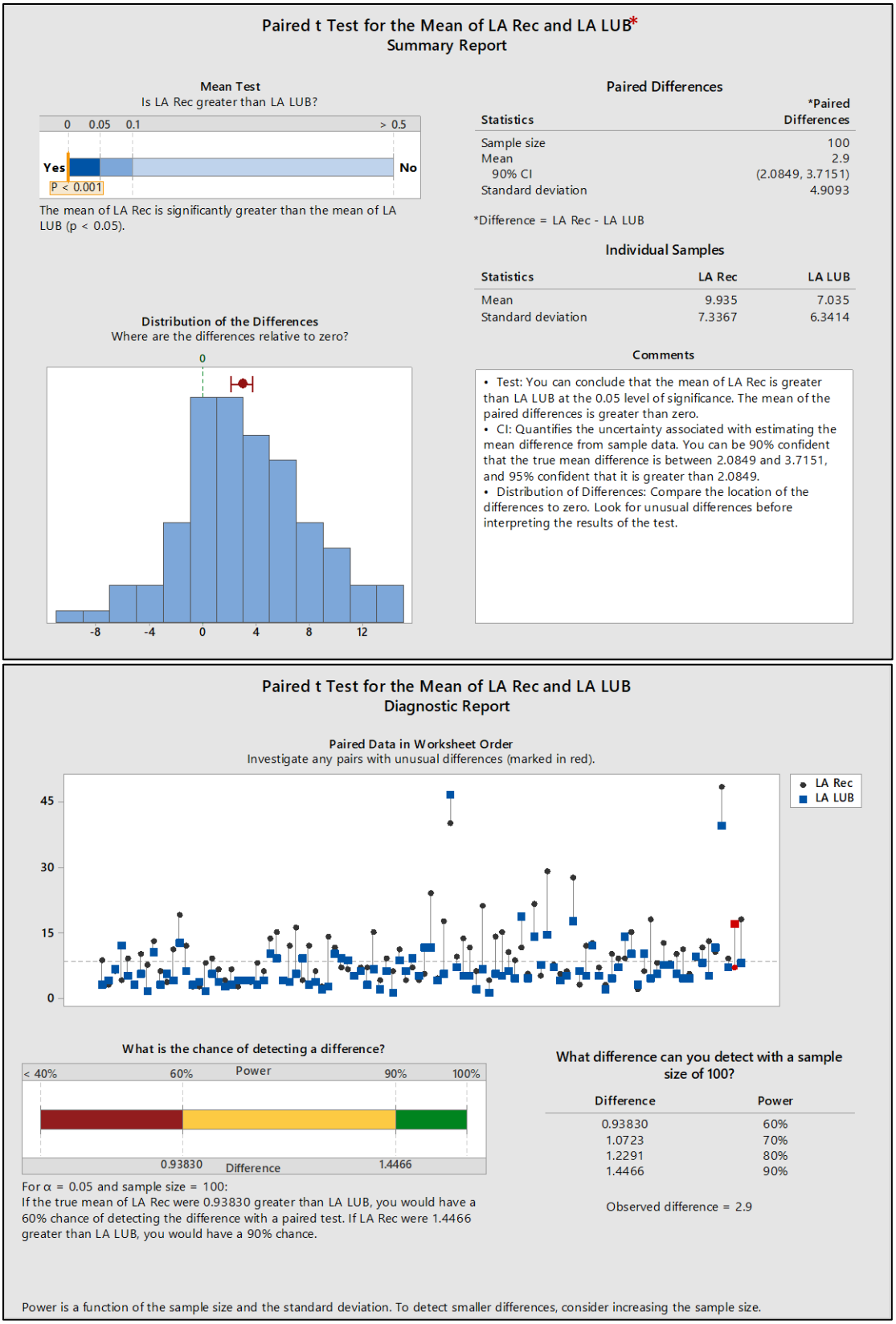


Figure A8: Paired t Test for OVERALL Sample - Latch Attempts.

**Note: For all intents and purposes, "LUB" is the same as "Elevated".*

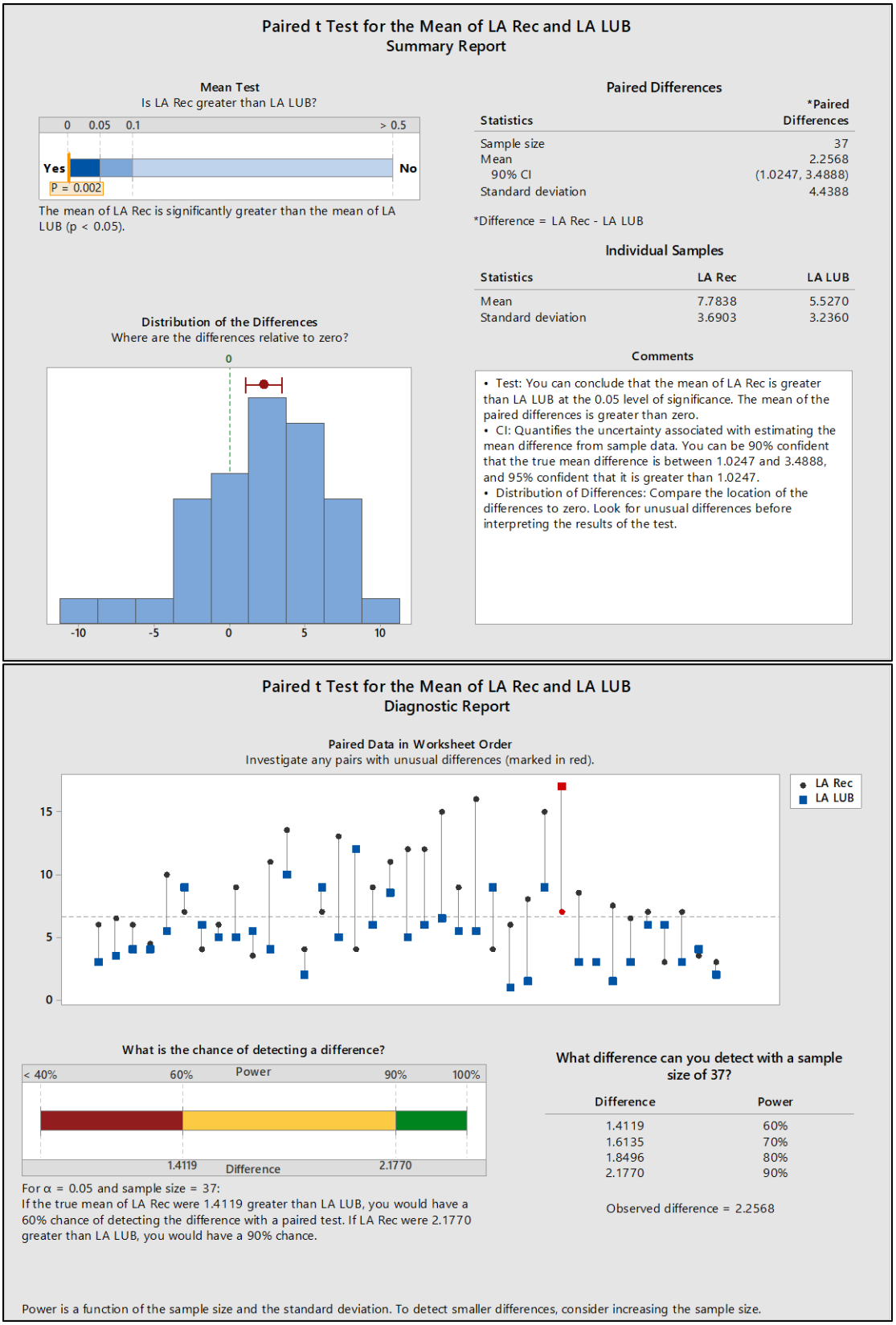


Figure A9: Paired t Test for Age 70-73 Sample – Latch Attempts.

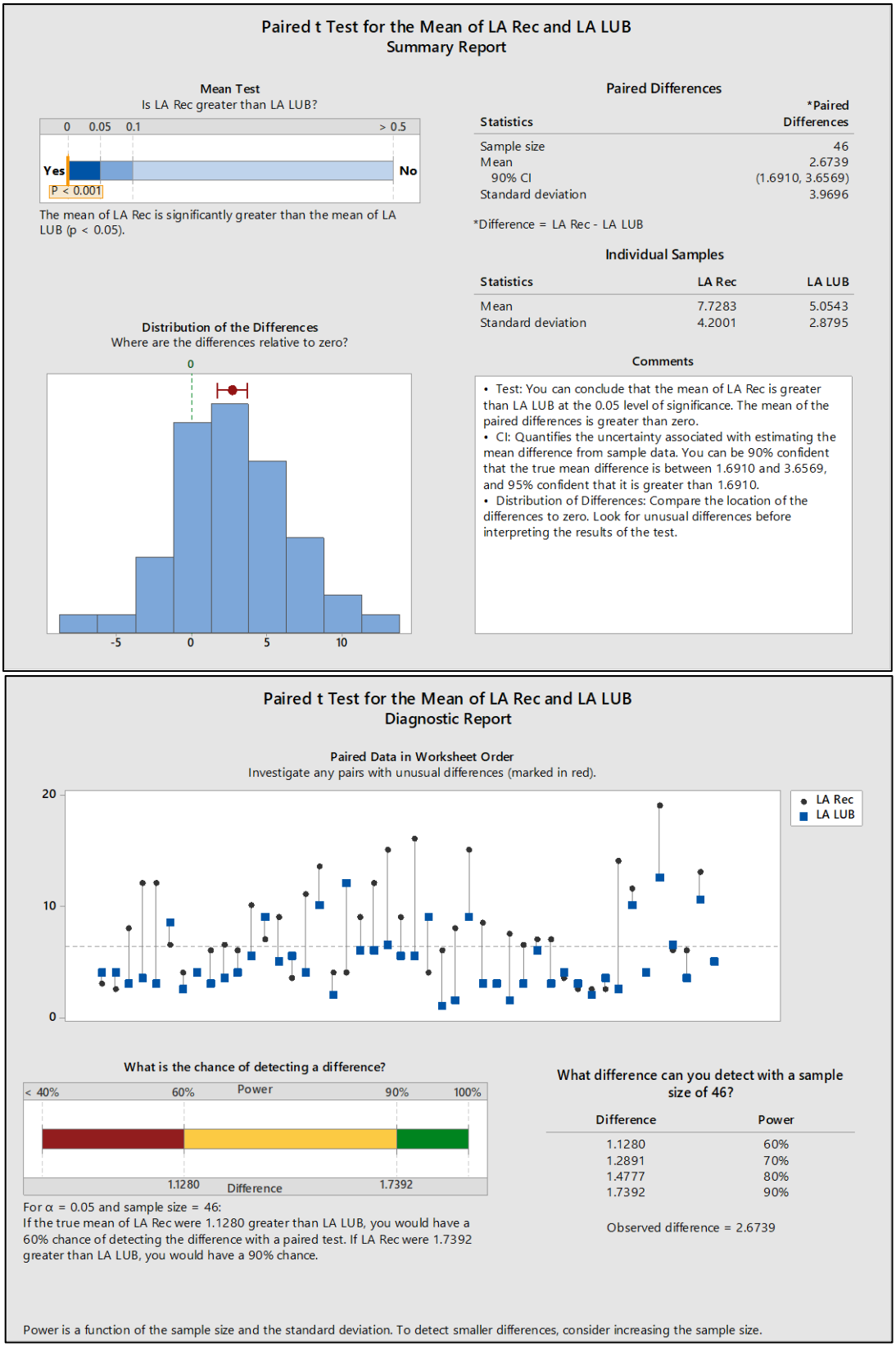


Figure A10: Paired t Test for Study Site 4 Sample - Latch Attempts.

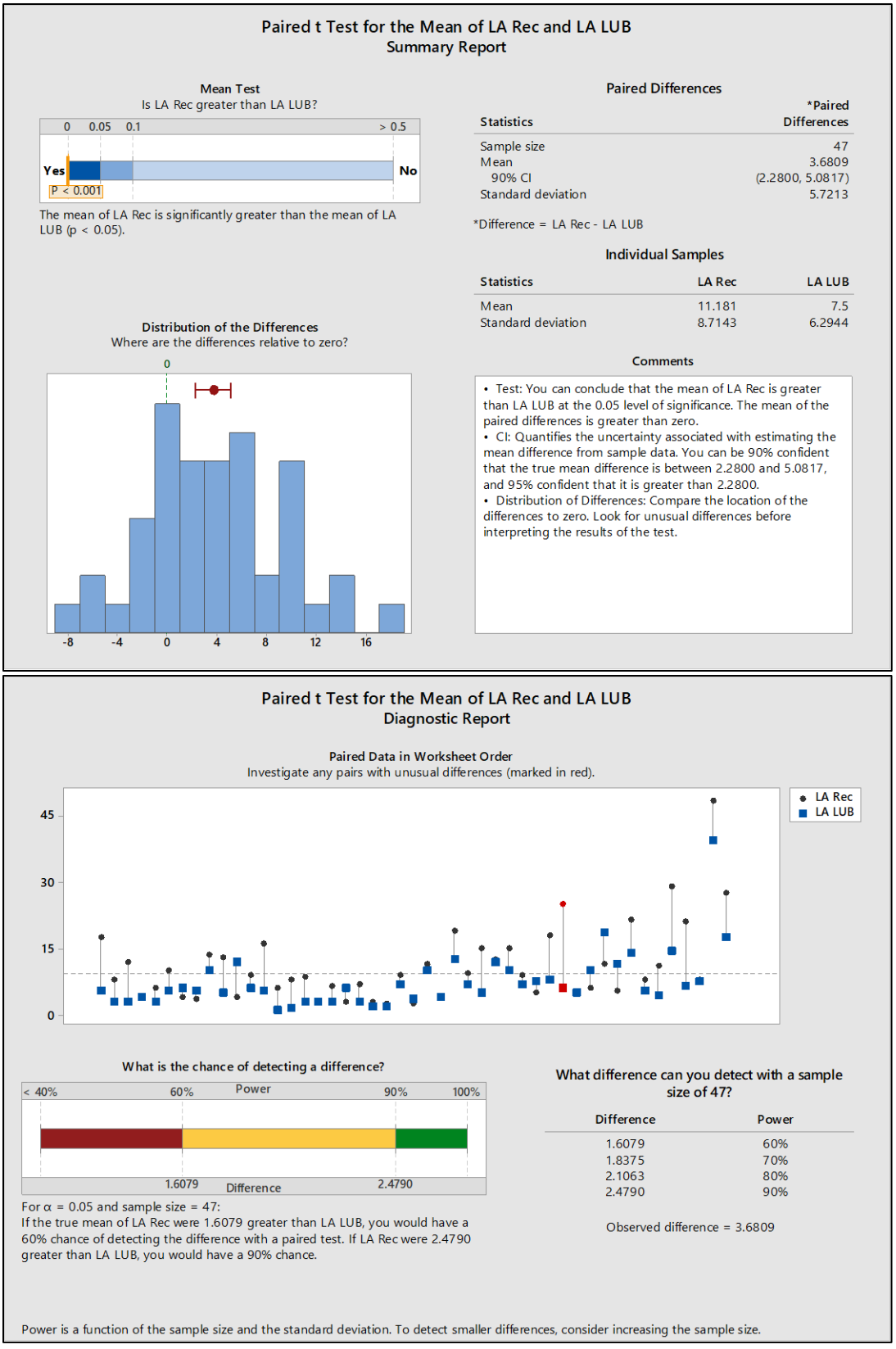


Figure A11: Paired t Test for Elevated Mode First – Latch Attempts.

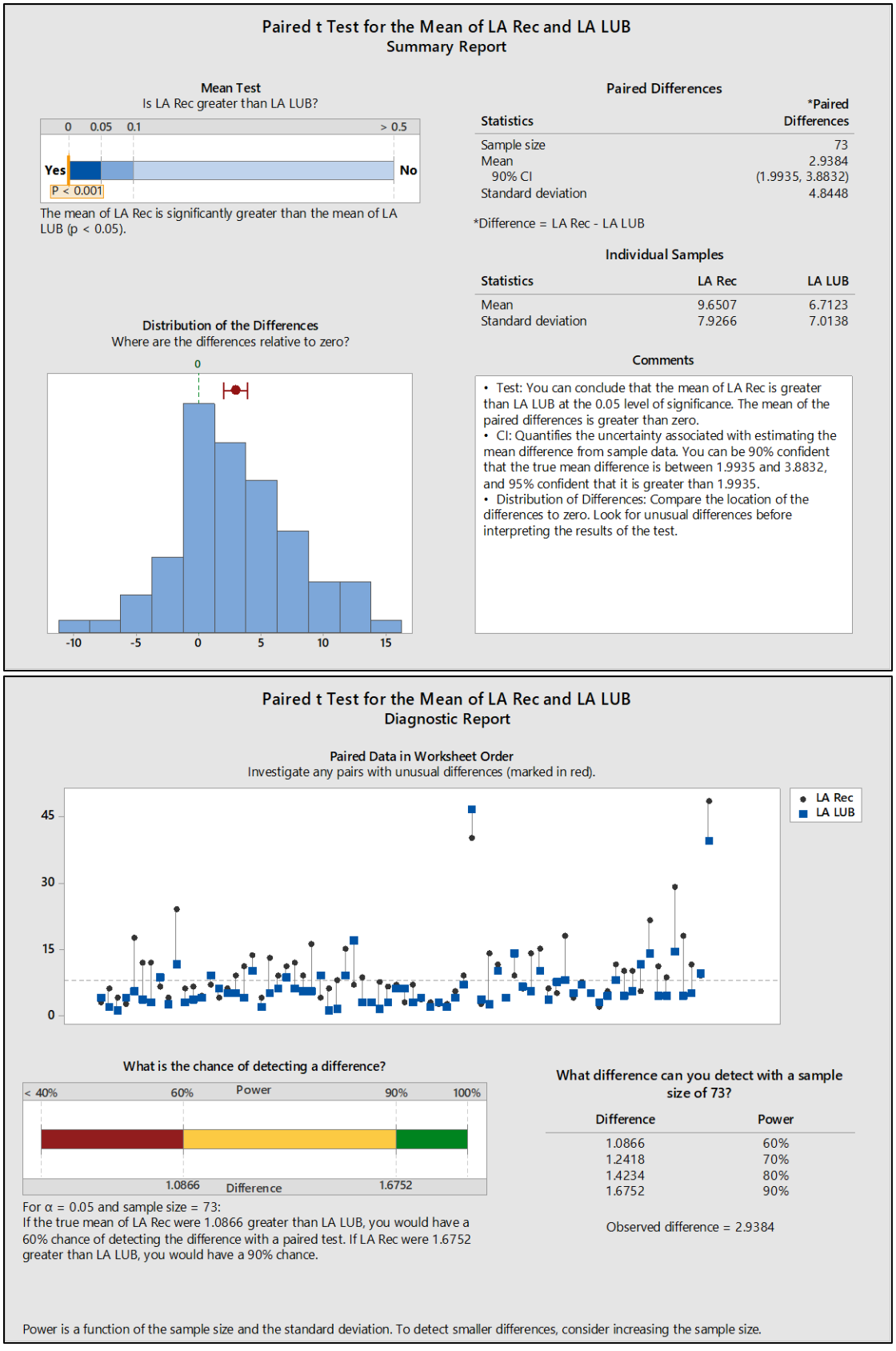


Figure A12: Paired t Test for Females – Latch Attempts.

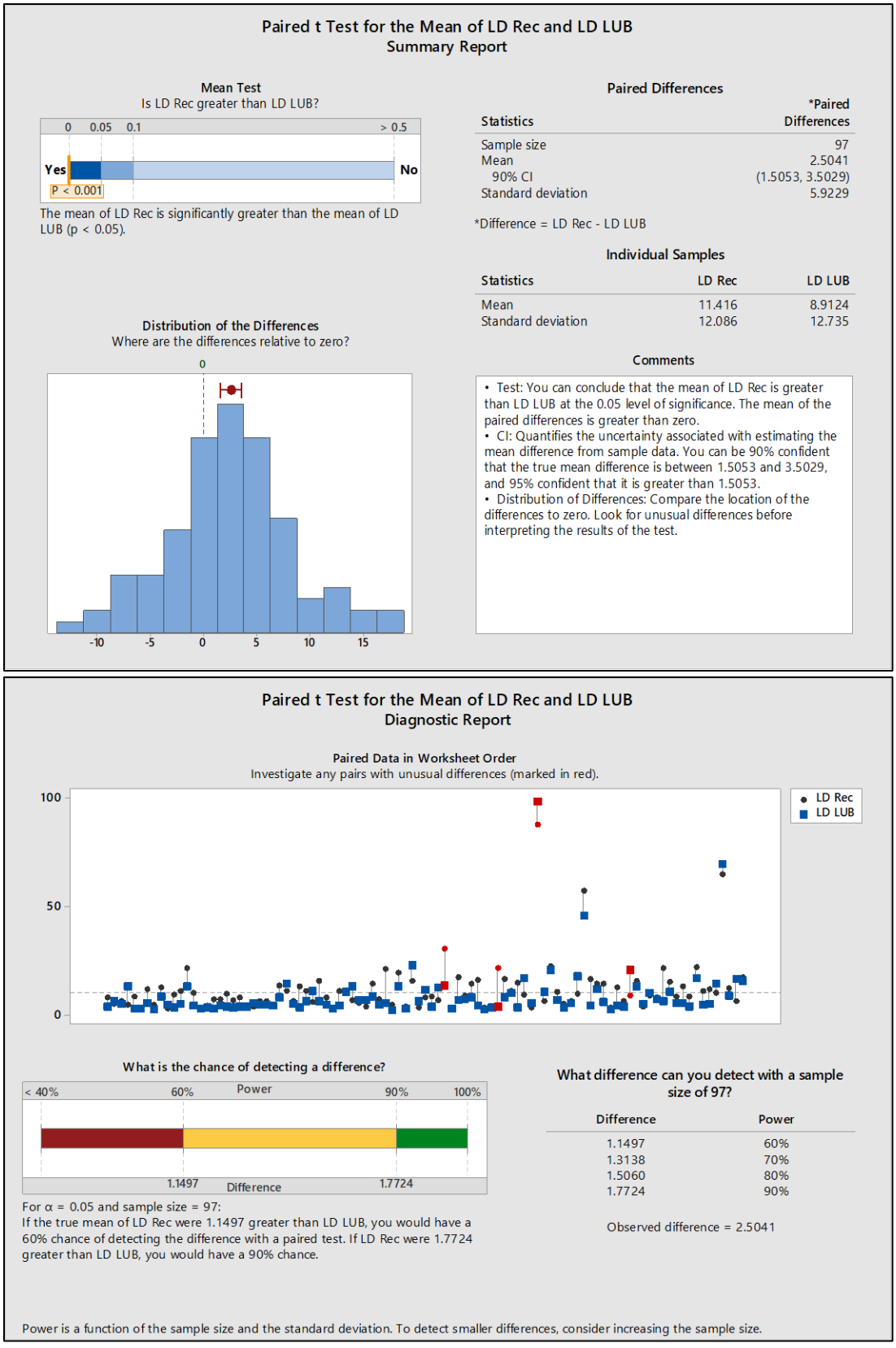


Figure A13: Paired t Test for OVERALL Sample – Latch Duration.

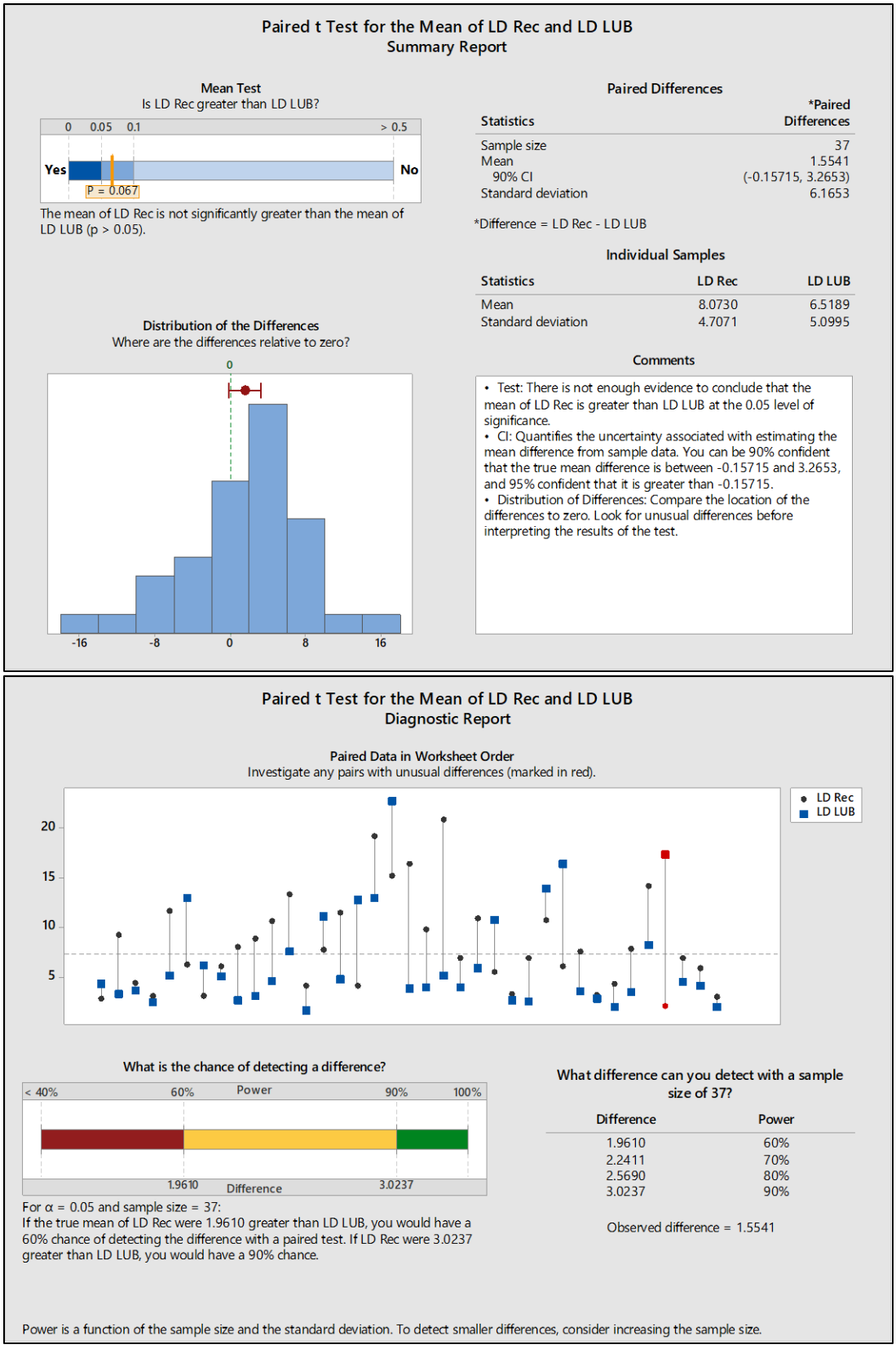


Figure A14: Paired t Test for Age 70-79 Sample – Latch Duration.

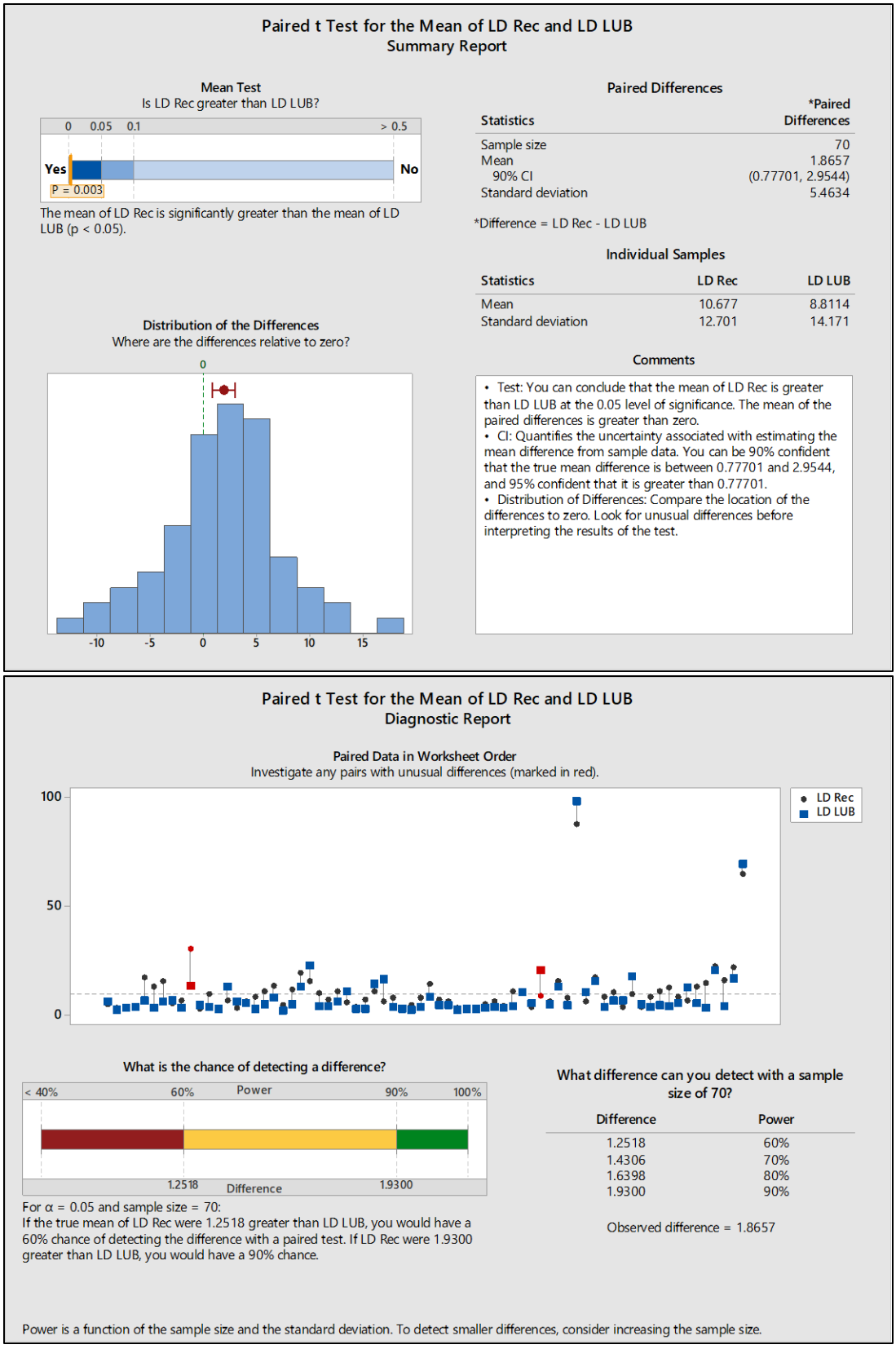


Figure A15: Paired t Test for Female Sample – Latch Duration.

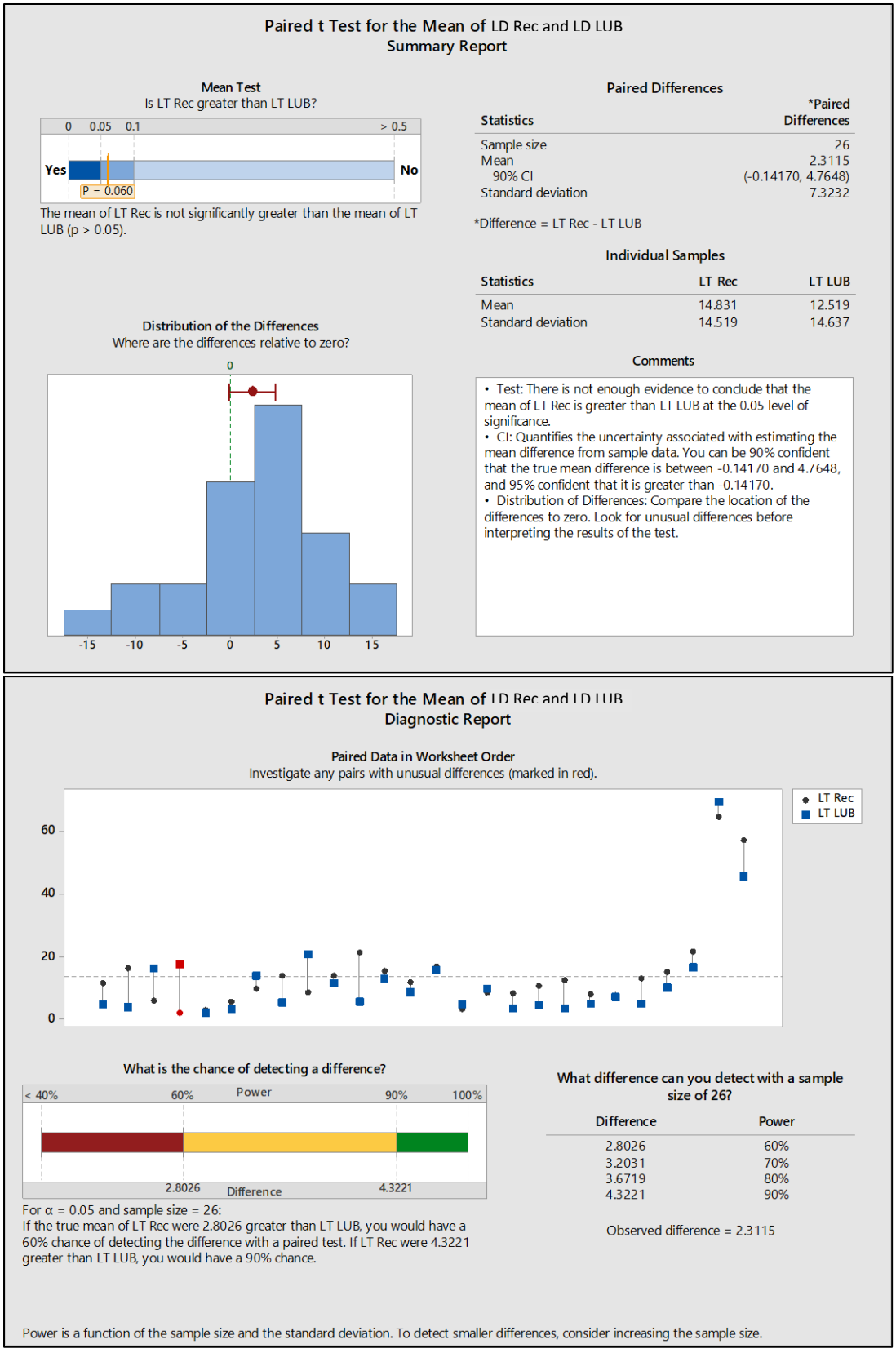
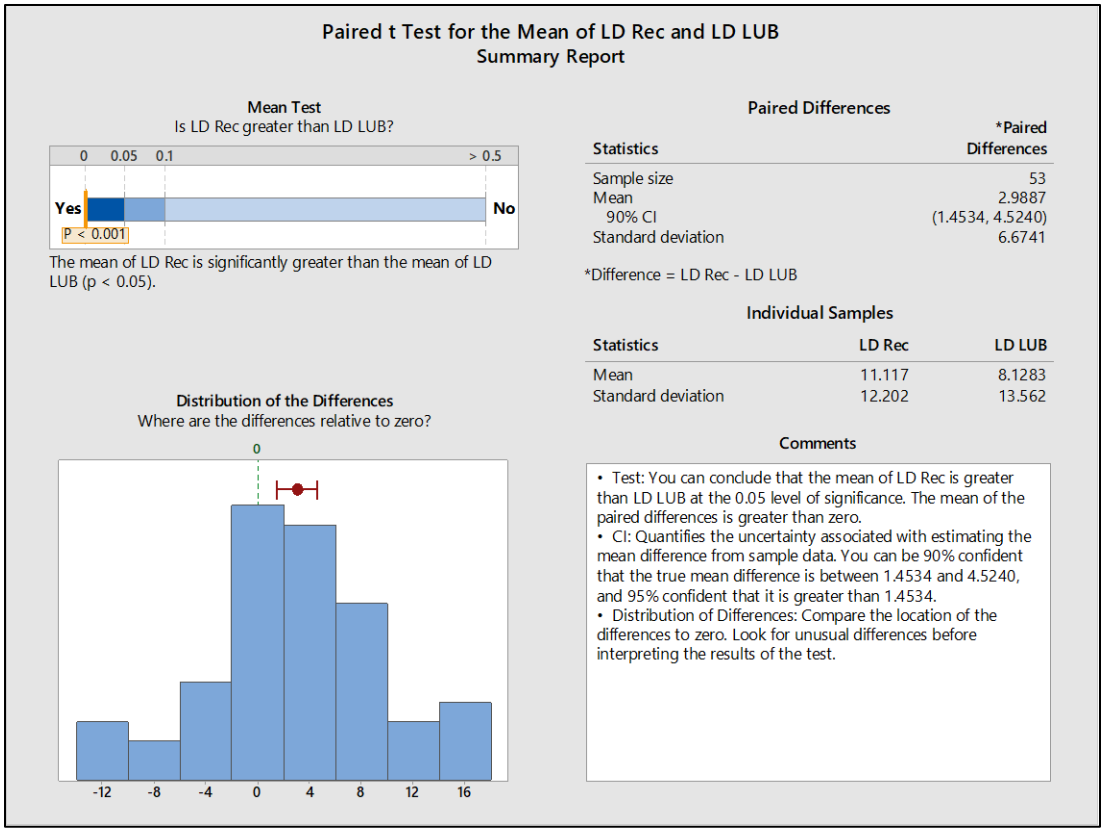


Figure A16: Paired t Test for Study Site 5 – Latch Duration.



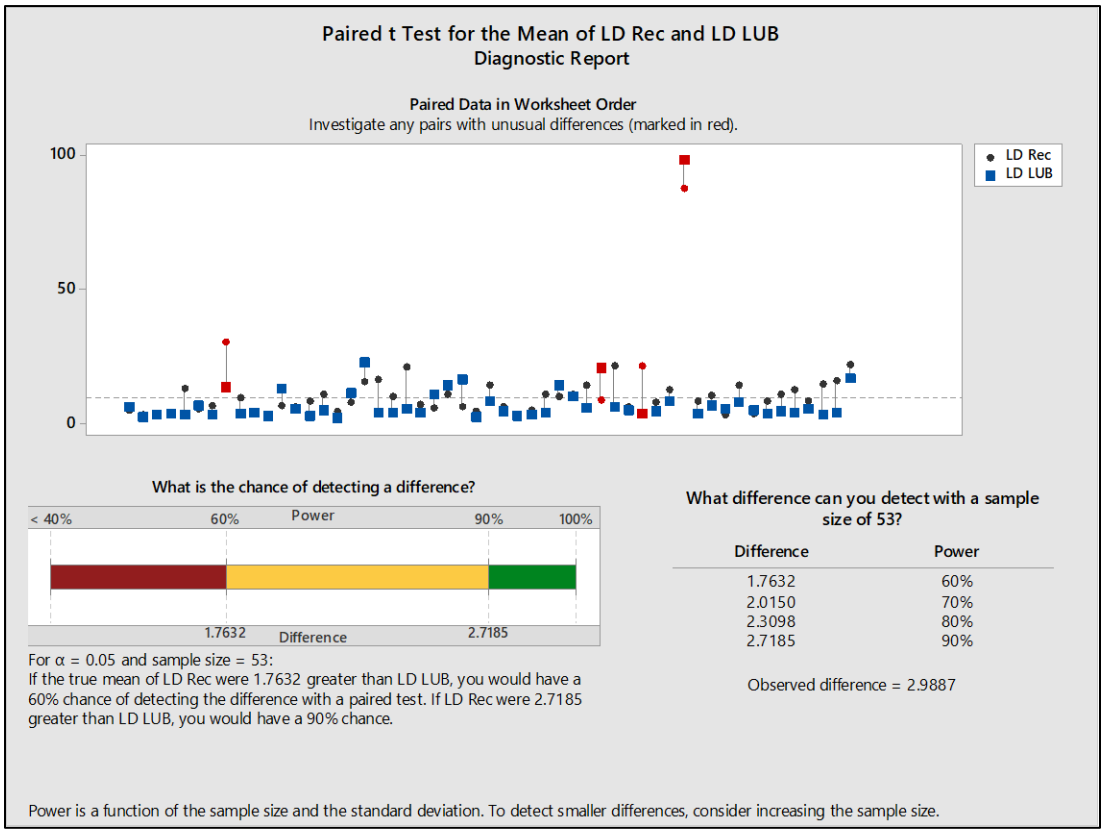
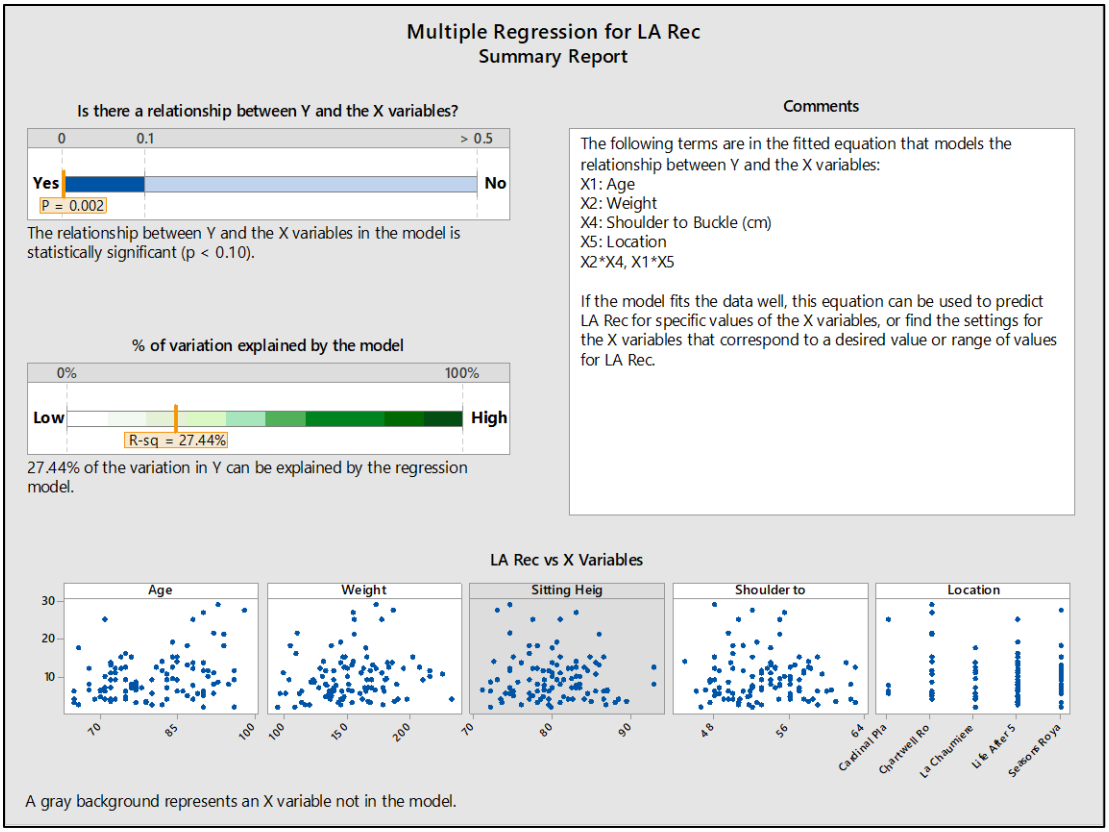


Figure A17: Paired t Test for Recessed Mode First – Latch Duration.



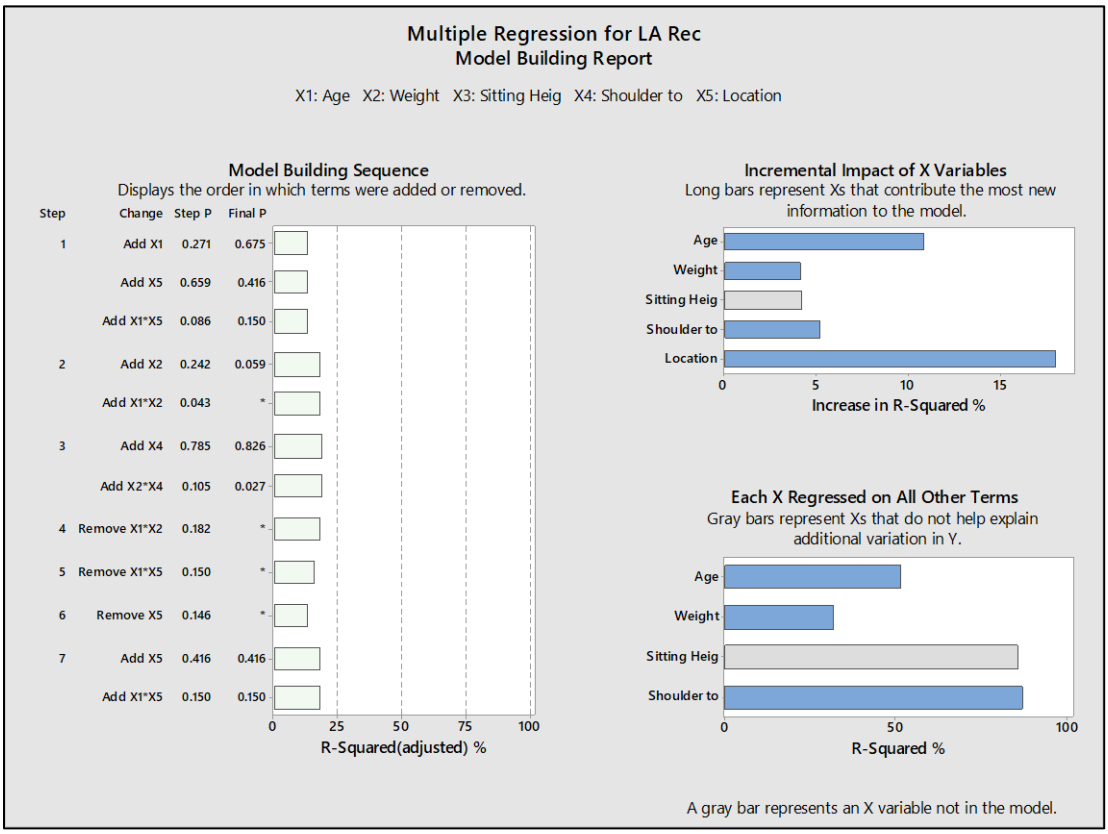
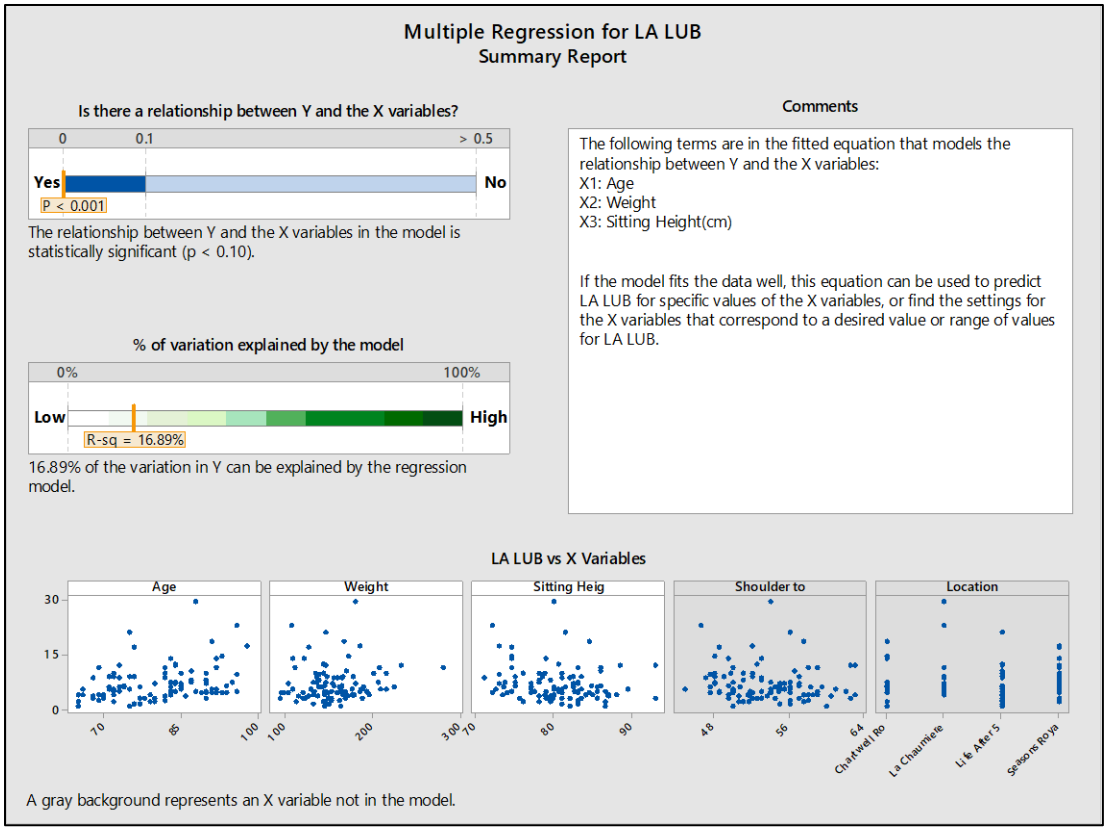


Figure A18: Regression Analysis for Latch Attempts – Recessed.



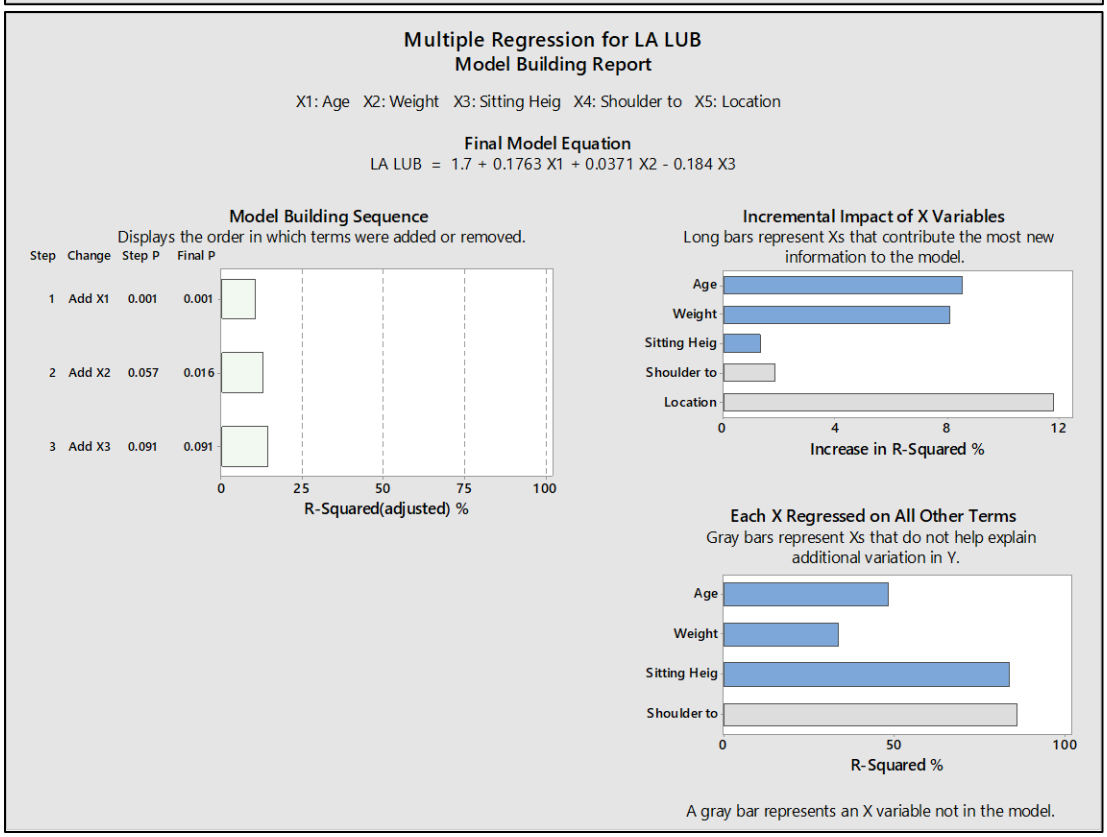
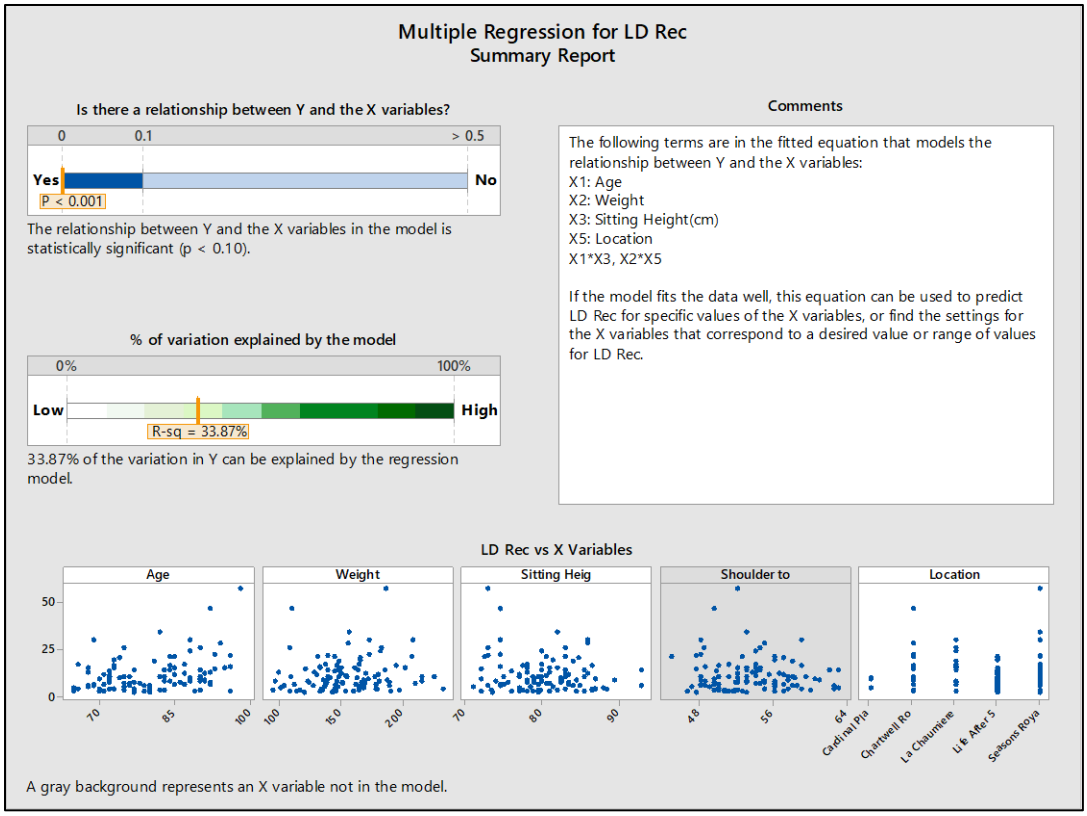


Figure A19: Regression Analysis for Latch Attempts – Elevated (LUB).



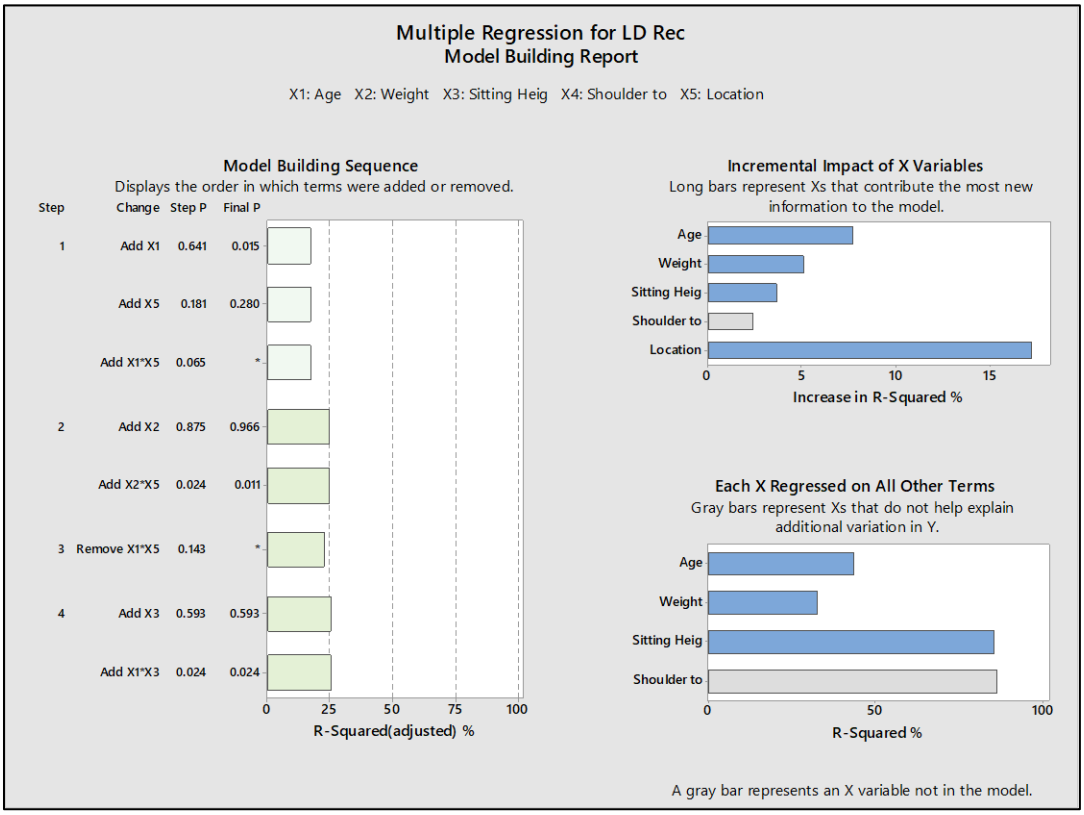
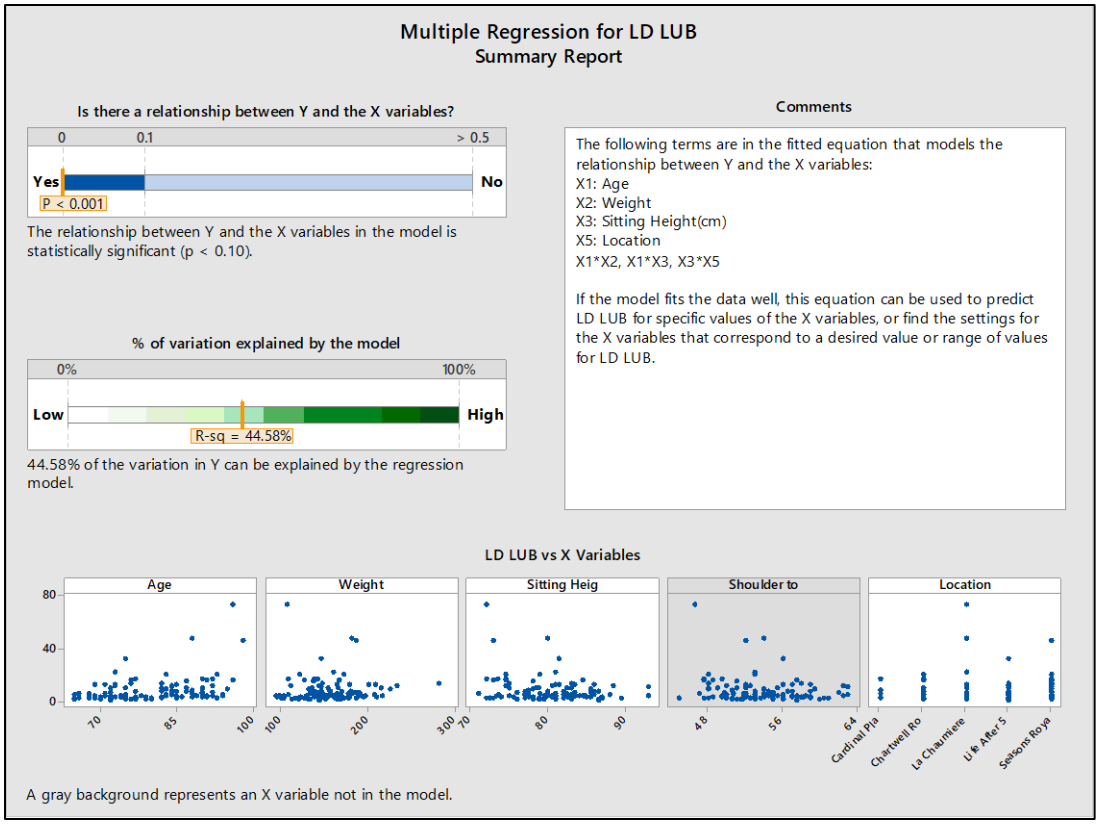


Figure A20: Regression Analysis for Latch Duration – Recessed.



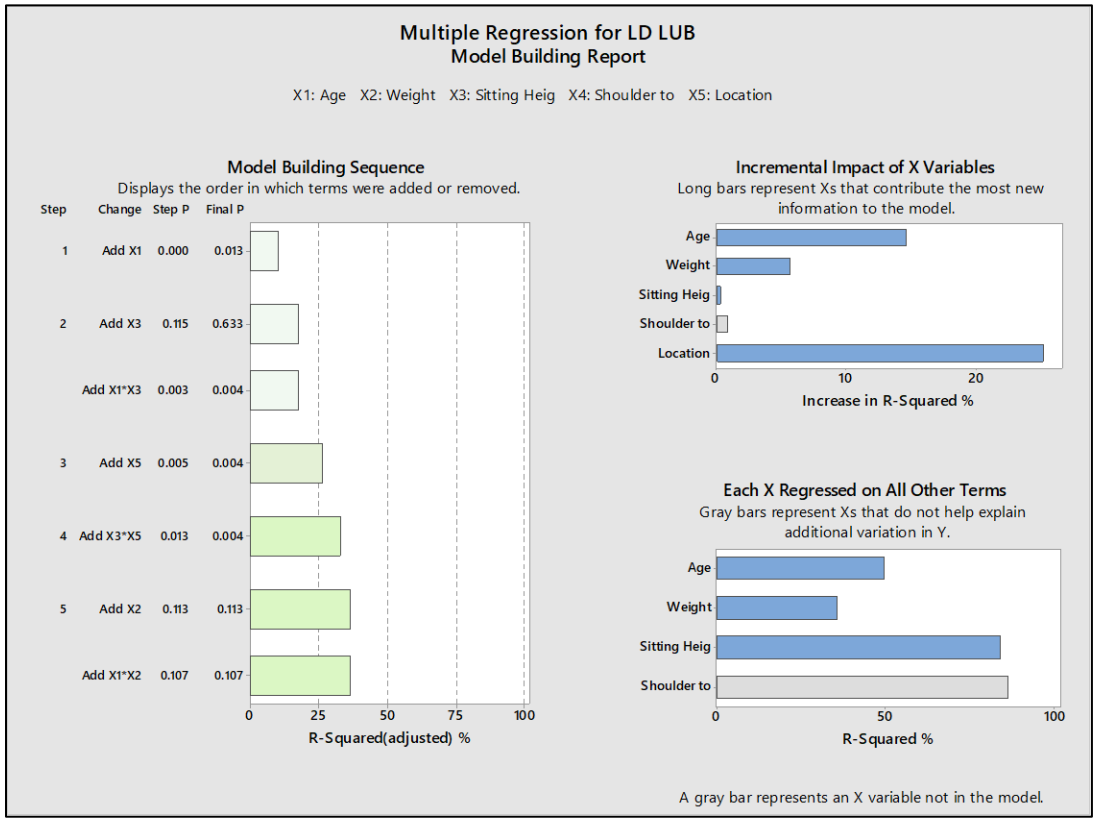
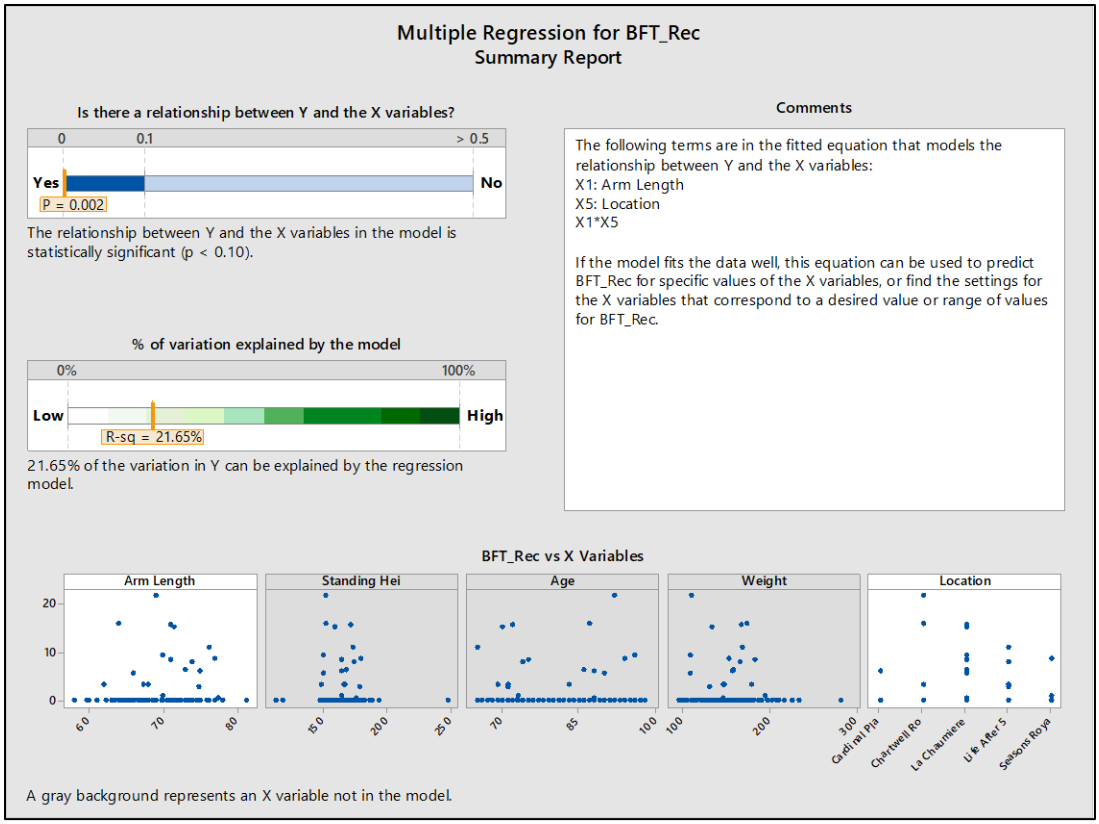


Figure A21: Regression Analysis for Latch Duration – Elevated (LUB).



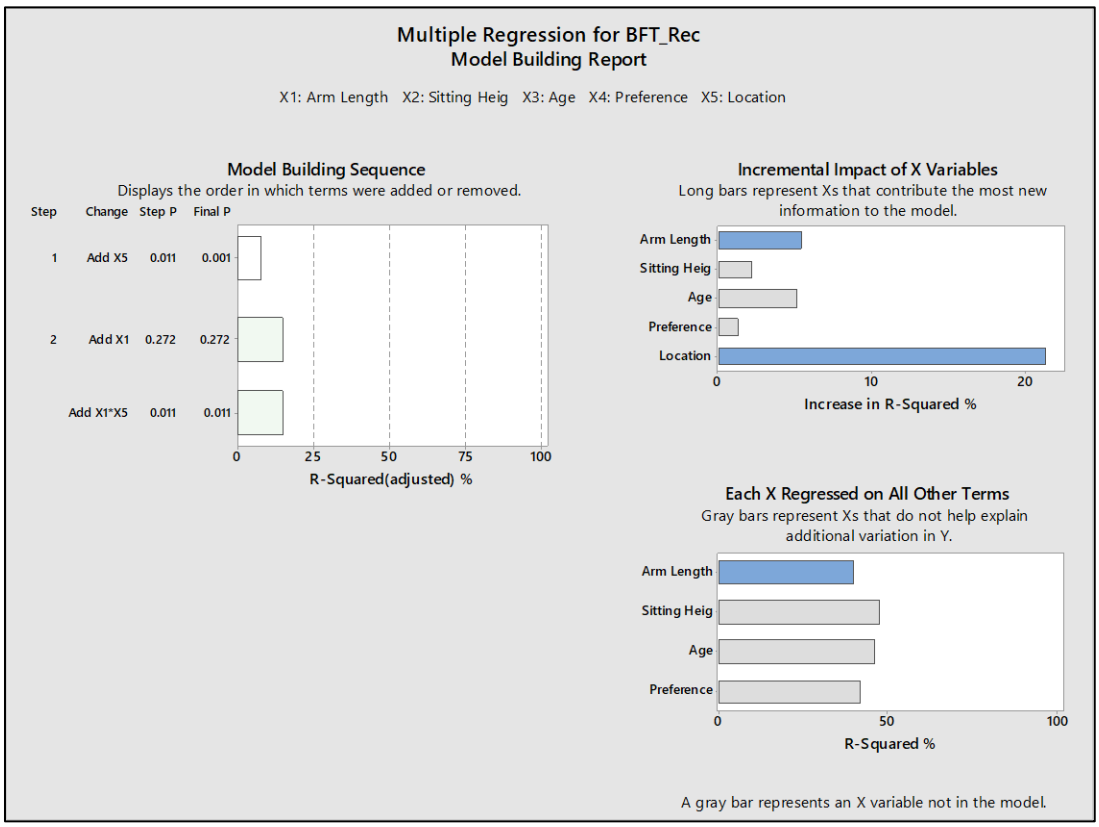
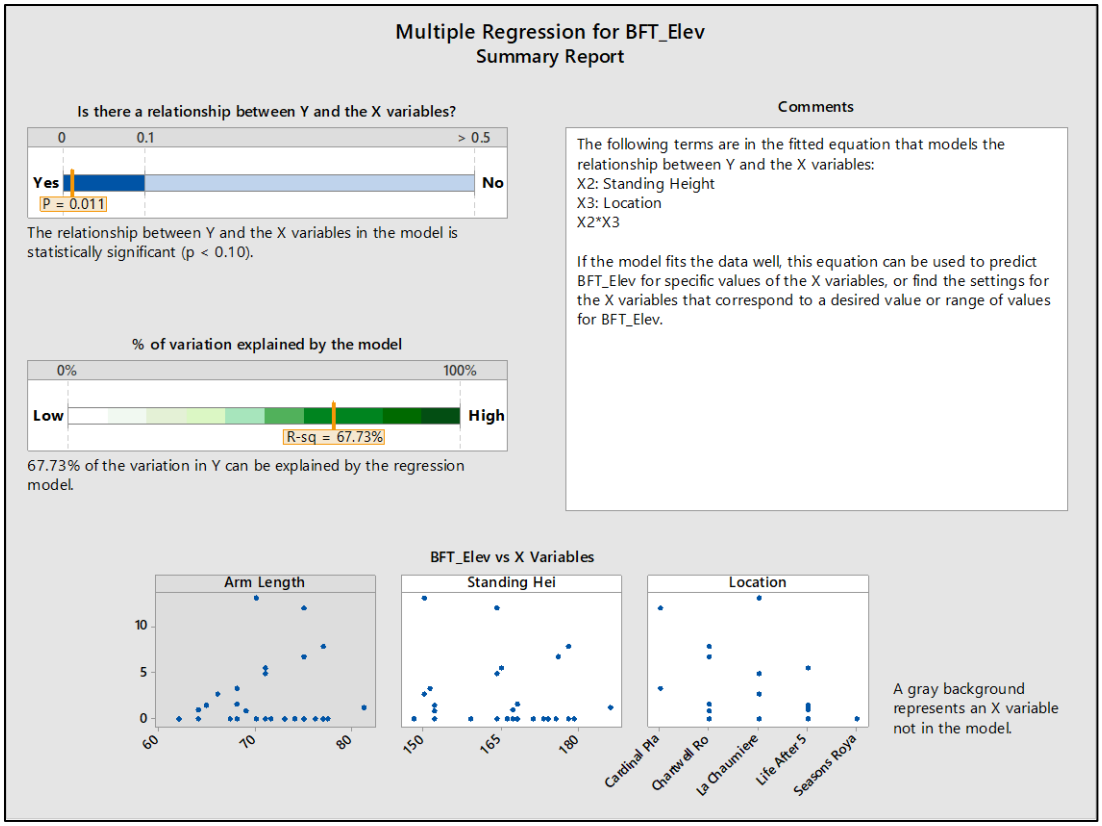


Figure A22: Regression Analysis for Buckle Find Time – Recessed.



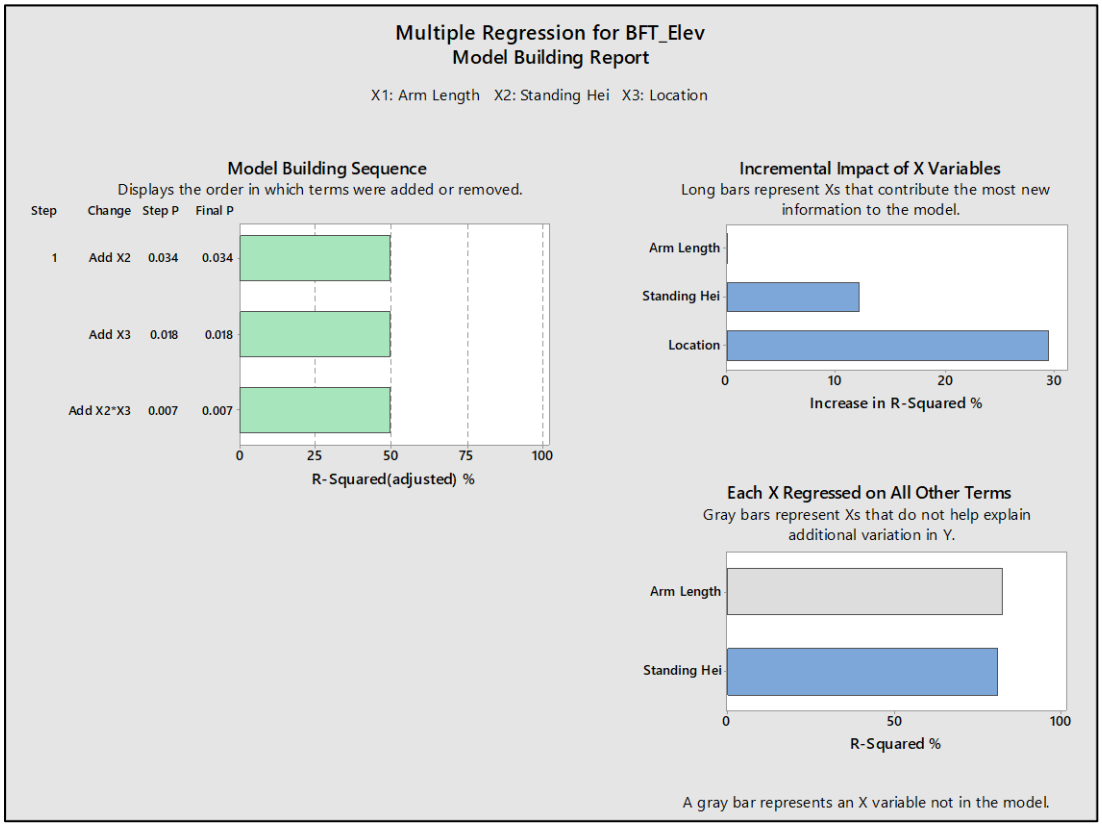
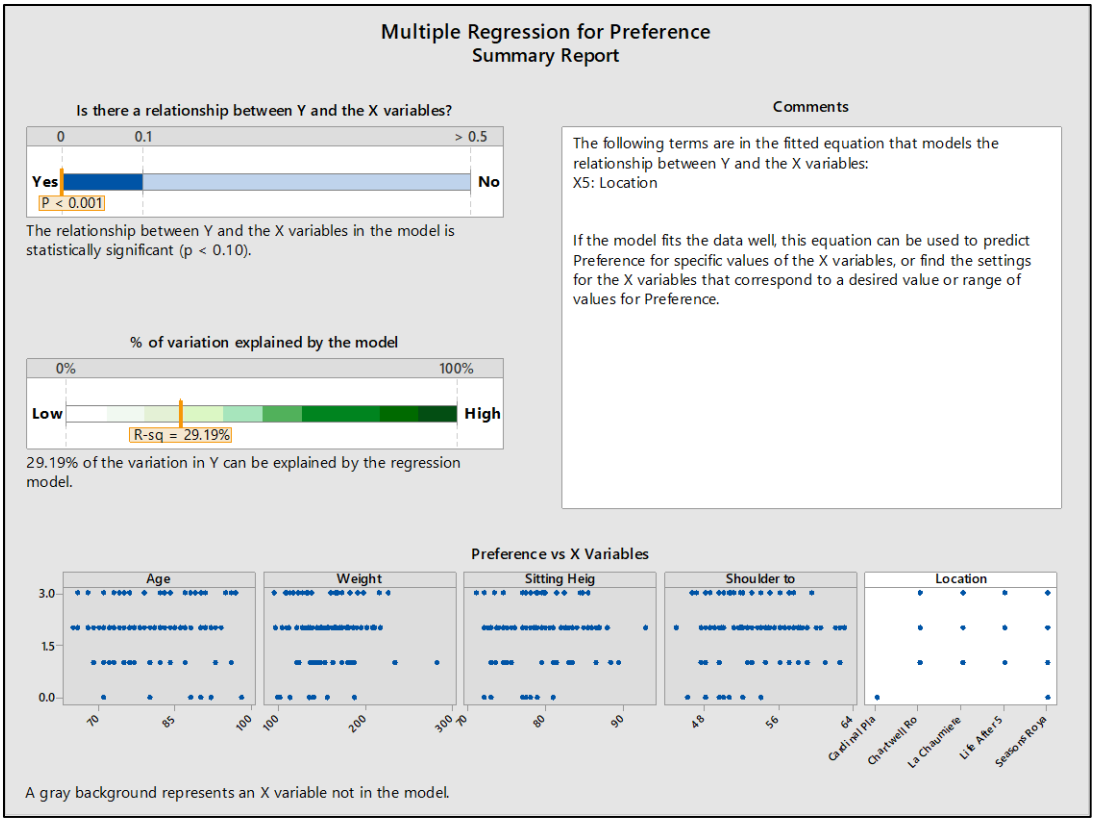


Figure A23: Regression Analysis for Buckle Find Time – Elevated.



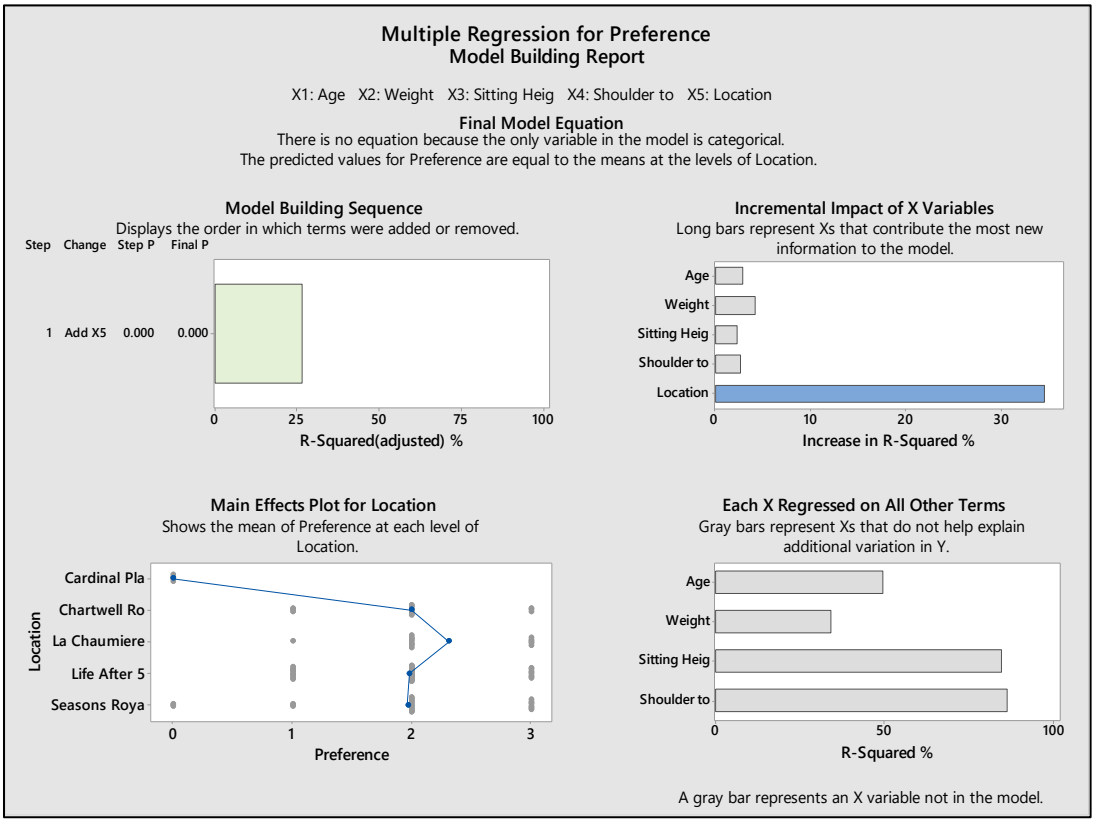


Figure A24: Regression Analysis for Buckle Preference.

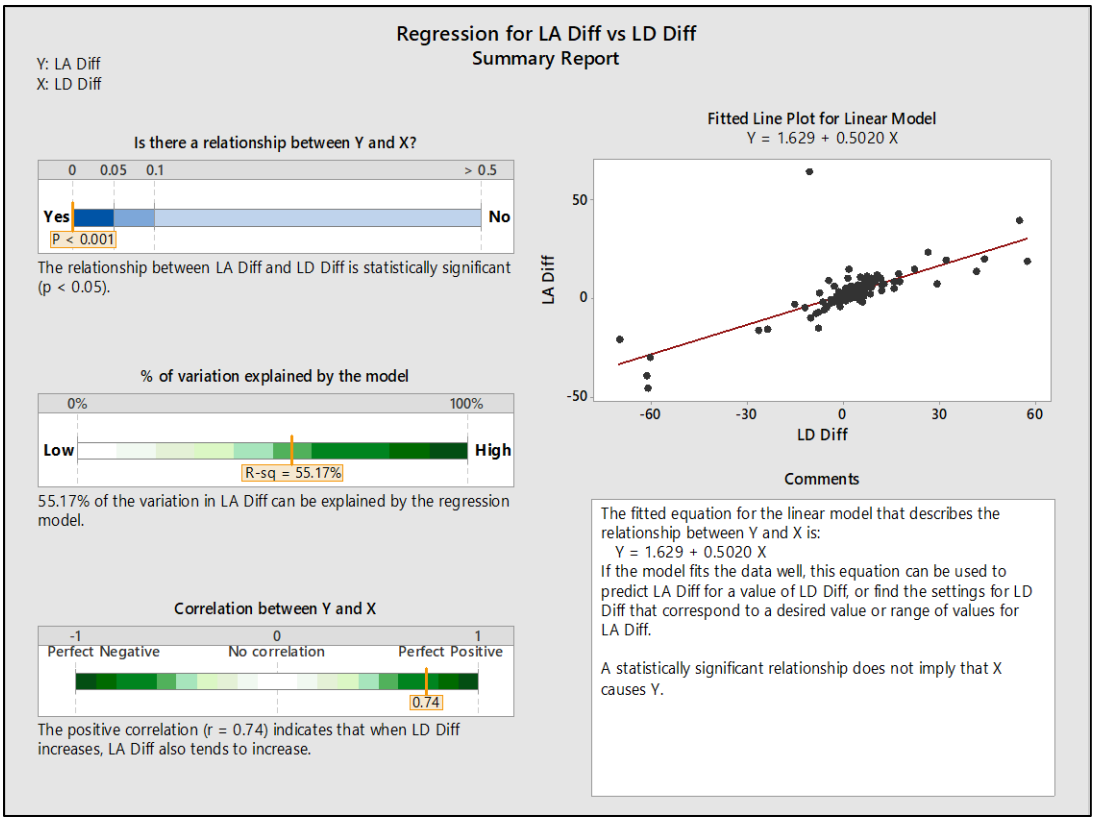


Figure A25: Regression Analysis for Overall Latch Attempts vs Latch Duration Results

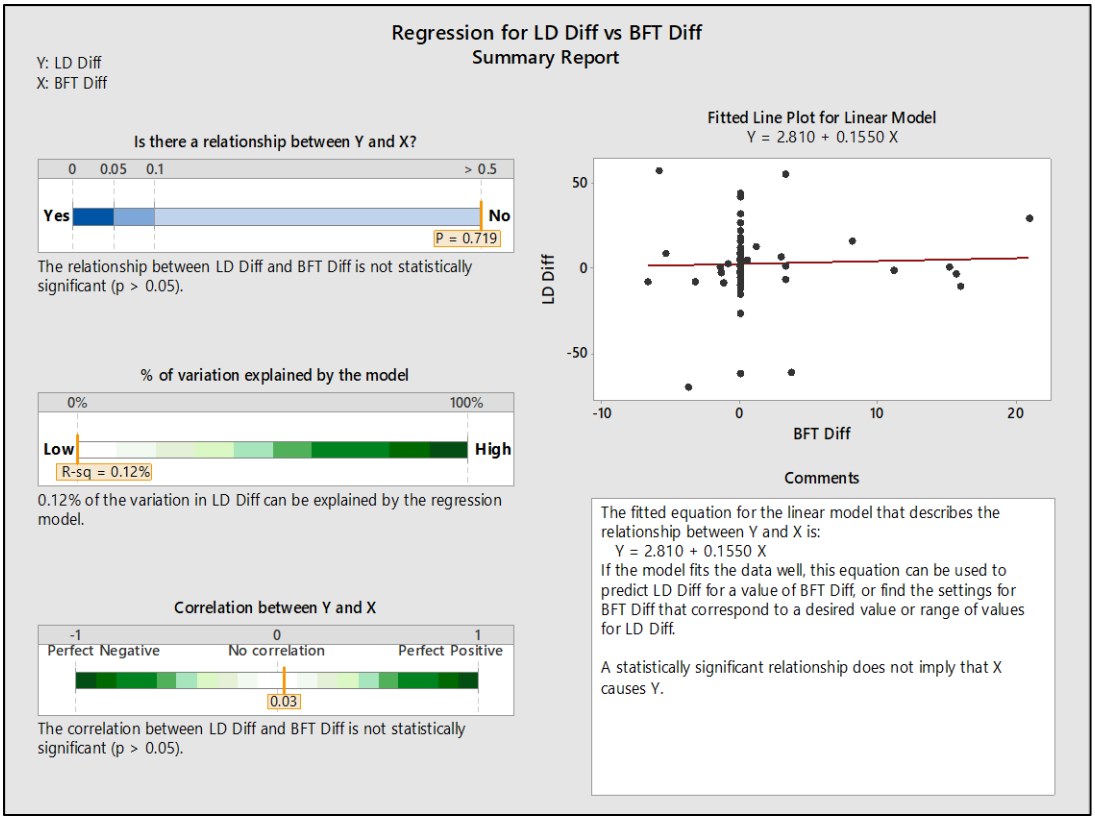


Figure A26: Regression Analysis for Overall Latch Duration vs Buckle Find Time Results

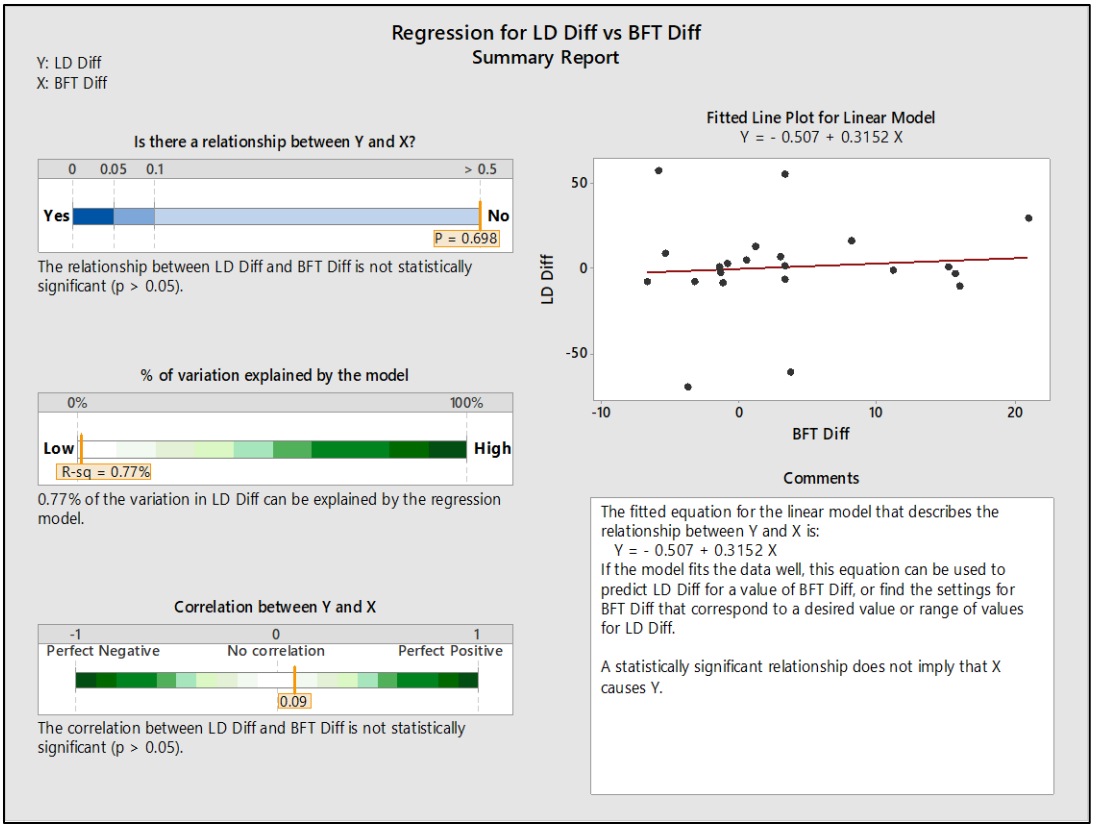


Figure A27: Regression Analysis for Latch Duration vs Buckle Find Time Results (for BFT Sample Size =26)

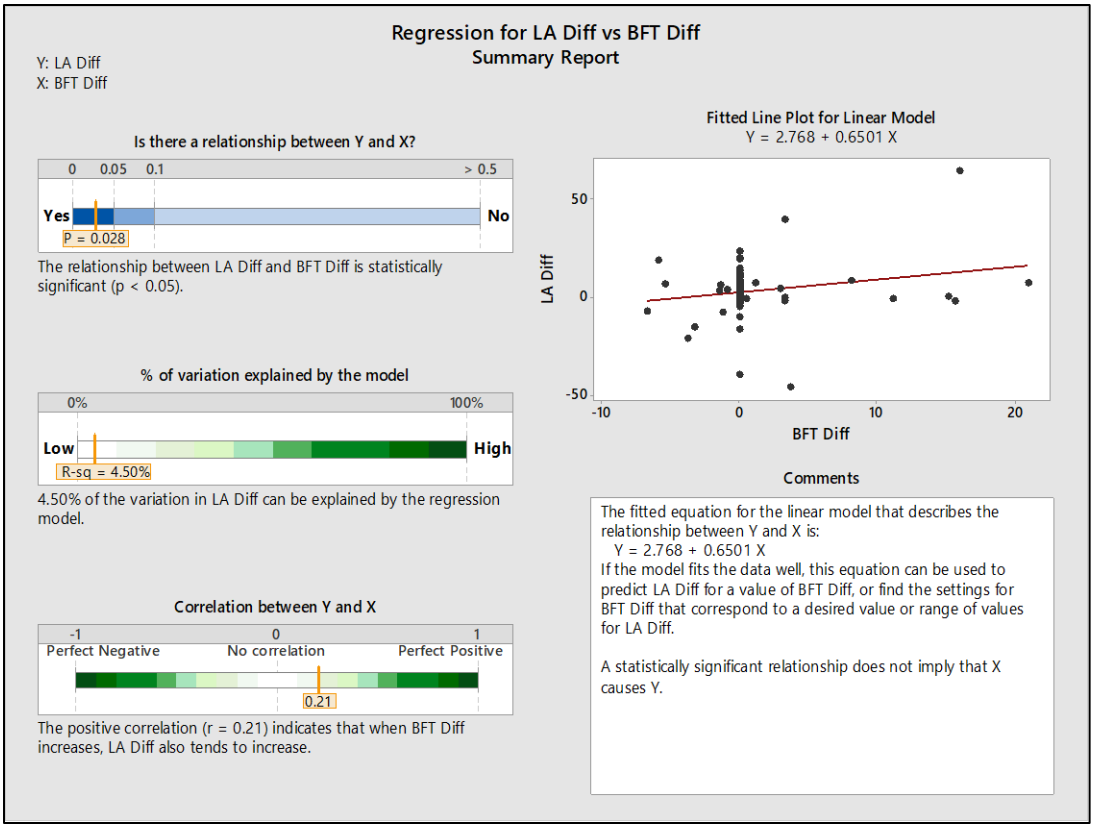


Figure A28: Regression Analysis for Overall Latch Attempts vs Buckle Find Time

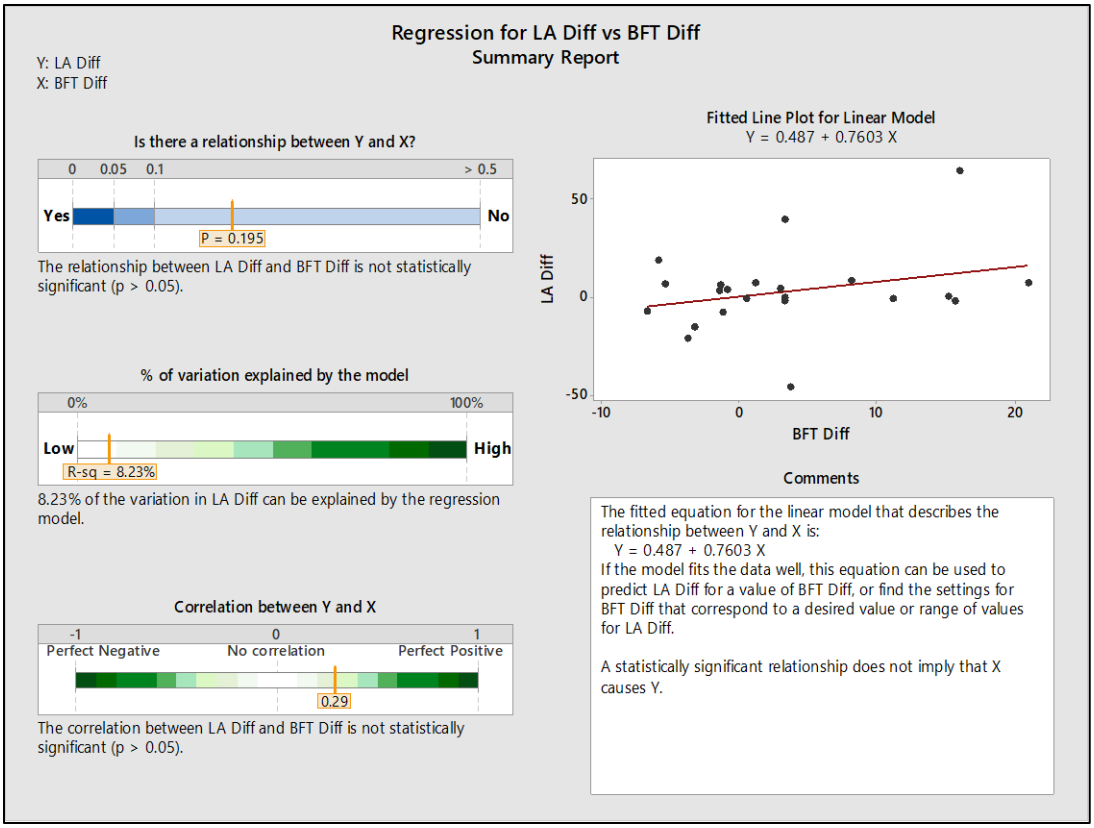


Figure A29: Regression Analysis for Latch Attempts vs Buckle Find Time (for BFT Sample Size =26)