A USABILITY STUDY OF SEATBELTS IN CONJUNCTION WITH BOOSTER SEATS

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ABSTRACT

Recent in-house benchmarking research has shown that seatbelt buckles in the rear seats of some passenger vehicles are becoming shorter and recessing further into the seat cushion in a possible effort to improve restraint geometry, achieve better Gabarit fit, or achieve other objectives. Despite the evident benefits associated with this trend, a major drawback could be that this recessed configuration reduces accessibility to the buckle for child occupants in booster seats.

Therefore, the objectives of this study were to:

1. Perform a series of usability studies with children to evaluate how the recessed position of the seatbelt buckle compares to an elevated position.

2. Demonstrate the effectiveness of a motorized adjustable buckle (seatbelt buckle technology that extends or retracts via an electric motor) as a possible way to maintain the intended recessed buckle geometry in-use, while simultaneously providing improved buckle accessibility for child occupants in booster seats.

A series of studies were conducted with a mounting fixture that simulated the rear right side seat of a midsized sedan with a booster seat. The fixture was equipped with a motorized adjustable buckle which replicated two buckle modes – recessed and elevated. Children of varying age, height and weight ranges were asked to buckle themselves with the buckle in both positions and observations were made of the number of latch attempts, latch durations, occupant preferences and difficulty level.

Evaluations show that the elevated mode was preferred among the sample size due to its ease of accessibility.

One specific seating configuration was used for this study – midsize right hand rear row sedan seat and average size booster seat. In order to universally confirm the study's hypothesis, varying combinations of seat sizes and booster seats would have to be further studied.

The study also suggests that child booster seat and vehicle seat designers should increase coordination of their respective product designs to better suit the abilities of child occupants. Furthermore, motorized buckles may be a viable alternative to the conundrum of maintaining the in-use buckle position intended by certain manufacturers while improving the accessibility of seatbelt buckles for child occupants in booster seats.

INTRODUCTION

Booster seat studies and analyses clearly show that booster seat use provides a remarkable advantage in child safety. Booster seats with seatbelts reduce the risk for injury in children aged 4 through 8 years over seatbelts alone by 45% [1,2], but when it comes to addressing the issue of geometrical compatibilities of booster seats with individual seatbelt components, there is limited available data.

Seatbelts are versatile devices with components that individually contribute to various aspects of vehicle occupant safety. Seatbelt buckles are vital to completing the seatbelt loop as well as maintaining restraint. Car makers may lower the buckle into the seat for various reasons such as improving restraint geometry or achieving better Gabarit fit [3].

However, achieving those objectives may reduce accessibility to the buckle for child occupants in booster seats who are attempting to latch themselves. This leads to the first objective of this paper, which is to study whether recessed buckles cause accessibility issues for children in booster seats compared to a more elevated seatbelt buckle position, via a series of usability studies. The second objective, based on the outcome of the first objective, is to study the effectiveness of a motorized adjustable buckle as a practical solution that would resolve the dilemma of increasing accessibility to the belt buckle whilst maintaining the manufacturer's intended in-use buckle position.

This paper specifically focuses on the compatibility of seatbelt buckle geometry with booster seats, among all the available child seat types. The reasoning for this limitation is two-fold – a) Stage-1 and Stage-2 seats use a different latching system that does not require frequent latching and unlatching of the 3 point seatbelt, nor operation of the restraint by the children themselves, b) Children in booster seats are typically learning or already know how to use the 3 point seatbelt, but given their small stature and developing motor skills require optimum compatibility between the various safety components. The intended outcome of this paper is to reveal and remark on how compatibility issues may arise when configuration changes are made to individual components that are intended to work as a part of a system. A second desired outcome of this paper is to discuss the efficacy of a specific technology (a motorized adjustable buckle) in reducing or eliminating one such compatibility issue.

METHOD

Surveying

Buckle and Vehicle Seat Survey: The first step in the data collection process was to establish a database of buckle and vehicle seat dimensions. This was done to establish buckle and seat measurements for the fixture to be used in the study. Buckles considered for this study were of outboard 1st rear row and metal anchor strap type (see Figure A1 in Appendix for different buckle mounting types). The rear rows of a vehicle are away from all front airbags, and are the safest seating positions for child seats [4], thereby making the rear row the choice for the study. Next, a buckle type that had a consistent mounting length and whose mounting structure provided limited flexibility was required. Web type and cable type buckles were incompatible with this requirement, thereby qualifying metal anchor strap type buckles as the optimum choice for the study. The measurements taken were those that would help determine buckle position with respect to the seat. Dimensional data of outboard 1st rear row buckles in vehicles of MY 2010-2016 was collected.
The measurements taken were (Figure 1):

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)

From the collected data multiple items were determined:

1. The average H, L', L and C buckle measurements for various vehicles from MY 2010-2016.

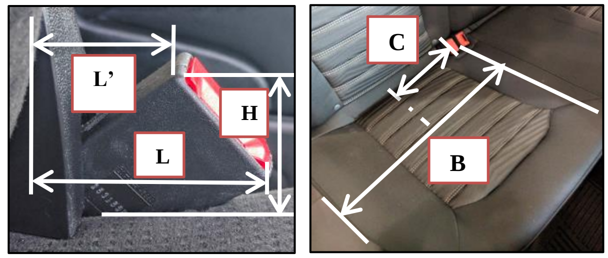

Figure 1a *Figure 1b*

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

2. The average, largest and smallest rear seats, based on B measurement:
    a. Smallest : 38.5cm
    b. Average : 50cm
    c. Largest : 60cm

This data was used to choose a seat for the study's mounting fixture. The initial seating configuration intended for this study was a combination of the largest booster seat with the smallest rear row seat, for a "worst case" scenario evaluation. The width (B) of the smallest rear seat, from the results shown above was 38.5cm, 2.5cm narrower than the width of the largest available booster seat, which was 41cm wide. This incompatibility led to evaluating the next configuration in the setup progression, which was a combination of the largest booster seat and a seat with B ≥41cm, with the buckle residing outside the seat edge. A rear row vehicle seat with a consistent B = 45cm was procured based on the above observations.
Table A1 in the Appendix lists the surveyed buckle dimensions and seat width measurements.

Booster Seat Survey: A total of 23 current Canadian market (high-back, no back, 2-stage and 3-stage) booster seats were measured for the following lengths (for the complete list, refer to Table A2 in the Appendix):

1. Maximum seat base width – the measurement across the largest span of the booster base (W, Figure 2a)
2. Seat base height (H', Figure 2b)

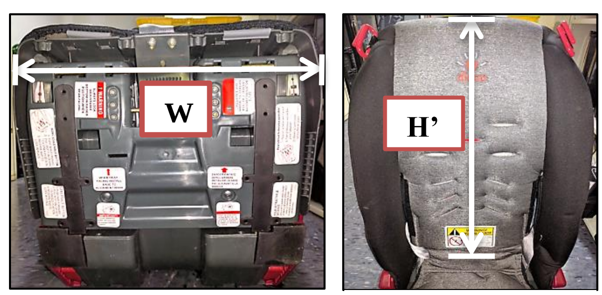

Figure 2a *Figure 2b*

Figure 2. Booster Seat Max. Width Measurement (Figure 2a), Booster Seat Height Measurement (Figure 2b).

These measurements were studied to determine the largest and average sized booster seats available in the market.

Backless boosters can be used when the vehicle seat and head restraint support the child's head to the tops of the ears [5]. As most of our sample size was expected to fall short of meeting this requirement, a booster with a back was selected. An informal survey with a child seat sales associate provided the information that 3-stage child seats were the most popular among booster seats with a back, which led to choosing the largest 3-stage booster based on seat width and seat height measurements. The Safety 1st Alpha Omega Select (W = 41cm, H' = 12cm, Figure 3a) and the Evenflo Symphony Platinum DLX (W=39cm, H' = 15.5cm, Figure 3b) were the two largest 3-stage boosters in the order specified, but were not available in stock. The Evenflo Platinum Safemax (W = 39cm, H' = 12.5cm, Figure 3c) was the finalized option. This model had a wider seat back width than seat base width and padded wings. This in combination with its W and H' measurements made it the best available candidate for a booster seat with the largest seat coverage. The booster had to be situated so that it was centered on the vehicle seat and off of the seat bolster on its right side, thereby placing it adjacent to the belt buckle on the left. Unfortunately, the size of the Platinum Safemax booster seat caused accessibility issues to the belt buckle. A trial study with an 8 year old occupant revealed that the test subject had significant difficulty in finding the buckle. The subject was completely out of position while trying to locate the buckle in both modes (recessed and elevated) and failed to latch in both scenarios. This led to a decision to replace the Evenflo booster with one of an average size. W and H' measurements of the 23 boosters were averaged (Wavg = 36.91cm, H'avg = 10.35cm) and the Evenflo Right Fit booster (W = 36cm, H' = 11cm, Figure 3d) matched the W result by a difference of 2.5% and the H' result by a difference of 6.3%. However, that booster seat was disqualified because it was a high back booster rather than a 3-stage booster. The Diono Radian R100 (W = 32.5cm, H' = 8.5cm, Figure 3e) was the ultimate choice, both due to its dimensional similarity to the average booster measurements and its ready availability in the market.

Figure 3a

Figure 3b

Figure 3c

Figure 3d

Figure 3e

Figure 3. Safety 1st Alpha Omega Select (Figure 3a), Evenflo Symphony Platinum DLX (Figure 3b), Evenflo Platinum Safemax (Figure 3c), Evenflo Right Fit Booster (Figure 3d), Diono Radian R100 (Figure 3e).

Usability Study

The intentions of this activity were to address – (a) Do recessed buckles pose convenience issues to child occupants in booster seats? (b) How do they fare in comparison to elevated buckles? (c) Will the data vary among different groups of occupants (sorted by age, weight, height, gender etc.), and how? (d) Are motorized adjustable buckles a viable solution?

Mounting Fixture: A mounting fixture was constructed emulating the outboard 1st rear row seating position of an average mid-sized sedan (Toyota Camry), as shown in Figure 4. This choice was based on an informal survey of popular online automotive websites [6, 7]. The fixture was affixed with an outboard rear row vehicle seat, as previously

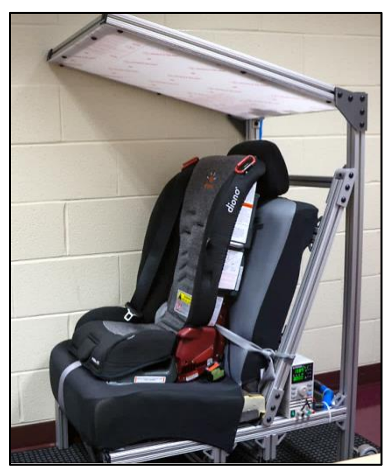

Figure 4. Mounting fixture used for the usability study.

discussed in the Buckle and Vehicle Seat Survey section. More pictures of the mounting fixture have been placed in the Appendix. A shelf-mounted seatbelt retractor assembly was placed over the right shoulder of the vehicle seat. The WSIR (Webbing Sensitive Inertial Response) VSIR (Vehicle Sensitive Inertial Response) and Automatic Locking Retractor (ALR) features were disabled so as to avoid interference due to locking during the study. A Diono Radian R100 booster seat (chosen from the booster seat benchmarking results) was placed atop the vehicle seat.

An electronically driven motorized belt buckle that replicated two buckle modes – recessed and elevated – was positioned to the left of the booster seat (Figure 5). In the recessed mode (Figure 5a), 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 the range of buckle benchmarking results for MY 2016. In its elevated mode (Figure 5b) the buckle extended 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 alter the buckle position between trials.

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.

Figure 5a

Figure 5b

Figure 5. Buckle in recessed mode (Figure 5a), Buckle in elevated mode (Figure 5b).

Study Constraints: The selection process involved picking consenting participants from three different local schools. All research ethics guidelines as defined in the Tri-Council Policy Statement by the Panel on Research Ethics [8] were adhered to in this process. Qualifications for candidates participating in the usability study were deemed as follows:

- Age : 4 – 8 YO [9]
- Weight: 18 – 40 kg [10]
- Height : 101-144cm – Diono Radian R100 User Manual recommended height range

Some allowance was made for occupants that did not fall in the above stated weight range if they satisfied the height conditions, by a tolerance of 2kg.

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 front of 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.

Study Procedure: The study commenced with the participant being asked to state their name, age, gender and whether they were currently using a booster seat.

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) measurements were recorded (Figure 6).

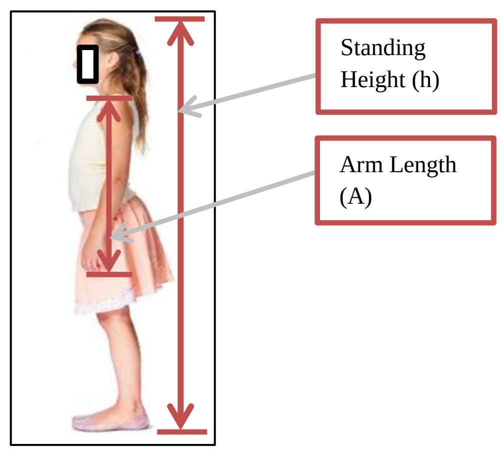

Figure 6. Standing Height and Arm Length Measurement.

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 in the recessed mode, (E)) measurements were taken (Figure 7). 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 (81cm) and Roof to Buckle (92cm) measurements, which were measured beforehand, to obtain T and E measurements. Next, inquiries

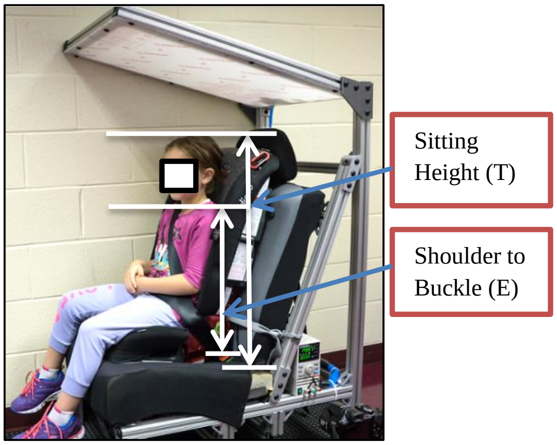

Figure 7. Sitting Height and Shoulder to Buckle Measurements.

pertaining to the participant's seatbelt wearing habits were made – if they knew how to independently use the seatbelt themselves, or if an adult had to assist them and how the adult would intervene. This was done to obtain an informal awareness of the participant's latching regimen and to determine whether they were qualified to participate in the study. 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 required assistance in the past 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.
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.
3. The participants were asked to latch the seatbelt, first for Trial A.
4. 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.
5. Trials A & B were recorded separately on both recording devices for each participant.
6. Any unique behaviour was observed and recorded.

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. It was important to verify at all times that the buckle was not over extended or under recessed. This was done by the simple act of affixing a measuring tape, 70mm long, on the visible side of the buckle. In the elevated mode, the 60mm mark had to coincide with the top surface of the adjacent vehicle seat cushion that the buckle was positioned flush against. In the recessed mode, the 10mm mark was to coincide with the surface of the vehicle seat cushion.
The data collected from the study can be found in the Appendix in Table 3. Figure A3 in the appendix shows images taken during the course of the study.

Analysis

Data assessment was performed in three phases:
<u>Paired t Tests:</u> The buckle video recordings from the usability study were evaluated to obtain the number of latch attempts and total latch duration for Trial A & Trial B of each individual participant. The statistical software Minitab 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)

It was important to define what counted as a latch attempt. After observing hand movements and body behaviour in multiple videos, the constraints to defining latch attempts were made. However it is essential to note that while these constraints do assist in outlining a method, latch attempt analysis was subjective in certain specifically abstruse cases. 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 accompanied 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 (Figure 8a). The slip tongue would interact with a single non-buckle surface (seat base, seat back, booster seat side).
- A single, deliberate and continuous movement in the buckle region outside of the buckle, below reference line 1 with zero interactions with any surfaces.

For the purpose of distinguishing between a continuous and a spasmodic 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.

Latch duration was defined as the difference between the start time and end time during the course of attempting a latch. Latch start and end times for each mode were as follows:

Recessed 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 1 (Figure 8a) 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 8b) 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). There were cases wherein the participant retracted the seatbelt or removed the slip tongue from the video recording frame to reform their grip. 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.

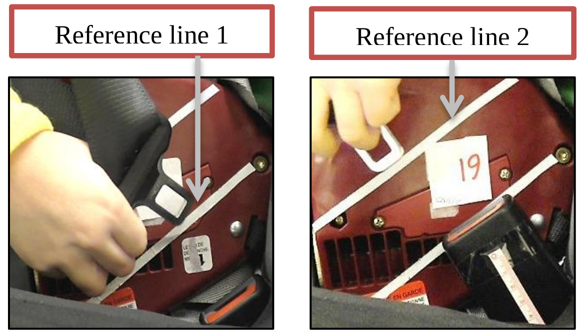

Figure 8a ***Figure 8b***

Figure 8. Reference lines used for latch duration assessment; Reference Line 1 (Figure 8a), Reference Line 2 (Figure 8b).

Regression Analysis: Latch attempts and latch durations 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 considered for the regressions were:

- Age (years)
- Weight (kg)
- Gender (M/F)
- Standing Height (cm)
- Sitting Height (cm)
- Arm Length (cm)
- Shoulder to Buckle (cm)

However, Standing Height and Sitting Height had a strong factor of correlation. This was calculated using a simple regression (Figure 9).

In order to avoid repeating and confounding data from predictor variables in regression assessment, Standing Height was taken out of consideration.

Weight was deemed an independent variable that was correlational to the other predictor variables (age, sitting height, arm length) but not causal to the response variables, and was therefore taken out of consideration. Simple regression charts for these analyses can be found in Figure A4 in the Appendix.

Ultimately, each of the response variables; Latch Attempts (Recessed), Latch Attempts (Elevated), Latch Duration (Recessed) and Latch Duration (Elevated) had multiple regressions with the collective five finalized predictor variables, namely

Age, Sitting Height, Arm Length, Shoulder to Buckle and Gender.

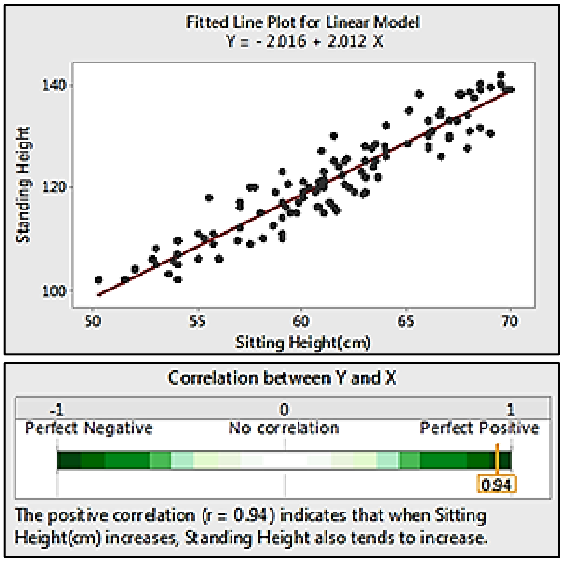

Figure 9. Fitted Line Plot for Standing Height vs Sitting Height.

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 test subject using the adjacent wall to push themselves closer to the buckle in order to perform the latch
3. Any other distinct behaviour

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

The study was initially set up as a retrospective probing activity, where the users would be asked for subjective input on their experience and buckle mode preferences. This proved to be an ineffective strategy as the test subjects were seen to mimic answers they had heard previously from previous participants without being able to provide adequate reasoning. Some test subjects would also get distracted, or simply not understand the context of the questions, thereby resulting in the abandonment of this strategy.

Results

Paired t Tests: The total sample size for overall analysis was 116 after removing test subjects that did not meet the recommended weight and height requirements. Latch Attempts and Latch Durations were assessed in two separate datasets as they were anticipated to have different final sample sizes. The difference in sample sizes between these two sets is because the reemergence of the buckle PRESS button at the time of latching was blocked by the participant's hand, making it difficult to record the end time of the event. It was still viable to count the latch attempts because a clear view of the buckle was not a necessary requirement to do so; the downward movement of the hand pressing down on the buckle followed by the immediate removal of the hand from the slip tongue was satisfactory in ascertaining the final latch attempt. Therefore, those cases that did not meet the requirements for the Latch Duration dataset were excluded from the Latch Duration dataset only, but included in the Latch Attempts dataset as long as they met all the requirements for the latter.

Table A4 in the Appendix shows the final results for Latch Attempts and Latch Duration. Figures A5-A9 in the Appendix show graphed data of the results.

Paired t Test evaluations were performed on these data groups using the statistical software Minitab. First, the outliers were calculated using the 1.5*IQR rule, which gave the following results:

Table 2.
Outlier Fences for Latch Attempts in Various Categories

Outliers – Latch Attempts					
Group	Sub-group	Recessed Mode		Elevated Mode	
		LL	UL	LL	UL
Overall	-	-3	17	-0.5	11.5
Age	4	-5.3	28.8	-1	19
	5	-7.5	24.5	-1.3	12.8
	6	-0.6	12.9	0.8	8.3
	7	-2.6	14.4	0.3	10.3
	8	-0.3	9.8	2	6
Sex	Male	-2.9	15.6	-0.7	11.8
	Female	-3.4	17.6	-1.8	12.3
Trials	Rec. first	-4.3	17.8	-0.5	11.5
	Elv. first	-3.8	18.3	-1.8	12.3

Note: LL – Lower Limit, UL – Upper Limit

Table 3.
Outlier Fences for Latch Duration in Various Categories

Outliers – Latch Duration (s)					
Group	Sub-group	Recessed Mode		Elevated Mode	
		LL	UL	LL	UL
Overall	-				
Age	4	-23.6	59.9	-14.1	41.9
	5	-14.3	40.6	-8.6	24.8
	6	-4.3	16.1	-1.5	10.3
	7	-0.1	10.1	-3.7	13.3
	8	-0.6	9.1	-1.5	8.9
Sex	Male	-3.4	16.8	-3.9	15.4
	Female	-5.5	18.4	-4.4	14.4
Trials	Rec. first	-1.9	15.7	-5.3	16.7
	Elv. first	-2.2	15.3	-1.8	12.3

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 were effectively 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 tables below show the results of the Paired t Test evaluations for the final sample sizes in each group:

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

Latch Attempts				
Group	Sub-group	Sample Size	Paired Diff µ	P-value
Overall	-	112	1.83	<0.001
Age	4	23	2.97	0.003
	5	23	2.78	0.001
	6	24	1.38	<0.001
	7	25	0.8	0.088
	8	19	1.18	0.044
Gender	M	67	1.3	<0.001
	F	45	2.42	<0.001
Trials	Rec. first	57	1.97	<0.001
	Elv. first	55	1.69	<0.001

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	P-value
Overall	-	96	1.21	<0.001
Age	4	22	3.55	0.062
	5	18	4.43	<0.001
	6	22	0.63	0.113
	7	22	0.62	0.16
	8	17	0.64	0.073
Gender	M	57	0.67	0.074
	F	38	1.77	<0.001
Trials	Rec. first	46	1.54	0.005
	Elv. first	50	0.91	0.023

Note: Alpha risk level for P-values: 0.05

For the purposes of evaluating the statistical significance of the data, all P-values > 0.05 were deemed not statistically significant.
Examples for each category can be found in Figures A11 – A18 in the Appendix.
The data demonstrates the following outcomes:

- Regarding Latch Attempts:
  - The probability of the population showing fewer latch attempts for the buckle in the elevated mode than the buckle in the recessed mode is >99.9%.
  - The percentage difference in mean latch attempts for the overall sample size is 24.02%.
  - The data determines a 95% confidence in that the true mean difference between recessed and elevated modes is greater than 1.33 attempts or 17.5% decrease in latch attempts over the recessed mode.
  - The greatest difference in mean latch attempts occurred among the youngest occupants (4-5 YO) in the Age category with a mean difference of approximately 3 attempts, and among females in the Gender category with a mean difference of 2.4 attempts. The order of the trials did not make an effective difference in the latching patterns of participants.
- Regarding Latch Duration:
  - The probability of the population showing lower latch duration for the buckle in the elevated mode than the buckle in the recessed mode is >99.9%.

- The percentage difference in mean latch duration for the overall sample size is 14.86%.
- The data determines a 95% confidence in that the true mean difference between recessed and elevated modes is greater than 0.62s or 7.6% decrease in latch duration over the recessed mode.
- The greatest difference in mean latch duration occurred among the youngest occupants (4-5 YO) in the Age category of 3.55-4.4s, and among females in the Gender category with a mean difference of 1.7s. The order of the trials did not make an effective difference in the latching patterns of participants.
- The older occupants (7-8 YO) were the least affected by the change in buckle mode.

Regression Analysis: As previously stated, multiple variable regressions were performed individually against the response variables. Only the initial set of residuals calculated by Minitab was removed and any residuals calculated by Minitab on the subsequent data were not excluded. Examples of individual response variable regressions can be found in Figures A19 – A20 in the Appendix.
The following were the results of regression analysis:

Table 6.
Results of Regression Analysis

Response Var.	Predictor Var. in Model	r^2 (%)	P-value
LA Rec.	Arm Length, Sitting Height	40.6	<0.001
LA Elv.	Age, Sitting Height, Gender, Shoulder to Buckle	43.1	<0.001
LD Rec.	Age, Sitting Height, Shoulder to Buckle	41.8	<0.001
LD Elv.	Sitting Height, Shoulder to Buckle	56.8	<0.001

Note: LA - Latch Attempts, LD – Latch Durations

As can be observed, the predictor variables in the model differ from case to case. In each case, the regression model opted for the variables that would help explain the variance in the output values the most without overfitting. It is evident from the resultant data that the predictor variables are only able to explain variance to a certain extent. The data resulted in the following outcomes:

- Age, Sitting Height, Shoulder to Buckle, Arm Length and Gender are significant predictors of the data.
- Other factors outside the scope of this study are responsible for the unexplained variance.
- This data will help analyze the group of the booster seat using population that will benefit most from a switch to the motorized belt buckle.
- This data will help examine the factors outside the predictor variables in the model that could influence latch attempt and latch duration outcomes, and if adjusting these factors would increase or decrease latch attempts and latch durations for the two buckle modes in future studies.

Other Observations: Miscellaneous subjective data recordings and observations helped provide further insight into differences in behavioural patterns when latching. It was observed that in 21.3% of recessed buckle cases, the occupants were out of position while attempting to latch themselves versus 13.8% in the elevated mode. In 17.3% of recessed buckle cases, the occupants had at least one foot up on the adjacent wall to position themselves closer to the buckle, and 10.3% of cases in the elevated mode (Figure 10).

Figure 10. Occupant Out of Position and with his foot against the wall while attempting to latch in recessed mode.

DISCUSSION

This study opens a doorway to questioning the compatibilities between various safety components intended to work together in a vehicle, outside of crashworthiness. The following incompatibilities were identified during various segments of this study:

- Vehicle seat and booster: Vehicle seat sizes were discordant with booster sizes. The smallest vehicle seat in our dataset (B=38.5cm) would have disqualified 14 out of the 23 of the boosters shown in Table A2 in the appendix just by accounting for seat width only. Additionally, these boosters exceeding seat widths cause issues when combined with other boosters in a vehicle. From an informal survey with parents of booster seat users, it was found that users opted for no-back boosters due to the above discussed issues, when they would have normally opted for a high back with side impact and rollover protection features.

- Buckle placement and booster: As discussed under Booster Surveying, the Evenflo Platinum Safemax booster seat experience showed that vehicle seat width (B) and booster seat width (W) measurements were not enough to assure accessibility. The booster had to be moved to the side where it was partially resting on the seat bolster and partially on the flat portion of the seat in order to access the buckle. When boosters obstruct access to the buckle, they have to be moved outboard until the buckle is accessible and re-centered after latching. This is inconvenient to do each time. Younger children cannot move the bulkier boosters and often end up requiring assistance. The recessed location of certain buckles adds to this conundrum. In cases where the booster was not sitting on top of the buckle, the extrusions of the attachments on the boosters made it difficult to find the buckle. The lack of available data in this area calls for further research addressing design compatibilities focusing on accessibility issues.

It was important to independently examine both the input variables, i.e. Latch Attempts and Latch Duration for this study. This is because the simple regression performed between Difference in Latch Attempts and Difference in Latch Duration showed that these variables were not strongly correlated (r^2 = 35.41%, Figure A10 in the Appendix). The possible reasons for this could be:

- Multiple latch attempts were performed in a short span of time, as demonstrated by some older children in the study.
- A single latch attempt was performed over a relatively long time span, as demonstrated by some younger children in the study.

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

- Different child seat types (2-stage, no-back, high back)
- Vehicle make
- Right or left handedness of the occupant
- Buckle distance from booster seat
- Buckle movement at the time of latching
- Buckle angle
- Buckle anchor type (webbing, cable)
- Seat back angle
- Test subject body size
- Latch force

This data may aid in examining how adjusting these factors would influence latch attempts and latch durations. It would also provide further insight into user population groups that would most benefit from motorized adjustable buckle technology. If the motorized adjustable buckle were to be implemented as a solution to the issues discussed in this paper, these variances would help optimize the design of such a technology.

The motorized adjustable buckle is designed to move to its recessed position after latching, therefore continuing to maintain the manufacturer's intended low buckle position whilst increasing accessibility at the time of latch. From the analysis presented in this paper, this technology shows improvement for latch attempts and latch durations in the elevated mode as compared to the recessed position of the buckle. Further studies to evaluate optimum latching height, reducing buckle movement and incorporating unexplained variances may show more success for this equipment.

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 and average size booster seat. Varying combinations of seat sizes and booster seats would have to be studied.
- The buckle in the elevated mode rotated sideways and downwards following thrusts from the occupant attempting to latch in certain cases. This may have influenced a higher latch attempt and latch duration count in the elevated mode. Having a sturdier buckle mount may reduce latch attempt and latch duration counts.

- Only five predictor variables were taken into account. Changing the seating configuration, buckle distance from booster seat, and other factors outside the scope of this study may influence the results of future evaluations.
- In the cases of some younger 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.

CONCLUSION

This study used the most recent data available to examine the effectiveness of current booster seat and rear seatbelt buckle compatibility. The analysis of the sample in the study confirmed objective 1 of the paper – the recessed buckle position is more difficult than the elevated buckle position for occupants in booster seats in the study sample that are attempting to latch themselves (from Paired t Test evaluations and subjective observational data).

From the collected data, we were also able to observe that occupants of ages 4-5 show the greatest improvement in latching patterns (attempts and durations) when switched over to a buckle with greater accessibility. Females show greater improvement over males in latching patterns when switched over to the higher buckle. The order of latching does not significantly change the latching patterns.

The regressions show the influential extent of factors like age, sitting height, arm length, shoulder to buckle length and gender on the variability of data.

Over the past decade, evaluations with child volunteers have examined how different booster seat designs improve belt fit using realistic vehicle and seat belt geometries [11, 12, 13] While latch attempts and latch durations show a significant improvement in the case of the elevated motorized adjustable buckle, further studies are required to assess their universal effectiveness.

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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	2017	Chrysler	Pacifica	46.5	23.25	2.6	6	2.6
2	2017	Ford	Fusion	50	22.5	6	4.5	0
3	2016	Dodge	Caravan	52	21	5	9.5	5.5
4	2016	Dodge	Dart	54	22.5	0.5	8	4
5	2016	Ford	Escape	46	16	5	8.5	4.5
6	2016	Ford	Focus	50	22	4.5	6	2
7	2016	Ford	Fusion	55	23	6.5	5	1.5
8	2016	Hyundai	Sonata	49	20	4.5	7	3
9	2016	Jeep	Cherokee	52	20	3	8	4
10	2016	Jeep	Grand Cherokee	50.5	20	1	8.5	4.7
11	2016	Mazda	3	49.5	24.25	3.5	7	2
12	2016	Mazda	CX-5	53	22.5	4	6	1.5
13	2016	Nissan	Rogue	52.5	22.25	3.8	12.5	8.5
14	2016	Chrysler	200	48	20	6	6	2.5
15	2016	Nissan	Maxima	38.5	19.25	6.5	5.2	1.8
16	2016	Chrysler	Town & Country	50	20	4.5	6	3
17	2016	Kia	Optima	39.5	N/A	7.8	7	3
18	2016	Mazda	CX-3	48	18	2	11.5	7
19	2016	Volvo	XC90	51.8	N/A	10	7	3
20	2016	Honda	HR-V	51.8	15.54	10	7	3
21	2016	Mercedes	GLC	46.5	19.5	4.5	9	5
22	2016	Toyota	RAV4	52.5	19	6	10.5	4.5
23	2015	Dodge	Caravan	47.0	21.5	5.0	5.0	0.0
24	2015	Ford	Escape	46.0	16.2	3.0	8.0	3.0
25	2015	Mazda	3	51.0	18.5	1.5	6.5	2.0
26	2015	Jeep	Cherokee	52.0	20.0	4.0	8.0	5.0
27	2015	Fiat	500L	41.0	15.0	5.0	18.0	13.0
28	2015	Ford	Fusion	48.5	18.0	5.5	5.5	1.0
29	2015	Toyota	Sienna	58.5	24	7.5	11	4
30	2015	Ford	Focus	50.0	22.3	4.5	5.3	1.5
31	2015	Chrysler	200	51.2	22.8	2.0	7.0	2.5
32	2015	Toyota	RAV4	52.0	19.5	4.4	10.8	5.8
33	2015	Chrysler	Town & Country	52.4	21.0	5.0	8.0	4.0
34	2015	Ford	Edge	50.0	20.0	-3.0	2.1	-2.7
35	2014	Chevrolet	Cruz	50.0	17.0	3.5	12.0	6.0
36	2014	Jeep	Cherokee	54.0	21.0	3.4	10.0	6.0
37	2014	Jeep	Grand Cherokee	50.5	19.0	0.0	11.0	7.5
38	2014	Ford	Fusion	47.0	18.0	5.0	5.0	0.0
39	2014	Dodge	Caravan	51.0	23.2	5.0	8.5	4.5
40	2014	Ford	Focus	51.0	23.5	5.3	5.1	1.5
41	2014	Ford	Escape	47.0	19.0	3.8	7.4	3.0

42	2014	Mazda	3	55.0	20.5	0.0	6.5	2.0
43	2013	Ford	Escape	46.0	17.0	3.0	7.5	3.0
44	2013	Ford	Focus	50.0	16.0	4.0	6.0	1.0
45	2013	Chevrolet	Cruz	49.0	17.5	4.0	12.0	6.0
46	2013	Chrysler	Town & Country	52.4	21.0	5.0	8.0	4.0
47	2013	Hyundai	Elantra	50.0	25.0	4.0	5.0	1.0
48	2013	Dodge	Dart	51.5	19.0	2.3	6.0	2.0
49	2013	Chevrolet	Malibu	51.5	23.0	4.0	12.2	7.7
50	2013	Ford	Fusion	50.0	22.0	5.5	4.3	0.7
51	2012	Dodge	Caravan	51.0	22.8	5.0	7.5	3.5
52	2012	Dodge	Dart	51.0	20.0	1.5	7.0	3.0
53	2012	Chrysler	300	50.0	17.0	5.5	5.0	0.0
54	2012	Jeep	Cherokee	49.0	17.0	0.0	9.0	4.5
55	2012	Ford	Focus	50.0	18.0	3.5	5.7	1.0
56	2012	Chevrolet	Cruz	49.5	17.0	5.0	12.0	8.5
57	2012	Dodge	Caravan	51.0	22.8	5.0	7.5	3.5
58	2011	Jeep	Cherokee	49.0	18.0	0.0	9.0	5.0
59	2011	Dodge	Caravan	52.0	21.0	4.0	7.6	4.0
60	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.

Table A2.
Booster Seat Measurements

Brand	Model	Booster Type	Seat base W (cm)	Seat base H' (cm)
Safety 1st	Grow N Go	3-stage	26.5	13.5
Cosco	Top Side No Back	No Back	27.5	7
Clek	Ozzi	No Back	30	9
Safety 1st	Alpha Omega Elite Air	3-stage	31.1	10.5
Diono	Radian RXT	3-stage	32.5	8.5
Diono	Ranier	3-stage	32.5	8.5
Diono	Radian R100	3-stage	32.5	8.5
Evenflo	Evolve	3-stage	34.5	11
Evenflo	Right Fit Belt Positioning	High Back	36	11
Britax	Pioneer	3-stage	38	11
Britax	Frontier Clicktight	2-stage	38	11
Graco	Nautilus	2-stage	38.5	10
Graco	Argos 65	2-stage	38.5	10
Clek	Oobr	High Back	39	10
Evenflo	Symphony Platinum DLX	3-stage	39	15.5
Evenflo	Platinum Safemax	3-stage	39	12.5
Graco	High Back Turbobooster	High Back	40	8
Graco	No Back	No Back	40	10
Safety 1st	Alpha Omega Select	3-stage	41	12
Graco	Affix	High Back	42.5	9
Evenflo	Maestro	2-stage	43.5	10
Britax	Parkway SGL	High Back	43.8	11
Evenflo	SecureKid	2-stage	45	10.5

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

Table A3.
Data Collected from Usability Study

#	Age	Sex	Weight	h	A	R	T	S	E
1	4	M	17.4	106	44	26	55.0	45	47.0
2	4	F	19.1	111	46	25.3	55.7	48.2	43.8
3	4	M	16.6	102	43	30.8	50.2	54.2	37.8
4	4	M	17.8	105.5	43	27.2	53.8	47.6	44.4
5	4	M	17.3	107	44	27	54.0	48	44.0
6	4	M	17.5	109.5	46	27	54.0	45.5	46.5
7	4	M	16.7	106	42	25	56.0	49	43.0
8	4	F	19.2	102	42	27	54.0	46.6	45.4
9	4	M	16.9	104	43	29	52.0	48	44.0
10	4	F	17.9	105	43	28	53.0	48	44.0
11	4	M	19.1	109	43	25.3	55.7	46.5	45.5
12	4	M	18.1	103	42	27.4	53.6	47.1	44.9
13	4	F	16.9	106	40	28.2	52.8	50	42.0
14	4	F	19.2	108	48	28	53.0	50	42.0
15	4	F	17.8	109.5	43	24.1	56.9	46.6	45.4
16	4	M	22.9	119	47.5	21	60	45.2	46.8
17	4	M	23.5	119	46	18	63	41.4	50.6
18	4	M	18.4	110	43	25.7	55.3	48.0	44.0
19	4	M	18.5	115	45	21.6	59.4	47.2	44.8
20	4	M	20.5	116	45	20.2	60.8	44.0	48.0
21	4	M	17.6	105	44.5	27	54	47.2	44.8
22	4	F	17.1	102	43	29.5	51.5	47	45.0
23	4	F	17	111	49	26	55	47.3	44.7
24	5	F	23.3	122	51	17.4	63.6	40.4	51.6
25	5	M	20	112	46	24	57.0	45	47.0
26	5	M	18.1	110	42	22	59.0	40.2	51.8
27	5	M	27.9	117	48	24	57.0	43.5	48.5
28	5	F	21.8	116	49	19.5	61.5	42.2	49.8
29	5	F	17.4	109	45	23.5	57.5	45.5	46.5
30	5	M	20.1	114	47	22	59.0	46.5	45.5
31	5	F	23.5	115	46	20	61.0	44	48.0
32	5	F	28.9	128	51.5	15	66	36.7	55.3
33	5	F	22.4	127	51	17	64	49.0	43.0
34	5	M	21.1	116	46	21.8	59.2	41.5	50.5
35	5	F	18.5	120	46	23.5	57.5	44.5	47.5
36	5	F	16.8	112.5	45.5	22.4	58.6	45.7	46.3
37	5	F	21	115.5	42	19.4	61.6	43.2	48.8
38	5	F	21.7	117	42	21.2	59.8	41.6	50.4
39	5	M	25.8	120.5	48	21.7	59.3	41.6	50.4
40	5	M	21.9	118	45.5	21	60	40.7	51.3
41	5	F	21.4	118.5	49	18.1	62.9	43.4	48.6
42	5	M	18.4	110	44	22.9	58.1	45.7	46.3
43	5	M	22.5	115	40	21.3	59.7	43.4	48.6
44	5	M	19.8	117	50	19.7	61.3	40.6	51.4
45	5	F	17	111	45	22	59	45.9	46.1
46	5	M	20.3	116	49	24	57	45	47.0
47	5	M	21.3	115	49.5	23	58	42.3	49.7
48	6	M	31.7	123	52	22	59.0	44.5	47.5

49	6	F	24.1	125	52	18	63.0	41.6	50.4
50	6	M	24.8	128.5	53	16	65.0	41.5	50.5
51	6	F	19.4	116	50	20.3	60.7	41.1	50.9
52	6	M	22.5	121	49	20.2	60.8	43.3	48.7
53	6	F	22.5	123	50	20	61.0	42	50.0
54	6	F	24.7	120.5	51	19	62.0	41.5	50.5
55	6	F	18.6	120	49	20.2	60.8	43	49.0
56	6	M	23.4	123	50	18.2	62.8	40.5	51.5
57	6	M	20.5	118	51	21	60.0	42.4	49.6
58	6	M	21.4	119	49	20.4	60.6	44	48.0
59	6	F	21	121.5	51	20	61	43.5	48.5
60	6	M	22.7	124	51	17.6	63.4	40.0	52.0
61	6	F	24.9	128.5	50	17.5	63.5	41.6	50.4
62	6	F	20.4	120	48	20	61	43.5	48.5
63	6	M	27.1	134	55	13.1	67.9	39.1	52.9
64	6	F	22.9	122.5	46.5	19.1	61.9	41.4	50.6
65	6	M	19.8	124	52	19.3	61.7	41.7	50.3
66	6	M	23.2	127.5	50	17.7	63.3	40.6	51.4
67	6	M	28.3	125.5	52	18.9	62.1	40.7	51.3
68	6	F	23.2	120	44.5	18.8	62.2	41.2	50.8
69	6	F	20	119	50	22.3	58.7	42.3	49.7
70	6	M	20.5	120	51	23.3	57.7	43.7	48.3
71	6	M	19.4	117	50.5	22	59	42.5	49.5
72	7	M	26.6	131.5	55.5	12.5	68.5	37.9	54.1
73	7	F	26.2	130	55	15	66.0	40	52.0
74	7	M	28	131	56	14.8	66.2	40.3	51.7
75	7	M	24.4	126	54	14.4	66.6	36.7	55.3
76	7	M	20.1	121	47	20	61	43.5	48.5
77	7	M	21.2	127	50	20.1	60.9	42.3	49.7
78	7	M	22.3	125	50	19	62	44.5	47.5
79	7	F	21	121	48	21	60	41.7	50.3
80	7	M	26	125	49	19.5	61.5	41.0	51.0
81	7	M	22.6	122	48	18	63	41.3	50.7
82	7	M	27.9	138	52	13.4	67.6	37.5	54.5
83	7	M	27.4	128	52	17.1	63.9	40.7	51.3
84	7	M	29.3	130	53.5	19.5	61.5	41.0	51.0
85	7	F	19.8	120	46	20.7	60.3	44.0	48.0
86	7	F	29.3	137.5	56.5	12.8	68.2	35.8	56.2
87	7	M	29.8	139.5	58	12	69	37.3	54.7
88	7	M	24.4	129.5	52.5	14	67	39.0	53.0
89	7	M	26.8	130.5	50	12	69	36.6	55.4
90	7	M	27.3	133	53.5	14	67	38.7	53.3
91	7	M	34.8	132	57	17	64	40.7	51.3
92	7	M	20.9	118	54	25.5	55.5	45	47.0
93	7	M	24	119	50.5	18.5	62.5	41.5	50.5
94	7	M	31.2	134	58.5	14.5	66.5	38.1	53.9
95	7	M	36.2	134	59	14.5	66.5	38.2	53.8
96	7	M	24.9	127.5	56.5	13.1	67.9	35	57.0
97	7	F	22.1	120.5	53	20	61	42.3	49.7
98	8	M	25.4	127.5	54	15	66.0	40.7	51.3
99	8	M	39.4	140	61	11.5	69.5	37.3	54.7
100	8	F	29.5	138	58.5	15.4	65.6	41.3	50.7

101	8	M	27.1	131	58	13	68.0	40.9	51.1
102	8	M	28.8	135	58.5	15.9	65.1	40.6	51.4
103	8	M	26.6	130	56.5	14	67.0	39.9	52.1
104	8	M	27.1	133	53.5	15	66	35.0	57.0
105	8	F	31.7	133	52.5	13.6	67.4	38.4	53.6
106	8	M	32.7	139	52	11	70	37.0	55.0
107	8	F	33.7	142	56	11.5	69.5	35.8	56.2
108	8	F	29.8	139	56.5	12.5	68.5	36.3	55.7
109	8	F	27.5	139	57	11.3	69.7	37.5	54.5
110	8	F	34.6	140	56	12.5	68.5	35.6	56.4
111	8	M	24.5	125	56	17.5	63.5	41	51.0
112	8	F	40.8	135	61	14.4	66.6	36.5	55.5
113	8	M	25.3	128	56.5	18	63	39	53.0
114	8	M	22.3	126	55.5	17	64	37.3	54.7
115	8	F	30.8	138.5	60	13	68	33.5	58.5
116	8	F	24.7	134	57	14.4	66.6	39.6	52.4

Table A4.
Trial Latch Attempts and Latch Duration Results

							Time to Latch (Rec)			Time to Latch (Elev)			
#	Age	Trial A	Trial B	LA Rec	LA Elev	LA Diff	Start	End	Duration	Start	End	Duration	LD Diff
1	4	2	1	19	12	7	00:16.5	01:07.0	50.50	00:40.9	01:04.6	23.70	26.8
2	4	1	2	16	10.5	5.5	26.31	54.8	28.49	14.67	34.3	19.63	8.86
3	4	2	1	27	16	11	00:08.9	01:15.9	67.00	40.83	01:51.3	50.5	16.5
4	4	1	2	26.5	23	3.5	10.54	56.11	45.57	00:09.6	01:03.0	53.4	-7.83
5	4	2	1	12.5	8.5	4	9.38	29.45	20.07	26.77	40.06	13.29	6.78
6	4	1	2	8	9	-1	4.04	11.63	7.59	3.75	11.71	7.96	-0.37
7	4	2	1	17.5	12.5	5	4.95	33.68	28.73	7.94	42.39	34.45	-5.72
8	4	2	1	10.5	2.5	8	2.59	10.83	8.24	6.34	9.31	2.97	5.27
9	4	1	2	4	4.5	-0.5	15.6	23.31	7.71	4.6	17.93	13.33	-5.62
10	4	1	2	9	2	7	12.07	42.9	27.1	1.6	14.2	12.6	14.5
11	4	2	1	6.5	5	1.5	7.72	17.17	9.45	9.09	19.89	10.8	-1.35
12	4	2	1	14.5	22.5	-8	22.04	N/A	N/A	7.11	40.07	32.96	N/A
13	4	2	1	13	9	4	9.53	26.76	17.23	2.71	20.9	18.19	-0.96
14	4	1	2	5	8.5	-3.5	2.64	6.72	4.08	4.5	25.08	20.58	-16.5
15	4	2	1	3.5	3.5	0	17.11	22.41	5.30	11.67	16.02	4.35	0.95
16	4	2	1	4	6.5	-2.5	8.39	12.21	3.82	19.96	24.99	5.03	-1.21
17	4	1	2	7.5	8	-0.5	14.8	19.55	4.75	9.69	16.1	6.41	-1.66
18	4	1	2	16	10	6	13.88	28.26	14.38	8.43	23.41	14.98	-0.6
19	4	2	1	10.5	7.5	3	15.32	24.29	8.97	21.09	27.94	6.85	2.12
20	4	2	1	12.5	6.5	6	14.41	29.61	15.2	14.26	24.54	10.28	4.92
21	4	1	2	9.5	11.5	-2	8.85	17.77	8.92	10.89	24.81	13.92	-5
22	4	1	2	17.5	7.5	10	20.99	51.77	24.05	15.92	22.81	6.89	17.16
23	4	1	2	14.5	9.5	5	8.73	51.55	42.83	17.23	43.04	21.74	21.09
24	5	1	2	8	5.5	2.5	6.66	16.07	9.41	5.24	9.96	4.72	4.69
25	5	1	2	15	7	8	8.61	28.58	19.97	6.12	18.08	11.96	8.01
26	5	2	1	13	11.5	1.5	0.63	20.07	19.44	7.87	24.02	16.15	3.29
27	5	1	2	15	7.5	7.5	18.03	39.47	21.44	1.21	11.13	9.92	11.52
28	5	2	1	4.5	4	0.5	6.29	10.74	4.45	6.67	12	5.33	-0.88
29	5	2	1	15	5	10	5.79	45.53	39.74	32.35	00:46.0	12	27.74

30	5	2	1	5	3	2	1.9	6.01	4.11	4	6.04	2.04	2.07
31	5	1	2	12.5	10.5	2	20.21	43.5	20.2	23.69	37.02	13.33	6.87
32	5	1	2	9.5	4	5.5	11.25	24.66	12.30	11.43	14.08	2.65	9.65
33	5	2	1	4.5	4.5	0	7.27	10.53	3.26	6.83	10.13	3.30	-0.04
34	5	1	2	3.5	6	-2.5	6.35	N/A	N/A	4.21	N/A	N/A	N/A
35	5	2	1	19	12	7	8.08	32.07	23.99	25.49	42.84	17.35	6.64
36	5	1	2	12	5.5	6.5	7.12	15.15	8.03	3.85	12.08	8.23	-0.2
37	5	2	1	6	7	-1	10.23	21.60	11.37	13.31	20.6	7.29	4.08
38	5	1	2	8	6	2	25.63	32.27	6.64	12.39	21.42	9.03	-2.39
39	5	2	1	8	3.5	4.5	10.72	26.16	14.24	5.51	13.33	7.82	6.42
40	5	1	2	2	4	-2	6.16	N/A	N/A	2.88	N/A	N/A	N/A
41	5	1	2	4	3.5	0.5	12.41	20.62	8.21	4.89	8.46	3.57	4.64
42	5	2	1	8.5	9	-0.5	6.49	16.07	5.31	6.5	19.77	7.33	-2.02
43	5	2	1	28.5	6.5	22	11.54	1.01.93	63.97	4.47	16.98	12.51	51.46
44	5	2	1	3.5	4.5	-1	10.21	17.02	6.81	17.90	21.99	4.09	2.72
45	5	2	1	12	10	2	22.02	59.13	33.12	31.61	50.08	18.47	14.65
46	5	1	2	5.5	7	-1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
47	5	1	2	12.5	2	10.5	N/A	N/A	N/A	6.47	9.88	3.41	N/A
48	6	2	1	7	3.5	3.5	2.67	11.14	8.47	6.2	9.51	3.31	5.16
49	6	1	2	8	5.5	2.5	5.34	11.21	5.87	2.58	7.21	4.63	1.24
50	6	1	2	7	5	2	3.59	6.66	3.07	1.55	5.62	4.07	-1
51	6	2	1	4	4.5	-0.5	7.17	10.64	3.47	8.11	11.59	3.48	-0.01
52	6	1	2	5	7	-2	11.75	17.37	5.62	1.5	9.74	8.24	-2.62
53	6	2	1	5	5.5	-0.5	3.15	7.34	4.19	5.49	10.59	5.1	-0.91
54	6	1	2	9.5	5.5	4	8.61	14.83	6.22	3.45	9.08	5.63	0.59
55	6	2	1	6	5.5	0.5	10.56	14.35	3.79	16.93	22.09	5.16	-1.37
56	6	1	2	7	4	3	4.07	12.6	8.53	1	4.85	3.85	4.68
57	6	2	1	2.5	3.5	-1	3.62	6.76	3.14	5.96	8.66	2.7	0.44
58	6	1	2	4	3	1	8.39	13.6	5.21	5.54	8.46	2.92	2.29
59	6	1	2	5.5	3.5	2	10.87	16.37	5.5	8.02	10.99	2.97	2.53
60	6	2	1	5	6	-1	7.47	12.41	4.38	6.35	13.05	6.70	-2.32
61	6	2	1	4.5	4	0.5	6.16	8.76	2.60	8.81	12.58	3.77	-1.17
62	6	2	1	10	7.5	2.5	10.29	24.31	14.02	7.46	28.78	12.00	2.02
63	6	1	2	8	4.5	3.5	17.96	24.36	6.40	10.86	14.10	3.24	3.16
64	6	1	2	9.5	7	2.5	5.51	15.7	10.19	3.9	14.75	10.85	-0.66
65	6	2	1	12.5	11	1.5	19.09	33.33	14.24	35.61	56.09	17.51	-3.27
66	6	1	2	4	2.5	1.5	7.45	N/A	N/A	1.99	N/A	N/A	N/A
67	6	2	1	5.5	5	0.5	2.8	4.85	2.05	4.9	7.81	2.91	-0.86
68	6	2	1	4	3	1	5.74	8.63	2.89	10.93	13.83	2.9	-0.01
69	6	1	2	7.5	4	3.5	17.37	25.99	8.62	22.41	26.89	4.48	4.14
70	6	2	1	4.5	4	0.5	2.3	6.52	4.22	5.19	7.64	2.45	1.77
71	6	2	1	6	4	2	37.74	51.53	13.79	43.43	49.32	5.89	7.9
72	7	2	1	5	7	-2	1.95	13.21	4.56	13.59	24.12	6.99	-2.43
73	7	1	2	6	3	3	23.49	27.81	4.32	2.49	6.47	3.98	0.34
74	7	2	1	4	4.5	-0.5	4.25	7.97	3.72	6.87	11.43	4.56	-0.84
75	7	1	2	4.5	6.5	-2	5.98	8.26	2.28	5.66	11.48	5.82	-3.54
76	7	2	1	10.5	4.5	6	3.36	13.75	10.39	5.63	11.24	5.61	4.78
77	7	1	2	5	5	0	3.45	8.32	4.87	1.77	4.56	2.79	2.08
78	7	1	2	8.5	4.5	4	3.44	8.64	5.2	2.21	4.55	2.34	2.86
79	7	2	1	3	3	0	5.22	7.37	2.15	15.72	18.15	2.43	-0.28
80	7	2	1	3.5	3	0.5	2.77	7.37	4.6	6.71	11.29	4.58	0.02
81	7	1	2	3.5	4	-0.5	6.61	8.39	1.78	1.12	3.4	2.28	-0.5

82	7	1	2	9	9	0	4.35	12.71	8.36	4.63	11.75	7.12	1.24
83	7	1	2	8	4.5	3.5	2.01	7.87	4.34	2.8	6.17	3.37	0.97
84	7	2	1	5.5	9.5	-4	3.7	7.52	3.82	4.57	11.49	6.92	-3.1
85	7	1	2	9	4.5	4.5	1.51	8.05	6.54	5.01	6.99	1.98	4.56
86	7	2	1	5	6.5	-1.5	4.05	8.98	3.40	9.47	17.03	7.56	-4.16
87	7	1	2	3	4	-1	14.27	N/A	N/A	9.32	N/A	N/A	N/A
88	7	1	2	17	4.5	12.5	10.82	N/A	N/A	10.75	20.34	9.59	N/A
89	7	2	1	7	5.5	1.5	5.78	19.27	13.49	19.56	26.64	7.08	6.41
90	7	1	2	3.5	8	-4.5	5.24	N/A	N/A	4.51	27.09	15.9	N/A
91	7	1	2	6	6.5	-0.5	16.60	20.74	4.14	6.01	10.66	4.65	-0.51
92	7	2	1	8	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A
93	7	2	1	9.5	3	6.5	11.34	18.41	7.07	8.96	12.08	3.12	3.95
94	7	1	2	4	5	-1	10.51	16.68	6.17	7.99	11.48	3.49	2.68
95	7	2	1	7	4	3	7.31	11.9	4.59	10.44	15.17	4.73	-0.14
96	7	2	1	7.5	7	0.5	5.19	11.19	6	5.77	14.1	8.33	-2.33
97	7	1	2	3.5	3	0.5	10.94	14.58	3.64	8.73	10.91	2.18	1.46
98	8	2	1	5	4.5	0.5	2.32	5.12	2.8	2.54	5.66	3.12	-0.32
99	8	1	2	5.5	3.5	2	4.44	7.52	3.08	2.32	7.81	5.49	-2.41
100	8	2	1	6	2.5	3.5	4.67	8.84	4.17	2.26	4.67	2.41	1.76
101	8	1	2	3	7	-4	1.59	7.11	5.52	1.52	7.72	6.2	-0.68
102	8	2	1	4	3.5	0.5	4.8	11.68	4.55	11.11	13.55	2.44	2.11
103	8	1	2	3	3.5	-0.5	2.47	5.97	3.5	2.88	6.17	3.29	0.21
104	8	1	2	5	4	1	8.57	12	3.43	6.78	9.79	3.01	0.42
105	8	1	2	9	4.5	4.5	11.66	22.17	9.45	7.46	10.12	2.66	6.79
106	8	2	1	6	3.5	2.5	4.89	9.23	4.34	6.34	10.49	4.15	0.19
107	8	1	2	3	2	1	17.81	20.8	2.99	6.57	8.81	2.24	0.75
108	8	2	1	3.5	4.5	-1	2.68	5.17	2.49	5.19	7.61	2.42	0.07
109	8	1	2	4	3.5	0.5	8.39	13.81	5.42	10.93	13.55	2.62	2.8
110	8	2	1	2.5	3	-0.5	7.19	10.41	3.22	1.69	4.09	2.4	0.82
111	8	1	2	7	4	3	10.89	16.58	5.69	4.17	6.94	2.77	2.92
112	8	2	1	4.5	2.5	2	10.39	15.95	5.96	10.13	14.3	4.17	1.79
113	8	1	2	14	6	8	16.02	29.78	13.76	14.06	25.02	10.96	2.8
114	8	1	2	5	6.5	-1.5	11.19	16.53	5.34	12.11	16.68	4.57	0.77
115	8	2	1	5	8.5	-3.5	28:48.0	26:24.0	2.54	43:12.0	28:48.0	5.74	-3.2
116	8	2	1	8.5	4	4.5	4.12	14.26	10.14	8.69	N/A	N/A	N/A

Figure A1a

Figure A1b

Figure A1c

Figure A1. Metal anchor strap type buckle mount (Figure A1a), Cable type buckle mount **[14]** ***(Figure A1b), Webbing type buckle mount (Figure A1c).***

Figure A2a

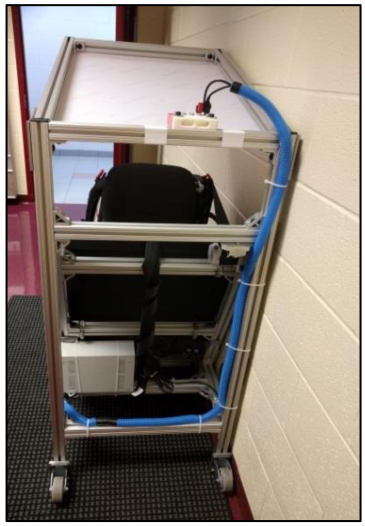


Figure A2b

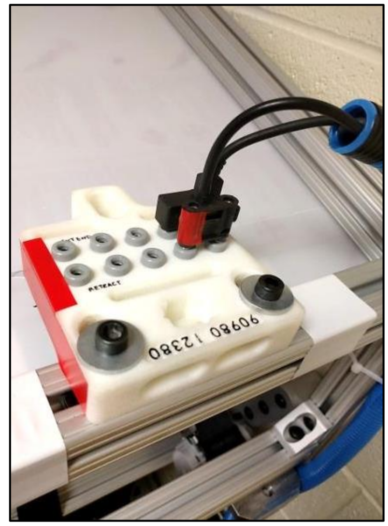


Figure A2c

Figure A2. Close-up of booster seat in the mounting fixture (Figure A2a), Rear view of mounting fixture (Figure A2b), Buckle switch (Figure A2c).

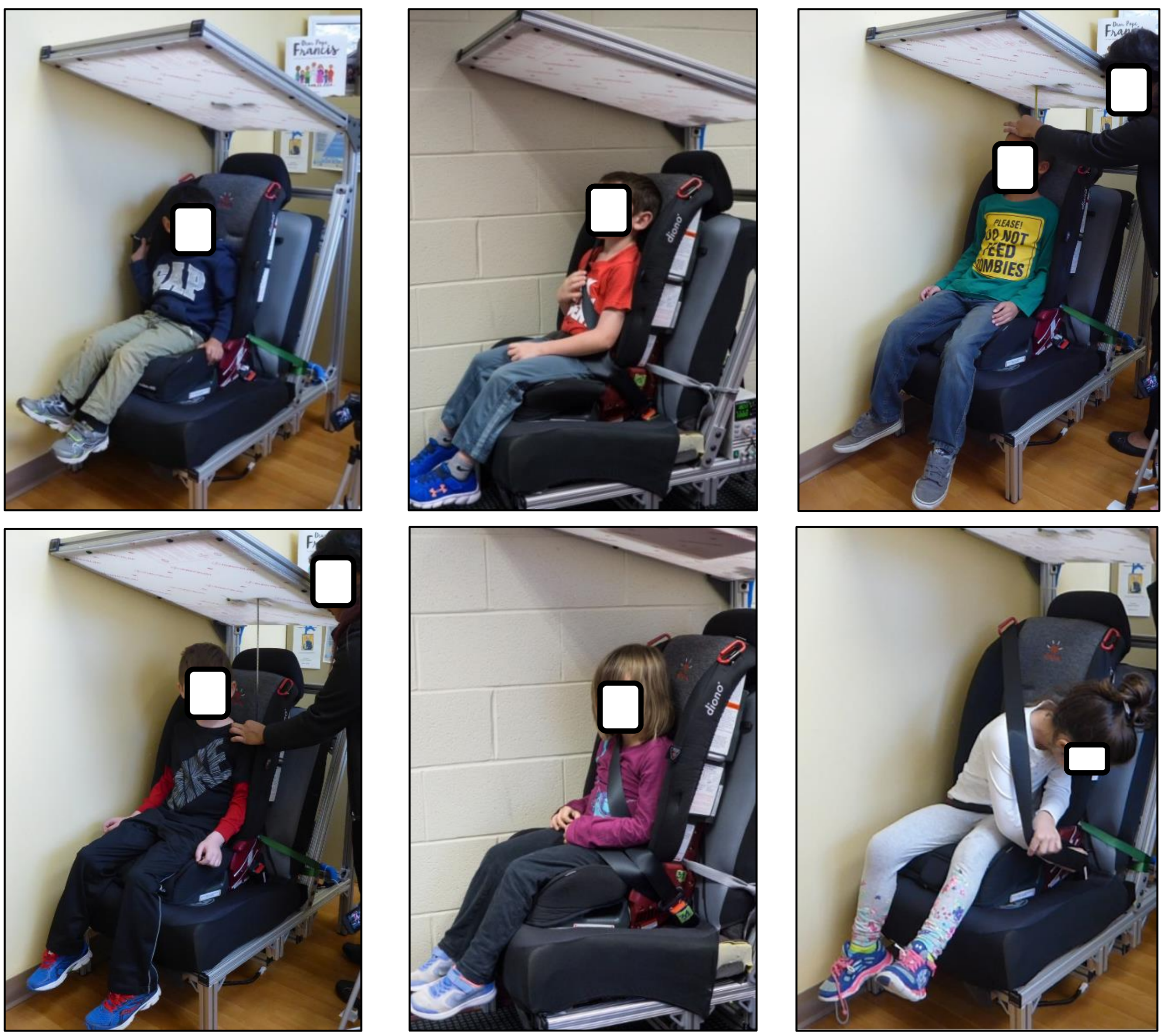


Figure A3: Participants of the Usability Study.

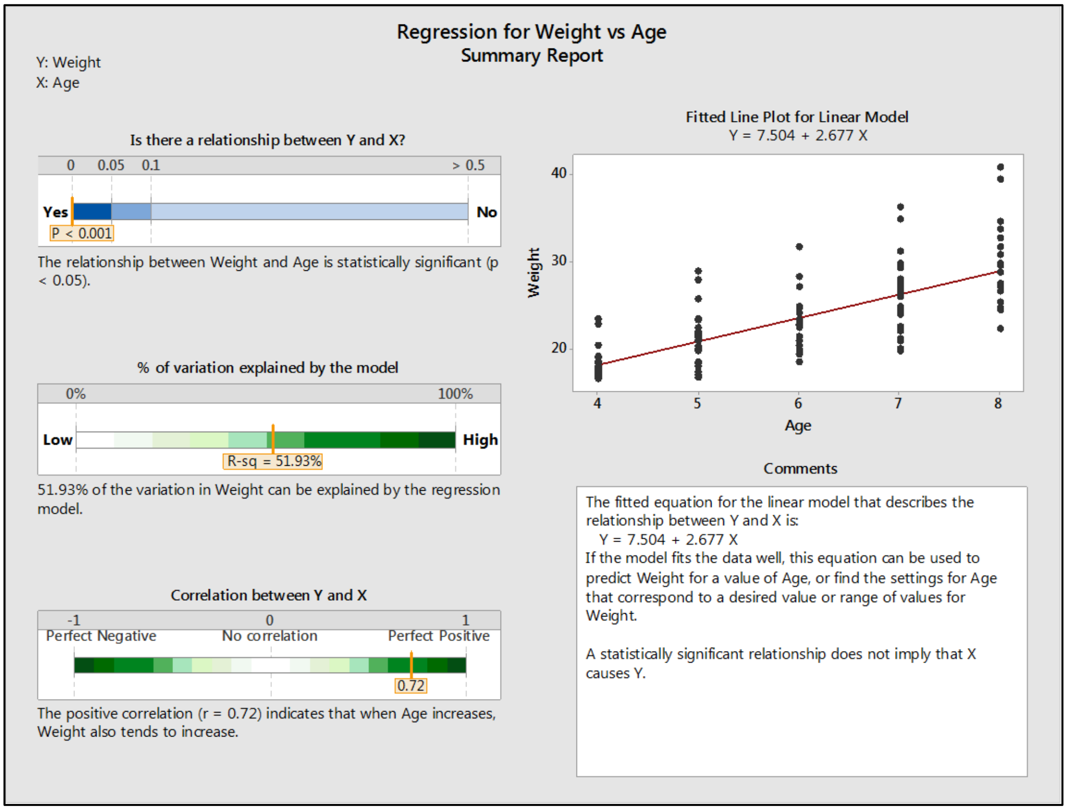


Figure A4a

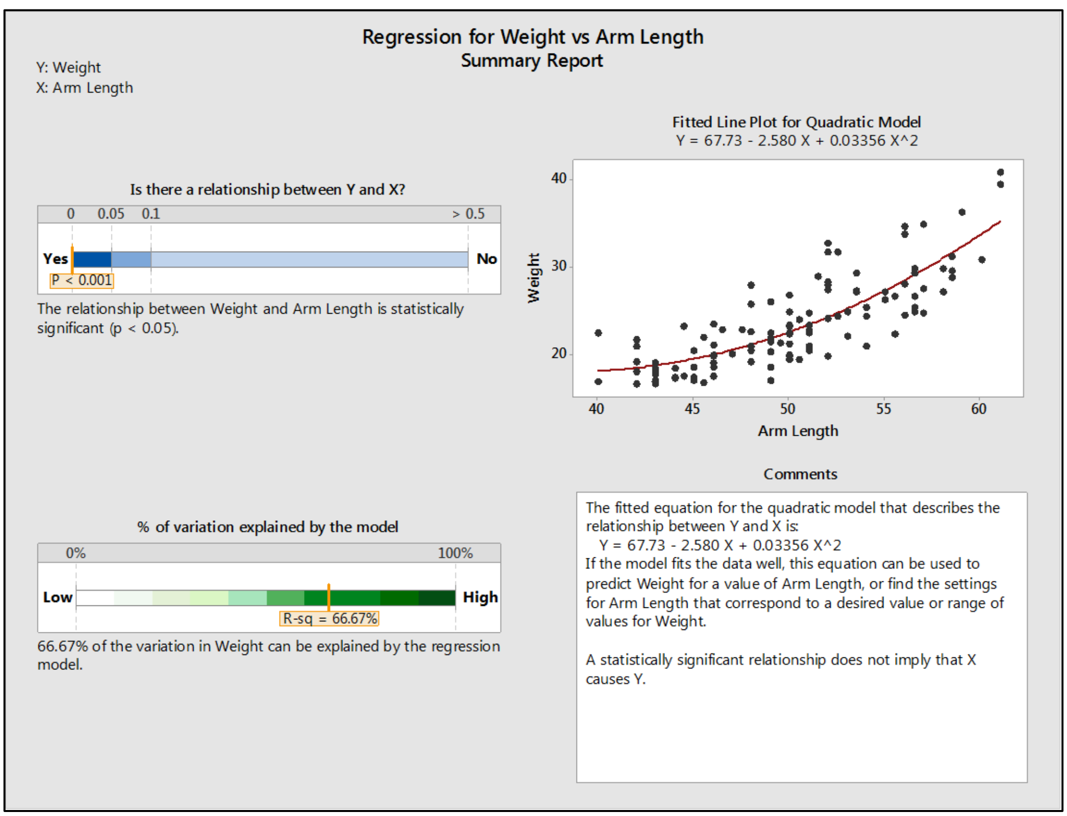


Figure A4b

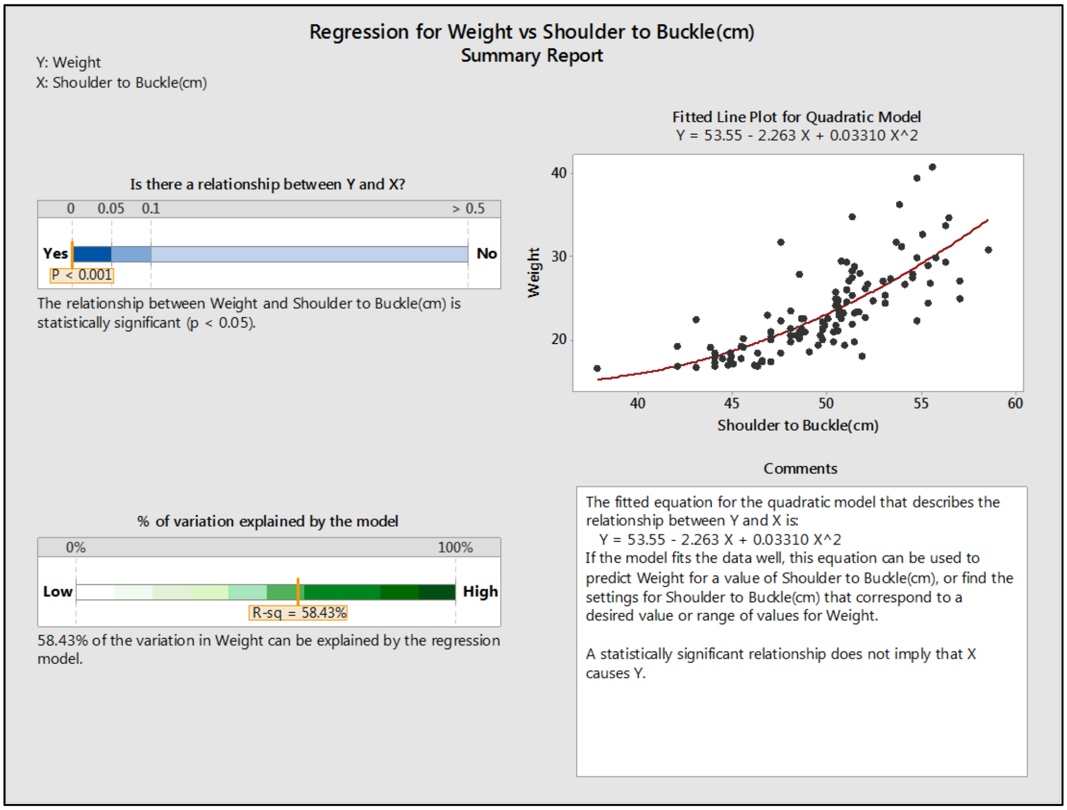


Figure A4c

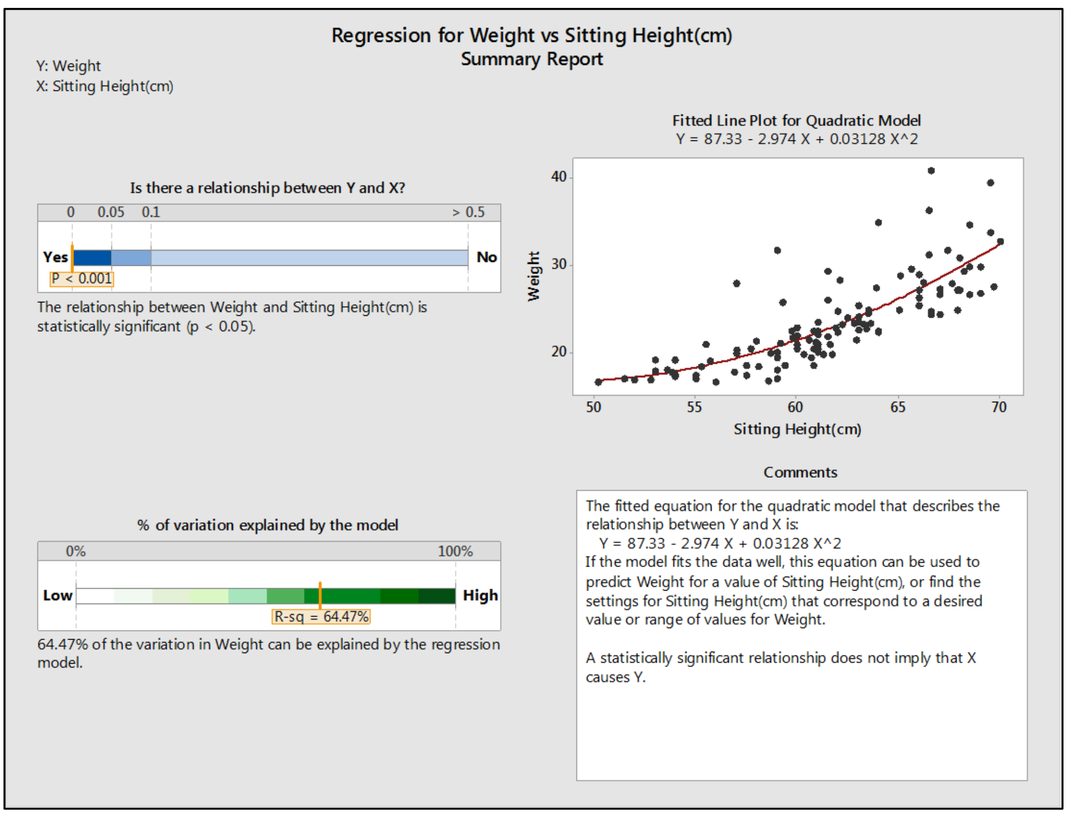


Figure A4d

Figure A4. Simple Regressions; Weight vs Age (Figure A4a), Weight vs Arm Length (Figure A4b), Weight vs Shoulder to Buckle (Figure A4c), Weight vs Sitting Height (Figure A4d).

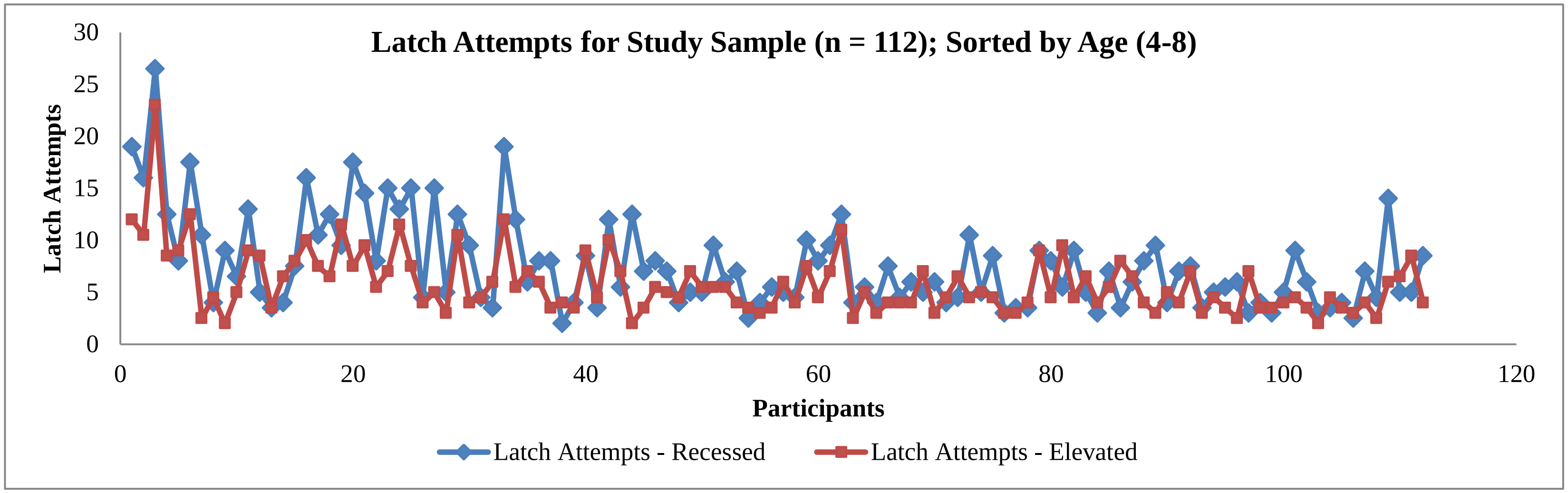


Figure A5. Graph Showing Latch Attempts for Study Sample.

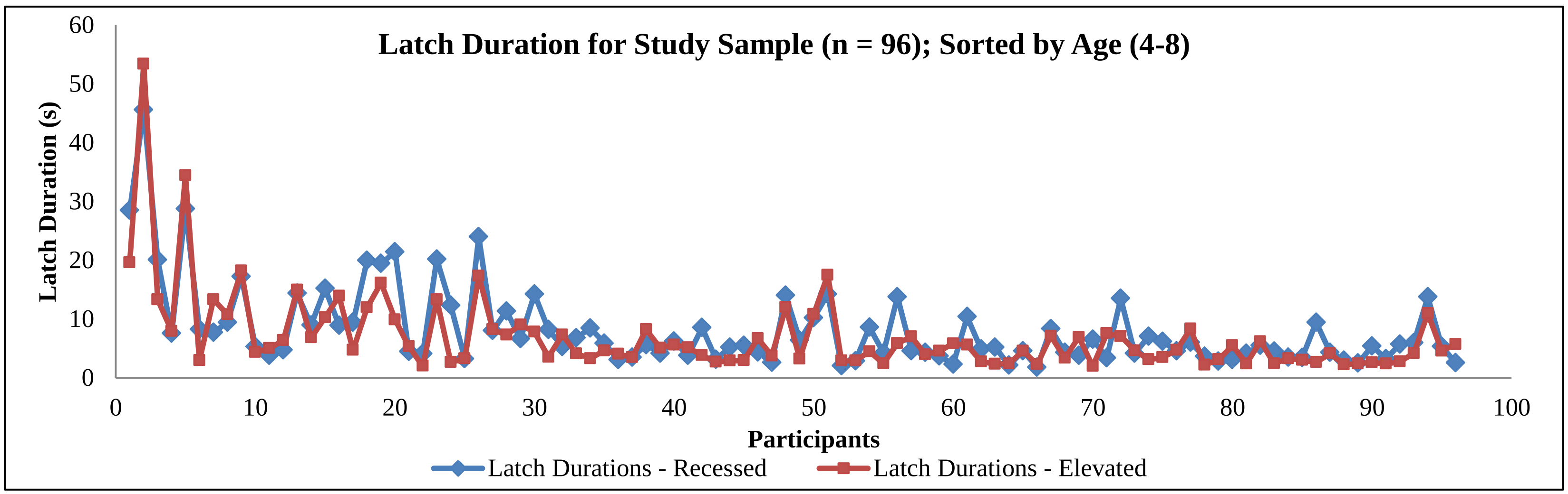


Figure A6. Graph Showing Latch Durations for Study Sample.

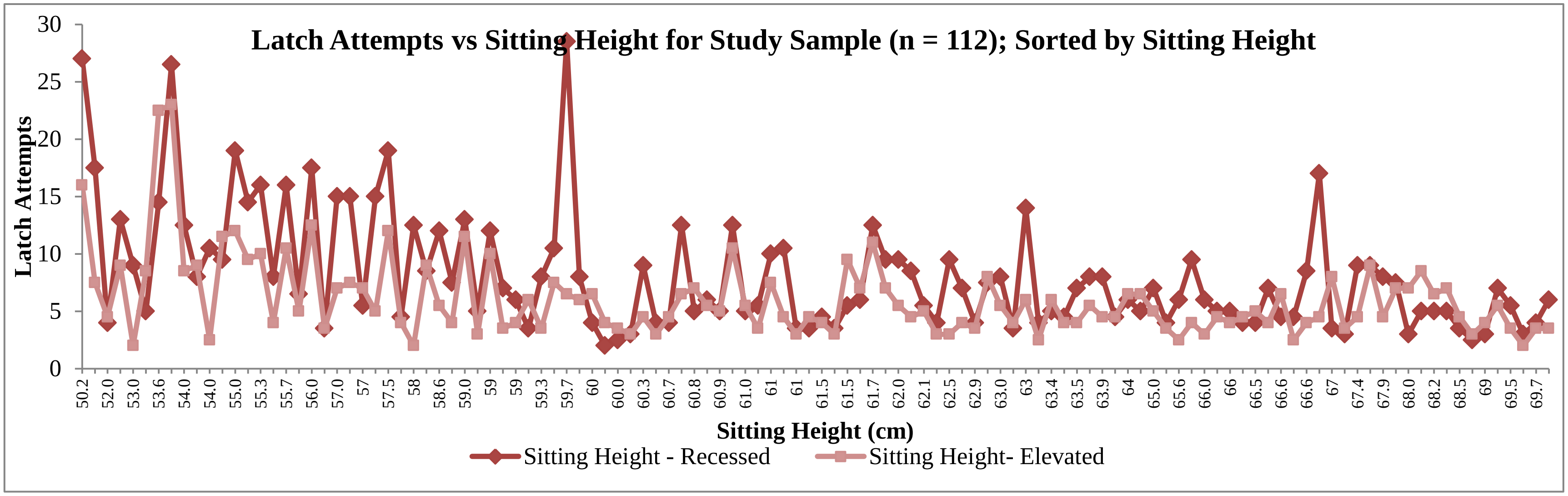


Figure A7. Graph Showing Latch Attempts vs Sitting Height for Study Sample.

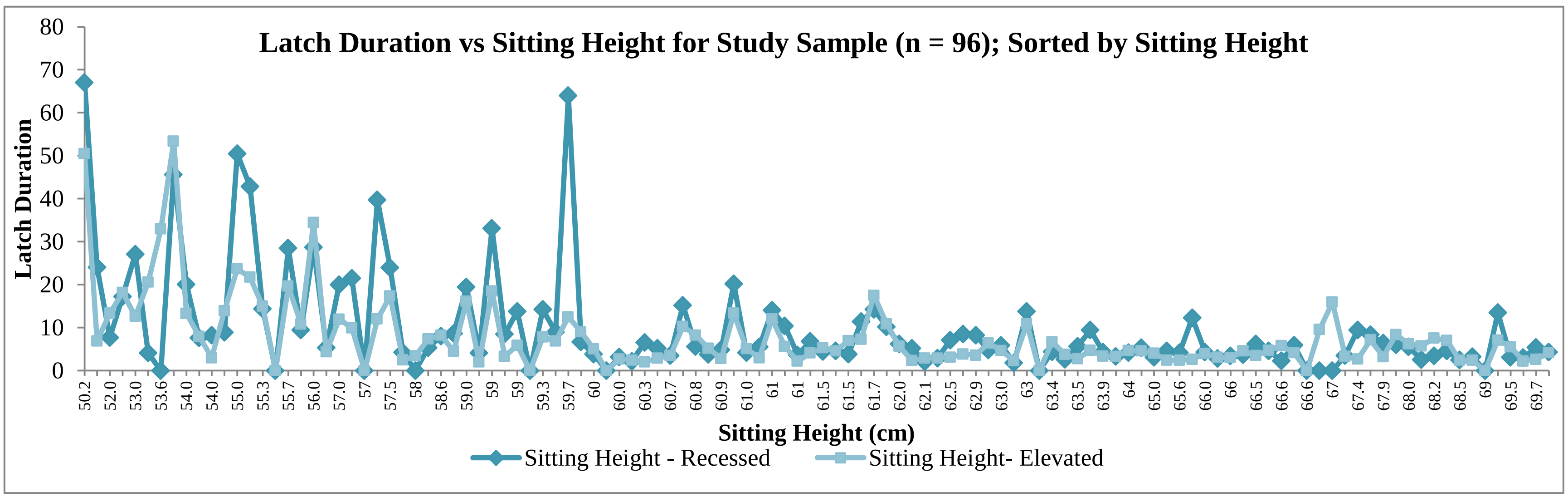


Figure A8. Graph Showing Latch Attempts vs Sitting Height for Study Sample.

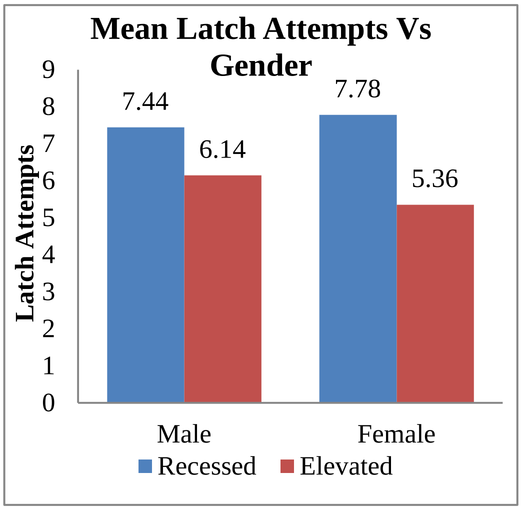


Figure A9a.

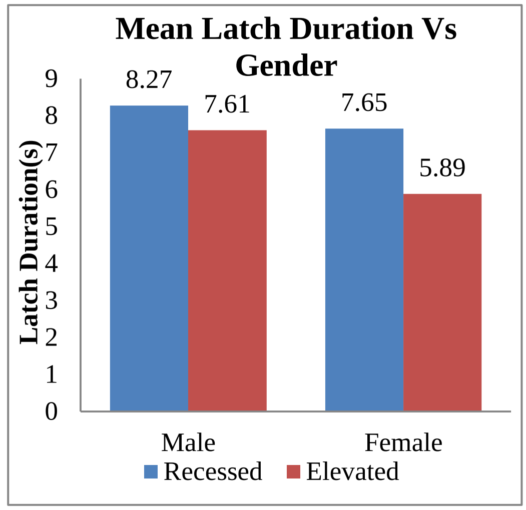


Figure A9b.

Figure A9. Graph Showing Mean Latch Attempts vs Gender (Figure A9a), Graph Showing Mean Latch Durations vs Gender (Figure A9b).

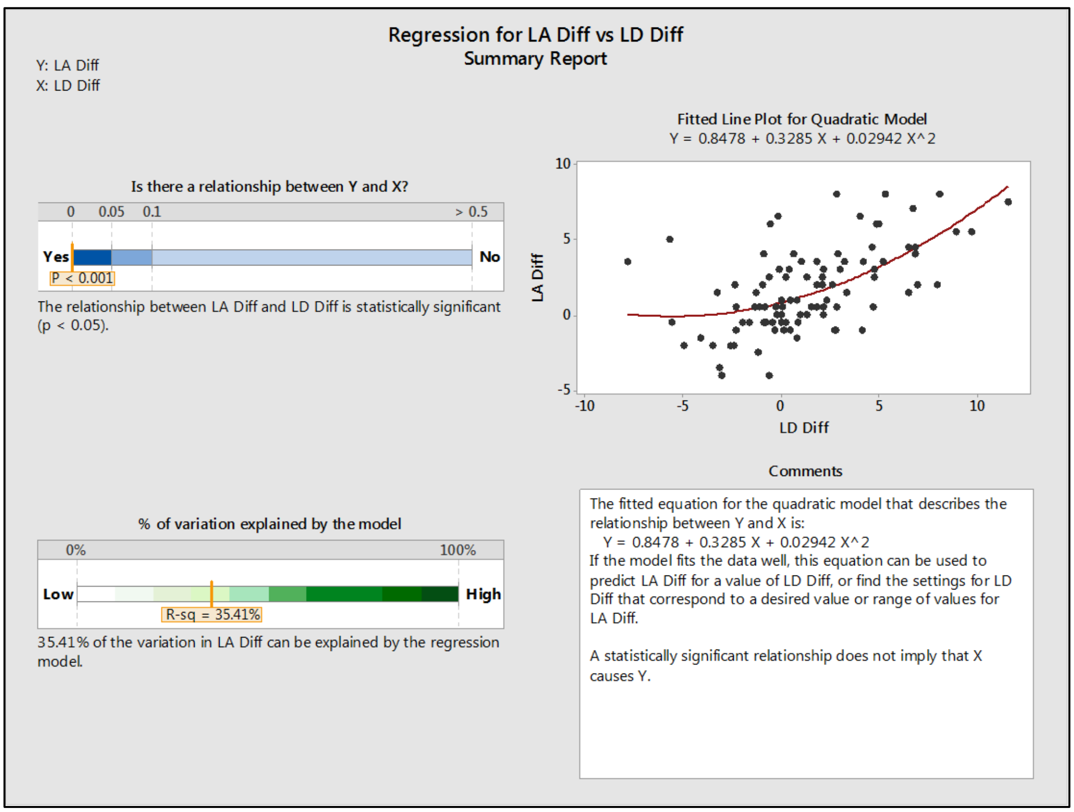
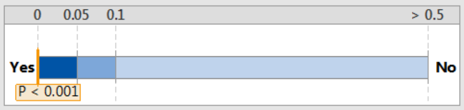


Figure A10. Simple Regression for Difference in Latch Attempts vs Difference in Latch Duration.

Paired t Test for the Mean of No of LA Rec and No of LA Ele
Summary Report

Mean Test

Is No of LA Rec greater than No of LA Ele?



The mean of No of LA Rec is significantly greater than the mean of No of LA Ele (p < 0.05).

Paired Differences

Statistics	*Paired Differences
Sample size	112
Mean	1.8304
90% CI	(1.3314, 2.3293)
Standard deviation	3.1833

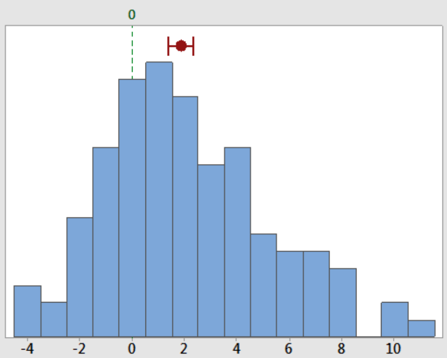
*Difference = No of LA Rec - No of LA Ele

Individual Samples

Statistics	No of LA Rec	No of LA Ele
Mean	7.6205	5.7902
Standard deviation	4.3838	3.0102

Distribution of the Differences

Where are the differences relative to zero?



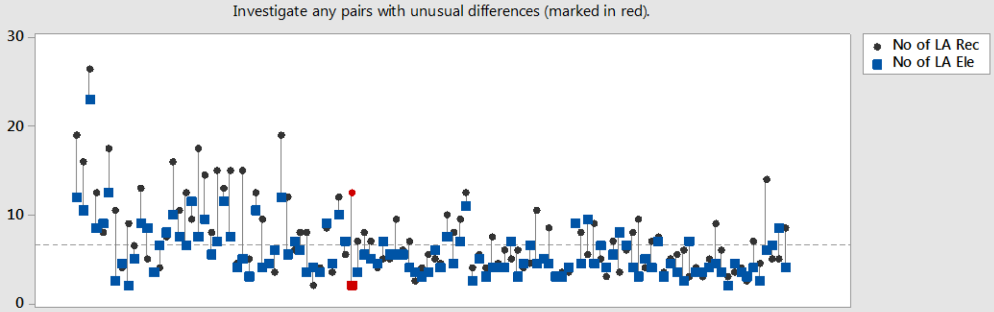
Comments

- Test: You can conclude that the mean of No of LA Rec is greater than No of LA Ele at the 0.05 level of significance. The mean of the paired differences is greater than zero.
- CI: Quantifies the uncertainty associated with estimating the mean difference from sample data. You can be 90% confident that the true mean difference is between 1.3314 and 2.3293, and 95% confident that it is greater than 1.3314.
- Distribution of Differences: Compare the location of the differences to zero. Look for unusual differences before interpreting the results of the test.

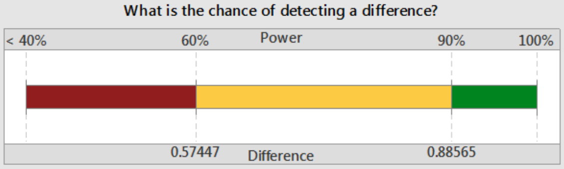
Paired t Test for the Mean of No of LA Rec and No of LA Ele
Diagnostic Report

Paired Data in Worksheet Order

Investigate any pairs with unusual differences (marked in red).



What is the chance of detecting a difference?



For α = 0.05 and sample size = 112:
If the true mean of No of LA Rec were 0.57447 greater than No of LA Ele, you would have a 60% chance of detecting the difference with a paired test. If No of LA Rec were 0.88565 greater than No of LA Ele, you would have a 90% chance.

What difference can you detect with a sample size of 112?

Difference	Power
0.57447	60%
0.65650	70%
0.75251	80%
0.88565	90%

Observed difference = 1.8304

Power is a function of the sample size and the standard deviation. To detect smaller differences, consider increasing the sample size.

Figure A11.Paired t Test for OVERALL Sample – Latch Attempts.

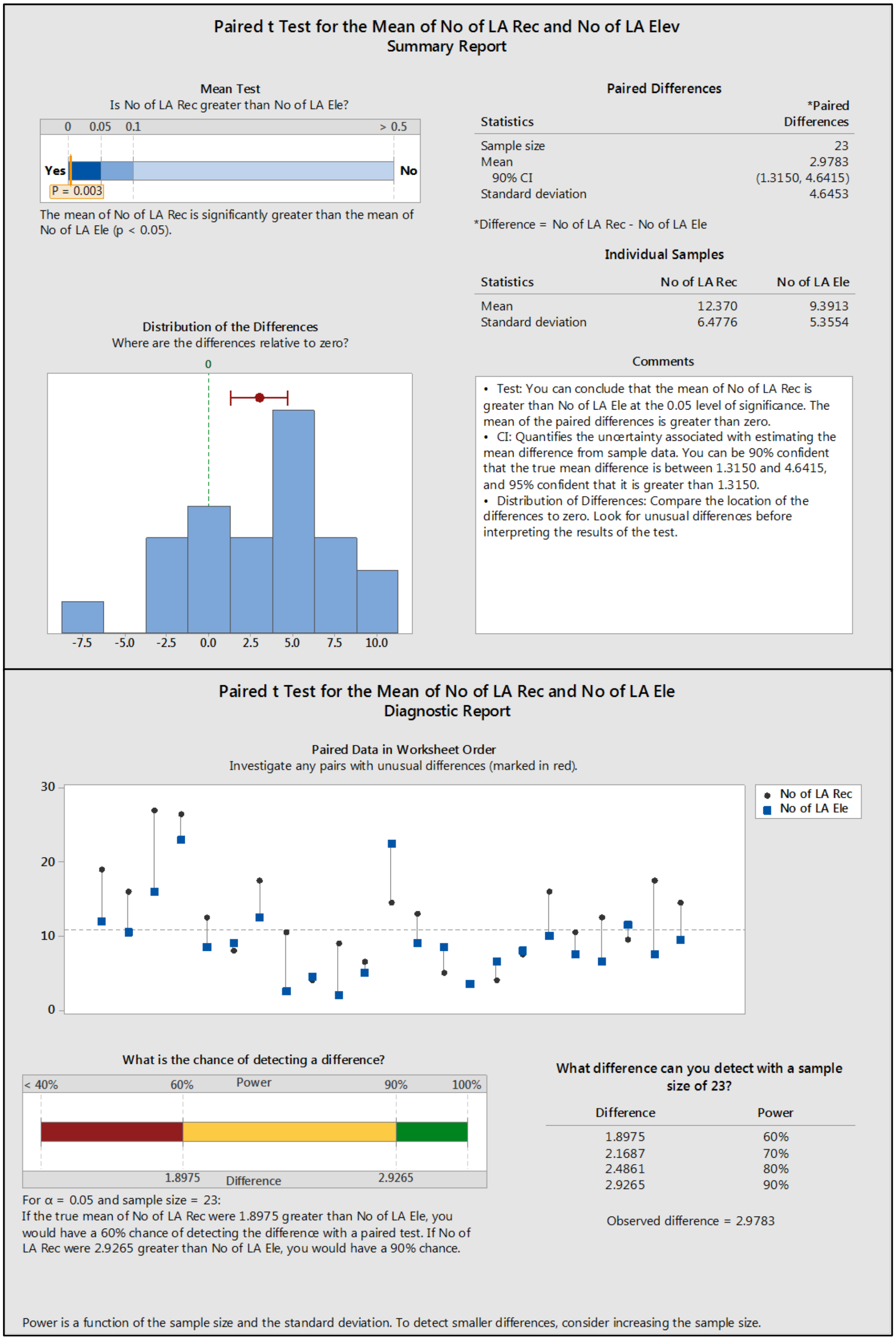


Figure A12.Paired t Test for Age 4 Sample – Latch Attempts.

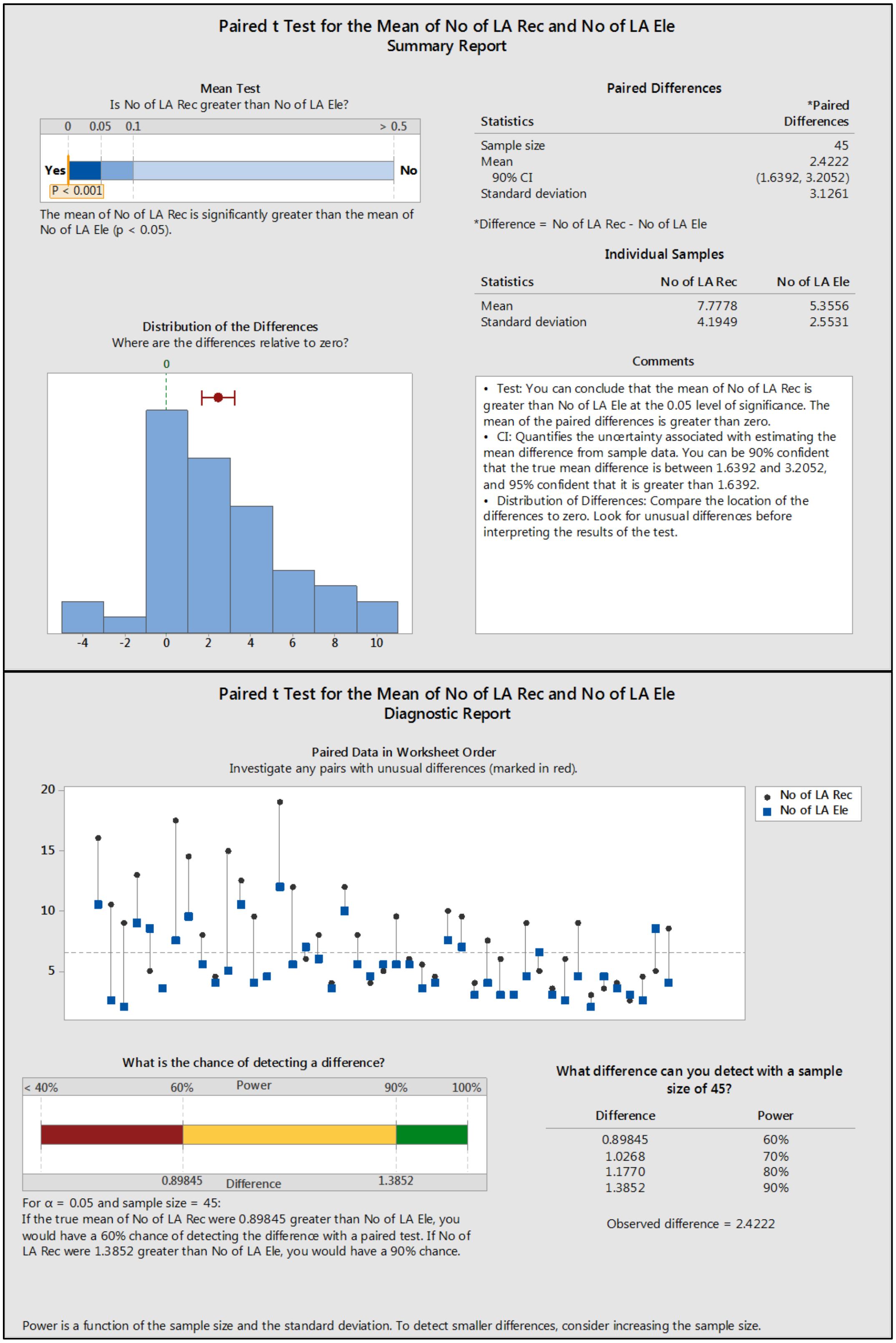


Figure A13.Paired t Test for Female Sample – Latch Attempts.

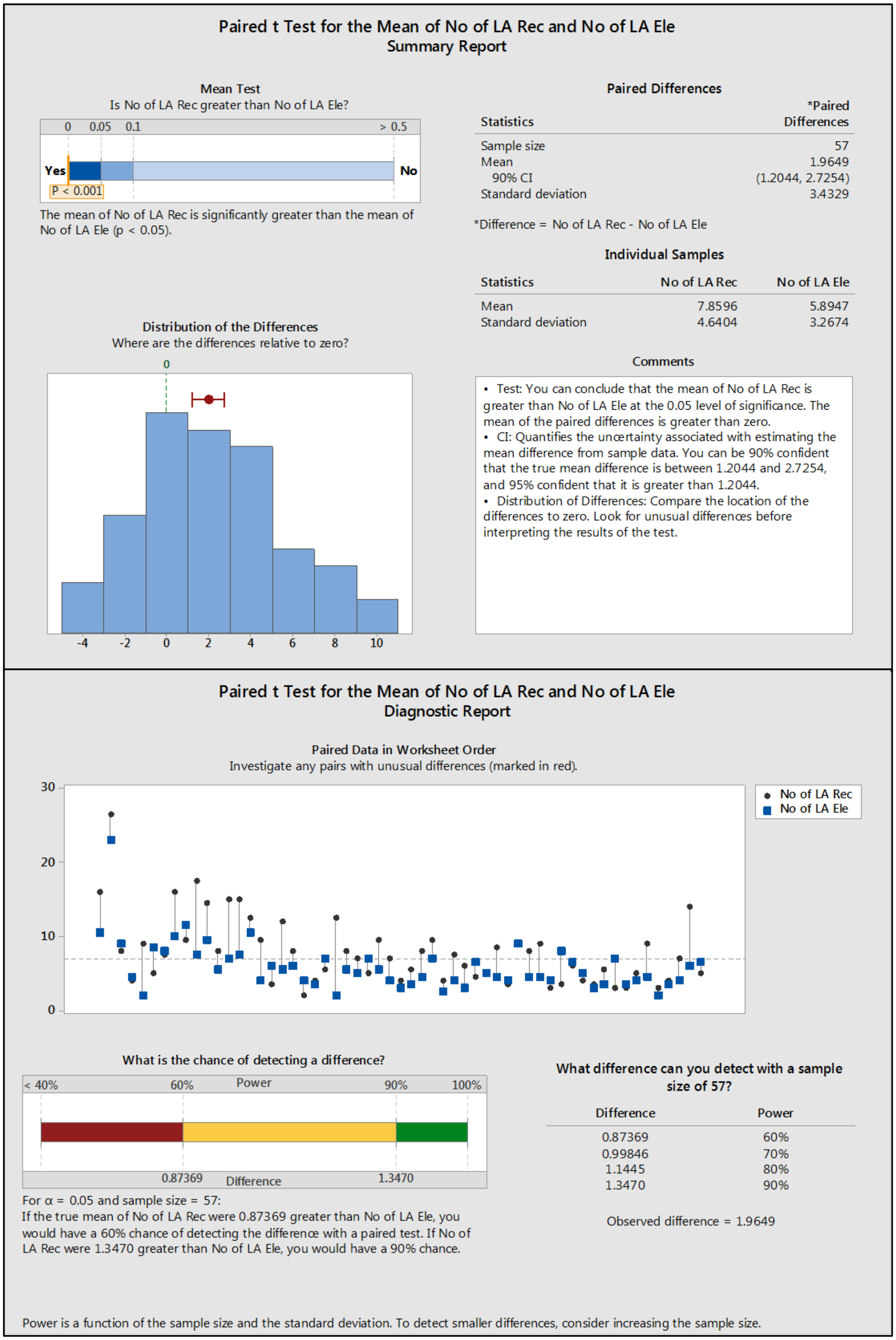
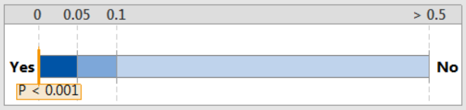


Figure A14. Paired t Test for Recessed Mode First – Latch Attempts.

Paired t Test for the Mean of LD Rec and LD Elev
Summary Report

Mean Test
Is LD Rec greater than LD Elev?



The mean of LD Rec is significantly greater than the mean of LD Elev ($p < 0.05$).

Paired Differences

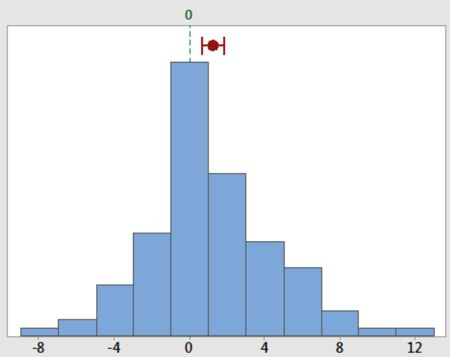
Statistics	*Paired Differences
Sample size	96
Mean	1.2133
90% CI	(0.61606, 1.8106)
Standard deviation	3.5231

*Difference = LD Rec - LD Elev

Individual Samples

Statistics	LD Rec	LD Elev
Mean	8.1642	6.9508
Standard deviation	6.9607	6.9575

Distribution of the Differences
Where are the differences relative to zero?

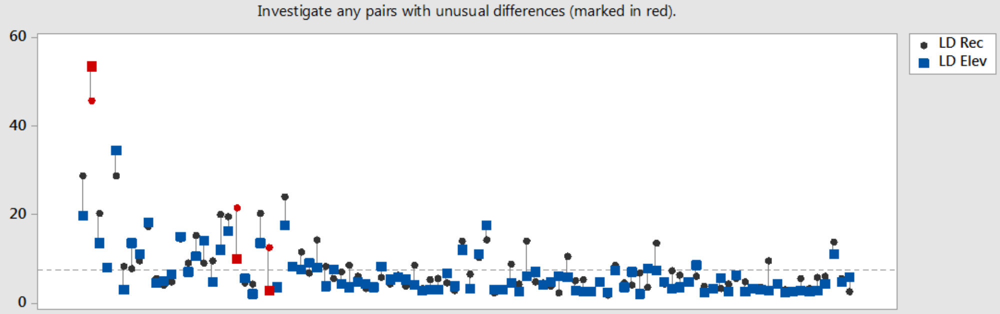


Comments

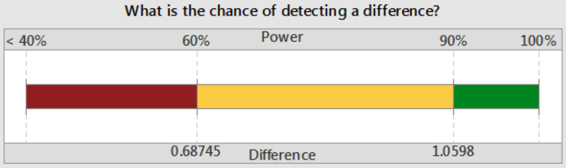
- Test: You can conclude that the mean of LD Rec is greater than LD Elev at the 0.05 level of significance. The mean of the paired differences is greater than zero.
- CI: Quantifies the uncertainty associated with estimating the mean difference from sample data. You can be 90% confident that the true mean difference is between 0.61606 and 1.8106, and 95% confident that it is greater than 0.61606.
- Distribution of Differences: Compare the location of the differences to zero. Look for unusual differences before interpreting the results of the test.

Paired t Test for the Mean of LD Rec and LD Elev
Diagnostic Report

Paired Data in Worksheet Order
Investigate any pairs with unusual differences (marked in red).



What is the chance of detecting a difference?



For α = 0.05 and sample size = 96:
If the true mean of LD Rec were 0.68745 greater than LD Elev, you would have a 60% chance of detecting the difference with a paired test. If LD Rec were 1.0598 greater than LD Elev, you would have a 90% chance.

What difference can you detect with a sample size of 96?

Difference	Power
0.68745	60%
0.78562	70%
0.90051	80%
1.0598	90%

Observed difference = 1.2133

Power is a function of the sample size and the standard deviation. To detect smaller differences, consider increasing the sample size.

Figure A15.Paired t Test for OVERALL Sample – Latch Duration.

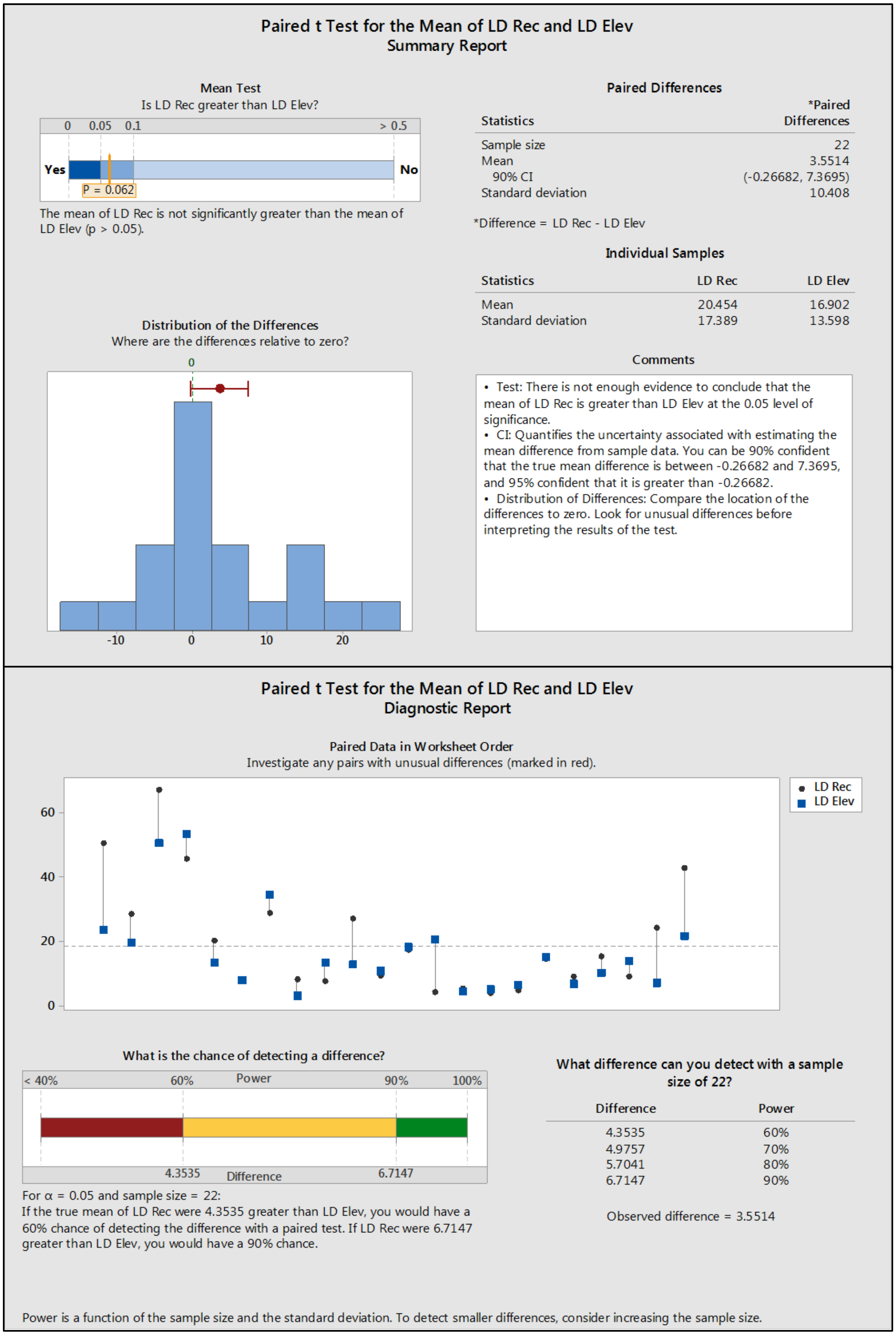
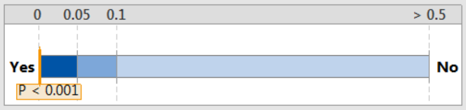


Figure A16. Paired t Test for Age 4 Sample – Latch Duration.

Paired t Test for the Mean of LD Rec and LD Elev
Summary Report

Mean Test
Is LD Rec greater than LD Elev?



The mean of LD Rec is significantly greater than the mean of LD Elev (p < 0.05).

Paired Differences

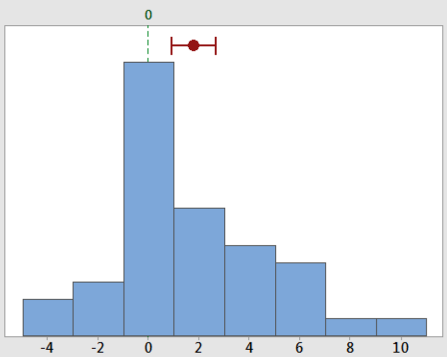
Statistics	*Paired Differences
Sample size	38
Mean	1.765
90% CI	(0.87989, 2.6501)
Standard deviation	3.2341

*Difference = LD Rec - LD Elev

Individual Samples

Statistics	LD Rec	LD Elev
Mean	7.6518	5.8868
Standard deviation	6.0856	4.6352

Distribution of the Differences
Where are the differences relative to zero?

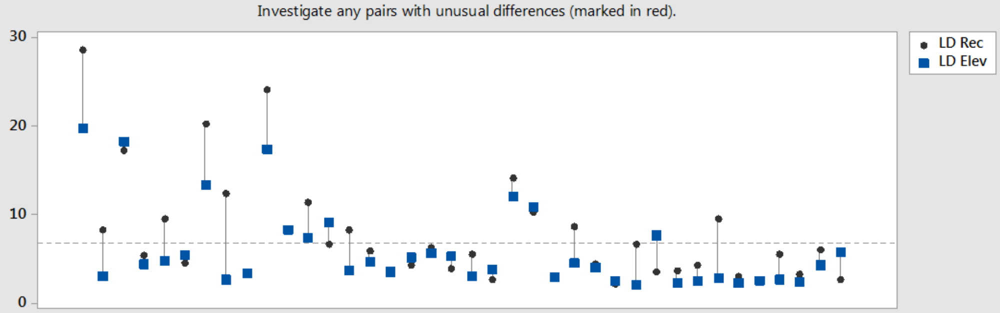


Comments

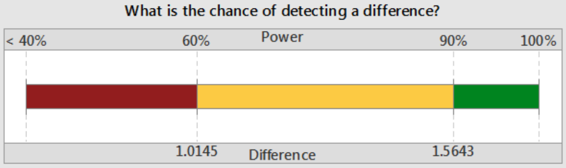
- Test: You can conclude that the mean of LD Rec is greater than LD Elev at the 0.05 level of significance. The mean of the paired differences is greater than zero.
- CI: Quantifies the uncertainty associated with estimating the mean difference from sample data. You can be 90% confident that the true mean difference is between 0.87989 and 2.6501, and 95% confident that it is greater than 0.87989.
- Distribution of Differences: Compare the location of the differences to zero. Look for unusual differences before interpreting the results of the test.

Paired t Test for the Mean of LD Rec and LD Elev
Diagnostic Report

Paired Data in Worksheet Order
Investigate any pairs with unusual differences (marked in red).



What is the chance of detecting a difference?



For α = 0.05 and sample size = 38:
If the true mean of LD Rec were 1.0145 greater than LD Elev, you would have a 60% chance of detecting the difference with a paired test. If LD Rec were 1.5643 greater than LD Elev, you would have a 90% chance.

What difference can you detect with a sample size of 38?

Difference	Power
1.0145	60%
1.1594	70%
1.3290	80%
1.5643	90%

Observed difference = 1.765

Power is a function of the sample size and the standard deviation. To detect smaller differences, consider increasing the sample size.

Figure A17.Paired t Test for Female Sample – Latch Duration.

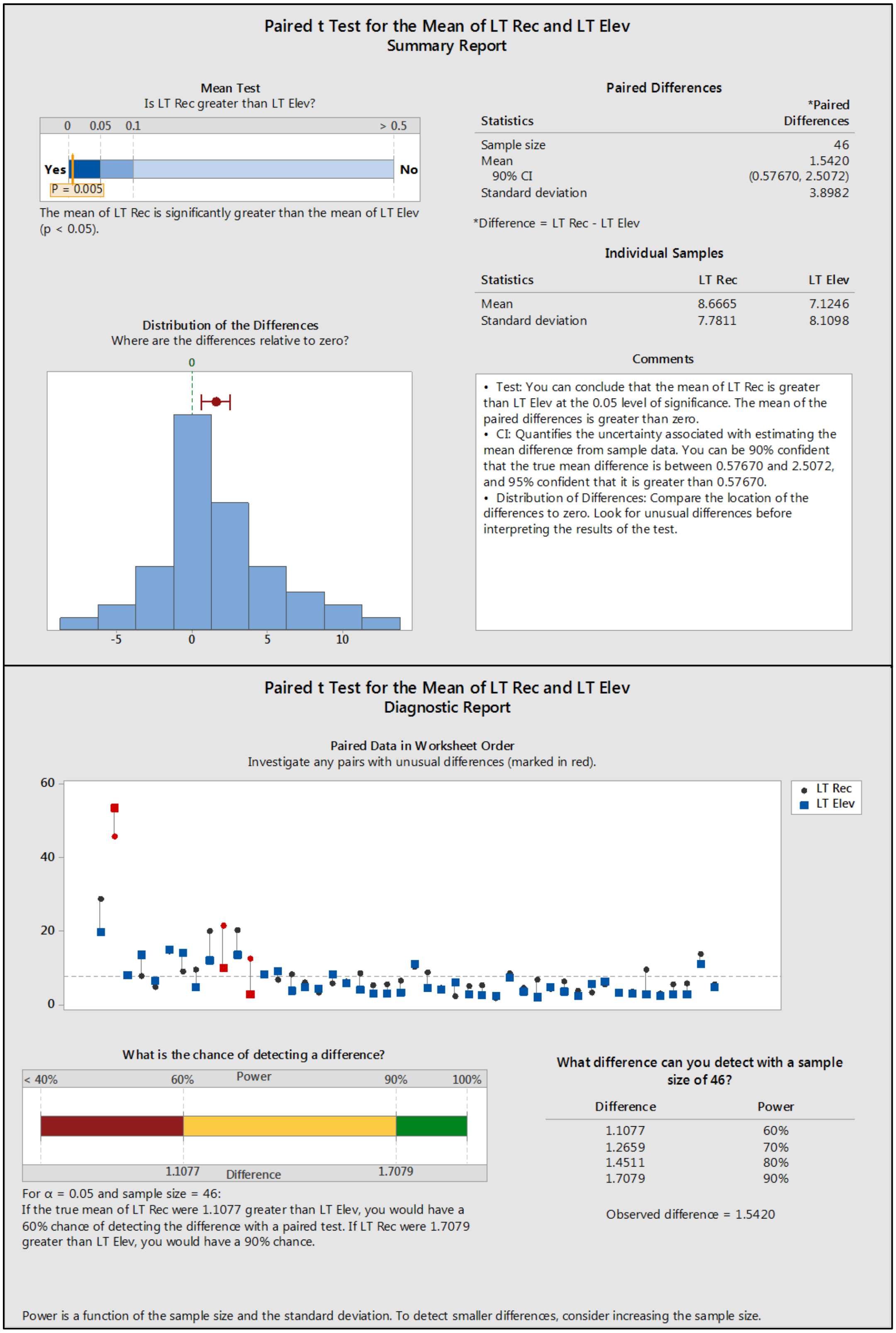


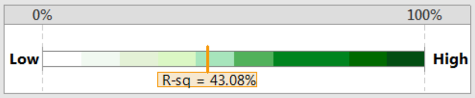
Figure A18.Paired t Test for Recessed Mode First – Latch Duration.

Multiple Regression for No of LA Ele
Summary Report

Is there a relationship between Y and the X variables?

The relationship between Y and the X variables in the model is statistically significant (p < 0.10).

% of variation explained by the model



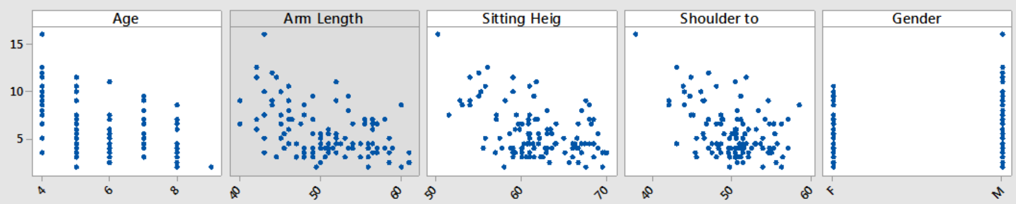
43.08% of the variation in Y can be explained by the regression model.

Comments

The following terms are in the fitted equation that models the relationship between Y and the X variables:
X1: Age
X3: Sitting Height
X4: Shoulder to Buckle
X5: Gender
X3*X4

If the model fits the data well, this equation can be used to predict No of LA Ele for specific values of the X variables, or find the settings for the X variables that correspond to a desired value or range of values for No of LA Ele.

No of LA Ele vs X Variables



A gray background represents an X variable not in the model.

Multiple Regression for No of LA Ele
Model Equations Report

X1: Age X2: Arm Length X3: Sitting Heig X4: Shoulder to X5: Gender

Gender			Final Equations
F	No of LA Elev	=	158.3 - 0.757 X1 - 2.397 X3 - 2.925 X4 + 0.04698 X3*X4
M	No of LA Elev	=	159.1 - 0.757 X1 - 2.397 X3 - 2.925 X4 + 0.04698 X3*X4

Figure A19. Regression Analysis for Latch Attempts – Elevated.

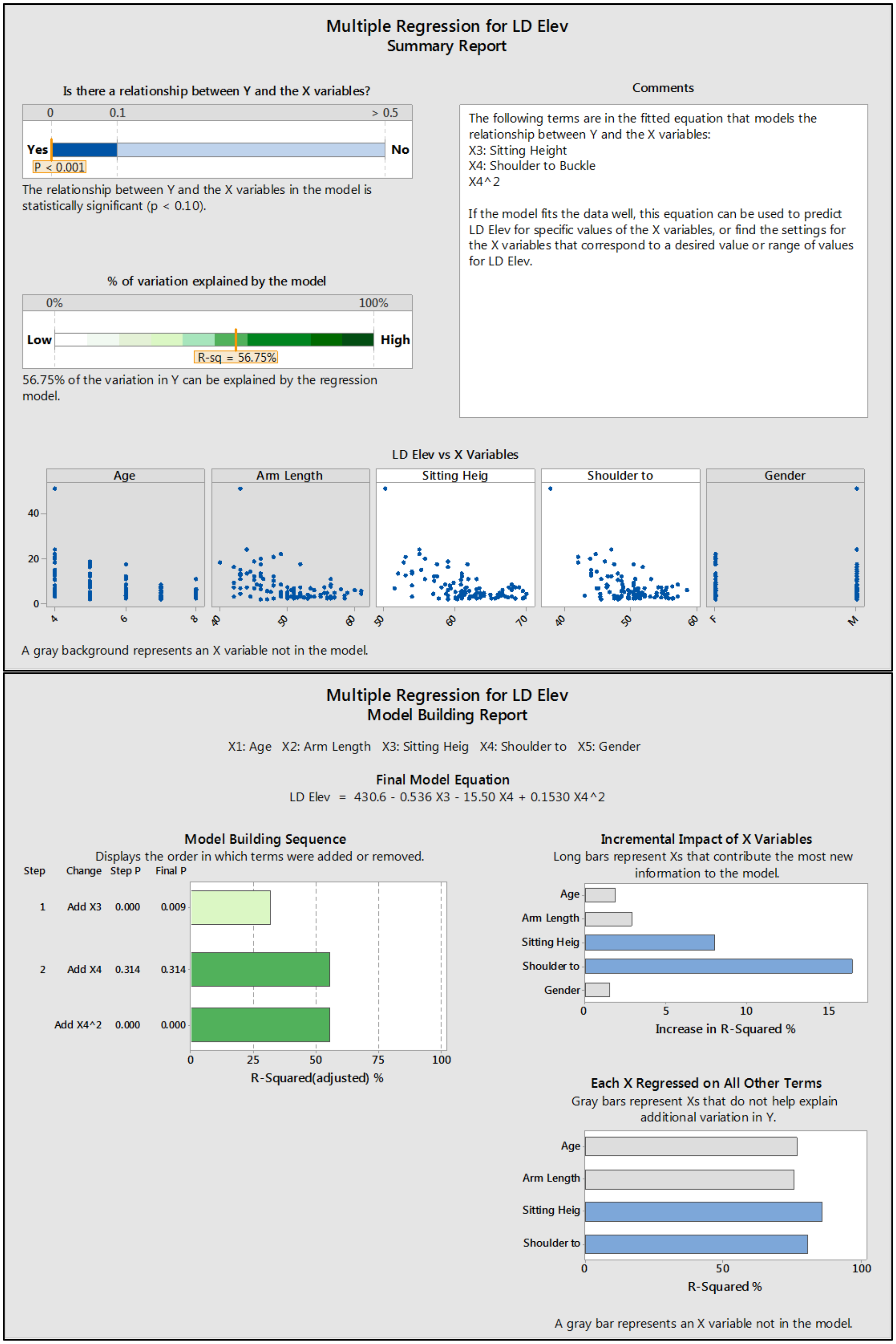


Figure A20. Regression Analysis for Latch Duration – Elevated.