Proof of Concept: Analyzing the Structure and Durability of an Autonomy-Supportive Skiing Aid

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Abstract

This study sought to assess the strength and durability of a novelly designed Autonomy Supportive Skiing Aid (ASSA). This innovation was created to address the challenge of maneuverability with a common children's ski learning aid, the Edgie Wedgie (EW). The innovation was designed using computer aided design (CAD) and was additively manufactured. Prior to testing, benchmarks were established to ensure the ASSA meets the standards of strength and resilience established by the EW. Tensile and cyclic fatigue testing were conducted to evaluate the product's response to varying amounts of load applied. Both tensile and fatigue testing were conducted over a range of temperatures, simulating authentic winter conditions. Several trials were conducted for each product, at each temperature. The change in length of the product before and after testing was assessed to determine the product's degradation after exposure to varying loads. Statistical analysis using a 2-Sample t-Test determined the difference in degradation between the ASSA and EW across the multiple tests to be insignificant. This indicates comparable trends in performance and degradation between the products compared. The novel ASSA device was shown to be non-inferior to the EW benchmark, allowing for progression to future second phase studies involving human participants. This future study will evaluate the effect of this novel device on its users' perceived autonomy and enjoyment while learning to ski. If proven effective, this novel innovation would help reduce the barrier to sport participation among children.

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Introduction

Participation in sports is an activity that has tremendous positive impacts on one's health, mood, personality, and more, especially in young children. Studies have proven a correlation between adolescent participation in sport and "positive psychological and social outcomes" such as greater social skills, self-esteem, and even less depression leading to lower rates of suicide (Eime et al., 2013). Participation in youth sports also is correlated with greater levels of physical activity later in life (Malm et al., 2019). Unfortunately, research by the American Academy of Pediatrics has shown that about 70% of these youth participants in sports will drop out by the time they turn 13 years old (Brenner et al., 2024). According to further research by Crance and Temple, there are five major factors associated with youth sport dropout. 2 of which are "lack of enjoyment" and "perceptions of competence" (Crane & Temple, 2014). 70% of adolescents who choose to stop participating in sports will potentially miss out on numerous internal and external benefits. By targeting these two issues (lack of enjoyment and perception of competence), children would theoretically be more inclined to stick with a sport and reap the many benefits.

To reduce the barrier of learning a sport for children, special modified sporting equipment has been situationally utilized. Research conducted by Brocken found that in 7–9-year-old children learning to play field hockey, the use of a modified training ball resulted in greater performance improvement than the group using the traditional field hockey ball (Brocken et al., 2020). Previous research has established that when the basic psychological needs (BPN) in sports are satisfied, greater self-motivation and engagement in sports participation occurs (Francisco et al., 2018; Álvarez et al., 2009). BPN is a component of the self-determination theory, outlining the 3 necessities for psychological wellbeing. They are perception of autonomy, competence, and relatedness. Research has shown that satisfaction of these needs even leads to “more satisfying learning experiences” (Hui & Tsang, 2012). Adaptive sport equipment for children primarily targets fostering autonomy and competence by empowering the child to complete a certain task and developing their skill in that task.

Statement of Purpose

Currently on the market, there is a product called the Edgie Wedgie (EW) which is a connector that adjoins the tips of a beginner’s skis. This simple connector encourages skis to stay in the correct alignment, preventing skis from separating too far and causing beginner skiers to repeatedly fall on the ski mountain. For many, this ski aid provides beginners with a tool to achieve more rapid success and helps minimize a barrier on the way to enjoying a life-long sport. Often this product is the difference between learning to ski in a couple weeks as opposed to a couple months or longer. A potential drawback to this device is that when a child reaches the bottom of the trail or a plateau, their skis are adjoined, and mobility becomes inhibited. The freedom just accrued from using this device coming down the mountain is immediately diminished until a parent or adult can come free the child from the rigid connector. Within this problem, an opportunity exists. Needing to rely on an adult to manipulate the device at the end of every run potentially reduces the user’s perception of autonomy and competence. Especially for a child, the action of executing and practicing a new skill, like skiing, without direct supervision by parents engenders an important feeling of independence. This is the same reason children love riding bikes. In that moment getting repeatedly on and off their bike, the child can think and act for themselves and become no longer reliant on their parents for growing their own budding autonomy. For these reasons, the ability to feel independent and capable are important qualities that could potentially make children happier and more engaged in activities they participate in. Developing a novel innovation on this device that addresses this challenge of maneuverability and lack of autonomy by incorporating a quick-release spring loaded mechanism, may foster this greater perception of autonomy and enjoyment when learning to ski.

The novel innovation was conceived of, modified, and improved in the first phase of this 2-phase study. In the second phase of this study, the psychological effects mentioned will be investigated, evaluating whether the users' sense of autonomy improves using this novel Autonomy Supportive Skiing Aid (ASSA). Prior to bringing this novel device forward to human testing, the ASSA device must be proven to be strong and durable enough for real-world use. In this first phase of the study, structural analysis of ASSA was performed, assessing the device's viability through laboratory tensile and fatigue testing. The purpose of the study was to prove that this novel ASSA device meets the standards of strength and durability established by the original product, the Edgie Wedgie.

Methods and Materials

Product Design

Product design was conducted using Fusion 360, Autodesk, Inc. (San Francisco, CA) a commercial computer-aided design software application. Approximately 19 different product iterations were produced during the prototyping process. Each successive prototype introduced modifications such as implementing springs, adjusting dimensional tolerances, and expanding functionality. Mimicking but not replicating the original product, a similar surgical tubing (Grafco) was selected (Graham-Field, Atlanta, GA). The compression springs (Part #9657KS42) selected were obtained through McMaster-Carr (Elmhurst, IL). Design feedback was provided by SpaceX mechanical engineer Becca Sung.

Manufacturing

Based on discussions with engineers at ITS (Innovative Test Solutions, Schenectady, NY), a test matrix (see Appendix A) was constructed for tensile and cyclic fatigue testing, based on attaining sufficient sample quantities for both the EW control and the novelly engineered Autonomy Supportive Skiing Aid (ASSA) samples. The products were produced in the home setting through additive manufacturing (3D printing) and were assembled manually. The Creality (Shenzhen, China) Ender 3 V2 was utilized for producing the plastic components. Prusa Research (Prague, Czech Republic) Prusament's Polycarbonate (PC) Blend was used. This filament was selected for its strength and resilience.

Benchmark Testing

Several benchmarks needed to be established before conducting mechanical testing on the ASSA. All tests to be conducted on the ASSA were also conducted on the original Edgie Wedgie product to provide a standard of acceptable product strength. The Edgie Wedgie's used were obtained from Ski Teaching Products LLC. Preliminary stretch tests were conducted for both products to determine the maximum possible displacement in normal use. Each product was attached to the skis and a 140 lb., 5' 10" individual stretched the skis to a maximum distance. The participant chosen for displacement testing was intentionally larger and stronger than the typical product demographic to determine an upper limit for testing of the displacement the ASSA device would be required to withstand.

Tensile Testing

To evaluate the sheer strength of both the ASSA and control EW, tensile testing was performed. To simulate winter weather conditions where the products would be used, tensile testing was carried out over different temperature ranges. The ASSA was tested at -30°C, -5°C,

& 20°C. Testing temperature was controlled by infusion of nitrogen into the testing environment. The EW was tested at -5°C. The ASSA was tested at temperature extremes to identify any tensile limitations at the boundaries of the product in a simulated winter environment. Three trials were conducted at each temperature. The testing process was conducted at ITS. Testing was facilitated by the trained engineers to ensure the safety of the testing. The machine used for all testing was a MTS 5 kip servo-Hydraulic Test Frame equipped with a Tovey Fatigue Rated Load Cell and a SenTech embedded linear variable differential transformer (LVDT) (see Appendix B, Figure B1) During testing, both the ASSA and EW products were attached to a piece of a ski which was fixtured to the testing machine (see Appendix B), allowing for evaluation of the entire device, including the screw connection between the device and the ski. The force and displacement data were outputted to the MTS Systems Corporation (Eden Prairie, MN) Series 793 software for analysis.

High Cycle Fatigue Testing

To evaluate long-term product durability, fatigue testing was performed. Both ASSA and EW products were tested using the same machinery and software, and under the same conditions as the tensile testing. Instead of a single cycle, however, the products were exposed to 600 repeated cycles, simulating the repeated load the product may exhibit over the lifespan of the product. This 600-cycle benchmark was chosen based on the products target demographic and predicted average number of trails skied in the product lifespan.

Statistical Analysis

All Statistical analyses were conducted using a Texas Instruments (Dallas, TX) TI-84 Plus CE Graphing Calculator. In tensile testing 8 of the 9 ASSA and 3 of the 3 EW devices held up for testing. The one ASSA device had the rubber tubing slip off and data collection could not be completed. For fatigue testing all 9 ASSA and all 3 EW devices succeeded. To evaluate degradation, represented by the sustained elongation of the device, product length measurements were taken before and after tensile testing. To evaluate degradation at -5°C, a 2-Sample t-Test was used to compare the change in length (in.) of both ASSA and EW before and immediately after testing. To examine the effect of temperature during tensile testing on the ASSA, a 2-Sample t-Test was used to compare the degradation at -5°C and -20°C. To evaluate any long-term product degradation for both the ASSA and EW, delayed length measurements were recorded 2 weeks after initial testing and a 2-Sample t-Test was used in this analysis. To examine the relationship between initial tube length (in.) and maximum force/load applied (N) exerted during tensile testing, a Linear Regression t-Test was performed.

For fatigue data, a 2-Sample t-Test was used to compare the change in load (N) over the span of fatigue testing (cycle 1 to cycle 600) between the ASSA and EW devices. Another 2-Sample t-Test was performed comparing the effect of temperature on the change in force (N) over the same cycle 1 to cycle 600 timespan.

Results

Tensile Data

Through additive manufacturing techniques, a novel autonomy supportive skiing aid was designed and produced. In collaboration with engineers from ITS, a test matrix was developed. Several benchmarks were established prior to testing to ensure the ASSA met the necessary standards as previously addressed. Tensile testing data was obtained for the 9 ASSA devices and 3 EW devices at varying temperatures (Table I).

Table I. Tensile Testing Data for ASSA and EW at varying temperatures (-30° to 20°), stretched from 1.96” to 8.96”

Specimen	ID	Test Cond Temp (°C)	Maximum Force Applied (N)	Initial Overall Length (in.)	Final Overall Length (in.)	Initial Tube Length (in.)	Overall length 2 weeks later (in.)
ASSA #1	TA301	-30°	65.94	8.18	8.51	5.03	8.18
ASSA #2	TA302	-30°	64.87	8.09	8.67	4.97	8.09
ASSA #3	TA303	-30°	58.60	8.13	8.80	4.98	8.16
ASSA #4	TA51	-5°	58.73	8.15	8.33	5.12	8.16
ASSA #5	TA52	-5°	51.66	8.19	8.31	5.08	8.22
ASSA #6	TA53	-5°	55.00	8.12	8.29	5	8.18
EW #1	TE51	-5°	63.50	8.18	8.31	5.63	8.18
EW #2	TE52	-5°	62.44	8.04	8.24	5.51	8.13
EW #3	TE53	-5°	70.07	8.02	8.26	5.48	8.16
ASSA #7	TA201	20°	59.41	8.16	8.27	5.08	8.25
ASSA #8	TA202	20°	59.16	8.11	8.182	4.96	8.18
ASSA #9	TA203	20°	59.06	8.13	N/A	4.97	N/A

Note. Sample ASSA #9 (TA203) experienced rubber hose separation from clip during test

Short term degradation was compared between the ASSA and EW at -5°C during tensile testing. When comparing the change in length (in.) of the ASSA and EW, there was an insignificant difference between the two products in degradation as demonstrated in Figure 1 (95% CI, -0.15 to 0.08; p=0.22). Since alpha 0.05 was used, the 95% confidence interval was assessed for all statistical tests. Comparing long term degradation from tensile testing at -5°C, there was also an insignificant difference in degradation between the ASSA and the EW (95% CI, -0.20 to 0.11; p=0.20), Table I.

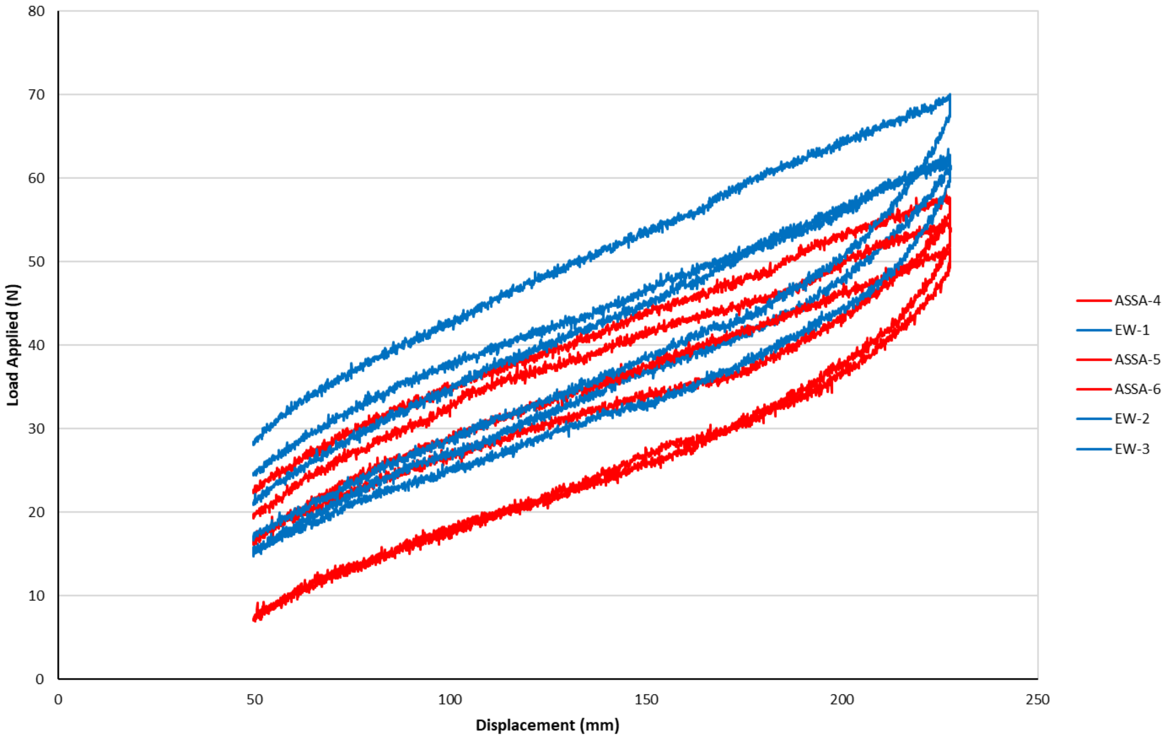

Figure 1. Load Applied (N) vs. Elongation (mm) for ASSA and EW at -5 °C at a rate of 5.0 in/min.

The effect of temperature on short term degradation of the ASSA was then examined. The change in length (in.) of the ASSA from before testing to immediately after testing was calculated and compared between the trials at -5°C and -30°C. Short-term degradation of the ASSA device compared with the EW control showed significantly greater short-term degradation of the ASSA at -30°C than at -5°C as demonstrated by Figure 2 (95% CI, -0.79 to 0.05; p=0.03). The effect of temperature on long term degradation of the ASSA between -5°C and -30°C was additionally examined. There was an insignificant difference in long-term degradation after 2 weeks between the samples tested at -5°C and -30°C (95% CI, -0.03 to 0.07; p=0.13), Table I.

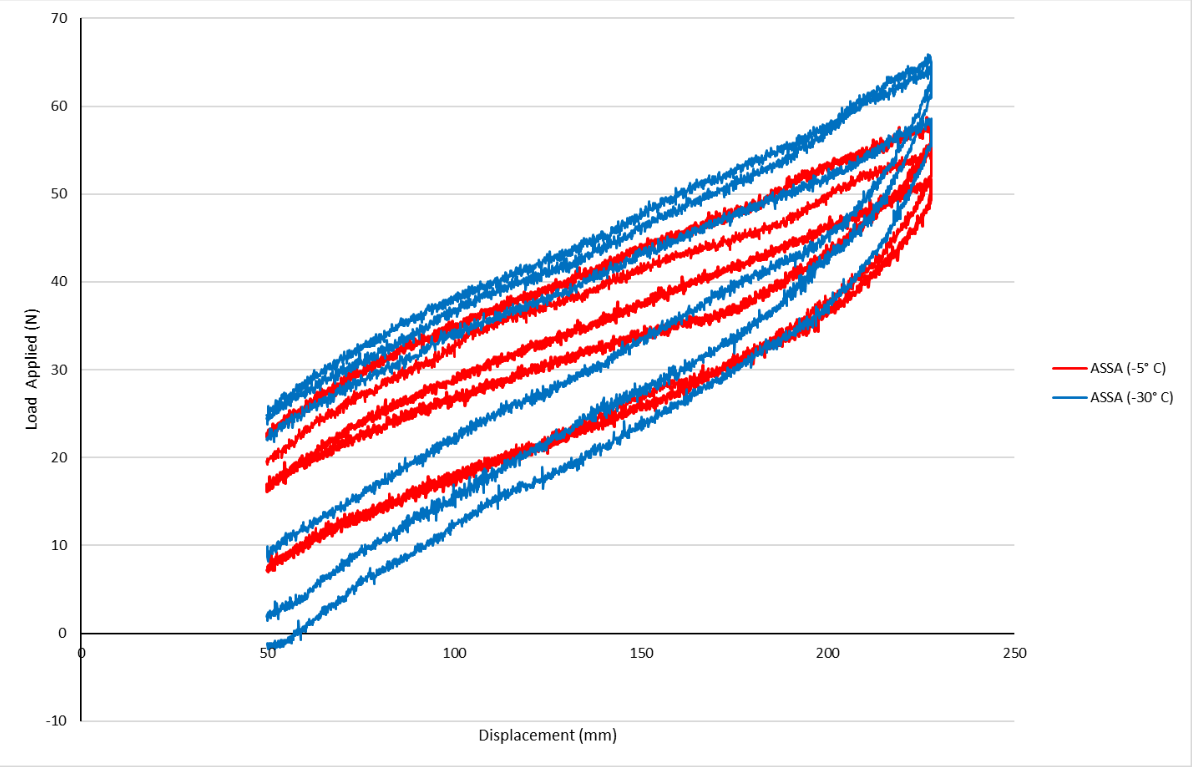

Figure 2. Load Applied (N) vs. Elongation (mm) for ASSA at -5°C and -30°C at a rate of 5.0 in/min.

To determine whether the length of tubing was responsible for the differing forces observed between ASSA and EW, the initial tube length (in.) and maximum load applied (N) during tensile testing were compared. For both products, the initial tube length correlated with and was a reliable predictor of maximum load applied. This was determined by a Linear Regression t-Test (95% CI, -0.56 to 40.09; p=0.03), Table I.

Fatigue Data

High cycle fatigue testing data was obtained for 9 ASSA devices and 3 EW devices at varying temperatures (-30° to 20°), (Table II).

Table II. High cycle fatigue testing data for the ASSA and EW

Specimen	ID	Test Cond Temp (*C)	Maximum Load Applied (N)	Median Stretch Applied (+/- mm)	Alt. Stretch Applied (+/- mm)	1st Cycle Max Load (N)	100th Cycle Max Load (N)	600th Cycle Max Load (N)	600th Cycle Load Range (N)
ASSA #1	FA30X1	-30°	65.94	114.3	50.8	55.1	57.1	52.6	46.2
ASSA #2	FA30X2	-30°	64.87	114.3	50.8	52.7	48.4	40.5	44.7
ASSA #3	FA30X3	-30°	58.60	114.3	50.8	54.2	52.6	53.0	47.2
ASSA #4	FA5X1	-5°	58.73	114.3	50.8	45.4	44.1	37.2	29.9
ASSA #5	FA5X2	-5°	51.66	114.3	50.8	53.3	42.4	50.4	30.6
ASSA #6	FA5X3	-5°	55.00	114.3	50.8	55.1	54.3	62.8	31.4
EW #1	FE5X1	-5°	63.50	114.3	50.8	60.4	54.9	54.2	31.0
EW #2	FE5X2	-5°	62.44	114.3	50.8	59.7	54.9	53.7	30.7
EW #3	FE5X3	-5°	70.07	114.3	50.8	60.6	54.9	53.6	30.6
ASSA #7	FA20X1	20°	59.41	114.3	50.8	50.5	47.4	46.6	23.6
ASSA #8	FA20X2	20°	59.16	114.3	50.8	50.0	46.6	45.2	23.8
ASSA #9	FA20X3	20°	59.06	114.3	50.8	47.2	44.0	41.7	24.2

Differences in degradation over the span of fatigue testing between the ASSA and EW at -5°C were compared by examining the decrease in maximum load (N) from the 1st to 600th cycle, Table II. During fatigue testing it was found that the differences in degradation between ASSA and EW were not significant as depicted in Figure 3 (95% CI, -25.26 to 14.73; p=0.19). In Figure 3, the upper 2 lines (blue and red) for ASSA and EW load represent the maximum load applied during each cycle. Although the ASSA is associated with a lower load compared with the EW device, the shape of each curve is not dissimilar, indicating similar and reproducible patterns of degradation.

The effect of temperature on degradation of the ASSA during fatigue testing was additionally examined between the samples at both -5°C and -30°C. Temperature did not have a significant impact on the degradation of the ASSA during high cycle fatigue testing (95% CI, -20.88 to 12.54; p=0.26), Table II.

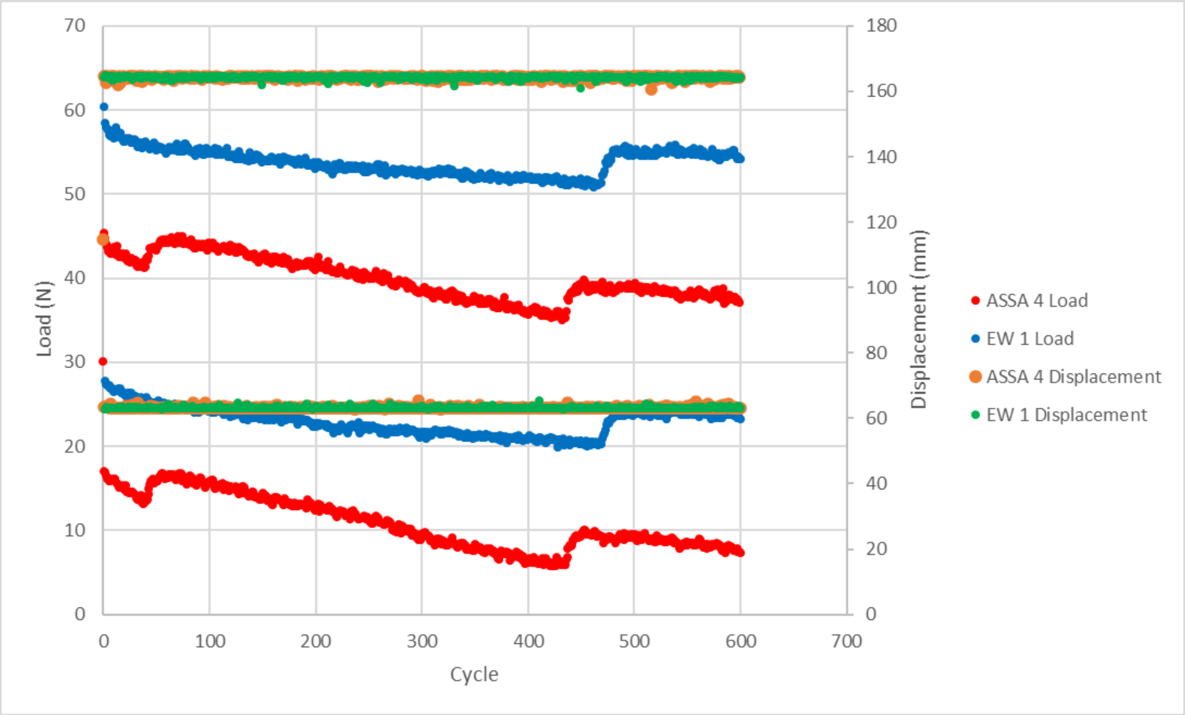

Figure 3. Load (N) & Elongation (mm) vs cycle for ASSA and EW in fatigue testing at -5°C, at .25 Hz rate.

Discussion

This study is the first phase of a larger 2-phase study. In the first phase, the purpose was to expose the novel ASSA device to a battery of durability assessments to ensure the product can withstand authentic stress and environmental conditions. The second phase, to be completed upon completion of the first, is aimed at assessing the ASSA's success in fostering the users' perceived levels of autonomy, engagement, and enjoyment when skiing while using the ASSA.

To evaluate the inherent strength of the novel ASSA device compared with the control EW device, tensile testing was performed at -5°C, mirroring typical skiing conditions. During testing, both the ASSA and EW devices were stretched past their yield strength (point of deformation) leading to a degree of potentially prolonged elongation, also referred to as degradation. The immediate (short-term) and two-week later (long-term) elongation measurements of both devices after testing were evaluated and the differences between devices was not statistically significant. The elongation seen may be attributed to intrinsic properties of the rubber tubing used in the ASSA and EW products. Although the ASSA data trended towards less degradation than the EW, the data did not reach statistical significance. These insignificant degradation differences between the ASSA and EW suggest that the durability of the ASSA is comparable to that of the EW and not inferior.

To evaluate the effect of temperature on the degradation properties of the ASSA device during tensile testing, trials were conducted at -5°C and -30°C, representing both typical and extreme skiing conditions, respectively. The effect of temperature was also examined on product degradation both immediately after testing (short-term) and 2 weeks after testing (long-term) intervals. The results revealed that immediately after testing, the -30°C specimens had degraded significantly greater (95% CI, -0.79 to 0.05; p=0.03). However, 2 weeks after testing, the difference in degradation of the ASSA between the -5°C and -30°C was not significant. This indicates that over time (2 weeks after testing), the ASSA returned close to its original length, suggesting the degradation was not irreversible. This again may be attributed to the intrinsic properties of the rubber tube used in the ASSA. Furthermore, it also suggests structural durability of the novel device long-term (2 weeks) under harsh weather conditions the device would be expected to be exposed to.

During tensile testing, it was observed that the EW exerted a greater force on the Tovey load cell than the ASSA. Due to engineering differences, the ASSA tube length needed to be shorter than that of the EW to maintain consistent overall length between the two devices tested. To isolate the tubing component and determine the significance of the relationship between initial tube length (in.) and maximum load (N), additional statistical evaluation was conducted. By conducting a linear regression analysis, the tube length was determined to be the causative variable (95% CI, -0.56 to 40.09; p=0.03), contributing to the differing maximum load, or stiffness, of the ASSA vs. EW devices. This suggests that the tubing length of the ASSA and EW is more impactful on the maximum load exerted by the device than the tubing material.

To investigate the long-term strength and resilience of the ASSA compared to the EW, high cycle fatigue testing was conducted for 600 cycles at -5°C. Statistical analysis revealed that over the 600 cycles, the degradation of the ASSA was insignificantly different from that of the EW (95% CI, -25.26 to 14.73; p=0.19). Although the results did not reach statistical significance, the ASSA was trending towards less deformation than the control EW. During testing, the ASSA exerted a uniformly lower force by a small margin, indicating less stiffness than the EW. This is insignificant to the functionality of the product however, as the degradation patterns of both the ASSA and EW are similar as seen Figure 3.

To evaluate the effect of temperature on the long-term resilience of the ASSA, fatigue testing was conducted for 600 cycles at -5°C and -30°C. The results showed that temperature did not have a significant impact on the degradation of the ASSA during fatigue testing. While the samples at -30°C did become stiffer than the samples at -5°C, as seen by the greater load exerted, the degradation was insignificantly different than the samples at -5°C. This suggests that even under exposure to the most extreme temperatures, the ASSA device still managed to meet the expected standards of durability.

Significance

After conducting analysis of the ASSA device compared to the EW from a strength and functionality standpoint, the results suggested the ASSA device to be comparable to the EW in terms of strength and resilience. These findings enable progression to the second phase of this study. In this second phase, human trials will be conducted to evaluate the effect the ASSA product has on perceived levels of autonomy and skiing engagement of its users.

Conclusion

To address the challenge of maneuverability while using the Edgie Wedgie, a novel ski teaching aid innovation ASSA was designed in this study that incorporates a spring-loaded connector, enabling quick and easy detachment. Through strength and durability testing, it was successfully shown that the novel ASSA device performed insignificantly different than the benchmark EW. This suggests that this novel product holds up to the simulated conditions and stressors making it a candidate for further human testing. This future testing, to be conducted in the second phase (Winter 2024-25), will examine the effect the ASSA will have on its users' sense of autonomy and enjoyment while skiing.

Acknowledgements

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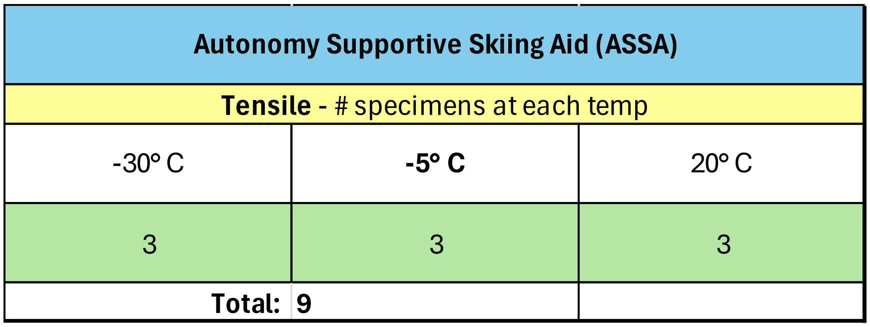
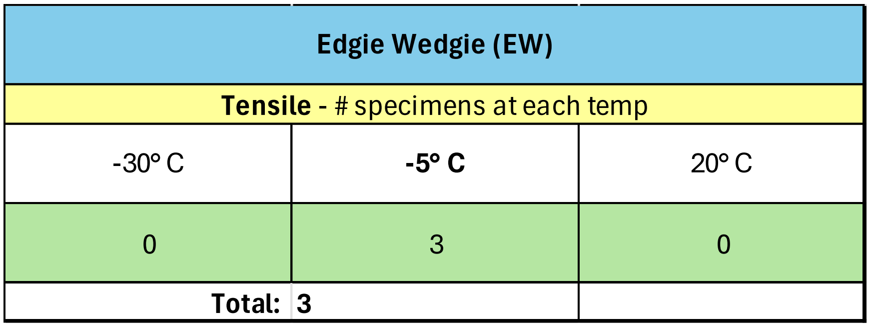
Appendix A

Testing Matrix outlining the types of tests to be conducted, quantity of samples, and the various temperatures that testing will be conducted at



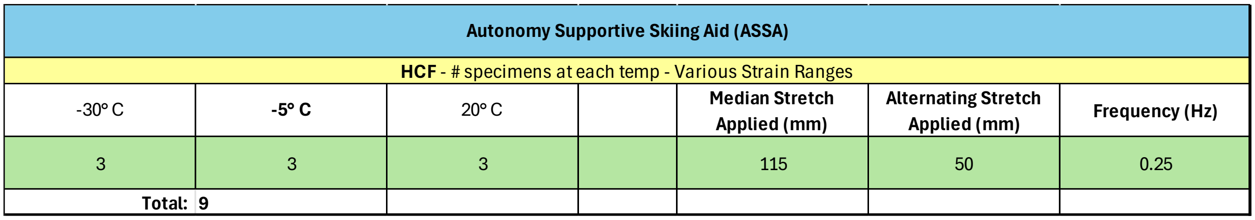
Autonomy Supportive Skiing Aid (ASSA)		
Tensile - # specimens at each temp		
-30° C	**-5° C**	20° C
3	3	3
Total:	**9**	

Table A1. The matrix for tensile testing of the ASSA device.



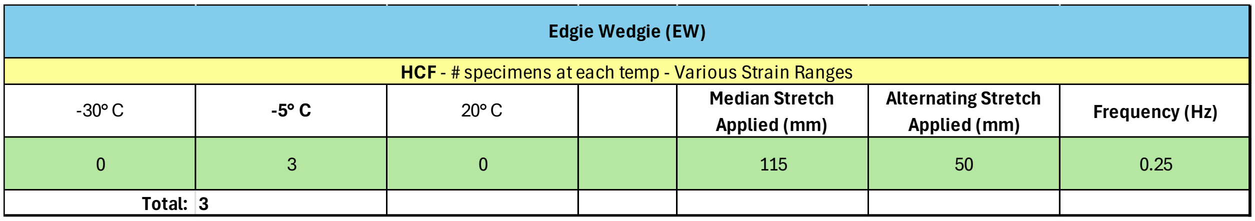
Edgie Wedgie (EW)		
Tensile - # specimens at each temp		
-30° C	**-5° C**	20° C
0	3	0
Total:	**3**	

Table A2. The matrix for tensile testing of the EW device.



Autonomy Supportive Skiing Aid (ASSA)						
HCF - # specimens at each temp - Various Strain Ranges						
-30° C	**-5° C**	20° C		**Median Stretch Applied (mm)**	**Alternating Stretch Applied (mm)**	**Frequency (Hz)**
3	3	3		115	50	0.25
Total:	**9**					

Table A3. The matrix for high cycle fatigue testing of the ASSA device.



Edgie Wedgie (EW)						
HCF - # specimens at each temp - Various Strain Ranges						
-30° C	**-5° C**	20° C		**Median Stretch Applied (mm)**	**Alternating Stretch Applied (mm)**	**Frequency (Hz)**
0	3	0		115	50	0.25
Total:	**3**					

Table A4. The matrix for high cycle fatigue testing of the EW device.

Appendix B

Visual documentation of the testing environment

Figure B1. The complete testing setup, including the tensile testing machine and the nitrogen tank used for temperature regulation.

Figure B2. The ASSA device was set up, ready to begin testing.

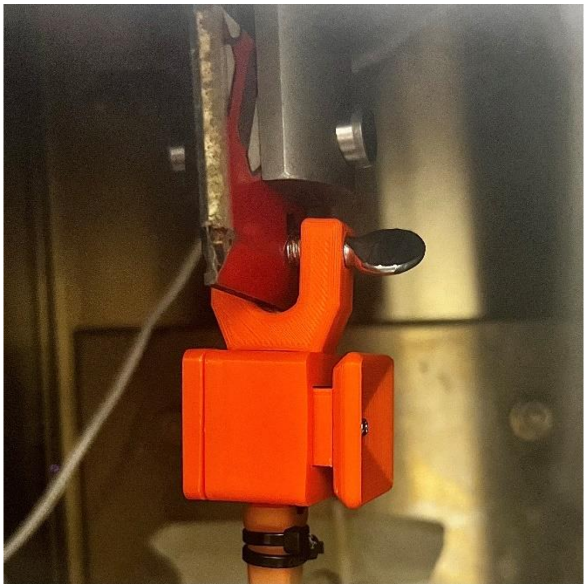


Figure B3. An up-close view of the fixturing of the ASSA device.