

Optimization of Backpack Design for Minimizing Lower Back Pain by Analyzing Points of Contact: A Literature Review and Experimental Study

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The prevalence of lower back pain (LBP) among students necessitates the exploration of effective solutions to mitigate the issue. This study aims to provide valuable insights into minimizing back strain and delaying the onset of back and shoulder pain by examining the points of contact between a conventional backpack and the back through a literature review and experiment. A ten-document literature review pertaining to experiments on LBP associated with backpack use highlights the prevalence of this issue and underscores the urgency for enhanced backpack designs. To simulate the effect of a heavy backpack load, a standard school backpack was loaded with a weight of 25 pounds and worn by two subjects of varying body sizes and shapes. The duration until pain emerged in any upper body region was measured while subjects wore the backpack with various support modifications. Subjective assessments, including pain-scale ratings and open-ended comments, were also recorded. Statistical analyses, such as ANOVA and Tukey HSD multiple/pairwise comparison tests, were conducted on the data collected from the subjects. We report that achieving complete lower-back contact and providing adequate shoulder support outperformed other modifications in reducing the onset of back pain. Consequently, a simple attachment was devised to supplement backpacks and alleviate back strain which is yet to be tested due to manufacturing limitations. This study serves as a foundation for informing the future design of ergonomic backpacks that prioritize optimal load distribution across the back while considering the importance of function and fashion.

Introduction

Backpacks are imperative in daily life, providing a convenient method of carrying supplies for everyone from students to workforce employees [3]. Despite their convenience, backpacks are widely known to cause back strain [1-3, 5-10, 13, 21, 21-25, 27-31, 33, 36]. For the context of this paper, back strain is synonymous with lower back pain (LBP).

Back strain can arise due to awkward posture, repetitive movement, spine compression, and heavy lifting [11]. Increases in shift length and work intensity have made professionals prone to excessive back strain. Consequently, all back pain has increased considerably in recent years, making neck pain and LBP the leading causes of medical rehabilitation, disability, and days taken off from work [17, 19]. Repetitive back strain can exacerbate issues with posture, cause permanent LBP, lead to early spine degradation, and result in poorer emotional well-being [12, 13].

LBP point prevalence (the measure of cases at one point in time), ranges from 1 to 58 percent in the general population and from 11 to 52.1 percent in teenagers [15, 21]. Past studies have shown a direct correlation between backpack load and back strain [5-10]. Heuscher et. al found that a 4 kg increase in backpack load results in a 25% increase in the chance of recurrent LBP [8].

Many factors influence backpack load, meaning certain groups are more likely to experience LBP. Females have a 12.4% heavier average backpack load when compared to men, and younger students are five times more likely to carry a “heavy” backpack than older students [1, 23]. Backpacks typically weigh 30 to 40 percent of the carrier’s body weight (BW), measuring out to roughly 20 lbs (9.07 kg) to 30 lbs (13.61 kg) for young children [2]. Additionally, height and BMI are associated with back pain [16].

The factor this paper will be focused on is the structural design of the backpacks, which must be accounted for when examining backpack-induced back strain. Common backpack forms include traditional two-strap bags, three-strap camping bags, and one-strap shoulder bags. Each type has various structural features that are optimal in certain situations.

LBP is typically best treated with non-steroidal inflammatory drugs, muscle relaxants, or physical therapy [20]. However, the treatment of LBP is known to be costly, with the total expenditures of patients with back pain going over \$100 billion yearly [17]. With LBP being the leading cause of disability in low-income countries, providing proper treatment may not be viable [18]. Therefore, the development of LBP prevention techniques is crucial.

The center of gravity of a human of average weight is generally low on the human body, specifically the lower abdomen area. However, when carrying a backpack or a

heavy load, the center of gravity is raised and shifted backwards, causing tension in the spine and the lower back. This heavy load causes a dangerous arch in the spine and drastically changes the posture, therefore affecting the lower back region. The optimal weight concentration is at the center of gravity as that is where most of the weight is concentrated as opposed to the other weaker areas. A case study was performed at Suwon, Korea, where ten male mountain climbers traveled at the same speed for 15 minutes while simultaneously carrying a 20 kg load as a backpack. The majority of the mass was concentrated at the center of gravity due to adjustments in the backpacks' design, which facilitated the reduction of tension on the back, as opposed to the regular backpacks which lead to chronic posture problems and the unhealthy bending of the back.

In this study, past case studies were evaluated through a comprehensive literature review on the effects and implications of backpacks on back strain. Then, we conduct an experiment to analyze how to reduce back strain by supporting backpack points of contact. We propose a relatively rigid curved attachment to the backpack to reduce strain along with waist straps which have been proven to be effective in previous literature [24-26].

Literature Review

The inclusion of a literature review was imperative in the investigation of LBP as it facilitated a comprehensive exploration of instances where backpacks exert an influence on the human body, particularly in the context of the lower back region. Additionally, it afforded us a holistic understanding of the prior research pertaining to the detrimental consequences of heavy loads of backpacks in a broader sense. By incorporating all this information, we were able to structure our experiment effectively and formulate a proposal that supports various literature viewpoints, thereby proposing viable strategies to mitigate the repercussions from LBP.

Search Strategy

In order to find the articles, we searched up different critical structures that were affected by heavy loads from a traditional backpack on Google Scholar. Google Scholar provided us with more search results for the specific queries we inputted compared to PubMed which was our secondary option for finding literature. Queries for the Google Scholar search include "lower back pain from backpacks," "optimized backpacks for reducing lower back pain", and "physiological impacts of lower back pain from backpacks". An approximate number of search results can be found in Figure 1. We then conducted a search on the chronic and lifelong impacts of frequently carrying heavy loads on the back and relating it to muscle activation. From there, we were able to differentiate between helpful and irrelevant sources by checking whether there were case studies or experiments with a pertinent purpose that tested heavy backpacks fairly and accurately. Studies that were not directly linked to backpacks were excluded. After selectively choosing ten sources, we reported the authors, the main

purpose of the study, the subjects of the study, the experiment conducted, and the results/conclusions derived from

Query	Results
Lower Back Pain from Backpacks	~17300
Optimized backpacks for Reducing Lower Back Pain	~18100
Physiological Impacts of Lower Back Pain from Backpacks	~19600

Figure 1: Query Search Results Reports the approximate number of results found when each query was put into Google Scholar. For the literature review, we primarily utilized the search results from the first two pages of the search query.

the experiment. The table of the literature review can be found on Figure 1.

Review of Each Article

Purpose of Research

Each study had different claims, experimental designs, and purposes. A prevalent area of study was the relationship between backpack usage and LBP [5,21] and the relationship between backpack weight and LBP [8,30,31]. Other studies important to the literature review measured the impact on the anatomy of the spine [30,32]. Aside from anatomy and LBP, some literature also improved backpack designs and subjectively highlighted shortcomings of the current modern backpack [29, 33-35].

Participant Characteristics

Given different locations, resources, funding, demographics, and cultures, each study encompassed different populations of subjects. The main characteristics of participants that we found differentiate each study were age, gender, and population size. The subjects encompassed a diverse age spectrum that included elementary [33], middle [29, 30], and high school students [21], with two experiments also being exclusively amongst university students [8, 31]. Overall, many subjects fell under the age range of 7-20 years old [8, 21, 30, 32, 34]. This incorporates the prime ages when students would utilize backpacks the most. From elementary school to post-secondary education, the backpack helps to transfer materials from one class to another. The experiments involved subjects of various genders, with one experiment exclusively containing male students [30], while most experiments included both male and female participants. In addition, the participant size varied from study to study. Specifically, three experiments used a relatively low number of participants [30, 32, 34] - less than fifty, whereas the rest of the studies included over a hundred participants each, with two studies having over a thousand participants [5,29].

Weight of the Backpack Load

Instead of solely examining the specific weights of backpacks, many studies have chosen to consider the weight relative to the individual's body weight (BW) [21, 30, 33].

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This approach ensures that students with different body weights experience a comparable load in relation to their own weight. On average, the backpack weight was typically within the range of 5-20% of the individual's BW [21, 30, 33]. However, for a comprehensive understanding of the weight spectrum examined backpack weights spanning from 0% to 25% of the individual's BW [33]. This broader range allows for insights into both the lower and upper extremes of the weight scale, encompassing very light and extremely heavy loads. Aside from the load of the backpack, two studies experimented with developing new backpacks that assist in reducing LBP.

Duration of Backpack Usage

Given different researchers and their motives, the duration of backpack usage varied from 5 minutes to a month [5,33], with the outlier being the case study where students were advised to record feelings of pain for five school days [29]. Excluding the outlier, the time that the subjects were told to carry the heavy load for the experiment was on average 12 minutes. Varying duration of backpack usage can track both temporary LBP and more prominent LBP.

Measures of Physical Pain and Discomfort

Lower back pain was assessed in students throughout the duration of one school week through an extensive questionnaire in three distinct studies [29,21,34]. In another study, the body weight of the participants and their corresponding backpack loads were measured, and akin to the studies, the subjects were interrogated on incidents of lower back pain ahead of the experiment [36]. Two studies highlighted discomfort and activation of the musculoskeletal regions of the body, which principally pertained to the spinal and lower back regions, through personalized surveys [33,35]. One study encapsulated the

adverse effects of heavy backpacks using the Visual Analogue Scale (VAS), which operates by assessing the presence of physical pain on a numerical scale with a range 1 to 10 [31]. Finally, the last study employed a unique approach that determined the response of the spine through upright magnetic resonance imaging (MRI) scans, which occurred subsequent to the subjects wearing backpacks of varying weights to school [32].

Findings

Of the 10 studies about the physiological impacts of backpacks, 5 studies reported a correlation between heavy backpacks [5,8,30,31,32] and LBP and 1 study reported no correlation between the two [21]. The study with no correlation reported a Daily Pain Index of 0.75 from a scale of 0-10. Additionally, they noticed that physically active individuals have higher Daily Pain Index scores. However, the study also highlights that it contradicts other reports due to the use of a lighter backpack from a pre-university participant cohort and fewer participants in the study [31]. Two studies highlighted the adverse effects of the backpack on the spine, specifically lumbar lordotic curvature and disk compression [30,32]. Three studies developed new backpacks built to support the lower-back region through a participant or user-centered-design [33,34,35]. The VAS scale utilized in the study appraised average scores of 5.2, 5.73, and 6.02, which signified discomfort experienced in the cervical, lumbar, and sacral regions, respectively [31]. The designed backpacks resulted in less muscular activation, reduced neck/shoulder muscle spasms, and the preference switch from appearance to function and fit. One study showed a strong relationship between headaches and tiredness during school and heavy backpack loads [29].

Source	Purpose/Thesis	Subjects of Experiment	Experiment Conducted	Major Findings
Geraldine et al. (2003)	Explore the correlation between the utilization of backpacks and the occurrence of back pain among adolescents."	• 1126 middle and high school students (ages 12-18) varied across 12 middle schools and 10 high schools	<ul style="list-style-type: none"> • One month study • Body weight, backpack weight, height measured before experiment • Used certain criteria to measure whether students had backpain after a month • Backpack usage categorized into four levels: <ol style="list-style-type: none"> 1. No backpack use: Does not wear backpack between classes and does not carry backpack while waiting. 2. Low backpack use: Does not wear backpack between classes, but carries backpack while waiting. 3. Medium backpack use: Wears backpack between classes, but not while standing. 4. Heavy backpack use: Wears backpack between classes and while standing. 	<ul style="list-style-type: none"> • 74.4% overall had back pain. • Students with medium/heavy backpack use had higher back pain rates. • 78.2% of backpack users between classes had back pain; 63.6% without backpacks did. • 78.6% of students with backpacks while standing/waiting had back pain; 60.9% without backpacks did.
Rai & Agarawal (2013)	Physical and emtional problems associated with carrying heavy loads	<ul style="list-style-type: none"> • 1446 middle schoolers • Age: 11 and 14 	<ul style="list-style-type: none"> •The students were apprised to carry their backpacks for an entire school week and record their thoughts in a diary •Potential causes of lower back pain recorded through conducting an efficient and detailed survey about the effects of carrying a heavy load 	<ul style="list-style-type: none"> •Strong relation between heavy backpacks and headaches, emotional and behavioral problems, and tiredness during the school day •Detrimental to the performance of students in their academic endeavors as well as their mental health

Source	Purpose/Thesis	Subjects of Experiment	Experiment Conducted	Major Findings
Chen & Mu (2013)	Analyze effects of backpack load on spine strains while walking	<ul style="list-style-type: none"> • 12 male middle schoolers • Average Age: 12.3 • Average Height: 151.3 cm 	<ul style="list-style-type: none"> • Subjects wore varying backpacks of 5%, 10%, and 15% of their bodyweight and walked for 10 min on treadmill. • Three positions on spine (T7, T12, L3) were examined for strain 	<ul style="list-style-type: none"> • Backpacks weighing >15% of body weight should be avoided • Lumbar lordotic curvature decreased because of counterbalancing and higher spinae activation as a result of increased backpack weight • Requires further investigation with varying participant population
Natasha et al. (2017)	Determine the relationship between backpack usage and LBP	<ul style="list-style-type: none"> • 101 graduating high-school seniors in Malaysia • 49 male, 52 female • Age:16-18 years old • Used 6% backpack weight/subject weight ratio 	<ul style="list-style-type: none"> • Weight of student with and without backpack was measured • Questionnaire provided additional demographic information <ul style="list-style-type: none"> • Roland- Morris Disability Questionnaire used to assess LBP 	<ul style="list-style-type: none"> • 61.4% of participants indicated previous history of LBP. • Daily Pain Index(0-10) mean was 0.75, showing no correlation between backpack and LBP • Physically active individuals have higher LBP scores
Junior & Cavalcanti (2014)	Develop an association between general pain and transportation of school supplies	<ul style="list-style-type: none"> • 373 university students • Selected by stratified sampling 	<ul style="list-style-type: none"> • Interview collected demographic data • Visual Analogue Scale(VAS) measured the precense of pain 	<ul style="list-style-type: none"> • 821.8% reported general pain from carrying school supplies • 29% reported that it was LBP • VAS reported 5.73 for lumbar, 6.02 for sacral, and 5.2 for cervical in a scale from 1-10
Heuscher et al. (2010)	Determine association between LBP and backpack weight	<ul style="list-style-type: none"> • 473 health education students from Colorado State University • Average age = 19.7 	<ul style="list-style-type: none"> • Asked about any past incident of LBP • Body weight and backpack weight of each patient was measured 	<ul style="list-style-type: none"> • Average weight of backpack = 11.5 lbs • Men are more likley to report LBP • Increased backpack weight reusults in increase prevalence of LBP • Does not specify a certain threshold of backweight for increase chance of LBP

Source	Purpose/Thesis	Subjects of Experiment	Experiment Conducted	Major Findings
Shymon et al. (2014)	Measure spine response to backpack load on children with LBP	<ul style="list-style-type: none"> • 15 pediatric patients • 4 boys and 11 girls • Age: 10-16 	<ul style="list-style-type: none"> • Upright MRI scan imaged the patients while wearing the backpacks with varying weights • IVD Height, lumbar lordosis, lumbar coronal deformity, and pain score were reported 	<ul style="list-style-type: none"> • 4kg and 8kg backpacks compressed L5-S1 discs • Backpack weight positively associated to disc compression (varying p-values) • Increased pain from backpack loads can possibly be attributed to muscle fatigue
Ramadan & Shayea (2013)	Develop and test a new backpack design that distributes the carrying load	<ul style="list-style-type: none"> • 238 male school children of various ages • No musculoskeletal injuries or pain in the past 	<ul style="list-style-type: none"> • Modified backpack was similar to a life jacket. • Wearing backpack weighing from 0-25% of body weight and walking for 5 minutes • Recorded rectus abdominus and erector spinae muscle activation 	<ul style="list-style-type: none"> • Modified backpack was better in less muscular activation and exertion ratings • Participants preferred modified backpack over commercial backpack • Modified backpack reduced can reduce nerve strains which can lead to muscle spasms and neck/shoulder pain
Amiri et al. (2012)	Developing user-centered design for a backpack to reduce back pain	<ul style="list-style-type: none"> • 120 elementary students • Age: 7-9 years old 	<ul style="list-style-type: none"> • Analyzed diaries of backpack experiences over the school day • Analyzed the user feedback and developed a 3D design from the ideas 	<ul style="list-style-type: none"> • Developed a user-centered-designed backpack with appearance and ergonomics in mind
Mackie et al. (2003)	Evaluate the desirability of 4 backpacks based on ergonomics	<ul style="list-style-type: none"> • 3 school-backpack and 1 standard backpack • 12 students (6 male, 6 female) 	<ul style="list-style-type: none"> • Survey evaluated regions of the body experiencing musculoskeletal discomfort • Subjects wore weight-loaded backpack and walking on treadmill for 20 minutes • Subjects were asked to choose their preferred backpack and report any musculoskeletal discomfort 	<ul style="list-style-type: none"> • Preferences for backpacks change once students have wore it • Reasons for choosing a certain backpack include, comfort, size, back padding, and overall style • Students' perspective changed from appearance to "function and fit"

Materials and Methods

The goal of the study was to analyze the most significant points of contact for the proposal of an improved ergonomic backpack through a two-subject study. Limited resources and access to subjects restricted a study with a larger population. For the sake of the study, Subject 1 will be referred to as S1, and Subject 2 will be referred to as S2. At the time of the study, S1 was reported to be 16 years old, 74 inches (118 cm) tall, and 135.2 lbs (61.2 kg). S2 was 11 years old, 66 in (167.6 cm) tall, and roughly 110 lbs (50.17 kg). Variation in the measurements between the two subjects allowed the analysis of backpack weight on two completely different body types and ages [23]. We had to assume the back posture between S1 and S2 is similar and were equally aware of the threshold of the pain of when to report it to the researcher.

An affordable cushioned adjustable two-strap Swiss Gear backpack without any significant back support was used. This allowed us to attribute any support findings to the additions made to the backpack rather than attributing some increased support to the original backpack design. We also assume no significant weight of the backpack itself when documenting the backload. When worn on S1/S2, the backpack was adjusted such that the bottom of the backpack reaches the end of the spine near the lumbar spine. An adjustable dumbbell is the 25 lb weight of the backpack. The dumbbell lay on the bottom of the backpack near the lumbar spine region and dropped the backpack near the sacrum region of the spine. The backpack-to-body-weight ratio for S1 was 18%. The backpack-to-body-weight ratio for S2 was 22.7%. Back-support was cut foam tiles with each tile approximately 0.69 inches (1.75 cm) thick and 6 inches (15.24 cm) x 12 inches (30.48 cm) in size. The foam tiles had the perfect balance between compression, rigidity, and flexibility. Other support structures that were taken into consideration include rigid backpack straps, and additional waist straps [27]. However, we decided to ignore these structures to focus on improving back support by optimizing most of the backpack.

Each trial consisted of the subjects wearing the backpack with various thicknesses and locations of points of contact. Foam supports were attached to the backpack with super glue. They were placed in the lower cervical, upper thoracic, or lower lumbar regions of the spine as seen in Figure 2, which highlights all the different regions. The middle and lower thoracic region of the spine were skipped due to its curve and the difficulty of remaining in constant full contact with the backpack. For each trial, the supports were added cumulatively from top-to-bottom meaning that the first trial consisted of S1/S2 having only a 1.5 cm top support, but the last trial consisted of the backpack including a top, middle, and lower support with increased thicknesses. Figure 2 shows the description of each trial. We made the best attempt to make the experiment single-blind by placing the backpack on S1/S2's shoulders to prevent them from seeing the amount of artificial support from the foam support.

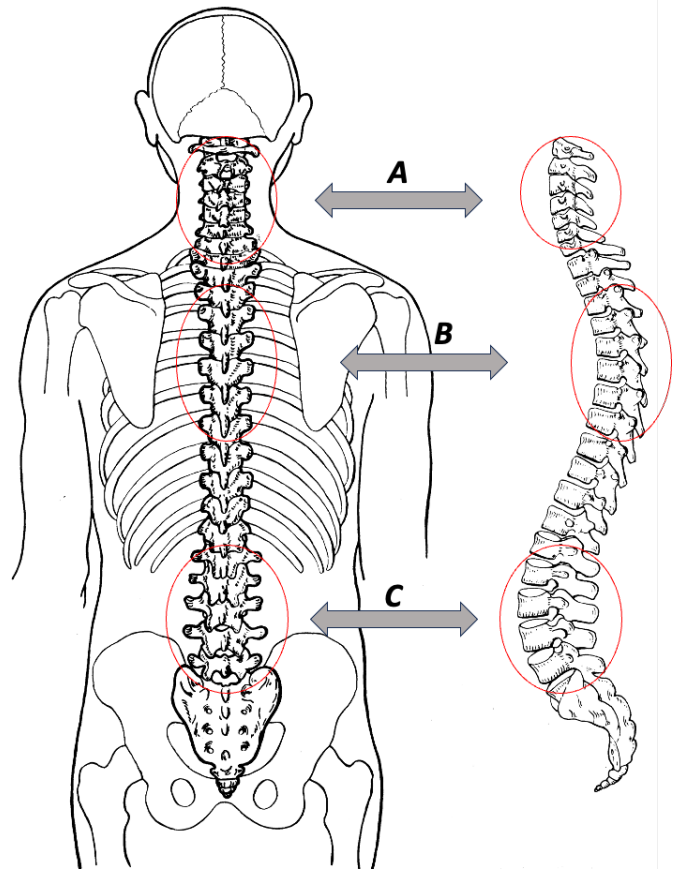


Figure 2: Locations of Backpack Support In The Spine (A) stands in the lower cervical and upper thoracic regions of the spine. This is where the shoulder support is located. (B) sits in the upper to middle thoracic region in the spine. For the purposes of the experient, this is referred to as the top support. (C) sits in the lower back near the lower lumbar and upper sacral region of the spine. This is referred to as the lower support

Following S1/S2 wearing each modification of the backpack, the time (seconds) until the first slight occurrence of back pain was measured. Three trials were conducted in each experimental trial. The average time and standard deviation of the time were calculated for each subject. A subjective scale of discomfort (1-5) and pain (1-5) helped to measure both the ergonomics and comfort that each modified backpack provides. In addition, S1 and S2 were requested to provide verbal comments to corroborate their rating. These subjective metrics provide additional information as to the viability of improving these contact points as a loss of possible comfortability and flexibility. Subjects of the experiment were ensured to rest between each trial to prevent any fatigue from the previous trial to affect the results of the next trial.

Following the experiment, based on a user-centered approach in Amiri et al's paper [28], we designed a simple 3D printed attachment with adjustable parameters for lower back and middle back support. The adjustable parameters allow for various back structures to adjust to the attachment.

Results

Following the experiment, metrics were analyzed through various statistical tests to determine statistically significant combinations of trials in Figure 2. The average

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time before the incident of LBP was measured with error bars of ± 1 SD. The 1-10 subjective uncomfatableness and pain scale was measured by comparing statistically significant means without any statistical tests. Evaluating both objective and subjective results from the experiment helps to create a cohesive understanding of the problem at hand.

As per the objective measurements, a one-way Analysis of Variance(ANOVA) test satisfying the original assumption and conditions was conducted. This test is used in research to find statistically significant groups of data by analyzing the variance(square-root of StDev). The p-value was approximately $3.324 \times 10^{-6}(p < 0.001)$. Other statistical tests were utilized to cross-validate the findings. The Tukey’s Honestly Significant Difference (Tukey HSD) for pairwise comparisons, Scheffe multiple comparison test, and the Holm-Bonferroni test for counteracting multiple comparisons all returned statistically significant p-values for analysis. The following groups were found to be statistically significant in the multiple comparison/pairwise comparisons - with each number representing the experimental group number. “1” represents Single Top

Support, and “5” represents Double Top (2.75 cm). Double Bottom Support (2.75 cm), and Shoulder Support (1.5 cm). (1,4), (1,5), (2,4), (2,5), (3,4), and (3,5) were found to be the statistically significant groups. These results can be cross validated with the graphs in Figure X where each error bar not intersecting the error bar of a subsequent graph is considered statistically significant.

A subsequent qualitative analysis with the discomfort scale was conducted in conjunction with the quantitative examination of the mean duration until the initial manifestation of pain. Notably, Figure X demonstrates a sustained pattern of decline concerning both the intensity of pain experienced and the degree of discomfort associated with the backpack.

With the lowest pain rating for Experimental Group 5 and the highest average time for pre-pain holding time, we can reasonably conclude that having a 2.75 cm attachment that has a curved design to match the structure of the lower and middle back. We preferred developing a curved design over a flat surface such as the foam tiles used in the experiment because everyone has different back structures, and it may not fit everyone’s physiological structure.

Iteration	Comments	Mean Time	SdDev	Uncomfortable Scale
Subject 1				
Single Top Support (1.5 cm)	- Very minimal contact with the back. - Uncomfortable near the bottom	71.873	10.843	5 + 3 = 8
Double Top Support (2.75 cm)	- Better contact with the back - Shoulder and LBP pain	72.183	5.879	4 + 4 = 8
Double Top (2.75 cm) and Single Bottom Support (1.5 cm)	- Similar to the previous trial - No significant difference	66.896	7.337	4 + 3 = 7
Double Top (2.75 cm) and Double Bottom Support (2.75 cm)	- Significant improvement from previous	103.803	27.976	2 + 3 = 5
Double Top (2.75 cm), Double Bottom Support (2.75 cm), and Shoulder Support (1.5 cm)	- Most comfortable design - Would prefer softer lower back support	165.561	13.921	2 + 2 = 4
Subject 2				
Single Top Support (1.5 cm)	- Dumbell hitting lower back	79.291	8.596	4 + 3 = 7
Double Top Support (2.75 cm)	- Good contact with back - Lower back is still irritating	91.820	16.135	4 + 2 = 6
Double Top (2.75 cm) and Single Bottom Support (1.5 cm)	- More comfortable near bottom	109.873	18.345	3 + 3 = 6
Double Top (2.75 cm) and Double Bottom Support (2.75 cm)	- LBP relieved - Can walk with good amount of range	169.423	32.158	2 + 2 = 4
Double Top (2.75 cm), Double Bottom Support (2.75 cm), and Shoulder Support (1.5 cm)	- Previous comments	207.419	49.328	1 + 3 = 4

Figure 3: Results Single top support indicates one foam pad at the middle of the backpack (Point B from Figure 1). Double top support is twice the amount of middle-backpack support as the previous experimental group (Point B from Figure 1). Double Top and Single Bottom Support is similar to the previous trial, but it includes a single foam pad for lower-back support (Point B and C from Figure 1). Double Top and Double Bottom Support adds another foam pad for lower-back support (Point B and C from Figure 1). Double Top, Double Bottom, and Shoulder support is similar to the previous trial, but it adds a singular shoulder support (Point A from Figure 1) for relieving shoulder strain. Each experimental group was repeated three times, each comprising of a trial. Each trial consisted of S1/S2 carrying the backpack and measuring the amount of time until they first experience backstrain. Following the trial, they were required to wait time ranging from 2-3 minutes until they can repeat the experiment without the previous trial affecting the subsequent trial’s results. After each experimental group, S1/S2 were requested to provide subjective comments regarding the comfortability and any suggestions for improvement. Finally, a subjective scale of uncomfatableness and pain is reported. Both are reported on a scale from 1-5 with 1 being the least uncomfatableness and pain and the inverse for 5.

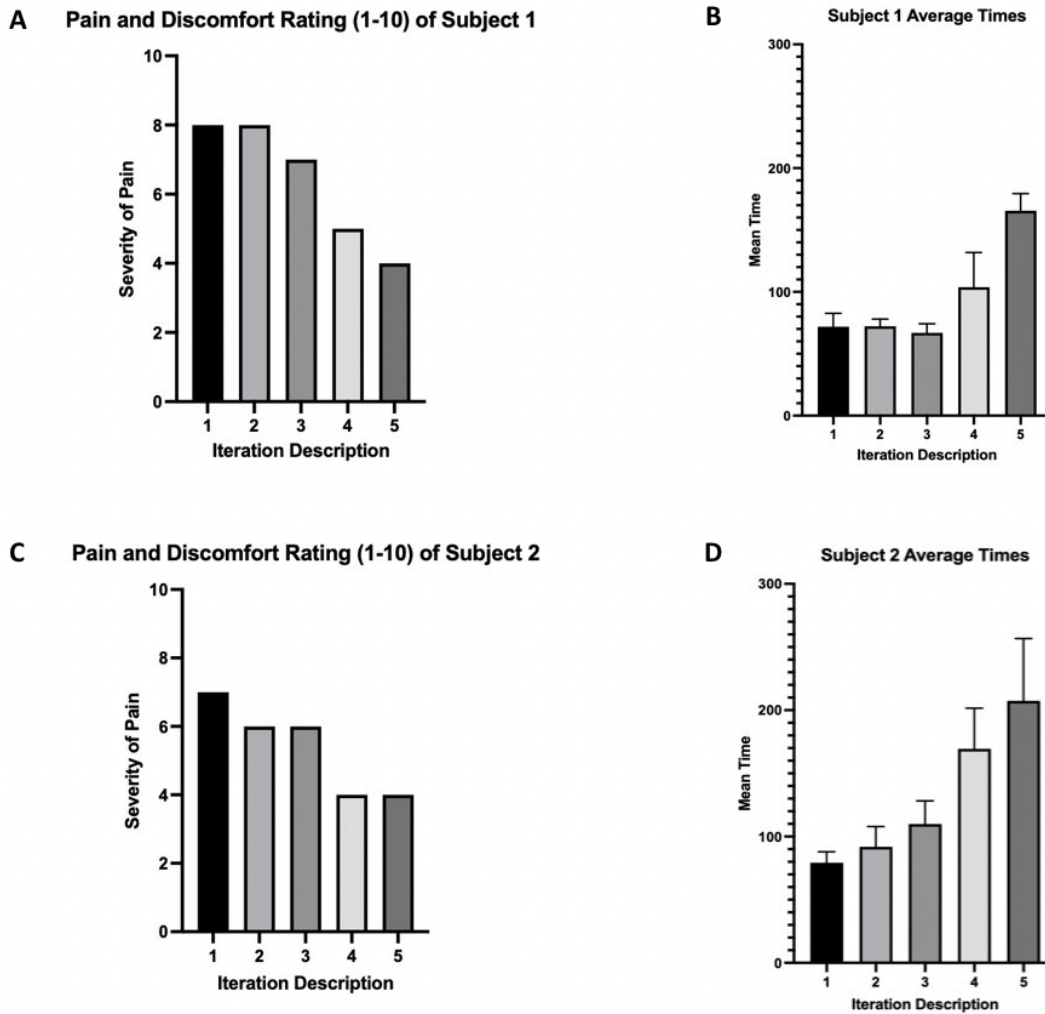


Figure 4: Result Visualization Each iteration description (1-5) is corresponding to the iteration from Figure 2. Error bars from the standard deviation are drawn for the mean time of holding the backpack. Statistical tests can then proceed to determine statistically significant pairwise groups that have a significant difference in the amount of holding time. Secondly, a graph of subjective pain scale is provided. It is important to notice that the pain tolerance of S1/S2 may be different, so it is not possible to compare S1/S2 in regard to pain tolerance but are allowed to compare the experimental group's pain tolerance within each subject trial.

We designed the attachment through Onshape using parameterized designing where the user can modify certain parameters based on the structure of the back such as the curve radius, height, and fillet. This allowed for a purely customized experience. In addition, the attachments include holes for straps to wrap around it. However, a more optimal and easier approach would be to have an adhesive on the back for direct application. We also propose this product to be made with a relatively soft material that has some compression. It is also important to mention that we are just proposing this design. No testing has been done, and more research is required to determine the viability of the product. Figure 4 to the right shows the prototype designed.

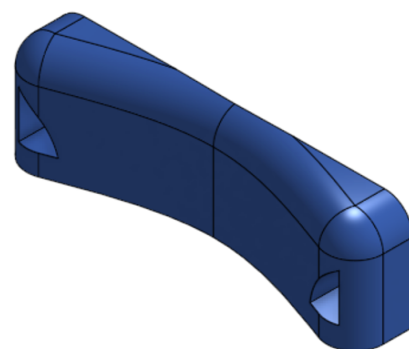


Figure 5: 3D Designed Model Shows the curved, parameterized attachment that we propose on the back of a backpack for proper back support. The two slits on the edges allow for a strap to properly attach to the back. Alternatively, an adhesive on the back of the attachment can directly attach to the backpack. This attachment would be best manufactured through a malleable but relatively hard material. Due to no access to a 3D printer or manufacturing materials, this was not made however we propose future research to do so.

Discussion

This study discussed the various effects of backpacks on lower back pain and back pain in general. A comprehensive literature review of nine articles provides critical insights into the current situation of school backpacks and their effects on the physiological structure of the back. Other studies provided insights into new designs of the backpack and the emotional impacts of heavy loads. Following the literature review, we proceeded to conduct an experiment by determining the most critical point of contact for support and then developed a parameterized-based design in OnShape for proper back support (Figure 5). One limitation of this study is that the attachment that we propose is yet to be tested; we anticipate future research can manufacture such attachment through a malleable but relatively sturdy material and test the dynamics of how this works for a traditional student experiencing back pain.

The experiment consisted of a simple two-subject experiment in which the subjects wore backpacks with varying support levels ranging from minimal support to maximum support. Each experimental group consisted of three trials for measuring mean and standard deviation in seconds. Following the experiment, pairwise and multi-group statistical tests confirmed the statistical significance of the backpack with the most support. The results show that the backpack with the most support in the lower and middle back can increase the amount of time that the subject can hold the backpack without experiencing some sort of back pain. This is consistent with previous research that proves that increased support of the back and more points of contact can ensure a more comfortable fit that is ergonomically optimal and can potentially reduce back pain.

A steady and consistent improvement of the backpack can reduce the prevalence of backpacks specifically in America. By targeting specific points where the back deteriorates more and addressing the problem there, backpack designs can alter to both provide a comfortable and ergonomic design while maintaining the current fashion standard. All in all, this can help to reduce the back pain epidemic around the world primarily arising from backpacks.

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