BODY TO BACKPACK INTERFACE DESIGN GUIDELINES:

AN INTERDISCIPLINARY STUDY OF THE HUMAN BODY

by

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Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee.

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ABSTRACT

Backpacks are part of a class of load-carrying devices. With a wide of form and features, backpacks carry a variety of loads from school supplies and books, high alpine gear and survival gear, and numerous other articles. Despite the multiple applications backpacks are used in, a common denominator to all backpack systems is the human body of the end-user.

The human body is complex, intricate, and dynamic, with numerous unique structures and functions. Numerous resources deal with human body related information. From anatomy and physiology to ergonomics and biomechanics, individual disciplines will describe and prioritize elements of the human body differently. However, human body information is typically packaged and arranged to meet the requirements and demands of a particular discipline or application. This creates a literature and knowledge gap since few if any human body resources exist specifically for the Industrial Designer.

Designing new, innovative products is by no means an easy task. Designing for compatibility with the human body— especially for products worn on the body— is a massive challenge. The purposes of this study are: 1) to determine the level and scope of human body information an Industrial Designer should be aware of; 2) develop a cursory human body information package to be used by individuals with limited or no human body knowledge or experience; 3) create a series of design guidelines based on that human body information package; and 4) demonstrate the application of the design guidelines with a backpack concept package as an example.

Based on the findings of the literature review, the Industrial Designer should be more aware of the body at a conceptual level; focusing on elements from the combined neuromuscular-skeletal systems. Specifically, this design-centric information should address a limited number of particular anatomical features and identifying their significance/relation to product design and backpacks in particular. The developed reference package addresses basic orientation material, basic composition of the various anatomical systems, the particular anatomical features most relevant to backpack design, and key concepts to consider in addition to common conditions to prevent. The guidelines created include five guidelines for dealing with the human body in general, and five guidelines specific to backpack design. To streamline the use of this information, a series of forms were developed to enable quick tabulation of the required design elements for a backpack design.

The backpack concept design demonstrates the benefits of using with these human body design resources. First, designers can utilize human body information to create backpacks that are more compatible with the human body. Secondly, the guidelines help remove the guesswork attached to human body accommodation within the design process. Finally, the design resources help the designer quickly gauge the viability of a backpack design based on end-user and environment considerations. This allows the designer to then focus resources on prototyping, and refining designs with a higher degree of positive compatibility with the human body.

ACKNOWLEDGMENTS

'Luck' as the author has come to recognize it has to do with having the right skills and knowledge, at the right time and place, to address the right problem or opportunity. A combination of my personal upbringing, my interest and experiences within design, and a personal, work-related hip injury in 2013 are what spurred me to take on this study and gave me the skills to accomplish this task. In this pursuit I have been exceptionally lucky, especially because of the individuals involved throughout this thesis and its progression.

The author would first like to thank the committee members of this thesis. It was your collective support, dedication, and guidance that helped me understand the scale of the project I was undertaking, set the bounds, and produce the practical resources that designers can use to better understand and design for the human body.

To Professor, Tin-Man Lau, thank you for heading this study, helping me develop the initial concept of my thesis, and pushing me to consider and act upon opportunities I may not have previously considered. To Professor Bret H. Smith, thank you for your numerous insights and guidance throughout my undergraduate and graduate studies, your enthusiasm, and your support of this thesis and its potential within the design discipline. To Professor Rich Britnell, thank you for your support and feedback during the research and development phases, your continued mentorship, and the invaluable learning

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1. INTRODUCTION TO THE PROBLEM

‘Backpack’ is a commonly known term for a number of load-carrying systems. Also known as rucksacks, satchels, day-packs, book bags, and numerous other names, these systems are used to store and carry loads for the user, ranging from books to computers, clothing, survival gear, camping equipment, and various other items. Common design considerations for backpacks and related artifacts include overarching factors such as weight of the product, feel and strength of the material, breathability, heat entrapment, cost of production, and construction methods based on end use. More specific design considerations may address pocket layout and placement, fastener means, ease of adjustment, tool attachment points, and in certain cases sustainability, streamlining to reduce overall cumbersomeness, and color schemes for aesthetics or safety applications.

Henry Dreyfuss (2012) speaks of putting the needs of the user first, because “what we are working on is going to be ridden in, sat upon, looked at, talked into, activated, operated, or in some way used by people individually or en masse” (p. 23-24). This is exceptionally true with backpacks, which are physically carried on the body with one shoulder, both shoulders, with or without the aid of a pelvic/hip belt. However, recognizing the numerous design requirements and considerations, the various types of backpack, and the different scopes of use, one consideration is often overlooked with backpack design. That consideration is the common denominator of all backpacks and designed artifacts: the human body itself.

There are countless resources for information about the human body, for multiple disciplines and various levels of complexity. However, those without a background dealing with the human body in some manner (such as industrial designers) may often find it difficult to identify and understand important information about the human body. This creates a dilemma for designers, particularly those working on backpack or backpack type systems. In order to have design guidelines, designers must understand aspects of the human body that deal or interact with backpacks. However, no current resource is catered to designers to explain aspects of the body related to backpack design. Because of this, the designer has neither a framework or body of information to ensure human body considerations are satisfied within the design process.

With this in mind the discipline of Industrial Design requires two new backpack-related resources: 1) an introductory-level reference guide emphasizing basic knowledge of the human body pertaining to backpacks, and 2) an associated series of product design guidelines using that knowledge to create more human body compatible solutions. To accomplish this, the present study will investigate a selection of the existing human body resources currently available on the market, condense relevant aspects of that into a baseline of important concepts and features the designer should know when developing backpacks, and use that information to create a series of human body design guidelines for backpacks. The benefits of this study are two-fold. These resources will provide designers with human body information needed within the backpack design process. Additionally, the guidelines provide a framework of creating backpacks that complement the dynamic form, structure, and movements of the human for the benefit of the end-user. For the present study, only aspects of the able-bodied adult male and female will be explored, and as such will not currently address the issues associated with children, teenagers and young adults, geriatrics, and individuals with disabilities.

1.1- Statement of the Problem

Backpacks belong to a constantly evolving product family and marketplace, where an emphasis is often placed on lighter, more versatile, and comfortable designs. When points of friction develop between the end-user, the sequence of use, the system/ application in which the product is being used, and the products themselves the effect may be profound. In some cases this effect may be minimal such as minor irritation or pressure, or may be as severe as causing tears, sores, neuropathy, or other forms of bodily harm. When these friction points develop, the backpack may be discarded since the benefits of that backpack to the end-user are nullified by the negative effects. Instances where backpacks hinder mobility, propagate injury, or cease to remain comfortable can often be the result of an overloaded, ill-fitted, or incorrectly sized backpack. It can also be the result of a lack of human factors and human body consideration in the backpack design itself.

The former instance is easily addressed: often corrected by proper adjusting of the backpack, or through better training and materials for the end-user to better understand the product. The latter instance is far more difficult to rectify and is within the realm of the designer. It is the responsibility of the designer to create a solution that addresses such issues as incorrectly fitting garments, friction or pressure points, and the various human factors considerations. Those considerations include the body type of the user, the application that the backpack is intended to be used for/in, as well as the individual and global needs of the human body.

Unfortunately within the design realms of backpacks and body-worn load-carrying systems, there is often a trend placing the function of the article before user needs. This is especially recognizable in protective garment systems, where "currently designed equipment suffers from a detachment from the soldier. Because of this detachment, these designs do not fully succeed and allow the soldier to operate to the fullest potential of their abilities" (Parker, 2010, p. 16). Those particular systems are outside the scope of this study, yet illustrate how worn products sometimes place manufacturer or product needs above needs of the user and the user's body. Another non-beneficial trend is the mantra of 'one-size-fits-all,' where proper scaling and adaption of one design to fit multiple sizes and body types is less preferable than one standard size that reduces stock amount and manufacturing costs. Henry Dreyfuss summarizes these thought-processes in *Designing for People* (2012) as "the cart…. being put before the horse." Ultimately the products created with these though-processes cause pain or discomfort to the end-user, and have shorter than anticipated life-cycles accordingly.

The information reviewed for this study reveals unmet opportunities for improving the compatibility of backpack systems with the human body. Based on the previously mentioned scenarios, there are two clear and present needs for designers. There is a need to better understand the human bodies they design for, and a need for a series of guidelines illustrating how to apply that information to backpack design so incompatibility with the human body is proactively addressed.

1.2- Need for Study

For backpack design, there is a need for the Industrial Designer to 1) understand certain elements and concepts about the human body, and 2) have guidelines that frame the significance of those concepts with examples of how to apply that information for more human body compatible solutions. In order to advance the knowledge and resources for backpack design, the first step will be to establish a base of human body information catered to the designer for use by the designer. The next step is to create a series of design guidelines for backpacks, which highlight critical concepts and illustrate how to apply them.

As previously stated, there exist countless resources for human body information. For the designer, there needs to be practical knowledge stemming from differing disciplines. Anatomy, anthropometry, ergonomics, and biomechanics are of importance for the designer since:

- Anatomy describes features and composition of the human body.
- Anthropometry describes body segment lengths, measurements of the user population by percentile, and sometimes ranges of motion of the body.
- Ergonomics describes the application of anthropometric data and considerations for the human body in different scenarios.
- Biomechanics describes the complex relationship between the world that movement occurs in and the body (or body parts) that are moved, and how body-generated forces alter based on build, fitness, and other factors.

Regarding anthropometry and ergonomics, a number of resources provide excellent information regarding user percentiles, procedures for conducting anthropometric studies, and ergonomics considerations (*Military Handbook Anthropometry of U.S. Military*

Personnel, 1991; Pheasant, 1996; Tilley, 2002). Anatomy and biomechanical resources by comparison are numerous and diverse in scope and application. Anatomical resources range in complexity from simple to exceptionally detailed (*Flash Paks*, 1990; Gray, Pick, & Howden, 1974; Kahle, Leonhardt, & Platzer, 1992; Kapandji, 1987; Kapit & Elson, 1977). Biomechanical resources also range from simple in application to in-depth and detailed (Enoka, 1994; Hamilton, Weimar, & Luttgens, 2008; Winter, 2009) with quite a number of backpack specific studies available (Sumner, 2012, pp. 1-14).

On top of this, there are cases of specialized information that overlap two or more of the subjects mentioned, such as neuroanatomy, trigger points, elements of acupuncture, and biomechanics of specific structures (AMA Guides, 1993; Bonica, 1990; Frankel & Nordin, 1980; Manter, 1958; Simons, Travell, & Simons, 1999; Travell & Simons, 1983). To paint a complete picture of the human body, a number of sources are needed as there is no single, one stop reference resource. This is understandable since such a resource would be massive in scope and detail, and well outside the means of a single discipline to produce or maintain.

This is when the Industrial Designer's needs become apparent, as the designer commonly has no experience with human body information. To gain a basic and generalized understanding of the body requires various resources from different disciplines which quickly add up. This easily and quite rapidly results in information overload for the designer, given the multitude of resources to draw from (see Fig. 1.1). This lack of an information resource compounds the problem of designing human body compatible backpacks. Even if the designer is able to obtain a baseline understanding of the human body, the designer currently has no framework of application for that

Fig. 1.1: Two-thirds of this study's literary research sources (24in. ruler as scale ref.)

information within product design. In essence it is a mutually dependent dilemma: where both the theory and application means for designing human body compatible backpacks are missing, and must be simultaneously developed based on human body information specific to the Industrial Designer's needs.

1.3- Statement of Purpose

The purpose of this study is to develop a guidelines and human body information package for industrial designers. These will be used for the designing of backpacks with improved body-to-backpack interface compatibility compared to existing solutions. Recognizing that one cannot be created without the other, the foci for the human body information segment will:

1. Review common, introductory-focused resources pertaining to the human body in anatomy, anthropometry, ergonomics, and biomechanics. Additional resources from different disciplines and focuses will be added as needed.
2. Collate such information as needed for designers to have a cursory understanding of the body and related principles:
   - Address the basic terminologies and principles of human body information so designers can understand and communicate with experts and specialists as best as possible. Essentially, this information will act as a thesaurus for designers when speaking to human body experts.
   - Address certain specifics and features of the human body that are directly impacted or influenced by backpacks.

Regarding the design guidelines for improved body interface with backpacks, this study will:

1. Use the findings of the human body information for backpacks to format generalized and backpack specific guidelines.
   - As there are general truths to consider when designing for the human body and for backpack specific designs respectively, it is advantageous to have guidelines for both. This permits the specialized guides to benefit and build off the generalized ones, which are important in their own right. By having

both, the overarching needs of the body as a whole and for the specific components and features involved with backpacks can be met.

  - The guidelines will use a format of 1) a statement of the guideline, 2) the significance of the guideline to backpack design, and 3) examples of that guideline in existing practice as a frame of reference.

2. Demonstrate the use and application of the guidelines with a design concept package illustrating the benefits of the new design for the end-user.
   - This design concept package will include 2D sketches, renderings, and illustrations to communicate the use of the guidelines.

1.4- Definition of Terms

ANATOMY- “A branch of morphology that deals with the structure of organisms” (Merriam-Webster, n.d.); in this instance it regards to the study of the human body by breaking it down into separate parts for analysis.

ANTHROPOMETRY- the measurements of the body, its subsequent parts, and the ranges of motion thereof. When compared to biomechanics and anatomy, anthropometry falls within the realm of studying the human body with quantifiable data.

BIOMECHANICS- the mechanics of biological and especially muscular activity (as in locomotion or exercise); also : the scientific study of this” (Merriam-Webster, n.d.). Specifically, the study and understanding on how the muscles of the human body are placed, function, and move.

ERGONOMICS- “an applied science concerned with the characteristics of people that need to be considered in designing things that they use in order that people and things will interact most effectively and safely" (Merriam-Webster, n.d.). For the purposes of this study, this will pertain to the physical rather than cognitive elements of ergonomics.

HUMAN BODY INFORMATION- For the purposes of this study, the collective information concerning the anatomy, physiology, anthropometry, ergonomics, and biomechanics of the human body.

PHYSIOLOGY- "a branch of biology that deals with the functions and activities of life or of living matter (as organs, tissues, or cells) and of the physical and chemical phenomena involved" (Merriam-Webster, n.d.).

1.5- Assumptions

For this study, it is determined there is a clear and present need for two new resources for the designer of backpacks. One of those needs is a resource highlighting important anatomical structures and their significance to backpack to body interface. The other needs is a set of design guidelines to be used to ensure the interface between backpack and human body is optimized.

For the information resource, it is assumed that this resource includes reference material illustrating and communicating components and functions of the neuromuscular-skeletal system of significance for backpack devices. Such knowledge is presumed to be important for understanding the human body at a generalized, basic level within the design process.

For the body to backpack interface design guidelines, it is assumed this resource is of value to the designer, as the present study has not found or identified an existing source of design guidelines. With a wealth of existing backpacks and related literature, it is assumed that no backpack— past or present— was purposely designed, refined, and subsequently marketed with the intent of being problematic or counter-productive to the end-user. Any such less-than-beneficial end result is assumed to be attributed a miscalculation or misunderstanding of some kind on the part of the designer, including but not limited to the human body's anatomy and physiology. It is assumed the body to backpack design guidelines will address the majority of these shortcomings in the current design process.

For this study, data and information from secondary sources, such as scholarly journals, books, magazines, government and civilian documents, test procedures, the Internet, and software packages available for purchase will be used. It will be assumed that any such material referenced and cited within this study is factual, accurate, and presented in as non-biased a manner as possible. It will also be understood that the authors of such studies and resources are experts within their respective fields and as such are credible individuals.

1.6- Scope and Limits

In terms of impact, the findings of this study may influence the lives of many users from all walks and stages of life. This is anticipated since backpacks are a commonly known and used means of load-carrying. As such, this thesis study will focus on and address the human body information and design guideline needs for backpacks. Specifically, the focus will address factors ensuring the interface created between the backpack and the user is optimized to compliment or augment the human body. A focus on the direct interface between body and backpack is emphasized, as this includes the sites of physical interaction and influence. The current focus addresses these factors so as to help prevent injury and restriction of movement. This includes structural elements of backpacks, their physical form as influenced by the needs of the body, and their organization and placement within a backpack system.

Given the vast scope of human body material and the numerous user-types, the present study will only address elements from the neuromuscular-skeletal systems of the adult male and female bodies at a cursory level of detail. This is primarily done as the majority of anatomical features and functions critical to backpacks belong to those systems. The additional information pertaining to the human body will include cursory elements of anthropometry, biomechanics, and physical ergonomics. Further, the study will be conducted at a layman's level of detail, allowing designers or related personnel to gain a practical understanding of the human body so as to conduct their work on backpack designs.

The design guidelines produced will fall into two categories: general and specific. 'General' guidelines may be taken as rules for any design application involving the human body as a whole. 'Specific' guidelines are refined versions of the 'general' guides, and deal with specific needs or concepts that backpack designs should address. It should be stated that all guidelines created by this study are important in their own right, and should collectively and completely be applied in backpack design. For the sake of conciseness, no more than five guidelines for each category will be developed. This way the designer is not over-burdened with an excessive list of guidelines to memorize or apply. For illustration purposes, examples of existing backpacks demonstrating both good and poor application of each guideline will be included.

The main limits of this study are as follows:

- The concept package demonstrating use of the guides is limited to two-dimensional deliverables. It will need prototyping and further development to become a testable piece of equipment.
- Time: the bulk of this study was conducted over a fourteen-month period spread over the course of five academic semesters (summer of 2015 to spring of 2016, and from fall 2016 through spring of 2017). All experimentation, research, and implementation took place during this span.
- Access to financial data: A complete picture of the current state of the backpack market is limited for this study due to the financial cost associated with those reports.

1.7- Procedures and Methods

Procedure One:

Research existing human body information resources: orientation material.

Method: Research and identify common terms or definitions for describing the human body, its components, and its movements.

Analyze and collate findings.

Procedure Two:

Research existing human body information resources: for backpacks.

Method: Research and identify critical concepts and facts about the human body and its parts that interact/interface with the human body.

Analyze and collate findings. Identify the significances of this information, draw initial conclusions.

Procedure Three:

Research the types of backpack currently on the market.

Method: Research, in brief, the history of backpack design, the distinctions between types, and identify the modifications/advances between major iterations.

Analyze and collate findings. Identify the significances of this information, draw initial conclusions. The combined findings of procedure one through three will form the basis of the human body information packet for backpack design.

Procedure Four:

Review and refine initial conclusions of the research to identify general truths to consider when designing for the human body.

Method: Create a series of generalized design guidelines to be used when designing for the human body (preferably no more than five in total). Include considerations as to the significance of the guideline, and examples (both positive and negative) of that guideline in practice pertaining to backpacks.

Procedure Five:

Review and refine initial conclusions of the research to identify specific truths to consider when designing backpacks for the human body.

Method: Create a series of specific design guidelines to be used when designing backpacks for the human body (preferably no more than five in total). Include considerations as to the significance of the guideline, and examples (both positive and negative) of that guideline in practice pertaining to backpacks.

Procedure Six:

Apply the guidelines to a specific backpack design application.

Method: Present an application of the guidelines by developing a backpack design. Address each of the guidelines in turn and the needs of the human body identified by the human body information packet for backpack design.

1.8- Anticipated Outcomes

The primary anticipated outcomes of this study are as follows. First, this study aims to collate and produce a brief reference guide introducing designers the human body for a specific design application. From the information gathered on topics of anatomy, anthropometry, biomechanics, and ergonomics, the designer will have cursory knowledge of common terminology and principles regarding those subject matters. Additionally, the guidelines and related resources will inform designers working on backpacks or backpack systems of the critical concepts and areas of the body that need to be protected and accommodated.

Secondly, this study aims to produce design guidelines based on human body needs and information for use in backpack design. It is supposed that with these guidelines backpacks can be designed to have a higher degree of compatibility with the human body. This not only increases the benefits for the end-user, but provides a framework for using relatively static figures of human body information to address the dynamic needs of the human body within the design process for real-world application. Further, they establish the groundwork for future guidelines based on human body information for different design applications.

2. LITERATURE REVIEW

For the benefit of the reader and for the purpose of clarity, the literature review will be subdivided based on subject matter.

Section 2A will summarize the field and application of backpack systems and the need for human body centered information and design guidelines for backpack designers. Section 2B will summarize the types of human body information disciplines needed for the designer as well as basic orientation concepts and terminology. Section 2C will investigate and address the important human body information to consider when designing backpacks, specifically for an optimized body-to-pack interface. Section 2D addresses some of the differences between men and women to consider for backpack design. Additionally, considerations for elements of the backpack involved with the interface with the body are addressed. Finally, Section 2E will summarize the pertinent findings of the literature to the present study.

2A- Backpacks: A Growing Field With Specific Applications and Needs

2A.1- The Lucrative Market of Backpack Artifacts

The production of soft good products for use by human users is not a new concept. According to Merriam-Webster (2015) soft goods are “goods that are not durable —used especially of textile products;” the first use of which is dated back to 1833. Ranging from simplistic animal hides of pre-historic periods through the complex moisture wicking fabrics used in modern cyclist and exercise garments, wearable soft goods are constantly evolving to help address human needs. And with all of their variations, soft goods as a field generate a large amount of revenue.

Fig. 2A.1: Outdoor products trade show

‘Apparel Market in the U.S.’ (“U.S. Apparel Industry - Statistics & Facts | Statista,” 2013) establishes the apparel market in the United States as “the largest in the world, comprising about 28 percent of the global total and [having] a market value of about 331 billion U.S. dollars.” This is a subcategory of the soft good market, indicating that soft goods as a whole are a great business concern. Another sub-category of the soft goods market is backpacks and backpack-like soft goods. This particular category is exceptionally wide, ranging from outdoor applications to military to school and business oriented goals. Bruce Horovitz (2007) in “Backpacks: A new ‘badge’ of cool,” states:

> Backpacks, which began emerging as an accessory for high school students in the 1980s, have become a $2 billion business with double-digit growth. And they’re everywhere: 58% of consumers own backpacks, with 61% of the packs bought on impulse, according to a JanSport survey. About half of sales come in the back-to-school third quarter.

The true financial impact of this field is difficult to establish due to the fees associated with such market reports: Research and Markets (2015a) charges $2,500 for a single file download, ResearchMoz (2014) charges $2,200 per download, and Transparency Market Research (2016) charges an astounding $5,795 per download. Despite this downside, available research suggests that backpacks and related soft goods are a continuously growing and lucrative market. What can be determined is the average going price for a backpack. Referencing an Amazon search for Osprey backpacks— a maker of outdoor backpacks— (Osprey Backpacks Search, n.d.) the unit price ranges between $45 through $310 apiece, depending on specific use and features. Horovitz (2007) shows that some can range from “[t]he simple, $15 packs with two zippered pockets” to “uber-cool $695 limited edition with a solar panel to charge iPods and cellphones.” Thus backpacks in all their forms can be a substantial form of revenue for designers and the companies they work for.

2A.2- Backpacks: A Brief History

Backpacks as a family of products have evolved greatly over the more recent centuries. The article “External Frame Backpacks – Applying the Old Ways to the New Journeys” (Kittner, 2012) briefly addresses this history and notable developments in backpack design. Kittner (2012) explained the rationale of exploring backpack history: “I believe that at the very least learning about old ways can provide us with food for thought, a comparison to our new directions and if necessary can inform any necessary adjustments to our course and design thinking” (para. 2).

Internal frame backpack designs are almost forty-years old (at the time of this study— 2017) whereas external frames date back almost fifty-three centuries to the time of Őtzi, a shepherd who “walked the Italo-Austrian Alps 5300 years ago” (Kittner, 2012, para. 6). These frames, little more than a series of sticks lashed together with rudimentary straps, provided a common means of load-carrying that have been documented in most of the world. In what is modern Norwegian they were known as ‘hjuringsmeis’, in Russia

Fig. 2A.2: Őtzi load carrying structure- multiple views as “ponyaga,” and, while no name is mentioned, were used by the First Nations of the Americas (paras. 8, 10, 21).

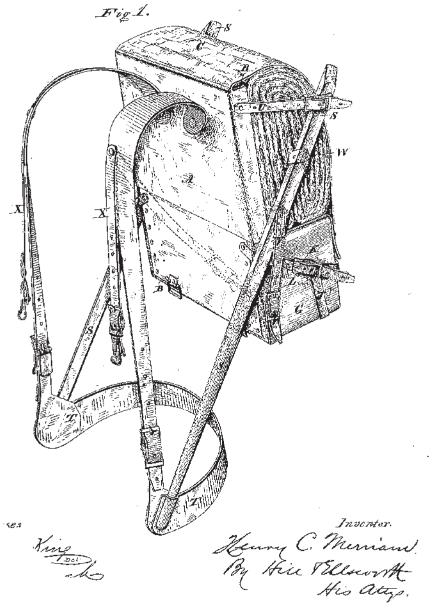


Fig. 2A.3: Figure 1- No. 204,066- Merriam

This arrangement would form the majority of all external-frame designs up to about 1886 with Colonel Henry C. Merriam’s external frame design. This particular pack included provisions for a belt that could rest the frame above the buttocks of the wearer. This “reduced the pressure from the traditional crossed shoulder straps which typically caused pain to the chest on marches” (para. 26). Building off this iteration was Ole F. Bergan’s metal frame backpack (Patent Number 20547) in 1909 (para. 27). This design in particular would form the basis of external frame backpacks and packboards up till 1952. Kittner (2012) explains its significance from a design perspective:

> Ole F. Bergans believed that a backpack should be shaped according to a persons [sic] shape and height and should follow the form of the body. So using light tubular steel Ole F. Bergans bent a simple structure to follow the shape

> of the human back. The light tubular steel structure also made the pack more comfortable to carry as it prevented any awkwardly packed harder objects from making contact with the user's back. (para. 27)

Fig. 2A.4: Back Profile *[Bergans Original 57106 rucksack]*

In 1952, Asher "Dick" Kelty and his wife Nena started Kelty Packs from their garage in Glendale, California. Kittner remarks this event is responsible for "the biggest leap in backpack development" since the husband and wife team was "not only one of the first to produce and market external-frame back packs specifically for civilian use, but Kelty is also considered to be the inventor of the rectangular aluminum framed backpack, the hip belt, using nylon, adding zippers to the pack pockets and the padded shoulder straps" (para. 36). Kittner (2012) cites the Kelty Pack website for the various initial innovations that were present in this new design.

> In 1952… Kelty packs first include aircraft-aluminum contoured frames, padded shoulder straps, hip belts, clevis-pin attachment of pack bags, nylon pack cloth, zippered pockets, hold-open frames, and nylon back bands. The first shoulder straps were produced using wool carpeting for padding. The original clevis pins were made from aircraft rivets. (para. 37).

Fig. 2A.5: Kelty Model A External Frame Pack (note hip belt at bottom)

Looking forward to the 1960's, it is easy to see how the US All-Purpose Lightweight Individual Carrying Equipment (A.L.I.C.E) pack owes its lineage to the first Kelty pack (para. 41). From the 60's onward, most innovation in external frame backpacks involved material selections of polymers from the Modular Lightweight Load Carrying Equipment (M.O.L.L.E.) frame to the carbon fiber Kuiu Icon Backpack system (paras. 41, 45).

The internal frame backpack by comparison is a relatively new invention whose origin is potentially contended on two different continents. According to the heritage page of Lowepro.com, the first internal frame pack was created by the climber and photographer Greg Lowe in his garage in Colorado in 1967. “This breakthrough design innovation helped packs fit close to the back and minimize load shifting – so gear-wearing adventurers can climb, bike, ski and scramble with more ease” (“Lowepro | Heritage of Design,” n.d.).

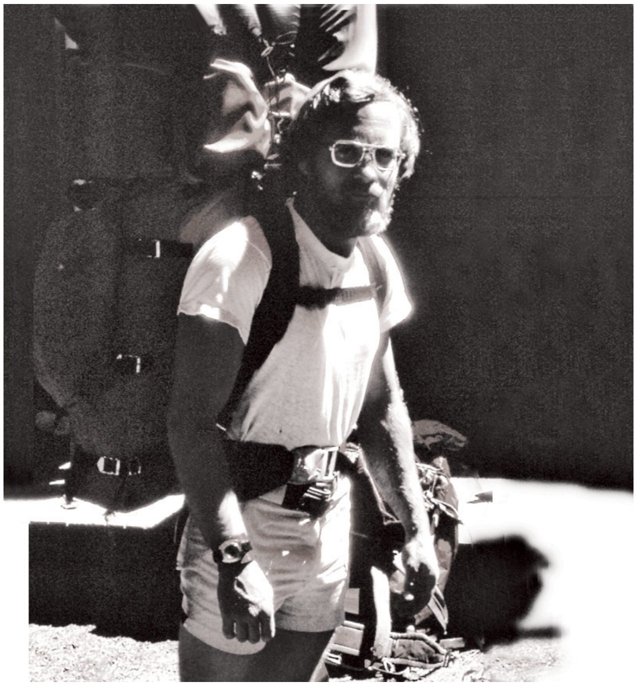


Fig. 2A.6: Greg Lowe and his internal frame backpack, 1967

The second to claim origin of the internal frame backpack is the outdoor company Berghaus, of the United Kingdom. Their heritage page states: “with its internal frame – arguably the first rucksack to have one – plus extra padding, the Cyclops was a hugely popular rucksack” although they document its release in 1972, almost five years after Lowe (Rucksack History, n.d.).

To address the issue of heat buildup characteristic of internal frame backpacks, Deuter of Augsburg-Oberhausen, Germany, developed Aircomfort (About Deuter, n.d.). Deuter Aircomfort, which a history of the company video explains the patent was filed in 1984 and issued in 1987, comprised a flexible spring steel frame inside the pack body with a mesh panel secured to the frame on the outside (Busch, 1987; Deuter, 2013). This mesh "forms a ventilation space between the wearer's back and backpack, allowing moist air to escape from three sides" (Deuter, 2013).

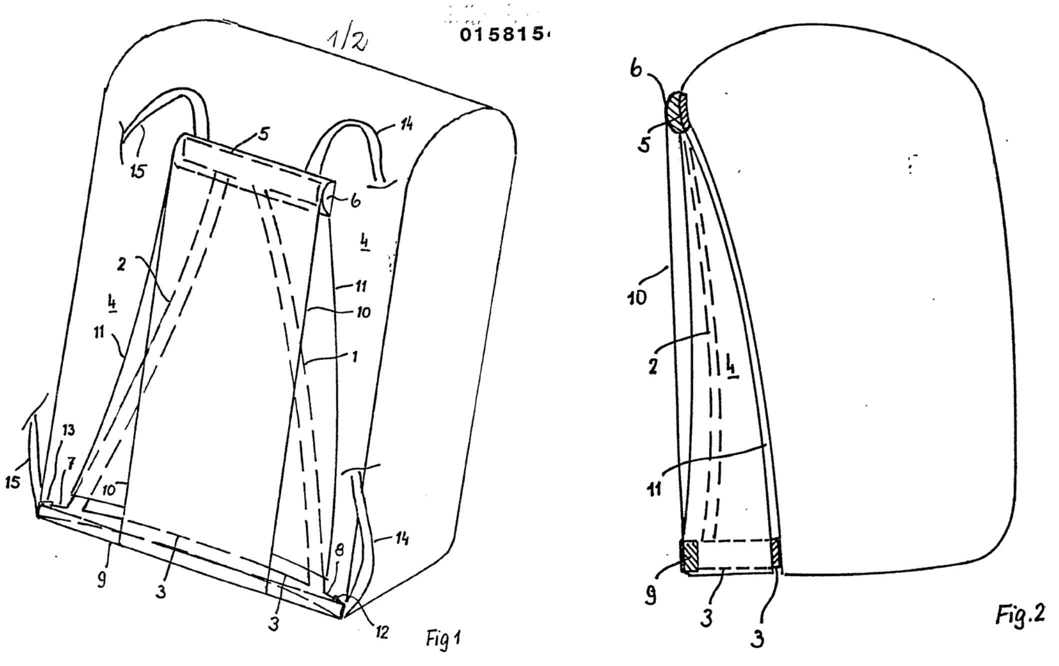


Fig. 2A.7: Patent Drawings- DE8410842U1

This again is but a cursory overview of the evolutionary path backpacks (both external and internal) have taken. Most advances in backpack design may be reflective of an advancement in materials manufacture, permitting the creation of lighter packs (some of which enable a higher load capacity). Combined with an increased emphasis of creating designs reducing the negative impact of the pack on the body of the user, the field of backpack and backpack-type systems has continued to grow.

2A.3- Scope of the Current Backpack Field

Fig. 2A.8: Lumbar day-pack

Fig. 2A.9: Hiking packs in use

The scope of applications for backpacks is enormous. Backpacks can be used to carry books and school supplies (Horovitz, 2007), carry small loads and hydration carriers (Transparency Market Research, n.d.), hiking and outdoor applications (Research and Markets, 2015b), and military use (Mansoor et al., 2012; Öz et al., 2010). Concerning outdoor and hiking applications, the article Global Outdoor Backpacks Market 2015-2019 (Research and Markets, 2015b) addresses common applications and scope of outdoor backpacks:

Fig. 2A.10: Assortment of light-use hiking backpacks

> Outdoor backpacks are mainly used by those who are engaged in outdoor recreational activities such as camping, hiking, and trekking. A diverse range of outdoor backpacks is available in the market, and they vary in size, insulation, design, material, temperature ratings, and various other parameters. Factors that play a key role in choosing outdoor backpacks include length of trips and types of activities.

One feature that permits such diversity is a backpack's structural elements. Depending on placement and composition, these structural elements are known either as an external frame or an internal frame (Kittner, 2012). Though Kittner (2012) introduced the basic elements of the different backpack setups, there are benefits specific to both.

External frame backpacks ("Backpack | The Hiking Life," n.d.; "Internal vs External Frame Backpacks," n.d.; Werner, 2014) typically comprise:

- A solid frame (usually aluminum) upon which a carrying bag is attached.
- Ample ventilation
- Promotes upright posture
- Designed to carry heavy loads (50-100lbs on average)

Fig. 2A.11: Example of an external frame backpack

Internal frames (“Backpack | The Hiking Life,” n.d.; “Internal vs External Frame Backpacks,” n.d.; Werner, 2014) comprise:

- A sewn body with internal, integrated frame (typically a rigid plastic insert) for structure.
- Greater inner storage compared to external frame packs
- Greater form fitting, compact design
- Designed ideally to carry light to medium loads (0-50lbs on average)

Fig. 2A.12: Example of an internal frame backpack

2A.4- The Impact of Backpacks on the User

For all the benefits that backpack systems can bring to users, there are still times when the use of backpacks can result in physical harm. Injuries such as bruising or skin ulceration (Kray, n.d; Reddy, 1986), spinal disc herniation or compression (Neuschwander et al., 2010), and backpack or ‘rucksack’ palsy (Mansoor et al., 2012; Öz et al., 2010; Yager, 2013) are of major concern for backpack designers and the users. Luckily, the majority of these conditions and injuries are preventable through proper sizing and adjustment of the backpack to the specific end-user, proper backpack selection for the task at hand, and reducing the weight of the pack (Öz et al., 2010). This is of significance to the industrial designer in particular, since these considerations for sizing, task application, and selecting a suitable load capacity are within the parameters of the design process.

To better understand the effects of backpacks and other load-carrying systems on the human body, numerous studies have been conducted. Some of these tests and studies include evaluation and ranking methods for backpack performance with the human body (Bryant, Doan, Stevenson, Pelot & Reid, 2001), load carry studies (Dean, 2008; LaFiandra & Harman, 2004; Martin & Hooper, 2000), postural analysis in response to backpack-type systems (Grimmer, Dansie, Milanese, Pirunsan & Trott, 2002; Keyserling, 1986; Knapik, Harman, & Reynolds, 2004), and other military-focused studies and documents (Knapik, Reynolds, & Harman, 2004; U.S. Department of Defense*,* 1991). The report “*The Modern Warrior’s Combat Load”* (Dean, 2008) is particularly interesting since it makes for the recommendation that backpacks (when worn in conjunction with other combat and protective gear) be limited in weight to seventy-two lbs. This report and others like it show injury and discomfort implications of backpacks are a serious concern to governing bodies and that there is a proactive effort to address them.

This sample of the resources available reveals another noteworthy element. The majority of the aforementioned resources and studies share at least one of two commonalities: they 1) have some affiliation with a military application, and 2) are biomechanical in nature or scope. The military aspect is easily explained: a large percentage of the existing anthropometric data for the human body is military in origin (U.S. Department of Defense*,* 1991; Pheasant, 1996) and research-funding for improving military equipment is well-established. On the second point, the biomechanical nature revolving around the aforementioned resources brings the focus of this study into light. Most if not all of the information pertaining to backpack studies involve a hard science discipline (such as biomechanics, anatomy, or kinesiology) addressing the human body.

2A.5- Initial Summary of the Problem(s)

The Industrial Designer is a crucial figure within the design process for backpacks. Generally speaking, however, a disconnect exists between the more artistically focused designer and the hard-science generated human body information available. This is significant as the Industrial Designer is not trained in these hard sciences and has little to no working knowledge of the human body accordingly. Further, the findings from these studies explain the ‘what’ and ‘why’ needed in backpack design, but do not address application of that information within a design process. These two compounding hurdles make it exceptionally difficult for the average designer to adequately accommodate the needs of the body within the design process of specific products such as backpacks.

Given the great influence backpack systems can have on the human body, it is desirable to address these hurdles by catering a selection of human body information to designers and pair it with application-focused design guidelines. With these two resources, designers will better understand what elements and concepts of the human body are critical to applications such as backpack design. Further, it provides them with a framework to repeatably and consistently apply that information within the backpack design process.

2B- The Need for Human Body Information in Backpack Design

2B.1- Henry Dreyfuss: Proponent for Human Factors in Design

One of the best known and influential designers in the United States, Henry Dreyfuss emphasized a focus on designing for the user. In *Designing for People,* he says “we all know that a machine-made commodity can be awkward or handy, ugly or beautiful. Industrial design is a means of making sure the machine creates attractive commodities that work better because they are designed to work better. It is coincidental, but equally important, that they sell better” (Dreyfuss, 2012, p. 22). He also states that the within the history of the design field, the “real job” of the designer begins with “dissecting the product, seeing what made it tick, and devising a way to make it tick better- then making it look better” (p. 23).

Aside from the argument of whether form follows function, this statement applies to more than just the physical product. “We begin with men and women and we end with them. We consider the potential user- habits, physical dimensions, and psychological impulses” (Dreyfuss, 2012). Thus, if the designer’s job begins when he/she sets forth to gain knowledge about what the product is and how it works, then by extension (since the designer creates products for people) the designer should have knowledge about the people the product is being designed for. This question then creates a potential stumbling point: what is the scope of information the designer learn about the human body.

Creating and improving designs while emphasizing human factors within those designs, has been a major consideration within the discipline of Industrial Design, especially since the mid-20th century when Henry Dreyfuss coined the term ‘designing for people' (Lupton, 2014, p. 6). Unfortunately, this is not always true. Sometimes, as Dreyfuss (2012) comments "I felt {feel} the cart was being put before the horse" (p. 18). An example in which this 'cart before the horse' method of design can be seen is in products where the outcome of "the core of the designs focused solely around the function of the equipment and not the individual user. (Parker, 2010, p 10)" Or, as Lupton (2014) asks, "Isn't all design centered around users? No. In fact, the forces that drive product development range from the short-term economic interests of manufacturers to the expressive or theoretical intent of designers to a community's entrenched habits and customs" (p. 21). In simplistic terms, this 'function first, user second' method is not in the best interests of the designer, manufacturer, or the end-user, yet frequently ends up being the approach used by one of those entities for one reason or another.

Factors of the human body considerations should always be in the forefront of the design process of the product being developed. Especially considering that if a product interacts well with a human user, that product will typically not cause undue hardship or aggravation. Without consideration of these factors, the end product is quite often doomed to customer dissatisfaction, or, in the worst case, the user ceases to use the product. "What we are working on is going to be ridden in, sat upon, looked at, talked into, activated, operated, or in some way used by people individually or en masse" (Dreyfuss, 2012, p. 23-24). Dreyfuss further illustrates this point of improving the end design of a product:

> The way to improve merchandise, I said, was to work directly with the manufacturers to learn what machinery and materials were available rather than second-guess after the manufacturers had finished their costly job… A

> fundamental premise was involved in my refusal- one from which I have never retreated. An honest job of design should flow from the inside out, not from the outside in (p. 18).

This element— or rather consideration— of human body factors applies to all artifacts. It is especially important to backpacks because of the frequency with which backpacks come into contact with people. It is vital that the factors and considerations of the human body that the product are designed for are followed.

> If the point of contact between the product and the people becomes a point of friction, then the industrial designer has failed. If, on the other hand, people are made safer, more comfortable, more eager to purchase, more efficient— or just plain happier— the designer has succeeded (Dreyfuss, 2012, p. 24).

2B.2- Interdisciplinary Resources for the Designer

There are various available resources that can be used to justify design considerations. As it will become apparent, there is a great deal of interconnectivity between various fields of study regarding both the information and its application. As relates to this study, such fields of endeavor and information include anthropometry, ergonomics, biomechanics, and human body information such as anatomy and physiology. This combination of resources is selected as the information addressed by these disciplines describes and meets various needs of the human body. Further, this combination enables designers to practice Dreyfuss' human based design philosophy of "fitting the machine to the man rather than the man to the machine" (Lupton, 2014, p. 24).

2B.2.1- Anthropometry

A number of texts relating to the human body for the design and production of products have been written. *The Measure of Man* (Dreyfuss, 1968) and its successor *The Measure of Man and Woman* (Tilley, 2002) contain the anthropometric drawings ‘Joe’ and ‘Josephine,’ a culmination of the work Dreyfuss (with illustrations by Alvin R. Tilley) and his associates did to bring human body knowledge to the design profession. It has been noted Tilley found the measurements information to create his series of drawings by studying military anthropometric data for men’s figures and the fashion industry for women’s figures (Lupton, 2014). Lupton continues describes the foundation off which these texts were developed:

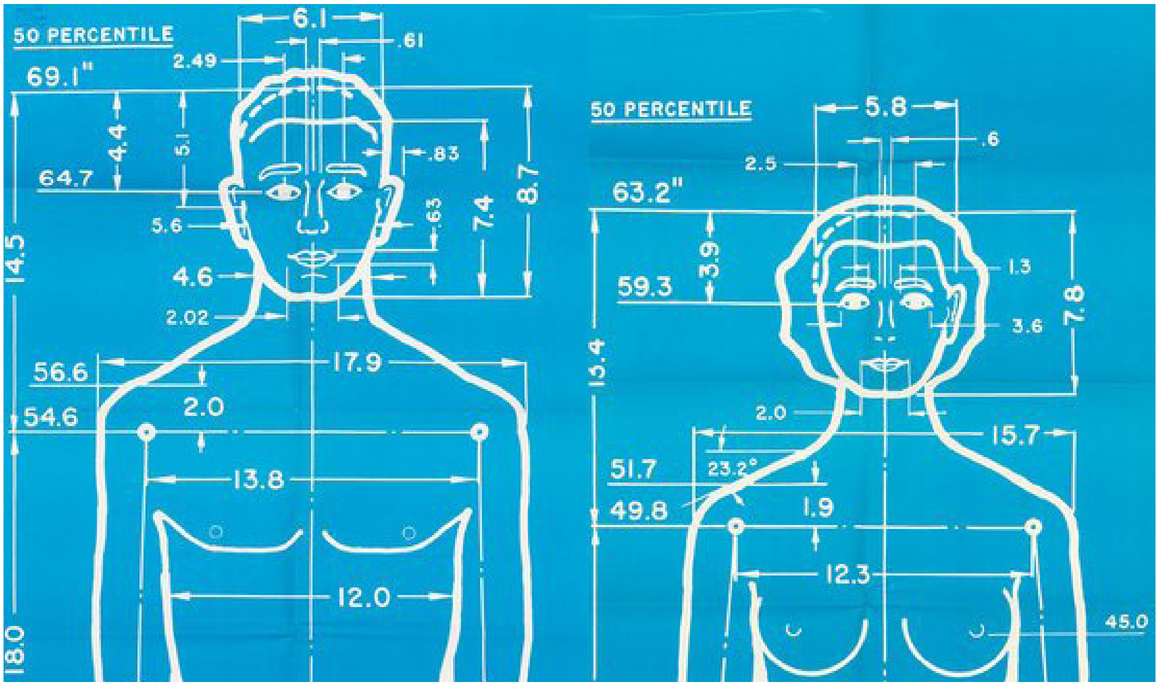


Fig. 2B.1: “Joe and Josephine” from Measure of Man

> *The Measure of Man,* which enabled designers to create products that fit average

> bodies with a greater degree of comfort, built on the international standards movement that took shape in the 1910s. The standards movement was concerned with improving efficiency in design and manufacturing more than with enhancing comfort. Measuring human movement and anatomy (ANTHROPOMETRY) was a key component to Taylorization, which employed time-and-motion studies to maximize the productivity of factory workers (p. 24).

2B.2.2- Anthropometry, Brought to You by the U.S. Armed Forces

It wasn't until the late 1940's that a vested interest in combining human factors into design project was prioritized. According to the *Military Handbook Anthropometry of U.S. Military Personnel* (U.S. Department of Defense, 1991):

> A major anthropometric survey of U.S. Army personnel was carried out by the Quartermaster Corps in 1946 at the end of the Second World War… This was the first extensive Army anthropometric survey to be conducted primarily to provide body size information for the design, sizing, and tariffing of military clothing and personal equipment (p. 21).

This is not to say this was the first time that an anthropometric study of soldiers has been conducted: evidence exists some studies can date back to the American Civil War and World War One (U.S. Department of Defense, 1991). Thus, anthropometry is not a "new or recent development," and has been revitalized numerous times throughout history to serve the needs of the military establishment (U.S. Department of Defense, p. 18).

The basis of the anthropometric data used immediately following the Second World War has its roots in studies done by the United States Army Air Force, as described by the *Military Handbook Anthropometry of U.S. Military Personnel* (U.S. Department of Defense, 1991):

> Both men and women were measured as early as 1942 and the anthropometric data were utilized in human engineering. Following the end of World War II, the collection, analysis, and applications of anthropometric data have been carried on as an integral part of military research and development programs, and anthropometry has become a recognized part of human factors engineering. As a result, a great deal of body size information has been amassed on the military personnel of the United States, both men and women (p. 18).

Accordingly, the details pertaining to these early studies were very much focused on designing components for military aircraft. The first, a study of cadets and gunners, took anthropometric measurements of "2,961 Army Air Force cadets and 584 gunners, primarily for the purpose of developing design and sizing parameters for aircraft

Fig. 2B.2: Assembling Emerson top aerial gun turret gun turrets" (U.S. Department of Defense, p. 34).The second survey documented the anthropometric data of "447 Women Army Service pilots (WASP) and 152 Army Air Forces flying nurses" (p. 34). Information pertaining to these two surveys may be found in ADB807323, or *Human Body Size in Military Aircraft and Personal Equipment* (Randall, Damon, Benton, & Patt, 1946).

Following 1942, an emphasis was placed on continued human factor considerations for the design of military equipment, and anthropometry became a standardized, scientific method of obtaining verifiable data on human body measurements. Out of subsequent studies, the *Military Handbook Anthropometry* details roughly fifteen to twenty surveys and studies between 1942 and 1970. These studies subsequently saw the creation of the uniforms and personal gear which saw the U.S. military through the latter half of the 20th Century (U.S. Department of Defense, 1991). The document also identifies the intents and purposes of these armed forces studies as well as some of the medium's shortcomings:

> Knowledge of body size and proportions is essential for the design, sizing, and tariffing of military clothing, protective, and personal equipment. Of even greater importance is the fact that anthropometric data are required as a basic input in the human factors engineering of military equipment systems: aircraft, vehicles, tanks, submarines, and many other types of weapons systems (p. 18).

2B.2.3- Limitations of Anthropometry Data for the Human Body

The greatest downside to the majority of anthropometric data is few organizations outside government agencies and bodies such as the military have the resources to conduct full-scale studies (Pheasant, 1996). As a result, Pheasant states:

> [we] have extensive and detailed anthropometric data for many of the world's armed services; but relatively few data [sic] for the civilian populations from whom they were recruited and of whom they may or may not be representative samples (p. 27).

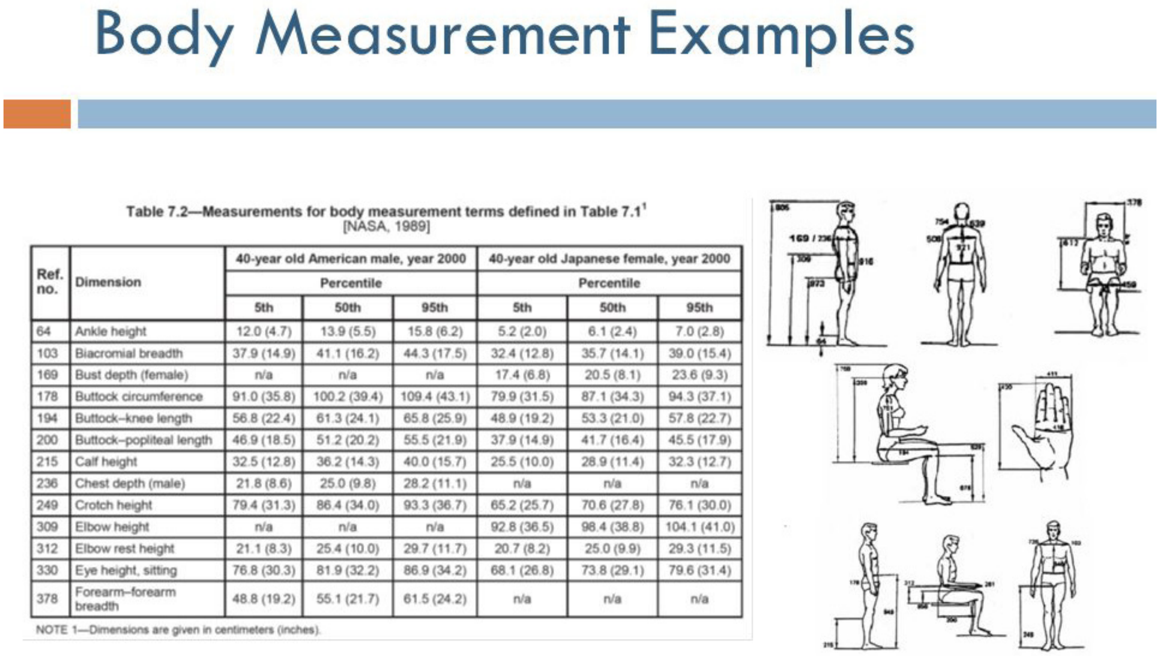
Concurrently, the *Military Handbook Anthropometry of U.S. Military Personnel* (1991) states:

> The importance and relevance of military anthropometric data is emphasized by the lack of adequate and definitive data on the U.S. civilian population of men and women. This paucity of civilian data presents a serious problem for designers and human engineers who, in many cases, are forced to resort to the use of anthropometric data on the U.S. military population. Due to the lack of civilian data, there is no alternative. As one example, there are still virtually no adequate anthropometric data available on the heads and faces or on the hands and feet of the U.S. civilian population (p. 18).

Pheasant (1996) continues that there are two ways to address this disparity of information. The first is to use "the purist approach and only quote sources of unimpeachable accuracy" or to "fill in the gaps…using various rule-of-thumb methods of estimations (and a certain amount of informed guesswork)" (p. 27).

2B.2.3.1- Clothing Correction

One of the greatest causes of faulty or inaccurate anthropometric data is the manner in which it is collected. The specific aspect in question is what exactly the participants are wearing during data collection. Typically, participants are either semi-nude or unclothed (Pheasant, 1996, p. 28). Because most data is collected in this way, environmental or job specific requirements are not accounted for. Pheasant describes the adjustment for this as “clothing correction” which is the process through which baseline semi-nude or unclothed origin anthropometric data is adjusted to include the articles involved for a specific task and environmental criteria and their restrictions (pp. 28-29). “[C]lothing corrections are in general likely to be small – except for very heavy outdoor clothing or for specialized protective gear, etc.” (p. 29).



Body Measurement Examples

Table 7.2—Measurements for body measurement terms defined in Table 7.1[1]
[NASA, 1989]

Ref. no.	Dimension	40-year old American male, year 2000			40-year old Japanese female, year 2000		
		Percentile			Percentile		
		5th	50th	95th	5th	50th	95th
64	Ankle height	12.0 (4.7)	13.9 (5.5)	15.8 (6.2)	5.2 (2.0)	6.1 (2.4)	7.0 (2.8)
103	Biacromial breadth	37.9 (14.9)	41.1 (16.2)	44.3 (17.5)	32.4 (12.8)	35.7 (14.1)	39.0 (15.4)
169	Bust depth (female)	n/a	n/a	n/a	17.4 (6.8)	20.5 (8.1)	23.6 (9.3)
178	Buttock circumference	91.0 (35.8)	100.2 (39.4)	109.4 (43.1)	79.9 (31.5)	87.1 (34.3)	94.3 (37.1)
194	Buttock–knee length	56.8 (22.4)	61.3 (24.1)	65.8 (25.9)	48.9 (19.2)	53.3 (21.0)	57.8 (22.7)
200	Buttock–popliteal length	46.9 (18.5)	51.2 (20.2)	55.5 (21.9)	37.9 (14.9)	41.7 (16.4)	45.5 (17.9)
215	Calf height	32.5 (12.8)	36.2 (14.3)	40.0 (15.7)	25.5 (10.0)	28.9 (11.4)	32.3 (12.7)
236	Chest depth (male)	21.8 (8.6)	25.0 (9.8)	28.2 (11.1)	n/a	n/a	n/a
249	Crotch height	79.4 (31.3)	86.4 (34.0)	93.3 (36.7)	65.2 (25.7)	70.6 (27.8)	76.1 (30.0)
309	Elbow height	n/a	n/a	n/a	92.8 (36.5)	98.4 (38.8)	104.1 (41.0)
312	Elbow rest height	21.1 (8.3)	25.4 (10.0)	29.7 (11.7)	20.7 (8.2)	25.0 (9.9)	29.3 (11.5)
330	Eye height, sitting	76.8 (30.3)	81.9 (32.2)	86.9 (34.2)	68.1 (26.8)	73.8 (29.1)	79.6 (31.4)
378	Forearm–forearm breadth	48.8 (19.2)	55.1 (21.7)	61.5 (24.2)	n/a	n/a	n/a

NOTE 1—Dimensions are given in centimeters (inches).

Fig. 2B.3: Body measurement examples, (NASA, 1989)

By way of example, a work environment may require an individual to wear welding gloves to protect the user’s hands from burns. When the actual environment involves sub-Arctic temperatures, then individual must also wear protective garments that would dramatically change the overall dimensions of the body (and hands). As such, the actual size the welding gloves fitting over the cold-weather articles would be significantly larger than the individual would wear in temperate conditions, and could cause a reduced range of motion and grip strength. Thus any designed artifact (power tool, clothing, car seat, etc.) must account for the physical aspects of the target user population as well as any variability in environmental or situational constraints said artifact and user may experience.

2B.2.4- Ergonomics

Pheasant (1996) not only provides the approaches in which anthropometric data can be applied and utilized, but he also details the way in which said data can be integrated into product design. Ergonomics, Pheasant (1996) explains, is "the science of work: of the people who do it and the ways it is done; the tools and equipment they use, the places they work in, and the psychological aspects of the working situation" (p. 4). This particular field of endeavor emerged in the post-Second World War environment of human factors consideration. As a result, the field of ergonomics was born in 1949, forming the basis of research for individuals whose professional and wartime backgrounds ranged from engineering to medicine and the human sciences (p. 4). The ergonomic approach to design (or "principle of user-centred [sic] design") was developed accordingly (p. 5). This principle of user centered design is described as such (Pheasant, 1996):

> If an object, a system or an environment is intended for human use, then its design should be based upon the physical and mental characteristics of its human users (insomuch as these may be determined by the investigative methods of the empirical sciences) (p. 5).

Through this principle, the ultimate goal of ergonomics in design is to create the best match of product for the task of the user (p. 5). Pheasant (1996) goes on to state that a number of criteria can be utilized to determine the degree and quality of that match. Some factors include "functional efficiency, ease of use, comfort, health and safety, [and] quality of working life" (p. 5). These, of course, must then be balanced with various factors of manufacturing, marketing, and retail: thus, ergonomics "sits on the boundary between the domain of empirical science and the domain of ethical values. That is one very good reason that it is important" (p. 6).

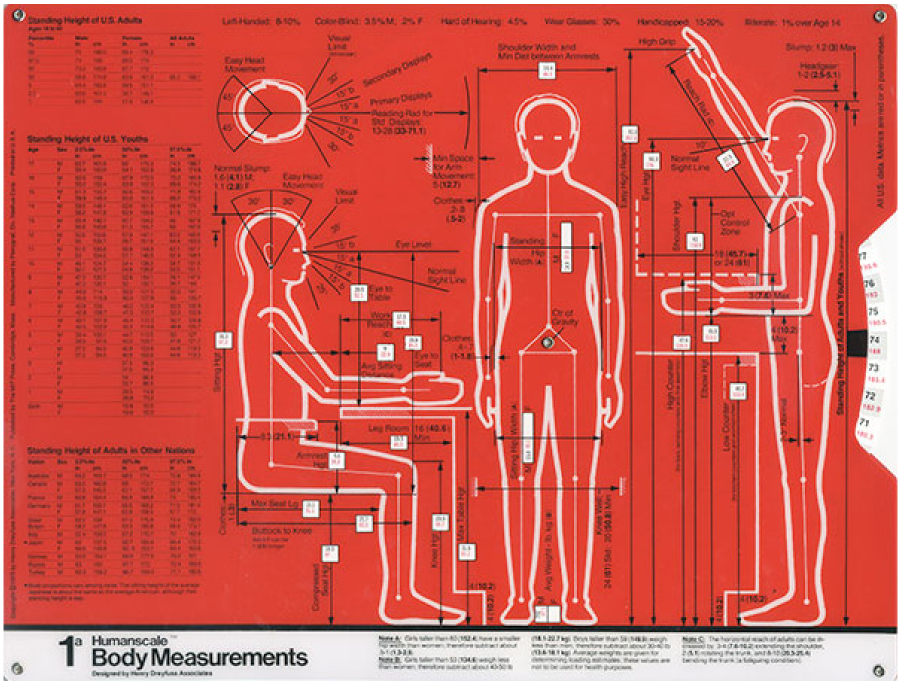


Fig. 2B.4: Humanscale Body Measures

As mentioned earlier, anthropometric data includes figures about human body size information. Ergonomics, Pheasant (1996) explains, is the manner through which "the physical form and dimensions of the product or workspace" are made to match the physical form and dimensions of human body and the task the product is being designed for (p. 7). When it comes to design, anthropometric and ergonomic data are not always factored. In some regard, this has to do with the availability of verifiable data. Other times it is the result of fallacies which Pheasant describes came about through discussions with his design students:

> [The five fundamental fallacies] revolve around two principle themes. The first is the contrast between the investigative methods of the empirical sciences and the creative problem-solving methods of the designer which, for want of a better word, we would call 'intuitive.' The second theme is that of human diversity. In my view this is the single most important characteristic of people to be borne in mind in the world of practical affairs in general and of design in particular… people come in a variety of shapes and sizes – to say nothing of their variability in strength, dexterity, mentality, and taste (p. 10).

The fallacies that Pheasant details are described in greater detail as to the implications of each one and the effects they produce in a product (pp. 10-12). The fallacies themselves are reproduced here (p. 10):

1. This design is satisfactory for me – it will, therefore, be satisfactory for everybody else.
2. This design is satisfactory for the average person – it will, therefore, be satisfactory for everybody else.
3. The variability of human beings is so great that it cannot possibly be catered for in any design – but since people are wonderfully adaptable it doesn't matter anyway.
4. Ergonomics is expensive and since products are actually purchased on appearance and styling, ergonomic considerations may conveniently be

ignored.

5. Ergonomics is an excellent idea. I always design things with ergonomics in mind – but I do it intuitively and rely on my common sense so I don't need tables of data or empirical studies.

These fallacies range from simple to complex subjects to the scope and difficulty of the project in question. "What is rather less obvious is how we should choose the best compromise" between the various factors present for a design, the anthropometric data of the user range, and ultimate goal of designing an artifact that sells and results in the greatest user benefits possible (p. 15). Pheasant continues:

> In order to optimize such decisions we require three types of information: (i) the anthropometric characteristics of the user population; (ii) the ways in which these characteristics might impose constraints upon the design; (iii) the criteria that define an effective match between the product and the user (p. 15).

2B.2.5- Biomechanics

Anthropometry, as established, is the study of the measurements of the human body as they relate to percentiles. Ergonomics, by comparison, is essentially the application of anthropometry to produce user-centric artifacts. By logical extension, biomechanics is the field of study that explains how elements of the body provide motion and how the forces generated by the body alter based on build, fitness, and various other factors.

Specifically, as stated by Enoka (1994) in *Neuromechanical Basis of Kinesiology* "biomechanics is defined as the application of the principles of mechanics to the study of biological systems... a mechanical characterization of the interaction between the world in which movement occurs and the body parts that are moved (biomechanics) (p. 1). A major aspect determining the outcomes of this analysis come in part from anthropometric data (Enoka, 1994). Enoka explains:

> In order to determine the location of the CG [center of gravity] in such movements as high jumping, biomechanists have developed a procedure known as a segmental analysis. This procedure involves estimating the mass and location of the CG for each body segment and then using this information to determine CG location for the whole body (p. 43).

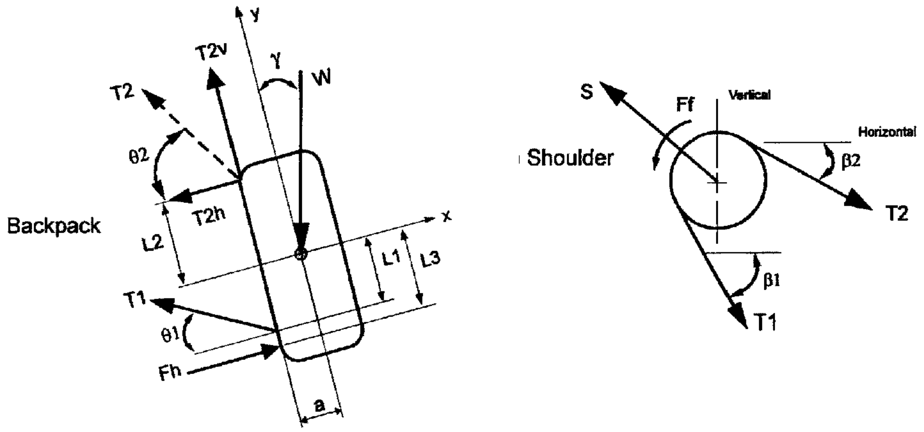


Figure 1. Biomechanical Model for Load Carriage. (a) Torso forces: T2 = upper strap, T1 = Lower strap, Fh = lumbar force, W = pack weight, γ = lean angle. **(b)** Shoulder forces: S = shoulder reaction force, Ff = friction force.

Fig. 2B.5: Biomechanics of Backpacks

Within the scope of movement biomechanics, *Biomechanics and Motor Control of Human Movement* describes anthropometry responsible for identifying the segment lengths and density, mass, and inertial properties of the body and its component parts (Winter, 2009). In that regard, it is a similar collection of figures but for a different application than anthropometry in ergonomics or design. “Dempster and coworkers

(1955, 1959) have summarized estimates of segment lengths and joint center locations relative to anatomical landmark” and a subsequent chart was developed by Drillis and Contini to illustrate these coefficients (Winter, 2009, pp. 82-83).

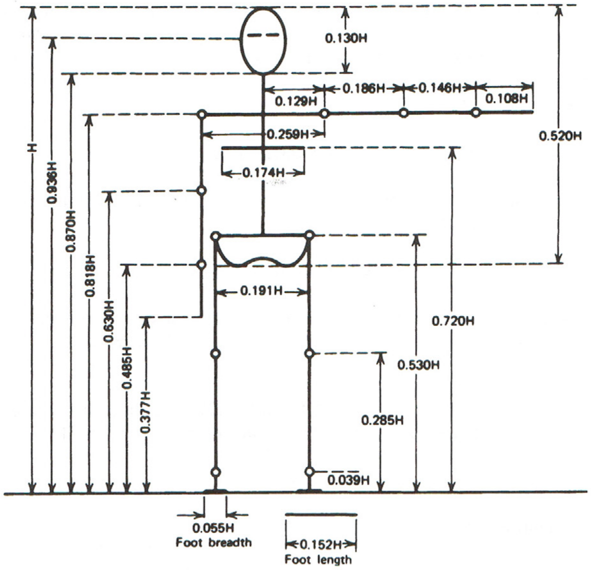


Fig. 2B.6: Nominal anthropometry coefficients to overall body height

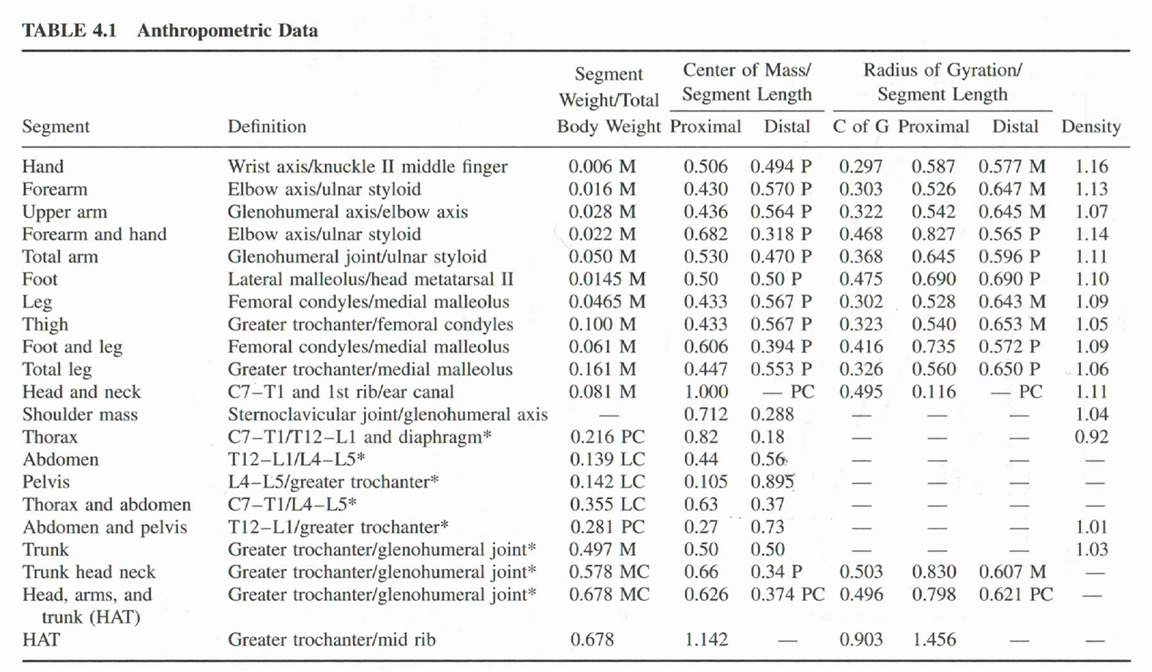


TABLE 4.1 Anthropometric Data

		Segment Weight/Total	Center of Mass/ Segment Length		Radius of Gyration/ Segment Length			
Segment	Definition	Body Weight	Proximal	Distal	C of G	Proximal	Distal	Density
Hand	Wrist axis/knuckle II middle finger	0.006 M	0.506	0.494 P	0.297	0.587	0.577 M	1.16
Forearm	Elbow axis/ulnar styloid	0.016 M	0.430	0.570 P	0.303	0.526	0.647 M	1.13
Upper arm	Glenohumeral axis/elbow axis	0.028 M	0.436	0.564 P	0.322	0.542	0.645 M	1.07
Forearm and hand	Elbow axis/ulnar styloid	0.022 M	0.682	0.318 P	0.468	0.827	0.565 P	1.14
Total arm	Glenohumeral joint/ulnar styloid	0.050 M	0.530	0.470 P	0.368	0.645	0.596 P	1.11
Foot	Lateral malleolus/head metatarsal II	0.0145 M	0.50	0.50 P	0.475	0.690	0.690 P	1.10
Leg	Femoral condyles/medial malleolus	0.0465 M	0.433	0.567 P	0.302	0.528	0.643 M	1.09
Thigh	Greater trochanter/femoral condyles	0.100 M	0.433	0.567 P	0.323	0.540	0.653 M	1.05
Foot and leg	Femoral condyles/medial malleolus	0.061 M	0.606	0.394 P	0.416	0.735	0.572 P	1.09
Total leg	Greater trochanter/medial malleolus	0.161 M	0.447	0.553 P	0.326	0.560	0.650 P	1.06
Head and neck	C7–T1 and 1st rib/ear canal	0.081 M	1.000	— PC	0.495	0.116	— PC	1.11
Shoulder mass	Sternoclavicular joint/glenohumeral axis	—	0.712	0.288	—	—	—	1.04
Thorax	C7–T1/T12–L1 and diaphragm*	0.216 PC	0.82	0.18	—	—	—	0.92
Abdomen	T12–L1/L4–L5*	0.139 LC	0.44	0.56	—	—	—	—
Pelvis	L4–L5/greater trochanter*	0.142 LC	0.105	0.895	—	—	—	—
Thorax and abdomen	C7–T1/L4–L5*	0.355 LC	0.63	0.37	—	—	—	—
Abdomen and pelvis	T12–L1/greater trochanter*	0.281 PC	0.27	0.73	—	—	—	1.01
Trunk	Greater trochanter/glenohumeral joint*	0.497 M	0.50	0.50	—	—	—	1.03
Trunk head neck	Greater trochanter/glenohumeral joint*	0.578 MC	0.66	0.34 P	0.503	0.830	0.607 M	—
Head, arms, and trunk (HAT)	Greater trochanter/glenohumeral joint*	0.678 MC	0.626	0.374 PC	0.496	0.798	0.621 PC	—
HAT	Greater trochanter/mid rib	0.678	1.142	—	0.903	1.456	—	—

Fig. 2B.7: Anthropometric data and biomechanical coefficients

These coefficients provide “a good approximation in the absence of better data” or ‘normative data’ (although measured data from the individual is preferred) (Winter, p. 83). A table with description of the segment, its anatomical definition, and ratios for factoring segment weight, center of mass and its segment lengths, as well as radius of gyration for inertial equations and formulas are provided in *Biomechanics and Motor Control of Human Movement* as well (Winter, 2009) These two figures provide the basis for much of the biomechanics equations needed to describe human motion (Winter, 2009)

With this application use of anthropometric data, it is possible to determine the force output and speeds of component assemblies such as the arm when throwing a baseball or running a sprint over a hundred yards. Combining this understanding with knowledge of the skeletal system, as well as the neuromuscular system with its origins, insertions, and the manner in which these systems influence one another, one begins to obtain a more holistic appreciation for the human body and how its various features provide the dynamic ranges of motion and force that it can produce.

2B.2.6- Human Body Information: Physio-Anatomical Data

A final component of interdisciplinary resources for this study is human body information. There is a vast wealth of medical data pertaining to the human body, which an industrial designer may find difficult to both navigate and determine what information is relevant or irrelevant. For the designer, intimate knowledge of physio-anatomy for the human body is not critical; however, it is important to be aware of it at a conceptual level as will be discussed. Various elements pertaining to this information will be explored in Section 2C.

2B.2.6.1- Medical Information Needed for Semantic Design Guidelines

Anatomy, as stated in *A Textbook of Human Anatomy,* “is the science of the structure of the animal body and the relations of its various parts” (Crafts, 1979, p. 1). Crafts states the description of any study which focuses on specific systems such as the nervous or skeletal systems is considered systemic anatomy (p. 2). This is useful to know: as this thesis focuses on components of the combined neuromuscular-skeletal systems, it by definition could then be considered a systemic anatomical study.

2B.2.6.2- Medical Publications: The Price of Information

There is a wealth of existing sources of information relating to the anatomy of the human body. Existing medical texts, cheat-sheet style publications, and even software packages are available to today’s market. Though the newer options have come onto the market in recent decades, the majority of this information is still retained in physical, hard-copy publications.

Something that may not be that surprising is that medical publications are worth money- a lot of money. In some instances, especially with medical students, specific texts are required reading and thus must be purchased for particular classes within a given curriculum. The price of such textbooks can easily range from the mid-twenties to hundreds of dollars, as the website Elsevier— a seller of medical texts— illustrates (Anatomy Books, Journals and e-Resources, n.d). This is of great impact on medical professionals and students: often these texts and publications are what such individuals need to keep up to date on the most recent medical advancements and information. This is of greater impact on the designer, who may not be especially versed in the terminology or knowledge of human anatomy as a medical professional and as such may need to pay a great sum in order to obtain a publication he or she may not be able to even comprehend.

A pair of individuals who sought to bridge this discrepancy of availability, cost, and comprehension were Dr. Henry Gray and Henry Vandyke Carter, the author and illustrator respectively, of *Gray's Anatomy*, formerly called *Anatomy: Descriptive and Surgical.* As Weiss (2009) explains in the article *Gray's Anatomy: An Effort to Simplify Shows How Complex Life Really Is. How Does It Get That Way?* that the publication came about because of a desire for a better anatomy resource:

> The young Dr. Gray undertook this project because he was dissatisfied with the existing anatomy books. One was by John Bell (1763–1820). Bell's book was noted for its realistic but gruesome figures, which accurately depicted the socially

Fig. 2B.8: John Bell medical drawings

> degraded people who were used in dissecting theaters at the time. Those whose parts were separated for medical students had first been separated from their resting places by graverobbing. Bell’s illustrations often of villains or paupers from the dregs of society further degraded them, and rather needlessly.... However, the standard text in Gray’s day was Quain’s. It was authoritative, but too detailed for students, who needed training as physicians and surgeons, not anatomists. Anatomy books sold very well, so with Carter’s artistic help and the publisher’s encouragement, Gray aimed at something that could be used effectively in class, a book with simple descriptions and clear, utilitarian drawings to train future surgeons.

Wiess continues that accordingly— and to no small degree because of the clear-cut descriptions from Gray and the clean, clear illustrations by Carter— the work was published in 1858 and its initial run of 2,000 copies quickly sold out. “Gray’s quickly

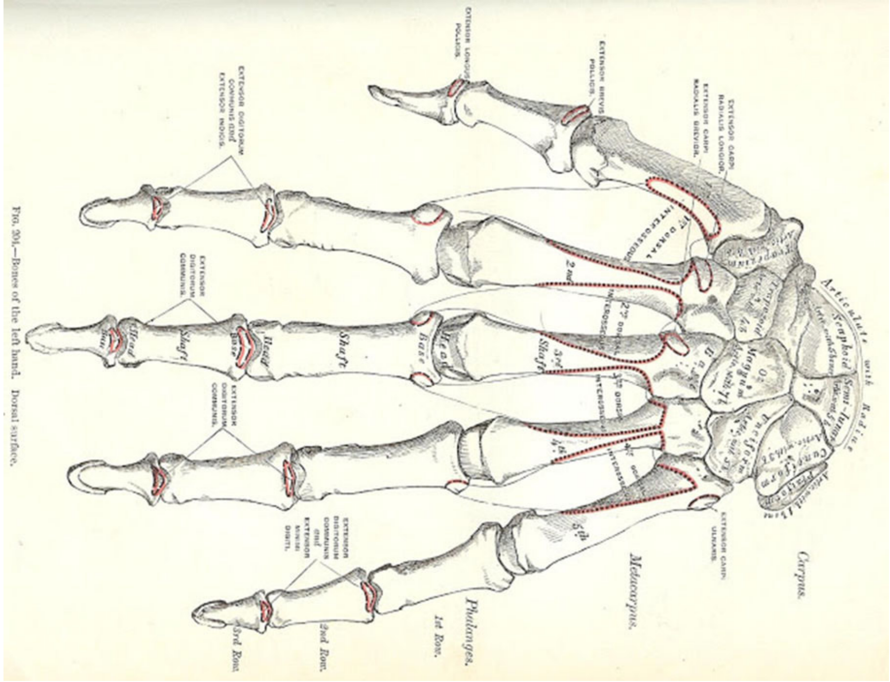
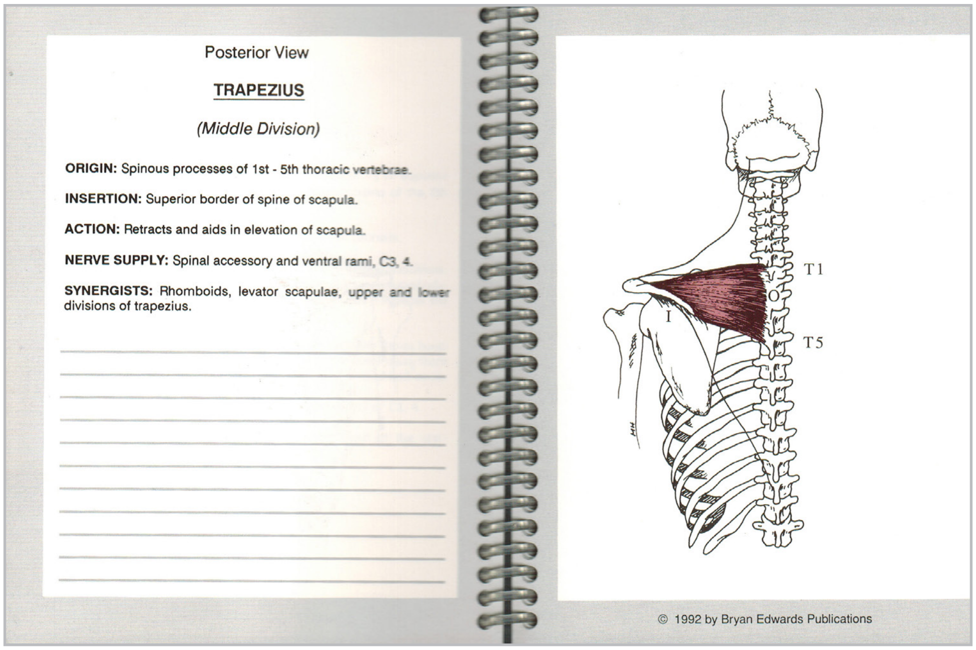


Fig. 2B.9: Bones of the left hand (dorsal surface) from Gray’s Anatomy went into subsequent issues and became the new standard. The result is history" (Wiess, 2009).

Accordingly, a new format of medical text publications arose: one emphasizing clear illustrations and authoritative descriptions. Some examples of such texts which fall into this category include but are not limited to *Textbook of Anatomy* (Hollinshead, 1974), *Review of Gross Anatomy* (Pansky, 1979), *A Textbook of Human Anatomy* (Crafts, 1979) and the large, graphically oriented *Human Anatomy* (Iazzetti, 2006).

Other examples which are mostly graphical in content with some written callouts include the *Anatomy Flash Paks* (Flash Anatomy, 1990): a collection of small booklets emphasizing the illustrations of individual and collective muscle grouping by region, the nervous system, and skeletal systems, among other anatomical subjects. These are especially of use since they show critical information about the respective parts and regions without being overwhelming, and have clean, clear illustrations in addition to a



Posterior View

TRAPEZIUS

(Middle Division)

ORIGIN: Spinous processes of 1st - 5th thoracic vertebrae.

INSERTION: Superior border of spine of scapula.

ACTION: Retracts and aids in elevation of scapula.

NERVE SUPPLY: Spinal accessory and ventral rami, C3, 4.

SYNERGISTS: Rhomboids, levator scapulae, upper and lower divisions of trapezius.

© 1992 by Bryan Edwards Publications

Fig. 2B.10: Scan of trapezius muscle from Flash Pak- Muscular System Vol. 1 small glossary of relevant terms within the opening pages.

A clear advantage the *Anatomy Flash Paks* possess is affordability. Based upon the Bryan Edwards Publishing website, the entire price for the *Muscular System Flash Pak* is $21.95, tax and shipping not included. For this one obtains “164 pages in a spiral-bound format with Volumes 1 and 2, upper and lower extremities. This *Flash Pak* reviews the origin, insertion, action, innervation, and synergists of every muscle in the human body from the shoulders down” (Bryan Edwards Publishing. n.d.).

Falling into this sub-category of illustration-centric publications as well is *The Anatomy Coloring Book* (Kapit & Elson, 1977). This is a resource which allows the reader a chance to study anatomy with “a minimum of rote memorization and a maximum of self-satisfaction (Kapit & Elson, 1977).” The author and illustrator further explain the rational of a coloring book as an anatomy resource:

> Coloring is one of the most effective and pleasant methods of learning. Grad school and high school students can gain familiarity with the basic structural and functional features of the human body by coloring the plates and relating them to their own bodies. College, graduate, and health professional students will find the coloring book particularly helpful in learning and reviewing human anatomy and physiology. Artists can learn the anatomical basis for the beauty of body form. People with specific disorders could color and learn about structures whose malfunction causes their discomfort. Physicians, doctors of chiropractic medicine, podiatrists, physical therapists, and other health professionals could employ the coloring book in helping their patients understand their own specific structural dysfunction.

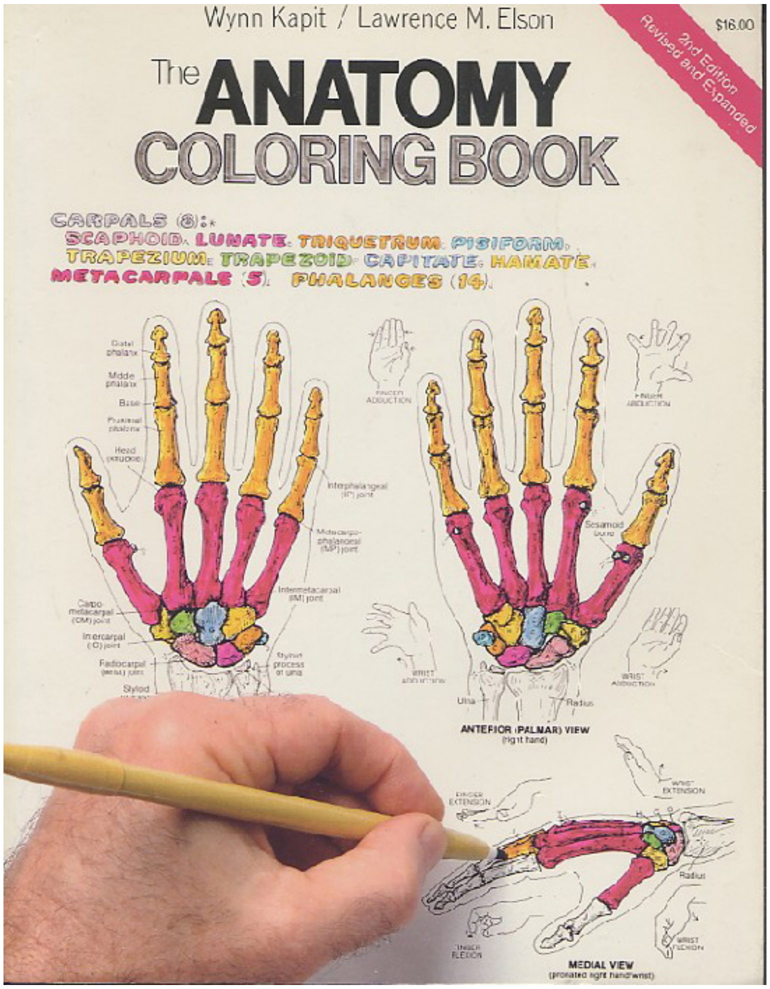


Fig. 2B.11: The Anatomy Coloring Book

Brief examination of the layout formats of the medical resources following *Gray's Anatomy* points to a common similarity and truth: works which communicate important points and show them through clean, consistent, and accurate illustrations tend to work the best for getting the concepts across when compared to wordy, non-illustrated works. This is ideal for the designer, who is more interested in understanding what features and parts of the body need accounting for and the means to do so. Thus any designer resources should focus on anatomically correct information and illustrations with an engaging visual style. Further, the resources should explain at a conceptual level why particular features of the body need to be understood. This allows the resources to emphasize the important features as well as the contextual and conceptual truths of the subject matter.

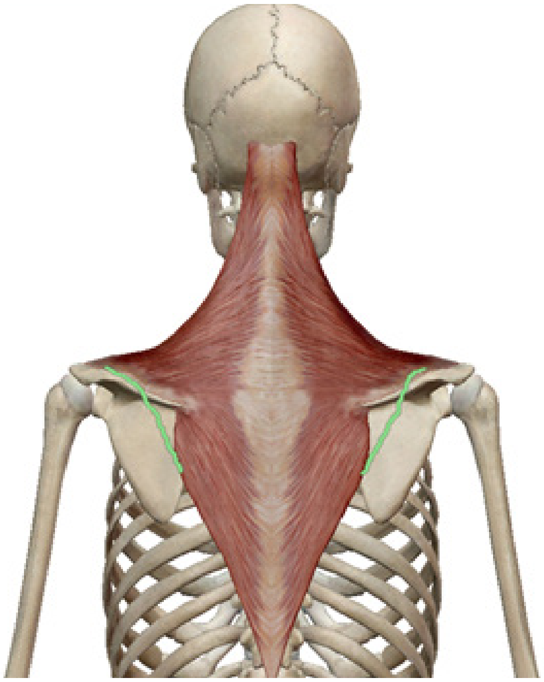
2B.2.6.3- 100% Accurate, No Context or Context, Not 100% Accurate

When creating a series of resources of human anatomy for the designer— someone who is not required to have all of the information retained in order to function in day-to-day duties— the communication of the important concepts in context is paramount. This is where existing medical publications and illustrations present a few issues.

Firstly, most medical publications like *Gray's Anatomy*, *Review of Gross Anatomy*, and the various *Textbooks of Human Anatomy* are created with college, graduate, and specialty students studying medicine, not the typical designer. This can rapidly produce information-overload in one who is not actively (or training to become) a medical professional.

Secondly, there is a discrepancy of accuracy and context: i.e. the illustrations and information are either accurate but lack a contextual form of communication, or are illustrated/written contextually and are lacking in accuracy. A good example of this is in the *Flash Anatomy Flash Paks* or the Sparknotes quick reference sheets. In it the muscles are shown with origin and insertion points, colored in such a way to stand out against the simple black and white line illustrations or collective illustrations of the rest of the body. The overall resource is fairly accurate but fails to show the muscles on both sides of the body and how those muscles shift through the different motions the body can produce. Another resource, which provides necessary context yet lacks in accuracy, is the digital software packages of “Muscle Premium” (Argosy Publishing, Inc., 2015a), “Skeleton Premium” (Argosy Publishing, Inc., 2015b), and “The Human Anatomy Atlas” (Argosy Publishing, Inc., 2015c). This combination of digital resources show the body in context, the movement and motion of limbs, joints, and muscles, etc.; however, some rather critical issues have been found through use of the programs.

A case in point of such an issue concerns the trapezius muscle within the “Muscle Premium” program (Argosy Publishing, Inc., 2015a). According to *Flash Paks*: The Muscular System, Vol. 1 (Flash Anatomy, 1992), the trapezius muscle’s origin ranges from the external occipital protuberance to the spinous process of the 12th thoracic vertebrae (p. 2). Its insertions are along the lateral third of the clavicle and acromion process of the scapula for the upper division of the trapezius, the superior border of the spine of the scapula for the middle division, and the medial third of the spine of the scapula (p. 2-4).



Correct path in green

Fig. 2B.12: Anatomically incorrect lower trapezius insertion point

Where the “Muscle Premium” software package falls short is it completely omits this last insertion point (see Fig. 21). As such, this brings the rest of the muscle attachments into question, for not only the trapezius but every other muscle in the human body as portrayed by the “Muscle Premium” software package. Thus the only way to ensure accuracy of muscle and bone placement is to reference multiple works, which as stated earlier are not typically written for the designer.

Lastly, the aspect of ‘why this is important and should be accounted for’ is unfortunately often missed when speaking of the designer. In the case of abduction and adduction (that is movement towards and away from the medial plane, respectively), these concepts might communicate to the medical professional how and what the types of movement are for a particular body part. For the designer, the aspects of these two movements could communicate how the perceived surfaces and forms of the body change with movement, and knowing this information could enable the designer to develop a product that accounts for these changes, unlike existing designs.

2B.3- Basic Orientation Material For Addressing the Human Body

The following is a brief summary of the important descriptors common to addressing the human body. This material is particularly useful for understanding the anatomical resources on the market and biomechanical data generated to evaluate backpacks. Further, it enables the designer (when asking for advice or seeking to address a particular need) to better understand the terminology used by experts in the disciplines relating to the human body.

2B.3.1- Frames and Definitions of Reference

Computer aided design programs such as SolidWorks often have an orientation introduction to explain navigation throughout the program (Dassault Systemes, 2015). With this orientation, the basic terminology is often explained and the different views and functions are described in cursory detail. The human body similarly has specific terminology to describe its planes of reference, movement types, and related definitions. This includes the basic terminologies to describe the three-dimensional space the body occupies in addition to the basic terminologies to describe key features.

Eastern and Western Anatomical Positions

Crafts (1979) states "man, in the anatomical sense, is always described as standing with eyes looking forward and with the upper limbs hanging down at the sides of the body with palms facing forward. This is called the anatomical position" (p. 2); also

Fig. 2B.13: Western or 'Standard' anatomical position known as anatomical neutral. The phrase "always described as" is potentially misleading and a source of confusion should an individual in the western hemisphere be working with clients or manufacturers in the Eastern Hemisphere, since this is only true when referring to Western medicine. In Eastern medicine, particularly Chinese medicine, both medical and traditional acupuncture describe the anatomical position as "man is viewed from the front, arms upraised with palms forward," (Helms, 1995, p. 82).[1]

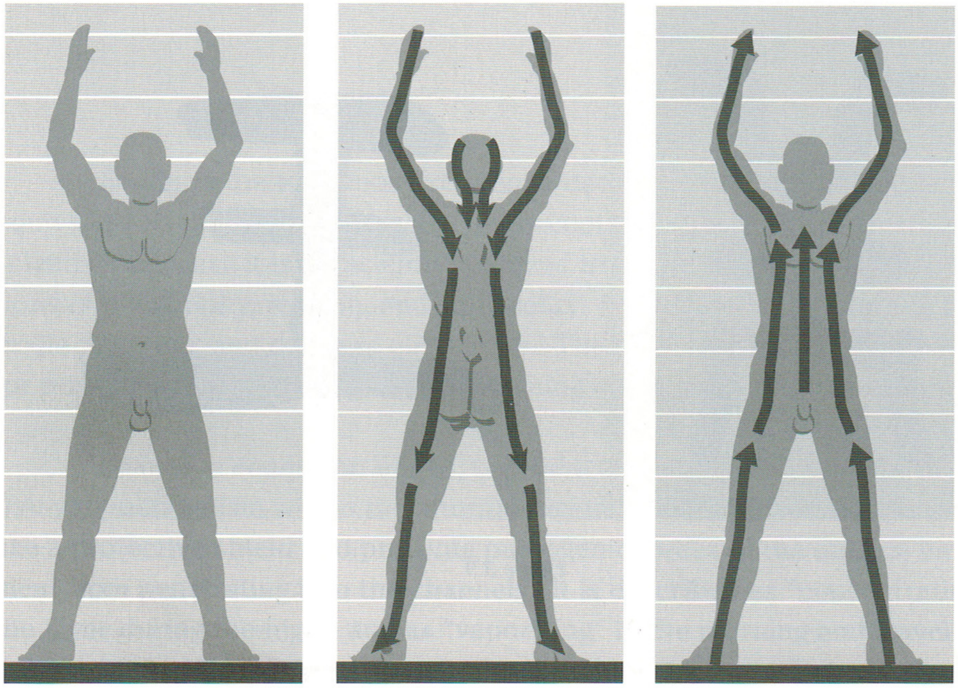


Figure 3.11 *Figure 3.12* *Figure 3.13*

Fig. 2B.14: TCM or "Eastern" anatomical position

For the reader hesitant to accept this particular anatomical position and its relative importance, some contextual consideration is necessary. Acupuncture and Eastern medicine are proven methods of treatment. Understanding there are two different anatomical positions is of great importance; as this may be a source of confusion between parties in the Eastern and Western hemispheres. Regardless, both are descriptive methods which establish a common means of orientating the human body. With the anatomical

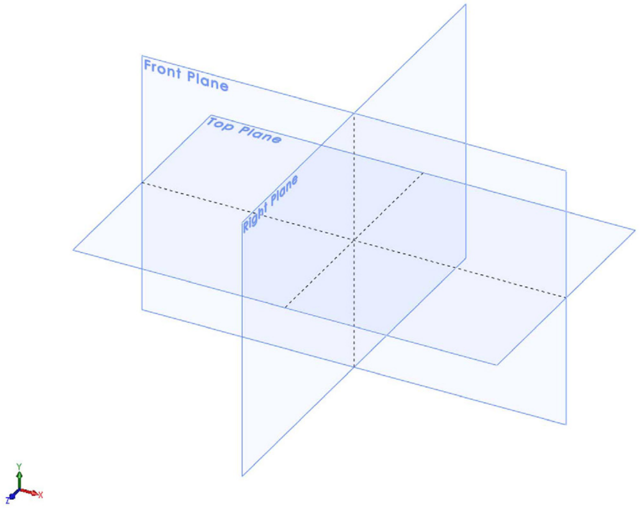


Fig. 2B.15: Reference planes in Solidworks 2015

position established, the terminologies to further describe the various relations of direction can be applied.

__Directions in Space__

Computer programs such as SolidWorks often have a reference triad in a corner of the graphics area to provide a means of orientation with regards to an X-, Y-, and a Z-axis. In these cases, “X” refers to width, “Y” refers to height, and “Z” refers to depth (Dassault Systemes, 2015). Just like these are used to describe width, height, and depth respectively, so too are specific terms used to describe the human body.

According to Crafts (1979) these are used when “describing the human body” (p. 2). Another approach to describing what these terms accomplish is to establish how to describe portions of the body or motions in relation to the body as a whole based upon the anatomical position. These terms should be known by anyone working with the human body, since they are the correct and most accurate way to describe it.

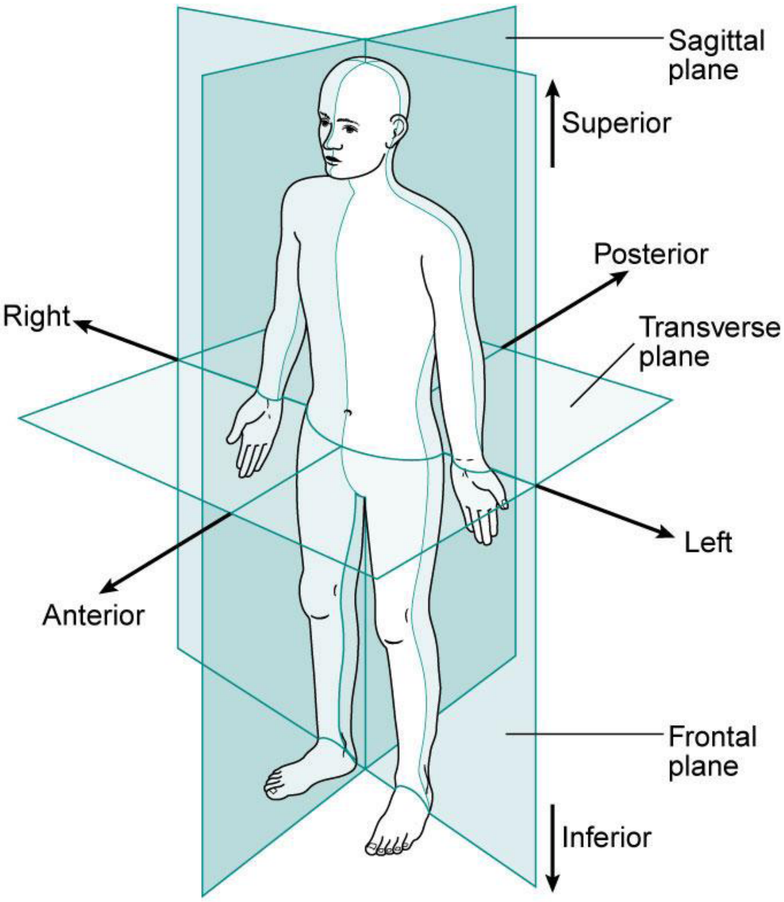


Fig. 2B.16: Anatomical body planes of the body

Before the positional terminology is discussed the frames of reference must be established. These frames of reference take the form of invisible, imaginary planes, which like in CAD programs divide the object (the body) into different regions.

A sagittal plane divides the body along its long Y-axis and its Z-axis. Such a plane "vertically divide{s} the body into two parts: left and right; only one of these planes divides the body into two parts approximately symmetrical" (Iazzetti, 2006, p. 19). This one plane which divides the body in an approximate manner of a left and right half is the medial or mid-sagittal plane.

Frontal (also known as dorsal or coronal) planes are at a right angle to the sagittal planes (Iazzetti, 2006). These divide the body along the X- and Y-axes into anterior and posterior sections.

Last are transverse planes which are perpendicular to both the sagittal and dorsal planes (along the X- and Z-axes), and thus normally are parallel to the ground when describing the standing body. This plane and its divisions result in superior and inferior sections.

These three anatomical planes play a critical role in sub-dividing the body and providing a framework from which movement in the human body can be described. A key point to remember with these anatomical planes is the prefix ‘mid’ is used to describe any anatomical plane positioned along a respective midline of the body (Kendall, 1993). Any mid or median plane separates the body into relatively equal halves; an interesting result of this is the intersection of the three median anatomical planes will correspond in the center of gravity for a given person (p. 12).

Just as there are section-views for programs like SolidWorks there are similar ‘section views’ for the human body that occur along the anatomical planes mentioned earlier. It must be restated that anatomical planes of the human body form the basis of these section views. A longitudinal section is “a cross-section attained by slicing in any plane parallel to the long or vertical axis, actually or through imaging techniques, the body or any part of the body or anatomic structure” (Longitudinal section, 2012). In some cases it is only described as parallel to the mid-sagittal (Crafts, 1979, p. 3) yet both definitions are equally correct, since both describe a section along a long-axis related plane.

A median section according to *Farlex Partner Medical Dictionary* (Midsagittal section, 2012) is described as one where:

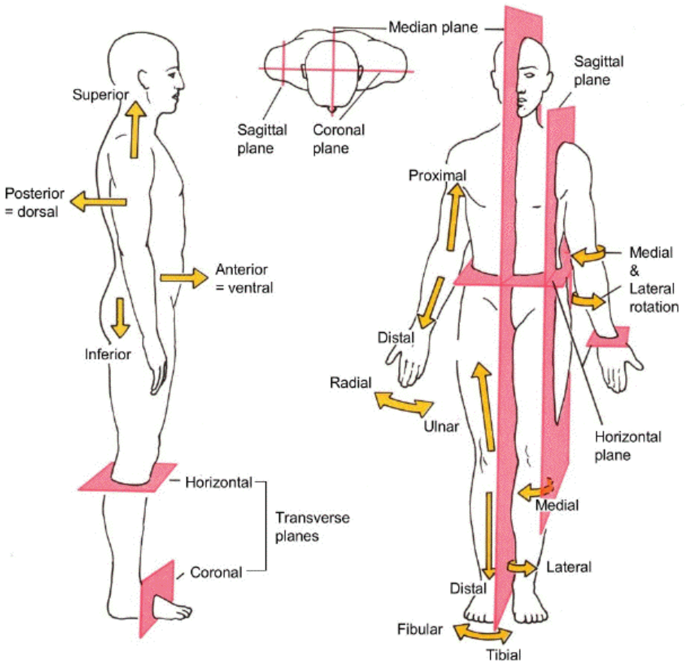


Fig. 2B.17: Anatomical position terms and planes of the body

> a cross section attained by slicing in the median plane.... the body or any part of the body that occupies or crosses the median plane or by slicing any generally symmetric anatomic structure, such as a finger or a cell, in its midline.

Thus median sections occur either along the midline of a specific body part or upon the main anatomical planes that bisect the body into halves (i.e. the mid-sagittal, mid-frontal/coronal, and mid-transverse planes respectively). If a median plane such as the mid-sagittal, mid-frontal, or mid-transverse plane is used to describe a section view, the resulting separations are described as halves; otherwise, if the 'mid' prefix is not present, the results are described as 'sections' (Weimar, 2016).

From here the sections are rather self-explanatory. Sagittal sections occur parallel to the sagittal plane, transverse sections parallel to the transverse plane, and frontal sections parallel to the frontal/coronal planes. Sometimes common usage results in confusing a section as one of the midline ones: again, unless the 'mid' prefix is present, it is not a median section. Additional prefixes such as ‘para’ are sometimes used to describe a section which is parallel to a median plane but does not intersect it (Crafts, 1979, p. 3). To illuminate, a mid-sagittal section passes directly through the median sagittal plane

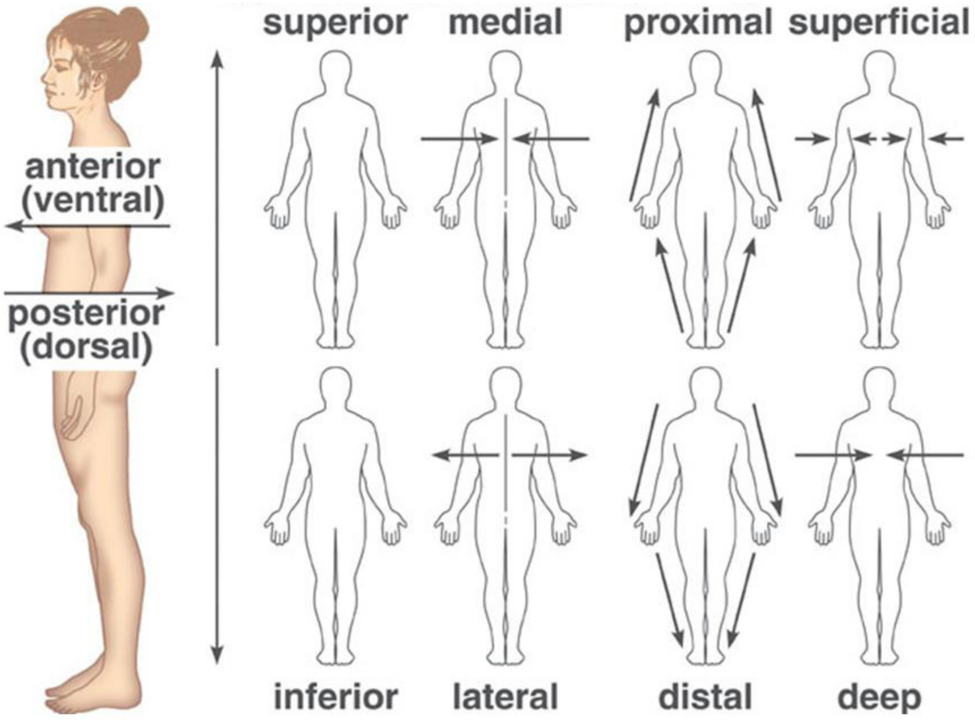


Fig. 2B.18: Body planes and anatomical position

while parasagittal sections remain parallel to the median plane but are not coincident with it. Understanding of this is critical as will be described later with describing movements in the human body.

With planes and sections explained, the terminology of direction in space for the human body can be described. These terms are used specifically in reference to position in relation to the body in space, and not describing the particular act of motion as a separate section will discuss. The first pairing of terms to define directions in space is superior and inferior. These are the correct terms when describing the body from head to feet (i.e. the relation of something along the body’s Y-axis) and are used in relation to the transverse planes (Iazzetti, 2006). Superior describes the direction towards the head, while inferior describes a direction towards the feet (Crafts, 1979). These are more technically correct than using ‘above’ or ‘below’ since above and below have no plane or axis of reference to be based upon. Crafts (1979) goes so far to say ‘above’ and ‘below’ should be avoided since “they are often used carelessly for ‘anterior’ and posterior’” (p. 2).

Anterior and posterior are terms used to describe the front and back of the human body along the Z-axis. Iazzetti (2006) establishes that the planes of reference in this instance are the dorsal (frontal) planes. Anterior describes the direction towards the front of the body, while posterior by definition is a direction towards the back of the body (Crafts, 1979). “The terms dorsal for posterior and ventral for anterior are equally correct and a synonymous with those terms,” Crafts (1979, p. 2) continues and this does make sense when comparing the anatomy of say a dolphin, whose ‘dorsal’ fin rides along the ‘back’ of its spine and its ‘ventral side” would compare to the belly or front of the human body. These should be used carefully since ‘dorsal’ and ‘ventral’ are more often associated with non-human anatomy due to the differing upright statures of those animals.

Medial and lateral are the terms used to describe the relation to the midline or medial sagittal plane made between the Y/Z-axes that equally bisects the body to form a left and a right half. Medial is when something is moving or is located towards that medial plane, while lateral is used to describe movement or location away from the medial plane (Crafts, 1979).

The following groups of definitions are used to describe relative position from a layering standpoint. Internal and external are the terms used to describe the relation “toward the inside or toward the outside of the body” (Crafts, 1979, p. 3). Proximal and distal are used to describe relations to points of attachment and are often used to describe the limbs and the related extremities. Proximal relates towards the point of attachment while distal relates away from the point of attachment (Crafts, 1979).

The next two terms have a tendency to be tricky, and Crafts recommends “limit{ing} the use of these terms to structures close to the surface” (Crafts, 1979, p. 3). Those terms are superficial and deep. Superficial describes a relation closer to the skin, whereas deep describes a relation away from the skin. The instance where these terms can become confusing is when describing the spine and its components.

Crafts (1979) describes these instances:

> For example, if one is looking at the back, it is obvious that the skin on the back is superficial to the vertebral column and, contrariwise, the column is deep to the skin; however, if you are attempting to visualize the back from the anterior side of the body, it is equally obvious that the vertebral column is not deep to the skin of the back but superficial. One usually describes a part of the body such as the back from the posterior view, however, so the problem should not arise. (p. 3)

Thus when using superficial and deep as descriptive terms, it is wise to choose the reference plane and structure which most closely associates with the point being referred to in order to prevent such events of confusion.

Unlike the previous definitions which relate most closely to the core body or to location compared to the surface of the body, the following definitions are specifically used to describe components of the limbs. For the wrist in particular there is radial and ulnar. Radial refers towards the radius and ulnar refers towards the ulnar (Kahle, Leonhardt, & Platzer, 1992, p. 2).This is normally illustrated in charts such as Figure 15 when the body is in the anatomical neutral stance with palms forward and arms at the sides. For the lower limbs, tibial and fibular associate with directions respective to the tibia and fibula bones (Kahle, Leonhardt, & Platzer, 1992, p. 2). Again referring to Figure 15, these terms are used to describe position relative to the ankle in the same manner as radial and ulnar are used for the wrist.

Additionally there are frontal, palmar, and plantar. These terms are used to describe the hand and feet respectively. Frontal is a synonym in these instances to the anterior surfaces of the body and most commonly used to describe the top of the foot or the back of the hand (Iazzetti, 2006). Palmar specifically refers to the palm of the hand: the surface which closes; and plantar refers to the similar surface of the foot which closes: in this case the sole of the foot (Iazzetti, 2006).

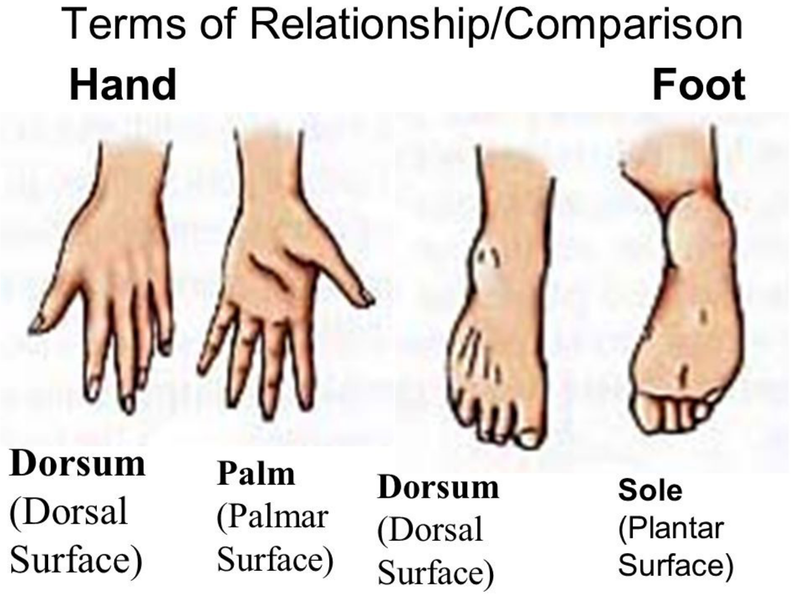


Fig. 2B.19: Terms of position for hands and feet

Lastly are afferent and efferent. These terms are listed last since they are used similarly distal and proximal, but only when referring to vessels or organ systems.

Afferent describes “blood or lymph flowing towards an organ… an efferent vessel as one carrying blood or lymph away from the organ” (Crafts, 1979, p. 3). He states further:

> A single vessel may be afferent or efferent, depending on the point of reference. A vessel carrying blood from the heart to the lungs is an efferent vessel of the heart but an afferent vessel of the lung. Afferent nerves conduct impulses towards the central nervous system, and efferent nerves carry impulses away from the central nervous system; these are sensory and motor nerves respectively. (p. 3)

It should be noted “these terms can be used in various combinations in order to give the best description of what is being observed” (Iazzetti, 2006, p. 19).

The knowledge and use of these terms when describing the human body is paramount. When speaking to an expert that deals with the human body, it helps the expert understanding the inquiry at hand. This also shows the designer has put in the effort to learn the terminology and descriptors of the human body. To some degree this can help improve the perceived professionalism of the designer in the eyes of the human body expert.

Axes of the Body Directions of Movement

From an anatomical and biomechanical perspective the motions of the human body all operate within the three main planes mentioned previously and about respective axes. As the last section described, the main anatomical planes of the human body are the sagittal, the frontal/coronal, and the transverse planes.

These planes, as previously demonstrated, are powerful tools for exploring and examining the human body since they not only provide a frame of reference of describing the body in space, but the anatomical planes themselves form the foundation of which movement can be described. Specifically when describing movement, the biomechanical approach of using an anatomical plane and its corresponding axis is most useful as it accurately establishes a frame of reference.

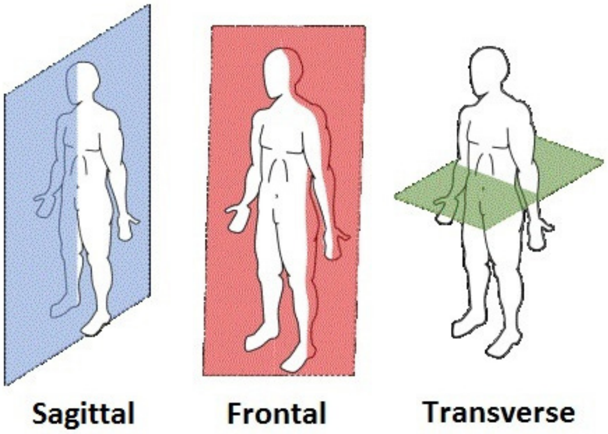


Fig. 2B.20: Main anatomical planes

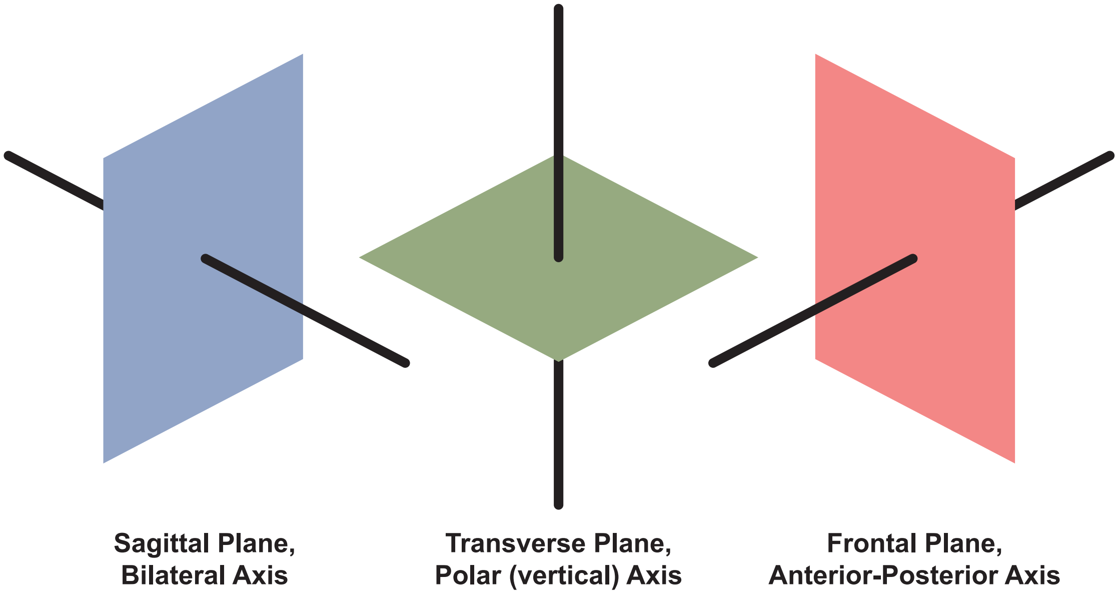


Fig. 2B.21: Anatomical planes and related axes of rotation

Each anatomical plane has its own axis of rotation, perpendicular to the plane itself (Weimar, 2016). A bilateral axis is one which infinitely runs perpendicular to the sagittal plane from left to right and vice versa (thus inferring a sagittal plane which results in left and right sections). Anterior-posterior axes are infinitely perpendicular to the frontal/coronal plane and can be inferred through the keywords anterior-posterior. Lastly are polar (vertical) axes that are infinitely perpendicular to the transverse plane. The main polar axis intersecting the mid-sagittal and mid-frontal planes is the longitudinal axis.

2B.3.2- Directions of Movement

With the terminology of describing the body in space established, the terms for defining the direction of movements for parts of the body must follow suit. Volume 1 of *Color Atlas and Text of Human Anatomy - Locomotor System* (Kahle, Leonhardt, & Platzer, 1992, p. 2), *Neuromechanical Basis of Kinesiology* (Enoka, 1994, p. 413-423), and *Muscles: Testing and Function with Posture and Pain* (Kendall, 1993) provide the anatomical terms of direction and definitions described in the combined list below:

Main Anatomical Terms of Motion
Flexion: a decrease in the angle between two segments (such as bending).
Extension: an increase in the angle between two segments (such as stretching).
Abduction: movement away from the midline of the body or the body part.
Adduction: movement towards the midline of the body or the body part.
Rotation: a motion in which all parts of the system are not displaced by a similar amount (pivoting or rotary motion).
Circumduction: circular movement (a circumferential movement).

Special Anatomical Terms of Motion: Torso
Clockwise rotation: rotating the thorax/pelvis left to right about the longitudinal axis. The 12 o'clock position is placed anteriorly to the body on the mid-sagittal plane.
Counter-clockwise rotation: rotating the thorax/pelvis right to left about the longitudinal axis. Opposite of clockwise rotation.
Lateral flexion: side bending where the upper body bends towards one side and the spine curves convexly towards the opposite side of the body.

Special Anatomical Terms of Motion: Foot
Dorsiflexion: ankle joint extension, towards the dorsal or posterior face of the body.
Plantar flexion: ankle joint flexion, towards the anterior face of the body.
Eversion: combination of foot pronation and forefoot abduction.
Inversion: combination of foot supination and forefoot adduction.
Foot pronation: sole of the foot rotates outwards (standing on inner side of the foot).
Foot supination: sole of the foot rotates inward (standing on outer side of the foot).

Special Anatomical Terms of Motion: Pelvis
Tilt: movement of the pelvis about various axes. Specifically:
Anterior pelvic tilt: when the anterior-superior spines of the pelvis are moved anterior to the main vertical plane that passes through the symphysis pubis.
Posterior pelvic tilt: when the anterior-superior spines of the pelvis are moved posterior to the main vertical plane that passes through the symphysis pubis.
Lateral pelvic tilt: one pelvic ilium crest is higher than the other in the frontal plane.

Special Anatomical Terms of Motion: Arms
Forearm pronation: from medical neutral, the palmar surface rotates to face posteriorly.
Forearm supination: the palmar surface rotates to face anteriorly as in medical neutral.
Lateral (external) rotation: rotating anterior surfaces away from the body’s midline.
Medial (internal) rotation: rotating anterior surfaces towards the body’s midline.
Horizontal abduction: abduction in a transverse plane away from the mid-sagittal plane.
Horizontal adduction: adduction in a transverse plane towards the mid-sagittal plane.
Horizontal flexion: flexion of the arms in a horizontal (transverse) plane.
Horizontal extension: extension of the arms in a horizontal (transverse plane.

Table 1: Chart of anatomical motions

A commonly asked question regarding the difference between horizontal flexion/extension and abduction/adduction is answered based on descriptions in *Muscles: Testing and Function with Posture and Pain* (Kendall, 1993). While flexion/extension may occur within all the anatomical planes, abduction/adduction specifically refers to movement of parts of the body as they move towards and away from the midsagittal plane (p. 12). Thus bringing the entire arm and rotating forward in a transverse plane so the hands move towards the midsagittal plane may be described as abduction/adduction movement in a horizontal plane by one school of thought. Others describe it as the horizontal flexion/extension as the angle between the midline increases or decreases respectively. Both are technically correct, and illustrates the point that when describing location and movement of the body in space, the frame of reference must be established for clarity’s sake.

2B.3- Summary of Section 2B

The designer's needs for understanding of the human body are directly related to the specialty of the designer and the project at hand. As previously quoted from by Henry Dreyfuss (2012), "we begin with men and women and we end with them. We consider the potential user- habits, physical dimensions, and psychological impulses." He reaches a poignant conclusion about the user in relation to the commodity which is created: "what we are working on is going to be ridden in, sat upon, looked at, talked into, activated, operated, or in some way used by people individually or en masse" (p. 23-24).

Thus a better understanding of the human body and the impact any design used by, worn on, or which otherwise has interaction with the human body will result in better products. Unfortunately, such a resource that accounts for the shortcomings of existing medical resources does not currently exist in a desirable form for the designer. To address this need, adapting a selection of human body information from the disciplines of anatomy, anthropometry, ergonomics, and biomechanics for use by the industrial designer is indicated. Further, a selection of the basic orientation, frame of reference, and descriptions of movement definitions is needed to educate the designer in some of the common language and terms used to describe the human body. Based on initial conclusions, such a resource would be beneficial not only to the designer but to anyone wishing to gain a functional, conceptual understanding of the human body.

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2C- Human Body Areas and Features of Interest For Backpack Design

2C.1- Introduction to Anatomical Areas of Interest for Backpacks

The industrial designer is typically taught that not all projects or problems can be approached the same way. Sometimes the project brief calls to satisfy systems-level needs first. Other times, the project brief calls to satisfy the needs of individual components or features before the overall needs of the system. This same concept applies to the human body. Occasionally the focus must address individual elements; other times addressing those features as they influence and affect the body as a whole is the ultimate goal. This relation of the elements to the whole for the human body, especially for neuromuscular-skeletal components, is best described as tensegrity. Tensegrity (which comes from tensile integrity) refers to "the forces of tension (provided by muscles, tendons, ligaments, and fascia) pulling on structure (bones and joints) that help keep the body both stable and efficient in mass and movement" (tensegrity, n.d.).

Considering the interconnectivity of the human body, the following section will address important features or 'areas of interest' that relate to the backpack design. For this study, areas of interest are the individual and collective groupings of anatomical features influencing or impacting the interface and relationship between the body and backpack. The relevant ergonomic and biomechanical data of those areas of interest will be addressed as well. By combining the anatomical, biomechanical, and ergonomic information for the areas of interest for this study, the designer will better understand the parts of the body most impacted by backpacks. Further, it allows the designer to better understand how the backpack to body interface can be improved; thus meeting the needs of the body as a whole within the backpack design process.

2C.2- The Shoulder Complex

The various muscles, bones, and joints of the upper limb attach to the upper body through the shoulder girdle and the shoulder joint. Since a significant degree of range for the shoulder and upper limb comes from the girdle it is more appropriate to view the two groups not a single, individual components but as a multi-jointed and complex assembly.

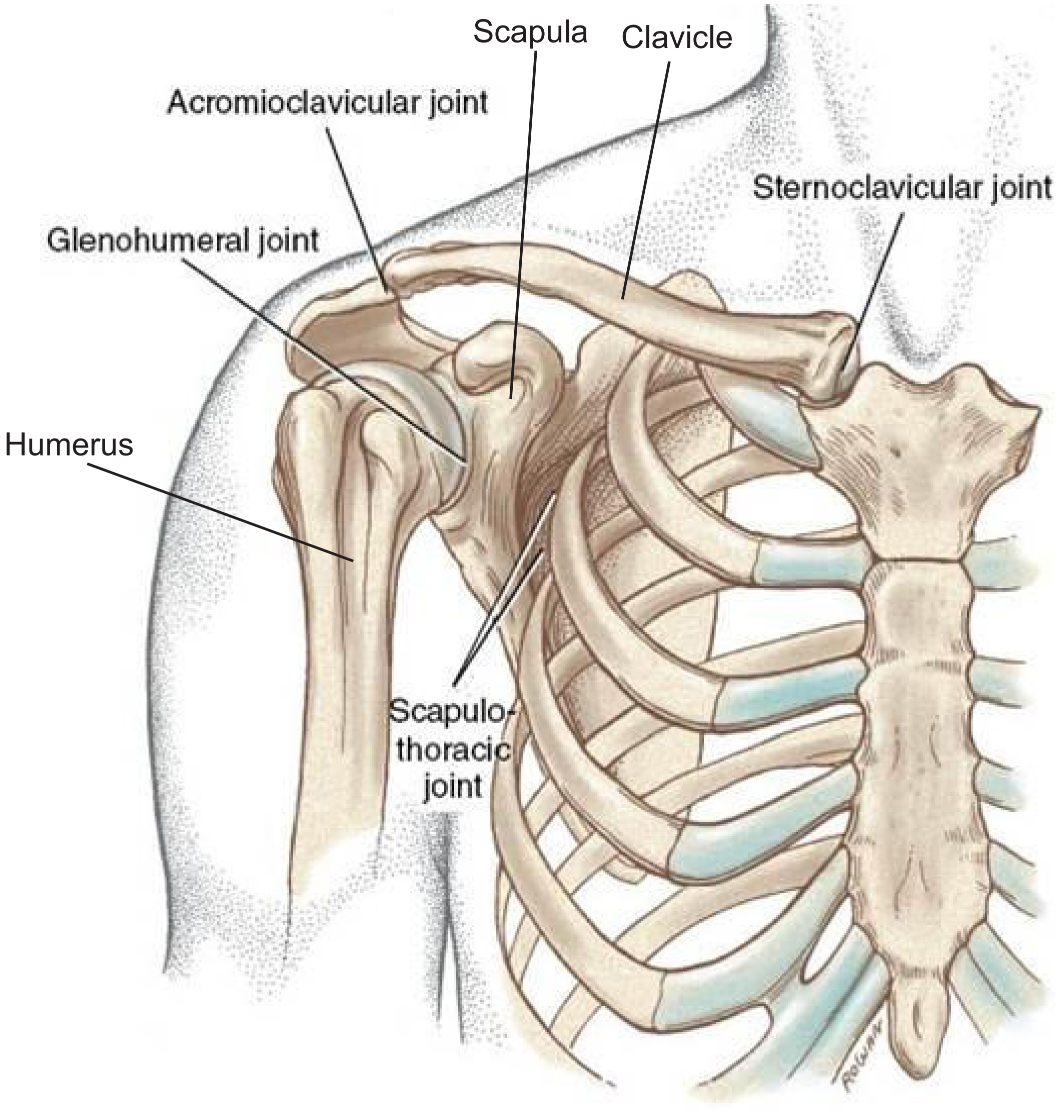


Fig. 2C.1: The shoulder complex: bones and joints

Composition

Floyd (2012) describes the shoulder girdle as a grouping of two bones that "generally move as a unit:" the clavicle and the scapula (p. 87). The clavicle holds special significance for the upper limbs and the shoulder as "the clavicle's articulation with the sternum" provides the only "bony link to the axial skeleton" (p. 87). This means that injury to the clavicle can have dire consequences to the normal ranges of motion and functionality for the upper limb. For the shoulder complex as a whole, the only additional bone needed for the shoulder (glenohumeral) joint is the humerus (Floyd, 2012, p. 110).

Muscularly, there are some significant distinctions between true shoulder and shoulder girdle muscles. Movements of the shoulder girdle involve the pectoralis minor, serratus anterior, trapezius, rhomboid, and levator scapulae muscles (Floyd, p. 92). Shoulder girdle muscles "have their origin on the axial skeleton, with their insertion located on the scapula and/or the clavicle" and "do not attach to the humerus, nor do they cause actions of the shoulder joint" (Floyd, p. 92). Highlights of the shoulder girdle's role, Floyd (2012) continues, include providing "dynamic stability of the scapula" to serve as a stable base for shoulder joint activities and helping to maintain spinal posture (Floyd, p. 92).

The muscles of the shoulder proper can originate on shoulder girdle bones. The difference, however, comes from their insertions into the humerus, unlike the shoulder girdle muscles (Floyd, pp. 116-117). Movements of the shoulder involve the deltoids, coracobrachialis, teres major, the rotator cuff group (subscapularis, supraspinatus, infraspinatus, and teres minor), latissimus dorsi, pectoralis major, and (depending on application or profession) the biceps brachii and triceps brachii muscles (Floyd, p. 116;

pp. 122-133). For a graphical interpretation of these muscles and relevant data, Table 4.1 (Floyd, p. 94) breaks down the muscles and their primary actions for the shoulder girdle, while Table 5.2 (pp. 116-117) does so for the shoulder proper. Nervous elements that feed into the upper limb and the shoulder complex are identified in Table 15 of the 4th Edition AMA Guides (1993, p. 54) and Figure 48 (p. 55). A major neural component for the shoulder complex is the brachial plexus, an area of interest in its own right which will be addressed later in more detail.

Range of Motions

The shoulder complex is a unique feature of the human body. This collection of muscles, numerous joints, and bones may be considered as the source of the widest and most dynamic ranges of motion. As such there are numerous types of anatomical movement with a variety of quantifiable degrees of motion. Determining the exact range of motion for the anatomical movements of the shoulder (glenohumeral) joint is difficult to accomplish without accounting for the involvement of the shoulder girdle (Floyd, 2012, p. 111). Specifically, to meet the maximum range of motion for shoulder flexion or abduction, for every two degrees of glenohumeral movement there must be one degree of upward scapular rotation (Lippert, 2011, p. 120). Floyd (2012) addresses the specifics of the shoulder's dynamic complexity:

> [i]f the shoulder girdle is prevented from moving, then the glenohumeral joint movements are generally thought to be in the following ranges: 90 to 100 degrees of abduction, 0 degrees adduction (prevented by the trunk) or 75 degrees anterior to the trunk, 40 to 60 degrees of extension, 90 to 100 degrees of flexion, 70 to 90

> degrees of internal and external rotation, 45 degrees of horizontal abduction, and 135 degrees of horizontal adduction. If the shoulder girdle is free to move, then the total range of the combined joints is 170 to 180 degrees of abduction, 170 to 180 degrees of flexion, and 140 to 150 degrees of horizontal adduction (p. 111).

Regarding the influence of the shoulder girdle to the overall range of total abduction, this motion involves "approximately 60 degrees of scapula upward rotation, 25 degrees of scapula elevation, and 95 degrees of glenohumeral abduction" (p. 111).

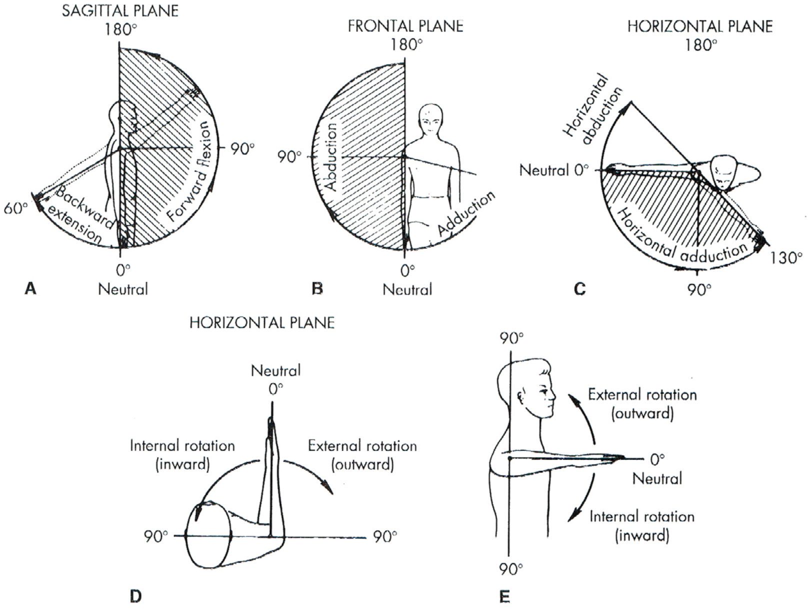


FIG. 5.6 • Range of motion of the shoulder. **A,** Flexion and extension; **B,** Abduction and adduction; **C,** Horizontal abduction and adduction; **D,** Internal and external rotation with the arm at the side of the body; **E,** Internal and external rotation with the arm abducted to 90 degrees.

Fig. 2C.2: Shoulder ranges of motion

This cursory exploration of the ranges of motion scratches the surface of the shoulder complex's dynamic characteristics. The additional specifics may be found in Kapandji (1982, pp. 2-71), the *Guides* (American Medical Association, 1993, pp. 41-45), and Floyd (2012, pp. 87-89, 110-113). Overall, this information proves to be of importance for this study and ideally will be included in a relevant series of guidelines for backpack design.

Significance

The shoulder complex and its various muscles are responsible for not only for movement of the upper limb, but the muscles and bones it comprises provide the physical form of the upper body. Additionally, the dynamic range of motion provided by the shoulder complex is the result of numerous components working together sequentially and simultaneously. These structures are directly interacting with and influenced by the straps of backpacks; as such understanding of this area of interest is critical for designing backpacks.

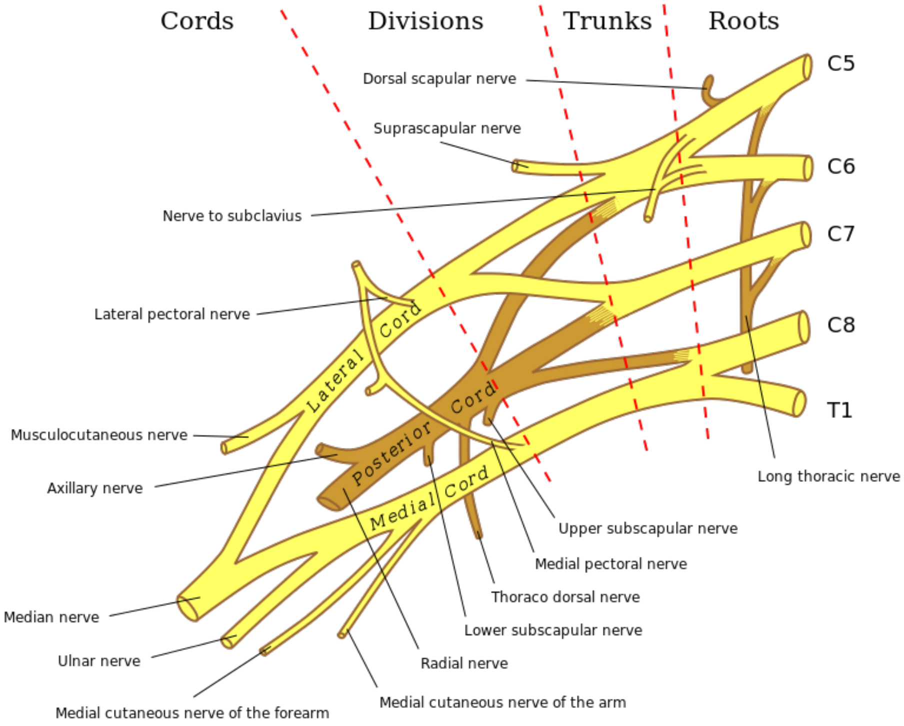


Fig. 2C.3: Anterior View of Right Brachial Plexus

2C.3- The Brachial Plexus

The second area of interest for backpack guidelines is the brachial plexus.

The brachial plexus is one of the intersecting nerve branches present in the peripheral nervous system, and the one that innervates the shoulder and upper limb (Floyd, p. 95). Introduced under the shoulder complex, this neural structure not only provides the pathways for nerve impulses for the upper limb and shoulder, but damage or irritation can result in major hindrances or impairment to those anatomical features.

Composition and Significance

According to the 4th Edition AMA *Guides* (1993) the brachial plexus is “formed by the anterior primary divisions of the C5 through C8 and T1 roots, which anastomose to form three primary trunks” (p. 52). These first deviations are the upper trunk (rooted or originating at C5 and C6), middle trunk (C7), and the lower trunk (C8 and T1) (p. 52). As one progresses laterally from the spine, the brachial plexus continues to split and divide to eventually provide neural pathways for the various muscles of the shoulder and upper limb (Floyd, 2012, p. 152). The full complexity of this neural structure is well beyond the scope of this study. However, there are aspects which are relevant to the designer.

First, the easiest way to describe the brachial plexus is through the analogy of a

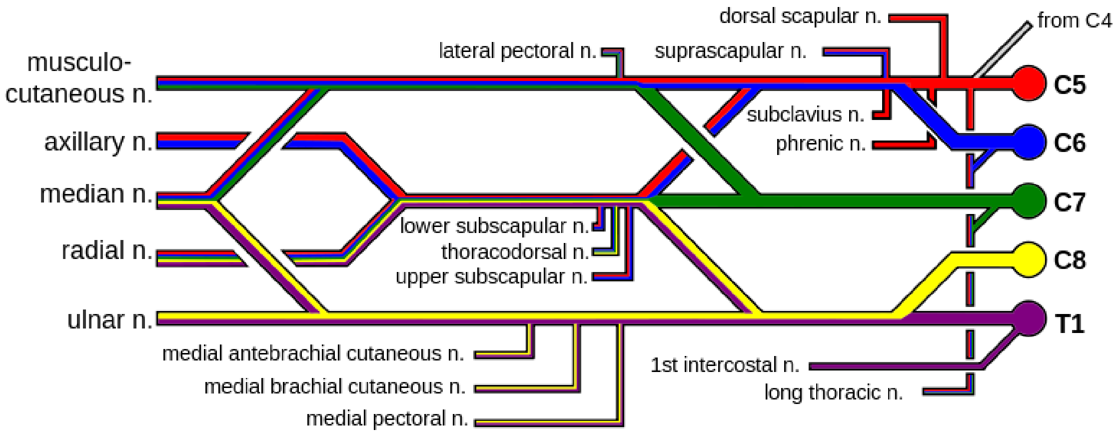


Fig. 2C.4: Wiring schematic of the brachial plexus complex wiring schematic. This intricate bundle weaves and interweaves its way through the upper body to the shoulder and the upper limb. Secondly, injuries to this plexus and the related nerves that continue from it can result in mild numbness through loss of functionality depending on the degree of the injury and its location. In the case of a total brachial plexus injury, the end results can include “flail arm, paralysis of a muscles of the hand, and the absence of sensation” (p. 52). This secondary aspect will be addressed in more detail with the various injuries and dysfunctions to avoid with backpack design, as the vast majority are pertinent or associated with the brachial plexus.

A cursory example based on the 4th Edition AMA *Guides* (1993) illustrates the significance of recognizing and protecting the brachial plexus. The implications of this are most easily shown through determining how such an injury relates to the whole body. “For each structure involved, impairment percents are calculated by multiplying the maximum impairment value of the nerve structure due to motor or sensory deficit.... by the estimated grade of severity of the sensory or motor loss....” (p. 46). If both sensory and motor deficits are present, a chart on pp. 322-323 is used to calculate the combined rating for that component (p. 46). Once the component impairment ratings (in this case based solely on the upper body impairments) are determined these are combined and converted to a whole body impairment rating.

Table 14 (p. 52) and the example on p. 53 details in the event of a full brachial plexus injury, the maximum impairment for the upper body is one-hundred percent. Subsequent conversion of a one-hundred percent upper body rating to whole body yields a sixty-percent whole body impairment rating. A statement from Bonica (1990) concerning nerve healing and regeneration following an injury relates to injury of nerves:

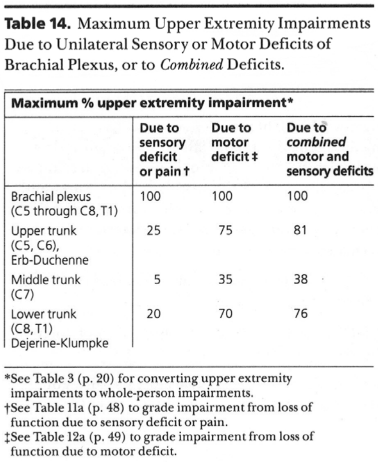


Table 14. Maximum Upper Extremity Impairments Due to Unilateral Sensory or Motor Deficits of Brachial Plexus, or to *Combined* Deficits.

Maximum % upper extremity impairment*			
	Due to sensory deficit or pain†	**Due to motor deficit‡**	**Due to *combined* motor and sensory deficits**
Brachial plexus (C5 through C8, T1)	100	100	100
Upper trunk (C5, C6), Erb-Duchenne	25	75	81
Middle trunk (C7)	5	35	38
Lower trunk (C8, T1) Dejerine-Klumpke	20	70	76

*See Table 3 (p. 20) for converting upper extremity impairments to whole-person impairments.
†See Table 11a (p. 48) to grade impairment from loss of function due to sensory deficit or pain.
‡See Table 12a (p. 49) to grade impairment from loss of function due to motor deficit.

Figure 46. Dermatomes of the Upper Limb.*

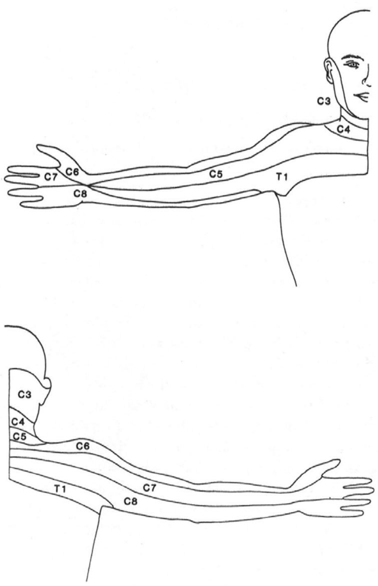


Fig. 2C.5: Table 14 and Figure 46 of the 4th Edition AMA Guides

> Regeneration of this segment can occur as long as the cell body remains intact and connective tissue continuity is preserved or can be fashioned…. In nerve rupture or clean sections, surgical approximation of the proximal and distal nerve endings or a nerve graft is required for reinnervation to possibly occur…. it takes about 1 month for the cell body to prepare itself for the regrowth process. The regrowth rate itself varies from 2.5 to 4 centimeters per month. In motor nerves, an additional month may be required to establish new myoneural junctions (p. 624).

Thus, if a backpack design causes a complete brachial plexus injury, that design results in a user who has a sixty percent whole body impairment. Such a significant injury to these components may result in prolonged recovery periods or no significant improvement/ no improvement at all after a period of a year and a half. This alone from a medical standpoint should be proper justification for protection of this area of interest.

2C.4- The Trunk and Spinal Column

Floyd (2012) states, "[T]he trunk and spinal column present problems in kinesiology that are not found in the study of other parts of the body" (p. 327). These problems, or rather design challenges, for the designer of backpacks are the reason of inclusion as an area of interest for this study.

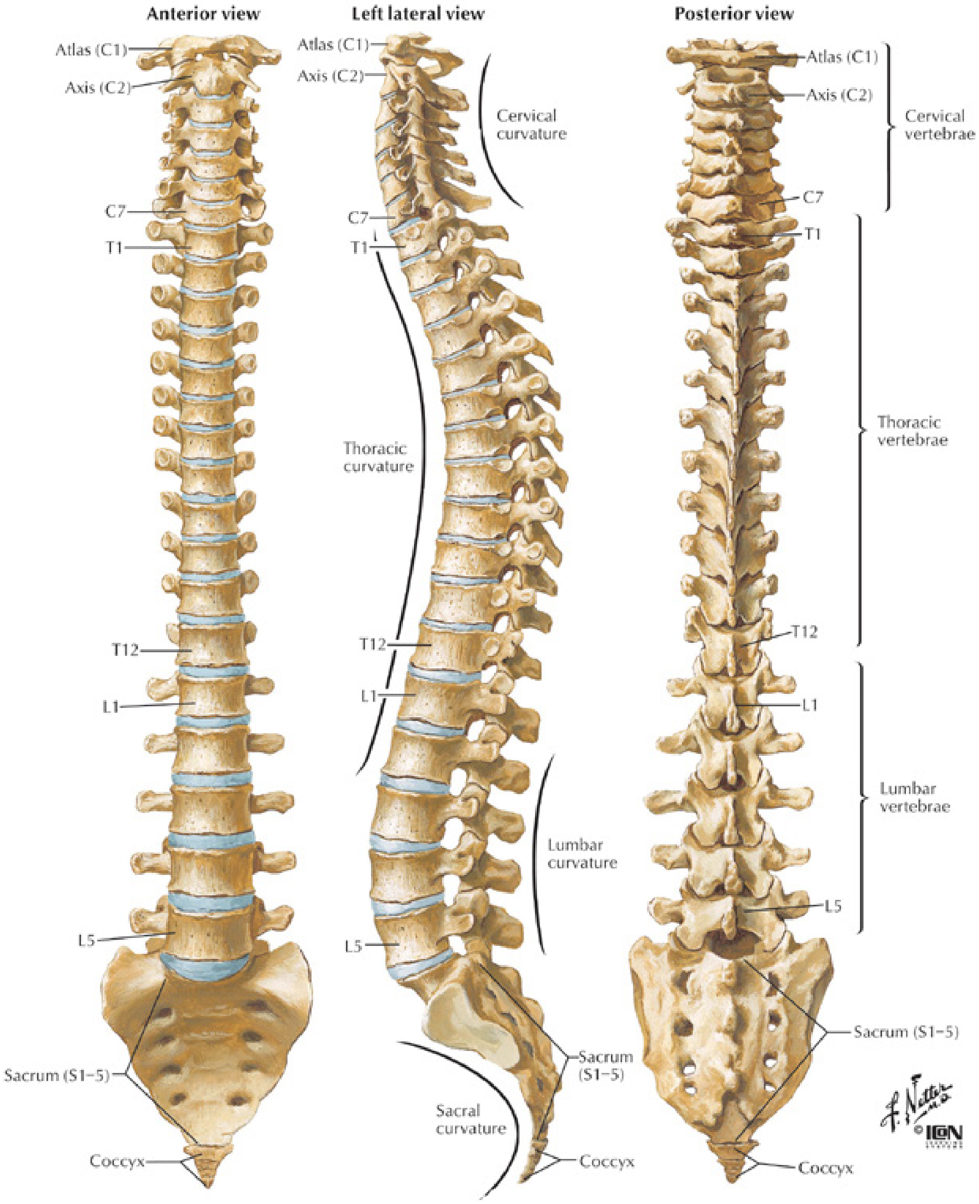


Fig. 2C.6: The human spinal column

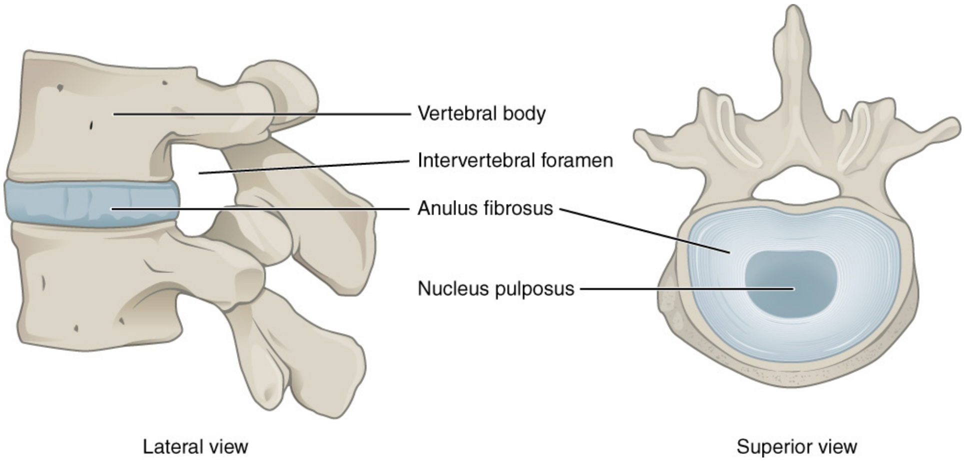


Fig. 2C.7: Intervertebral disc

<u>*Composition*</u>

The spinal column of the human body consists of "24 articulating vertebrae with an additional 9 nonmovable [sic] vertebrae. These vertebrae contain the spinal column, with its 31 pairs of spinal nerves" (Floyd, 2012, p. 327). Arguably next to the shoulder complex, the spinal column "is one of the more complex parts of the human body" (p. 327). Floyd (2012) goes into more detail about the shapes and curves of the vertebrae, which help with weight support and posture (p. 328). Adding to this aspect of complexity are the intervertebral disks "located in between and adhering to the articular cartilage of the vertebral bodies" (p. 332). Reiterating elements of the connective tissue introduced in Subchapter 2B, disks "are composed of an outer rim of dense fibrocartilage known as the annulus fibrosus and a central gelatinous, pulpy substance known as the nucleus pulposus" (p. 332). By having this combination of disk and vertebral body, the spinal column is able to "allow compression in all directions, along with torsion" (p. 332).

The trunk, or thorax, is the bony structure that not only provides protective space for vital organs such as the lungs and heart, but also provides the attachment means of

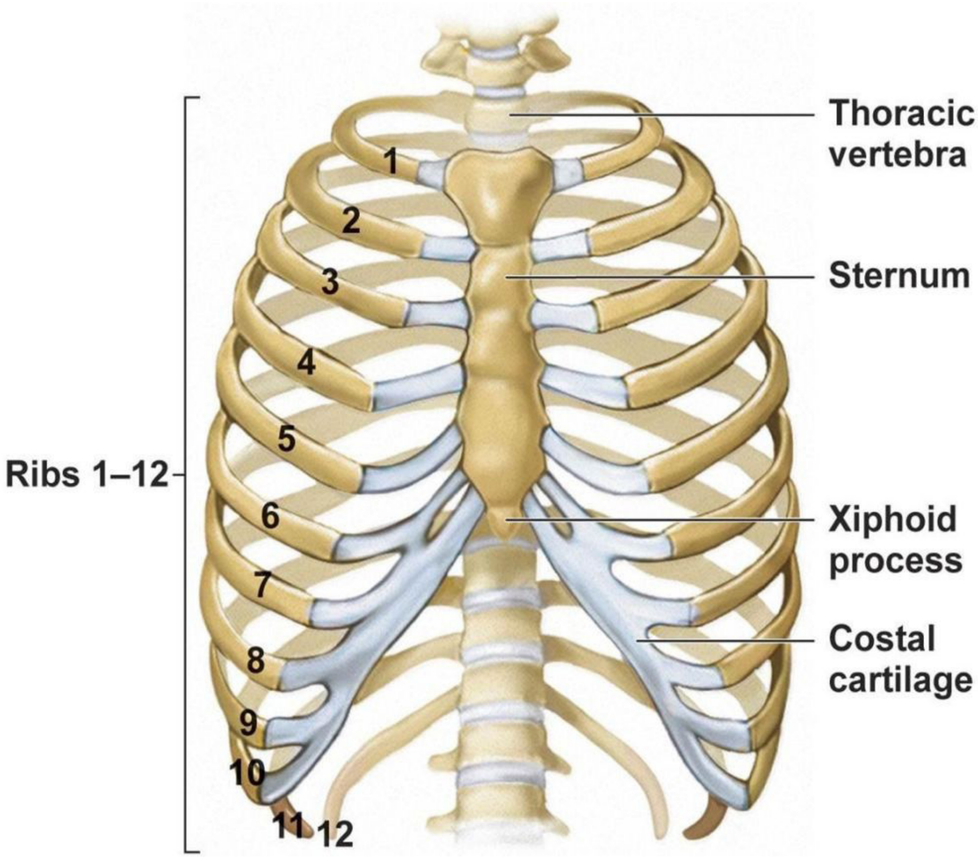


Fig. 2C.8: The thorax: human rib cage

the shoulder complex/upper limb to the spinal column (p. 328). The skeletal components of the thorax include the thoracic vertebrae, the twelve pairs of ribs (the seven pairs of true ribs that "attach directly to the sternum" and the five pairs of false ribs), the aforementioned sternum which consists of the manubrium, the main bony body, and the xiphoid process (p. 328). The ribs of the thorax attach "posteriorly to the thoracic vertebrae" (p. 328).

The muscles of the trunk and spinal column can be grouped into four main categories according to Floyd (2012): muscles that move the head, those of the vertebral column, those of the thorax, and those of the abdominal wall (p. 338). These muscles are listed in detail and are vital for a variety of muscle actions (pp. 339-354). When looking at the numerous small muscles of the spine Floyd states "detailed knowledge of these muscles is of limited value to most people who use this text," and this sentiment applies to the vast majority of the muscles of the trunk and spinal column for the purposes of this study (p. 335). What is important to recognize with the various muscles is that the majority are responsible for movement and posture of the spine, the act of respiration (breathing), and the various actions found with the head and neck (p. 335).

Range of Motion

The trunk and spinal column include not only the active ranges of motion but also the expansion and contraction of the trunk due to respiration (breathing). Once again for the spinal column the ranges are most easily grouped into the cervical spine and the thoracic/lumbar spine (Floyd, 2012, p. 333). The *Color Atlas and Text of Human Anatomy* (Kahle et al., 1992) provides more in-depth detail about the various components along with clarifying certain aspects. For rotation of the spine, the most noticeable degree of rotation occurs in the cervical and thoracic levels of the spine, though some rotation has been noted at the lumbar level (p. 62). Kahle et al. (1992) states that the degree of rotation is somewhere between three to seven degrees between any two vertebrae (p. 62).

Flexion and extension of the spinal column occurs "primarily in the cervical and lumbar spine" (Kahle et al., 1992, p. 62). Kahle et al. identify special aspects of backward bending or extension, which is most noticeable "between the lower cervical vertebrae, the eleventh thoracic and second lumbar vertebrae, and the lower lumbar vertebrae" (p. 62). With these more mobile regions of the spine "damage and injury to the spinal column due to over-strain is more frequent here than at other levels" (p. 62).

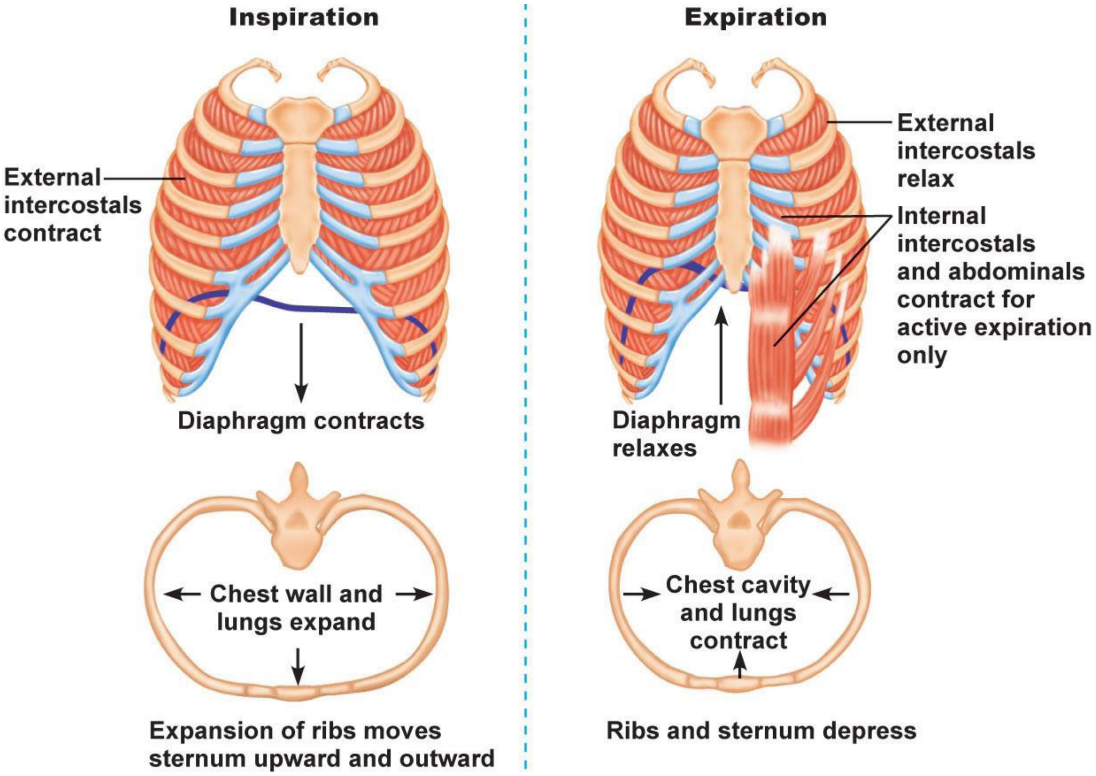
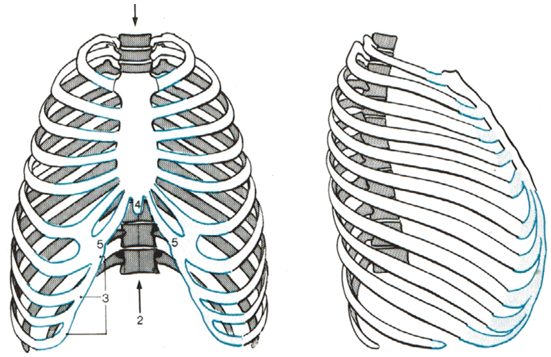
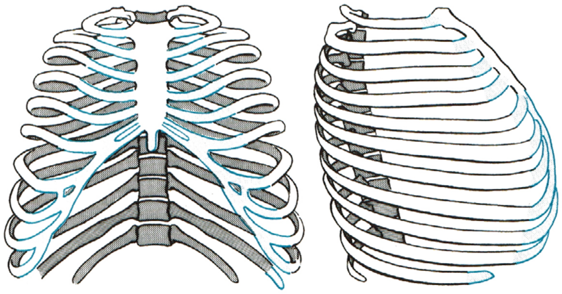


Fig. 2C.9: Inspiration and expiration



A Thorax – expiratory position from front

B Thorax – expiratory position from side



C Thorax – inspiratory position from front

D Thorax – inspiratory position from side

Fig. 2C.10: Changes in the thorax during breathing

A Note on Breathing

Recalling the exploration of connective tissues in Subchapter 2B, the purpose of cartilage in the trunk (most specifically the thorax) becomes clear when considering the action of breathing. Kahle et al. (1992) explains this change in shape comes from the "summation of individual movements. As limiting positions we distinguish maximal expiration (A, B) on the one hand and maximal inspiration (C, D) on the other" (p. 70-71). This expansion and contraction aids in the action of breathing. It also explains some of the inherent ranges of the shoulder complex, needed to account for this expansion and contraction of the thorax due to the shoulder complex's skeletal connection to and placement over and around aspects of the thorax.

Postural Effects on Disc Pressure

According to Dr. Nachemson (1981) disc pressures fluctuate when the body is in different positions. Statically, the absolute worst position for disc pressure is sitting, where pressures can increase by 40% compared to standing (Nachemson, 1981). Dynamic movements such as forward leaning to lift a load without proper lifting technique (of bending with the knees) can increase lumbar disc pressure by 100% (Nachemson, 1981). Luckily, sitting is not a major concern when it comes to standard use of a backpack, but the loading that occurs with forward leaning in a dynamic, real world situation illustrates the importance of keeping the load of a backpack close to the user's center of gravity and mounted to the pelvis. In this way the moment arms of the load are kept to a minimum, requiring less muscle force to maintain the user's natural posture and reducing excess pressure loading of the discs.

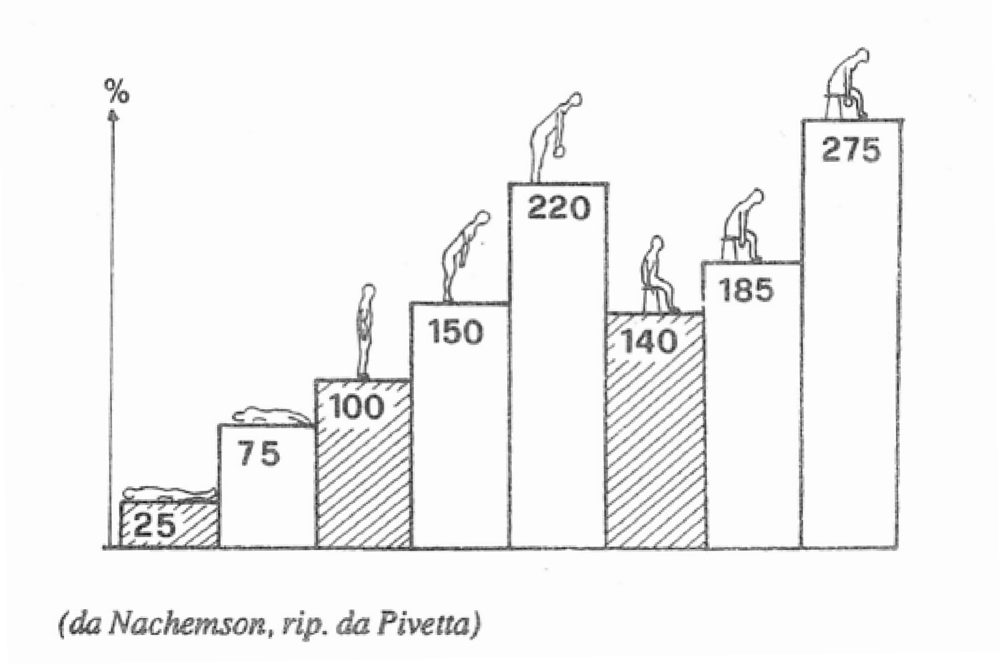


Fig. 2C.11: How posture affects disc pressure

<u>Significance</u>

There are a number of reasons for addressing the trunk and spinal column as an area of interest.

- The spinal column is a structure with shock absorbing elements that also protects and houses the spinal cord (University of Maryland Medical Center, n.d.). It should be noted that the load-bearing nature of the spinal column favors flexibility and support of the upper body, not external loads. Injury to it can prohibit normal movement and range of motion, cause paralysis, or a combination of all due to its complexity.
- The thorax (rib cage and thoracic segments of the spine) provide the skeletal points for the shoulder complex and upper limb to attach to the axial skeleton. Additionally, it is a dynamic structure in its own right since it expands and contracts to allow for respiration. From a backpack perspective, restrictive or

over tightening of straps can limit maximal inspiration and cause breathing issues.

- From a biomechanics standpoint the spine serves as a lever with its fulcrum at the pelvis. This viewpoint clarifies and identifies why external frame backpacks are considered better for load-bearing. With the fulcrum (A) at the pelvis, when the load of the backpack (F) is placed further up the spine, the force lever arm increases. This necessitates an increase in muscle force (R) to maintain the correct posture of the spine. Thus, if placing the weight on the pelvis (as occurs with the hip/pelvic belts of external frame backpack) the lever and moment arms of the resistance are close to nonexistent. Accordingly, little to no additional muscle force (R) is needed for maintaining posture of the spine.

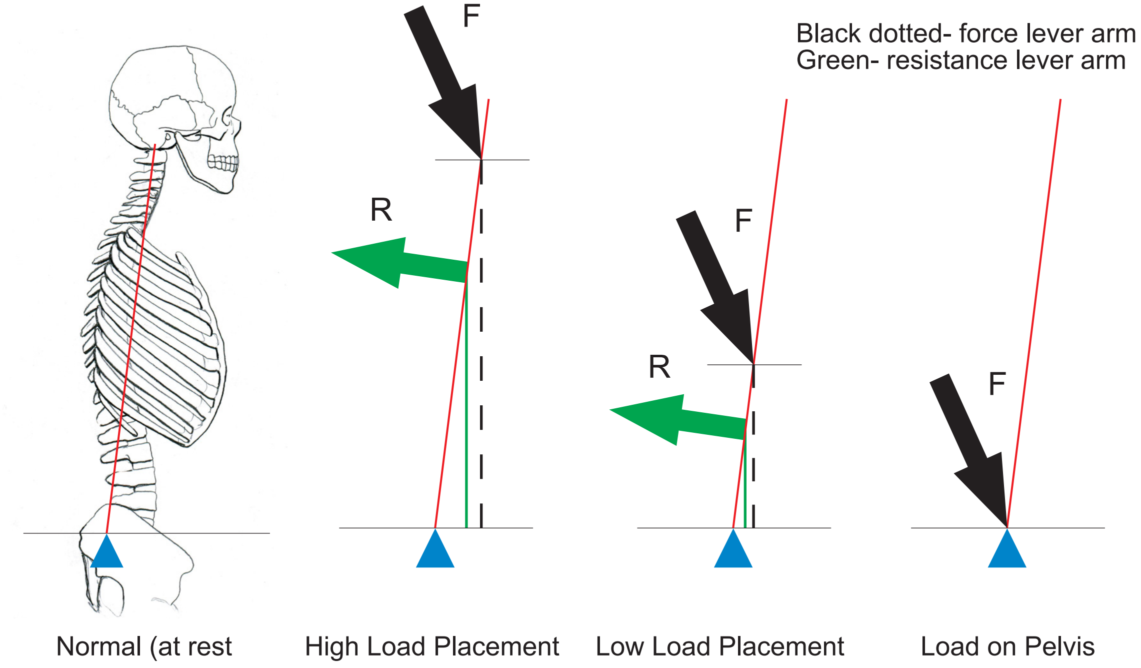


Fig. 2C.12: Lever arms of pelvis with backpack

2C.5- Pelvic Girdle and Hip Joint

The pelvic girdle and its related structures provide a number of critical services to the human body. Most importantly for the structure of the human body system, the pelvic girdle is critical to facilitating bipedal movement and the capability of standing upright. In addition a number of load-bearing structures interact with it, thus making the pelvic girdle a key area of interest.

Composition

Compositionally, the pelvic girdle comprises the left and right pelvic bones, the femurs, and a group of bones including the sacrum (which is often considered an extension of the spine and is also considered the point where the spine connects with the pelvis), the coccyx, and obturator foramen (Floyd, 2012, p. 227). The pelvis is held together via three joints: one anterior symphysis pubis between the pelvic bones and two

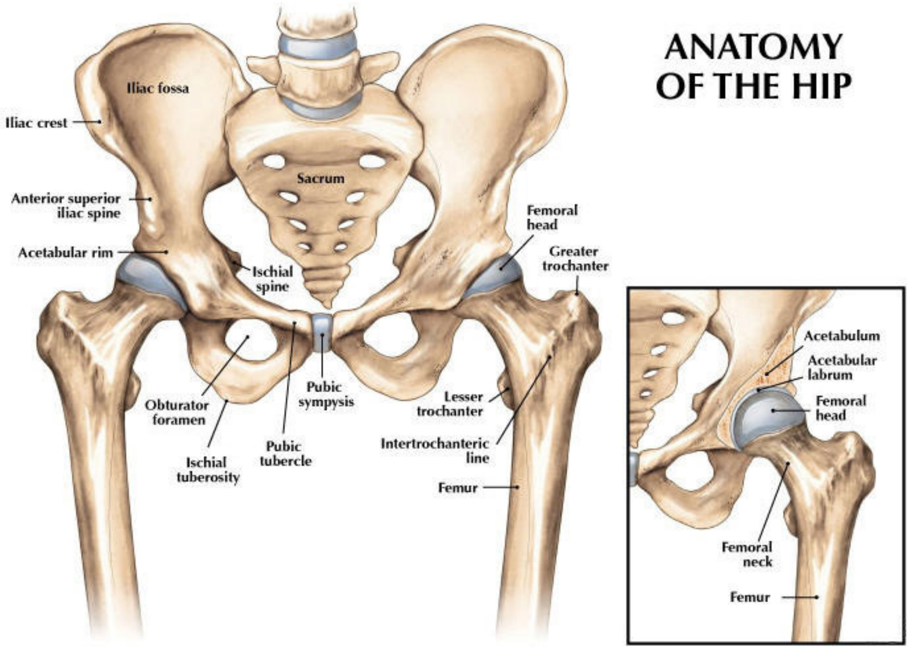


Fig. 2C.13: Anatomy of the Hip

posterior sacroiliac or SI joints between the sacrum and the two pelvic bones (Floyd, . 229). The concave surfaces of the acetabulums of the pelvis are the sites of the acetabular femoral or hip joint.

Muscularly, there a number of muscles involved with hip joint and pelvic girdle. These include the anterior muscles of the iliopsoas (iliacus and psoas), pectineus, rectus femoris, and sartorius; the lateral muscles of the gluteus medius, gluteus minimus, external rotators, and tensor fasciae latae; the posterior muscles of the gluteus maximus, biceps femoris, semitendinosus, semimembranosus, and deep external rotators; and lastly the medial muscles of the adductor brevis, adductor longus, adductor magnus, and gracilis (Floyd, p. 237-238; pp. 248-264). Nervous components for the hip, pelvis, and lower leg are easily found yet not of particular relevance to this study (Floyd, pp. 245-247).

Ranges of Motion

The most immediately recognizable benefit is the hip joint. The hip joint "is a relatively strong structure due to its bony architecture, strong ligaments, and large, supportive muscles" (Floyd, 2012, p. 227). Floyd (2012) goes on to describe the main functions of the joint as load-bearing and locomotion (p. 227). Because of the exceptionally dynamic range of motion it possesses, this permits the ability to "run, cross-over, side-step, jump, and make many other directional changes" (p. 227).

When describing the related ranges of motions the hip is typically the first to receive attention. This is primarily due to its dynamic nature; the ranges of motion for the hip and the associated movements are numerous and diverse (p. 232). While these ranges play a significant role in the dynamic movement of the lower limb as a whole, yet for this study are not of great relevance.

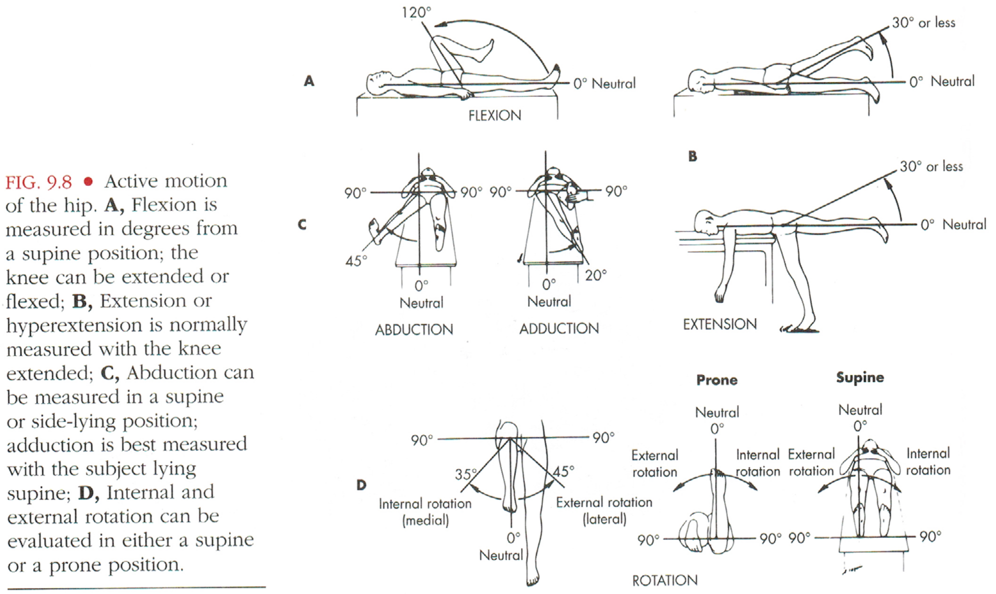


FIG. 9.8 • Active motion of the hip. **A,** Flexion is measured in degrees from a supine position; the knee can be extended or flexed; **B,** Extension or hyperextension is normally measured with the knee extended; **C,** Abduction can be measured in a supine or side-lying position; adduction is best measured with the subject lying supine; **D,** Internal and external rotation can be evaluated in either a supine or a prone position.

Fig. 2C.14: Ranges of motion of the hip

<u>Significance</u>

In addition to being site of the load-bearing joints for the lower limb, the pelvic girdle is ideal for weight bearing of backpacks through a waist or pelvic belt since it is a stable platform. The pelvic bones then communicate loads down through the leg and relieve loads from the spinal column. It should be noted that the shape of the pelvis differs between men and women: with men the brim of the pelvis is smaller, the pubic arch angle is less than 90 degrees, and a narrower pelvic outlet, whereas women's are larger with a wider brim, and a pubic arch angle greater than 90 degrees (Argosy Publishing, Inc., 2015b).

Due to the amphiarthrodial joints that join it together, the pelvic girdle may be considered a relatively immovable structure within the human body when compared to other joints; typically very minimal oscillating-type movements with the connective

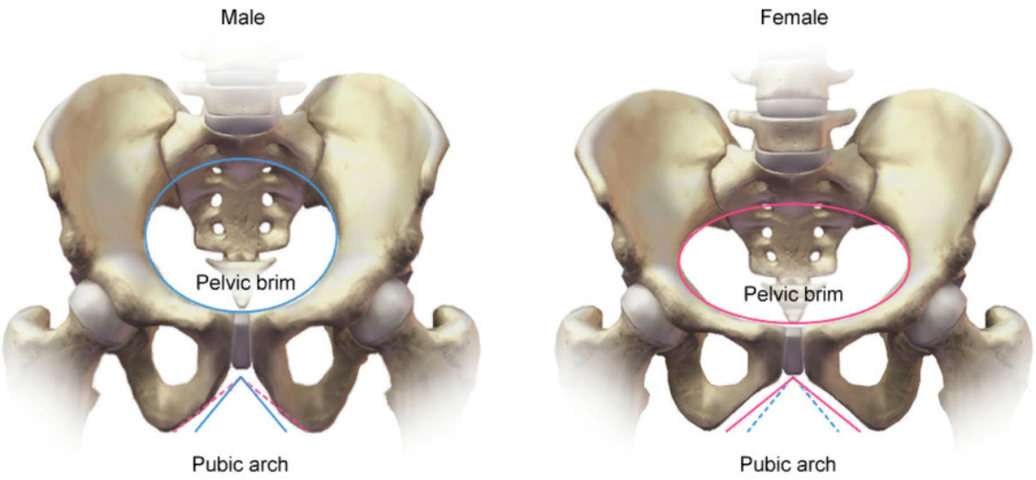


Fig. 2C.15: Anatomical differences in male and female pelvis

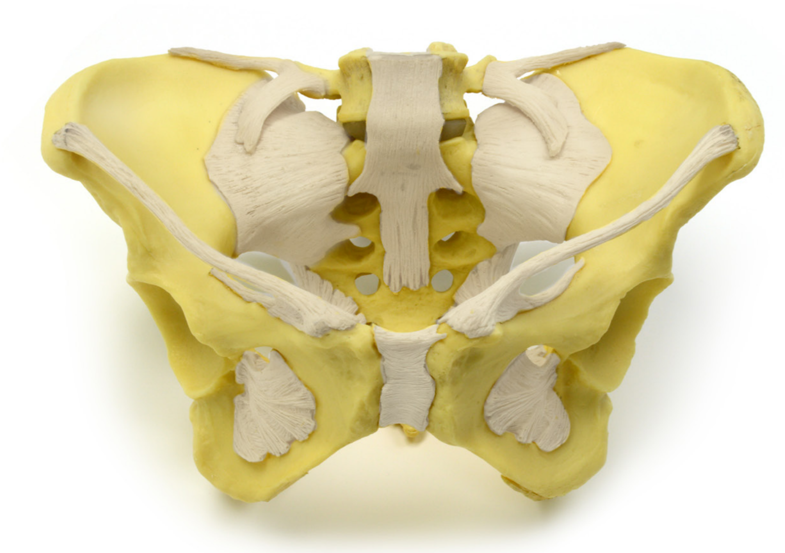


Fig. 2C.16: Pelvic girdle anatomical model with ligaments (in white)

tissues of these joints (p. 229). However, as noted with the effects of hormonal changes on connective tissues, the connective tissues of the pelvis will relax and lengthen to facilitate events such as childbirth. While this may make the pelvic girdle more susceptible to injury in certain cases, on the whole the pelvic girdle an exceptionally strong structure.

Another feature to consider are the SI joints themselves. They are shell-shaped

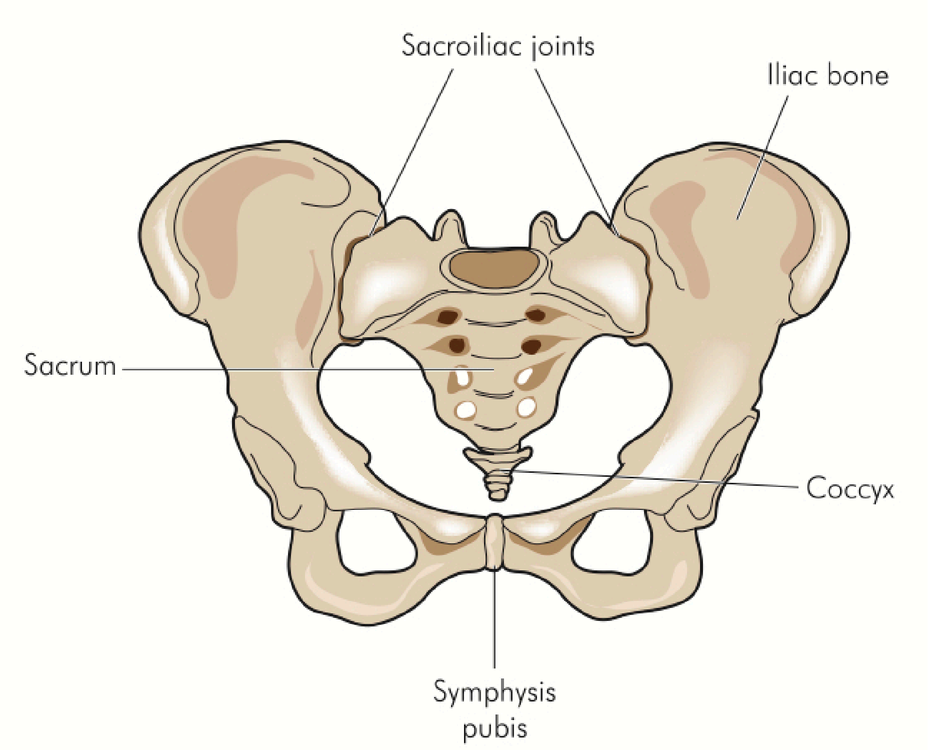


Fig. 2C.17: Sacroiliac joint locations in the pelvis

joints with an extensive ligamentous structure that helps hold the pelvis and the sacrum together. The purpose of the joint shape is to facilitate a small degree of dynamic axial rotational gliding between the sacrum and the pelvic bones (where more movement occurs superiorly than inferiorly where the point of rotation may be found). As previously stated, the sacrum itself may be considered an extension of the spine. Thus undue force or load placed on the spine (especially in the vertical planes) will translate to bear on the SI joints and the numerous ligamentous structures that support it.[2] Given the degree of ligamentous structures present and their level of interconnectivity in the pelvic girdle, any such injury resulting in a shear tear of the ligaments will greatly affect the entire structure. This again is rationale to remove weight from the shoulders, torso, and spinal column in favor of the pelvic crests.

2C.6- Lower Limbs and Significance

The areas of interest for the lower limbs, or legs and feet, are important for the design of backpacks from an inter-connective whole-body standpoint. The pelvis in particular has a role with backpacks as an anchor point on which weight can be placed, while the legs serve as the means of load-bearing and locomotion.

A lesser degree of information is important for these areas based on the subject matter, yet recognizing the role of this area of interest is still of importance. For additional consideration for the lower limbs and locomotion, *Human Walking* (Inman, Ralston, Todd, & Lieberman, 1981) is recommended, although it is exceptionally extensive and its content falls outside the scope of this study.

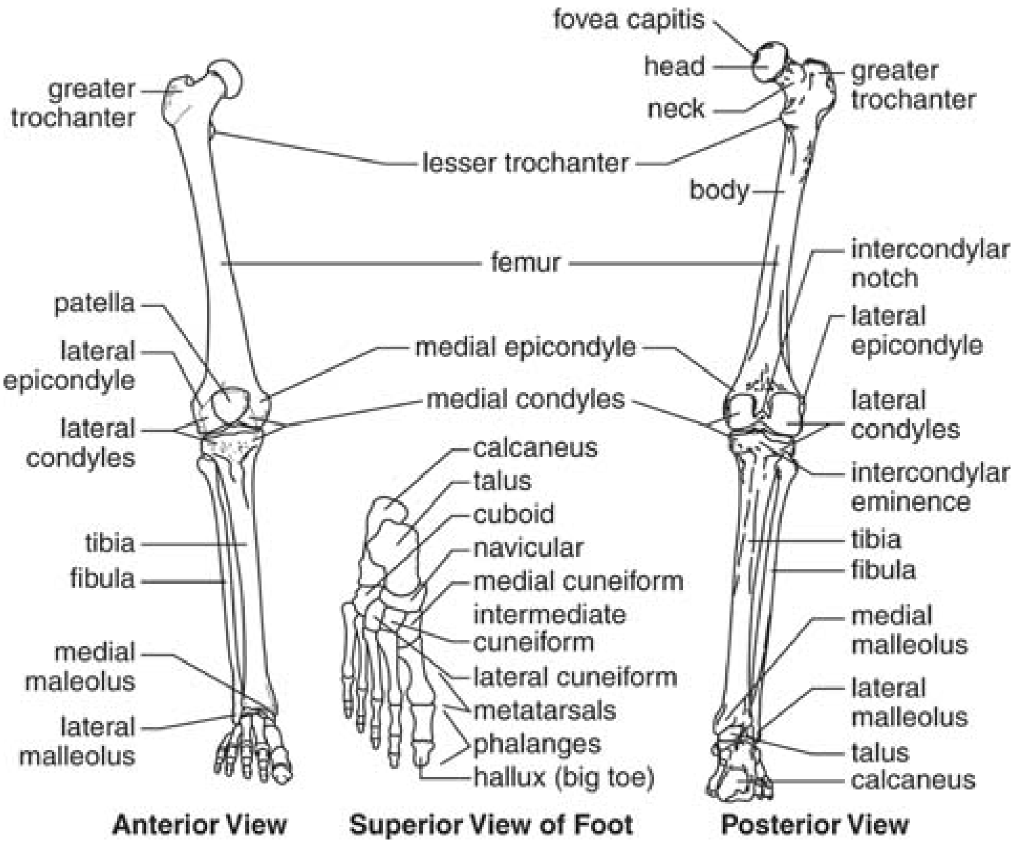


Fig. 2C.18: Bones of the lower limb

An important distinction between the male and female body can be found in the lower limb, particularly involving the femur. The Q-angle of the femur is the angle off the vertical from the knee through the femur, and is typically less than or equal to 15 degrees in men and greater than 15 degrees in women (“Q angle,” n.d.). Its significance is explored by Graci, Van Dillen, and Salsich’s study of a single leg squat (as cited in Fields 2012):

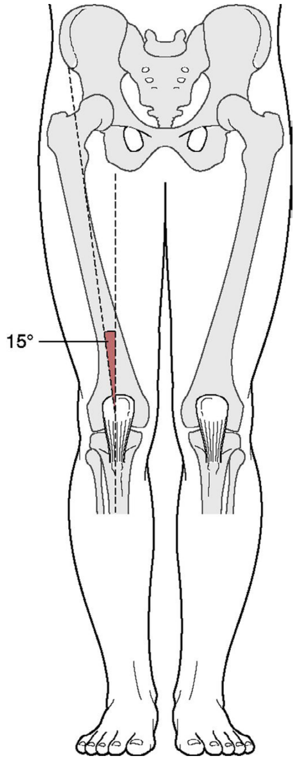


Fig. 2C.19: Q Angle of the Hip

> [t]he knees of men and women become torqued differently, exposing females to greater risk of ACL knee injuries... All of this makes perfect sense from a biomechanical standpoint. Women keep a more erect posture during the squat because they have less upper body core strength musculature than a man. Bending the trunk, as men do, requires the vertical gravitational force vector to move farther away from the hip joint center, increasing the demand on the hip muscles

> for support, but decreasing demand on the knee muscles. Females must rely more on the quadriceps, the large thigh muscle, which puts the ACL at greater risk for injury. Less hip muscle strength in females than in males might also explain why females perform the squat faster. (para 6-7).

Based on this knowledge that women are more likely to encounter ACL injuries without external loads, it is recommended that women use knee braces as a preventative measure when using backpacks (particularly heavy ones).

It should be noted, however, that loads placed on the body (such as backpacks) do alter the gait pattern. The most significant of these adaptations of the body due to posterior loading include a decrease in the length of stride, an increase in stride frequency and step width, decreased pelvic girdle rotation, and a decrease in balance (Sumner, 2012, p. 21-24). Luckily some of these factors are easily addressed through a lumbar belt, as Sumner states “Sharpe et al. (2008) [found] that loading participants with a lumbar belt equipped backpack resulted in significantly more pelvic girdle-to-trunk rotation pattern in addition to a more stable pattern in the participants’ gait” (p. 23). The rest are adaptations that will occur with any form of posterior loading of the body, which affects not only the Areas of Interest for backpacks but the center of gravity as well.

2C.7- Center of Gravity for the Body

According to Hamilton, Weimar, and Luttgens (2008), the center of gravity may be defined in a number of ways: first it is “the point representing the weight center of an object,” secondly it can be the “point in the body about which all parts exactly balance each other,” and thirdly it may be considered “the point at which the entire weight of the body may be considered concentrated" (pp. 32-33). Locating the center of gravity can be challenging at times since the center of gravity is not the same for each individual. Variables such as "the individual's anatomical structure, habitual standing posture, current position, and whether external weights are being supported" act together to result in a localized point for each individual that can also move (Hamilton, Weimar, & Luttgens, 2008, p. 33).

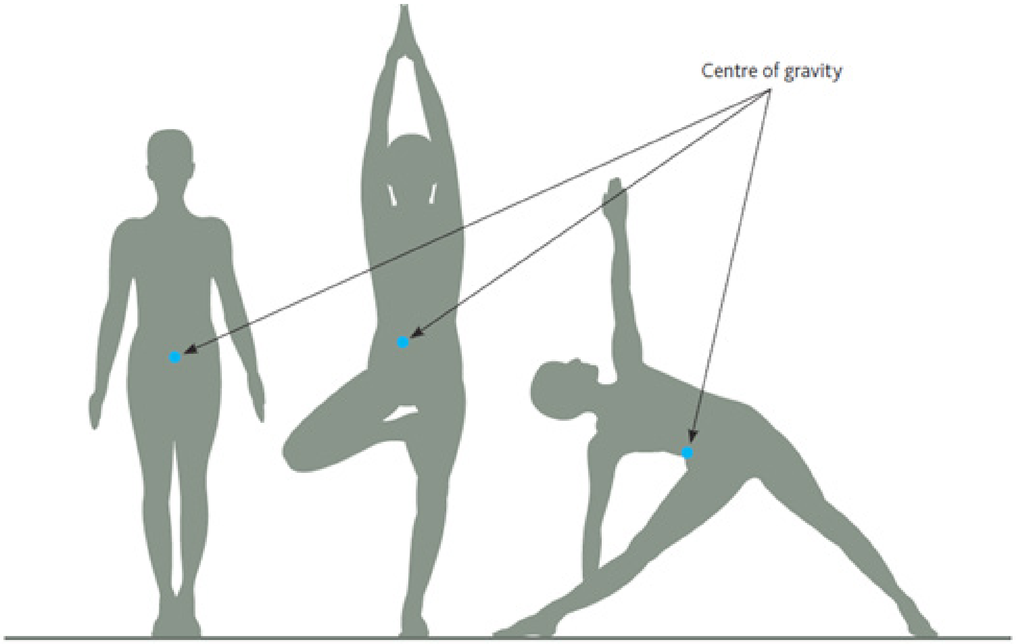


Fig. 2C.20: Center of gravity location with postural changes

<u>*Basic concepts of the Center of Gravity (CoG)*</u>

Generally speaking, Hamilton, Weimar, and Luttgens (2008) identify the position of the center of gravity:

> In a person of average build, standing erect with the arms hanging at the sides, the center of gravity is located in the pelvis in front of the upper part of the sacrum. It is usually lower in women than in men because of women's heavier pelvises and thighs and shorter legs. (p. 33)

More specifically, there exists a generally accepted ratio for the center of gravity's location in the male and female body. Measured from the ground in the transverse plane, the center of gravity is located approximately at the 55 percent of the standing height, while for men the center of gravity is approximately at 57 percent of the standing height. Different means of finding the exact center of gravity for an individual are described as well (pp. 377-386) yet are outside the scope of this study.

Of interest for this study is the discussion of stability and mobility within the chapter concerning centers of gravity (Hamilton, Weimar, and Luttgens, 2008). Specifically, nine points about stability are made, reproduced herein (pp. 375-376):

- Other things being equal, the lower the center of gravity, the greater will be [sic] the body's stability.
- Greater stability is obtained if the base of support is widened in the direction of the line of force.
- For maximum stability the line of gravity should intersect the base of support at a point that will allow the greatest range of movement within the area of the base in the direction of forces causing motion.
- Other things being equal, the greater the mass of a body, the greater will be [sic] its stability.
- Other things being equal, the most stable position of a vertical segmented body (such as a column of blocks or the erect human body) is one in which the center of gravity of each weight-bearing segment lies in a vertical line centered over the base of support or in which deviations in one direction produce torques that must be balanced by deviations producing torques in the

opposite direction.

- Other things being equal, the greater the friction between the supporting surface and the parts of the body in contact with it, the more stable the body will be.
- Other things being equal, a person has better balance in locomotion under difficult circumstances when the vision is focused on stationary objects rather than disturbing stimuli.
- There is one positive relationship between ones’ physical and emotional state and the ability to maintain balance under difficult circumstances.
- Regaining equilibrium is based on the same principles as maintaining it.

An additional component not addressed as a point for stability, but rather for mobility, is of equal value:

- There is an inverse relationship between stability and mobility. The greater the stability of a given body, the more difficult it will be to start the body moving. Conversely, the greater the mobility of the body, the less stability it possesses. A critical point in this relationship is the change from a position of stability to a state of mobility and eventually back to a position of stability. (p. 377)

Sumner, 2012: Biomechanical Effects of Posterior and Combined Anterior/Posterior Load Carriage

Biomechanically the significance of center of gravity considerations within backpacks is significant. Sumner (2012) reviews a number of biomechanical studies addressing the effects of load carriage on the center of gravity of the human body:

> It should be noted that there is the center of gravity of the load/pack (COGpack), the COG of the person (COGperson), and the COG of the pack/person system (COGsys). During posteriorly loaded conditions these adaptations are even more pronounced and include: increased muscle activity (Al-Khabbaz et al., 2008; Devroey et al., 2007), increased motion of the trunk and lower extremities (Chow, Leung, & Holmes, 2007; Devroey et al., 2007; Holt et al., 2003; Seven, Akalan, & Yucesoy, 2008), and a shift in the center of gravity (COGsys) of the combined load and body system (Cook & Neumann, 1987; Holt et al., 2003). (p. 21)

Specifically for posterior load-carrying systems, Cook & Neuman (as cited in Sumner, 2012) found that this load setup shifts the user's center of gravity posteriorly. This causes an extension of the trunk and spine, which the body seeks to balance by flexing the trunk forward to pull the center of gravity closer "to its unloaded position" (p. 32). As a result, this increases levels of activity in the trunk flexors. This ties in perfectly with the biomechanical load placement addressed in the Trunk and Spinal Column Area of Interest section, where the trunk flexors take the role of the resistance arm (RA). Further, Sumner (2012) states the most "significant changes in RA activity occurred at 20% BM, supporting previous research that loads of 20% BM should be avoided" (p. 33).

Significance

- The center of gravity (CoG) is different between men and women: located at roughly 55 percent of the standing height from the ground for women and roughly 57 percent for men. The anatomical neutral position is the most stable and has the least energy/ muscle force demands.

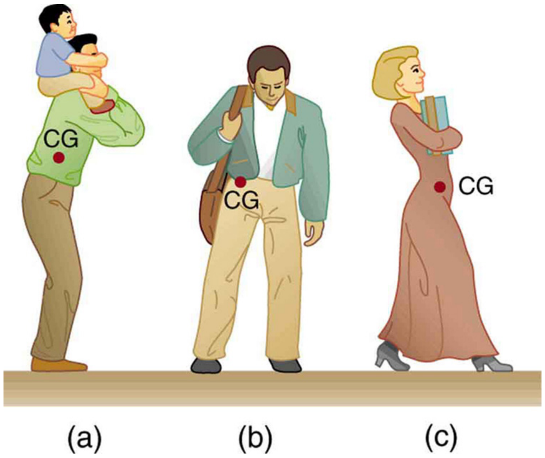


Fig. 2C.21: Center of gravity location with external loads

- The center of gravity is different between each individual and moves based on posture, position at a given time, and based on external loads such as backpacks. With external loads, the CoG will move towards the load, and the body will adapt its posture in the opposite direction to try and bring the CoG of the system closer to the position of anatomical neutral. With loads on the back, the body will lean forward (A); with loads on the side, the body will lean to the opposite side (B); with loads on the front, the body will lean back (C). Otherwise, the individual will fall over in the direction of the load.
- The externally loaded human body will exert energy to adapt its posture to try and bring its center of gravity back to its normal position. Overloading and excessive postural adaption may result in serious dysfunction or injury.

2C.8- Conditions to Prevent and Other Significant Findings

Having established the areas of interest pertaining to backpacks, it becomes necessary to address the different conditions and relevant information pertaining to backpacks and those areas of interest. It should be noted most if not all of these conditions are preventable with the proper use and setup of a backpack. Accordingly, it falls to the designer to help prevent these conditions during the design process.

2C.8.1- Backpack Palsy: Causes and Significance

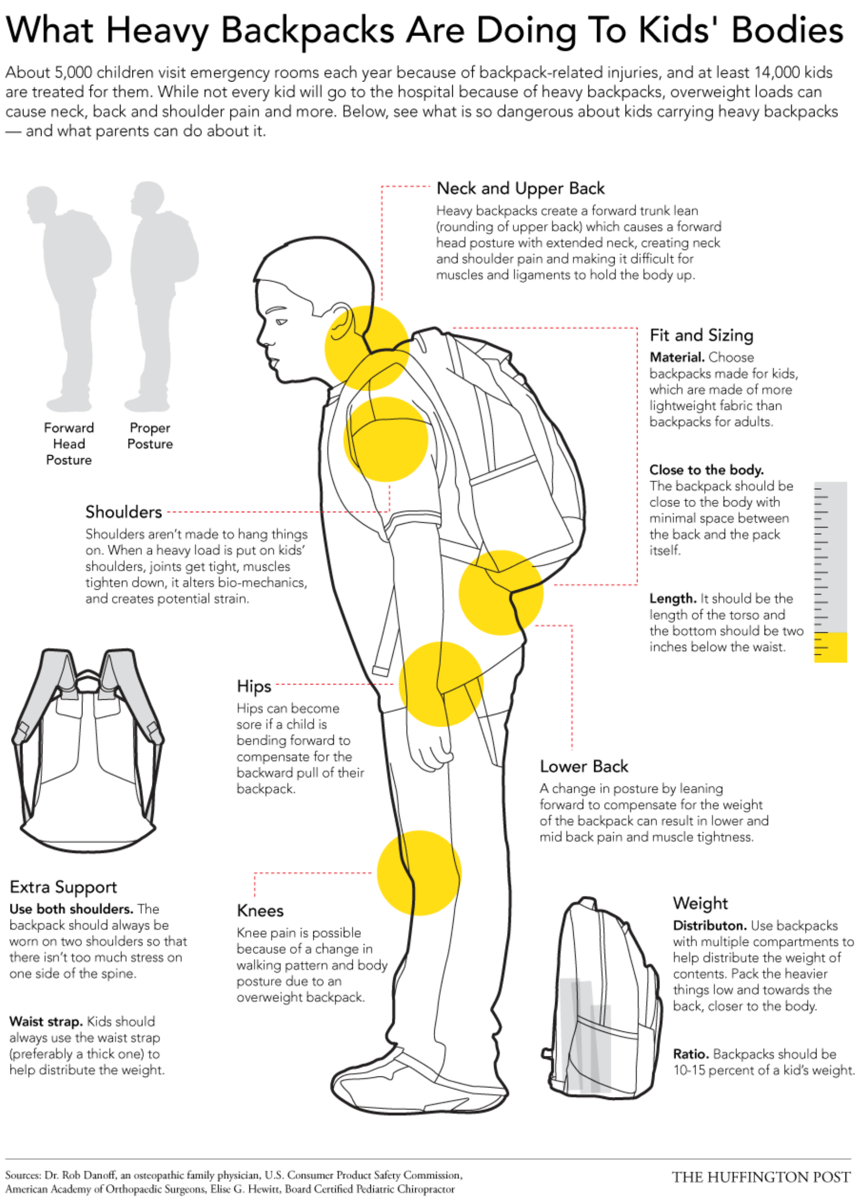
Of the many conditions that are associated with backpacks and backpack devices, one of the more well-known is backpack palsy. “Neurophysiological Findings in Patients with Backpack Palsy” (Öz, et al., 2010) finds that the compressive force a heavy backpack’s load exerts on the shoulders and clavicles of a user results in “the potential to cause brachial plexopathy. Upper extremity numbness, weakness and atrophy associated

Fig. 2C.22: Combat load of a US trooper, Vietnam-era with the use of a heavy backpack have been reported previously and termed as pack palsy or rucksack paralysis” (p. 395). Additionally, “[a]ctivities such as walking and running with a heavy backpack for extended periods without rest may cause varying degrees of brachial plexus lesions" (Öz, et al., p. 395).

“Neurophysiological Findings in Patients with Backpack Palsy”

Backpack palsy is not a new condition by any means. Cases of backpack palsy have been reported during the Second World and Korean Wars, particularly for “soldiers, scouts, and mountain climbers” during those eras (Öz, et al., 2010, p. 396). While the authors state “backpack palsy is rarely seen in today’s backpack-carrying students” there is documentation to prove otherwise, especially when Öz et al. (2010) states symptoms of backpack palsy “appeared acutely just after carrying a heavy backpack (18-25kg) during extended marching” (p. 396).

One source identifying backpack palsy in students is Dr. Stefanie Haugen (as cited in Yager, 2013), who explains the impact of backpack palsy on young children. She finds backpack palsy develops when “[p]ressure put on the nerves in the shoulder causes numbness in the hands, muscle wasting and in extreme cases, nerve damage.” Yager (2013) states this excess pressure comes from improper wearing of backpacks, using a backpack that is of the incorrect size, and by “carry[ing] a locker’s worth of books to home and back to school everyday [sic].” Addressing backpack palsy in children is paramount as their growing bodies are more susceptible to spine injury and conditions than those of adults (Yager, 2013). However, it is outside the scope of this particular study at this time.



What Heavy Backpacks Are Doing To Kids' Bodies

About 5,000 children visit emergency rooms each year because of backpack-related injuries, and at least 14,000 kids are treated for them. While not every kid will go to the hospital because of heavy backpacks, overweight loads can cause neck, back and shoulder pain and more. Below, see what is so dangerous about kids carrying heavy backpacks — and what parents can do about it.

Neck and Upper Back
Heavy backpacks create a forward trunk lean (rounding of upper back) which causes a forward head posture with extended neck, creating neck and shoulder pain and making it difficult for muscles and ligaments to hold the body up.

Fit and Sizing
Material. Choose backpacks made for kids, which are made of more lightweight fabric than backpacks for adults.

Close to the body. The backpack should be close to the body with minimal space between the back and the pack itself.

Length. It should be the length of the torso and the bottom should be two inches below the waist.

Shoulders
Shoulders aren't made to hang things on. When a heavy load is put on kids' shoulders, joints get tight, muscles tighten down, it alters bio-mechanics, and creates potential strain.

Hips
Hips can become sore if a child is bending forward to compensate for the backward pull of their backpack.

Lower Back
A change in posture by leaning forward to compensate for the weight of the backpack can result in lower and mid back pain and muscle tightness.

Extra Support
Use both shoulders. The backpack should always be worn on two shoulders so that there isn't too much stress on one side of the spine.

Waist strap. Kids should always use the waist strap (preferably a thick one) to help distribute the weight.

Knees
Knee pain is possible because of a change in walking pattern and body posture due to an overweight backpack.

Weight
Distributon. Use backpacks with multiple compartments to help distribute the weight of contents. Pack the heavier things low and towards the back, closer to the body.

Ratio. Backpacks should be 10-15 percent of a kid's weight.

Sources: Dr. Rob Danoff, an osteopathic family physician, U.S. Consumer Product Safety Commission, American Academy of Orthopaedic Surgeons, Elise G. Hewitt, Board Certified Pediatric Chiropractor

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Fig. 2C.23: What Heavy Backpacks are Doing to Kid's Bodies

Öz et al. (2010) continues by identifying factors which increase and reduce the likelihood of backpack palsy. One of these factors involves the waist or hip belt. Bom's "A case of 'pack palsy' from the Korean War" (as cited in Öz et al., 2010) found "[h]eavy backpacks used without waist support increase the risk of compression neuropathy. This increase is more evident particularly when the carrier is working with his or her hands in difficult terrain" (p. 398). Some figures found that simply using a pack frame with a hip

Fig. 2C.24: US Army soldiers and gear in addition to protective garments

belt decreased the risk of such compression injuries "in basic trainees from 1.17 / 1000 without the pack frame to 0.157 / 1000 with a pack frame" (p. 398). Other avoidance factors included "[l]ightening loads, improving load distribution, and optimizing load-carriage equipment" (p. 399). Based on the biomechanics example wherein loads are recommended to be placed close to or on the pelvis, it is easily deduced that such improved load distribution would be to try and keep the weight balanced as close to the pelvis as possible.

"Back Pack Palsy as an Unusual Cause of Shoulder Pain..."

"Back Pack Palsy as an Unusual Cause of Shoulder Pain and Weakness- a Case Study" (Mansoor et al., 2012) reports a Finnish study for backpack palsy, finding there to be roughly 53.7 cases reported per 100,000 persons. Additionally, a specific case report of “a twenty-eight years old previously healthy old soldier” reported with backpack palsy after carrying a “30kg backpack along with heavy weapon on his shoulder for ten hours” (Mansoor et al., 2012). This is of significance as Mansoor et al. (2012) states:

> The permissible weight to prevent backpack palsy varies from individual to individual depending on age, weight, physical build and fitness level. It is roughly between 25% to 35% of body weight. In our case, cause of palsy was heavy weight, 30kg, around 40% of his body weight and prolonged duration (10 hours) of carrying heavy backpack in a mountainous terrain [sic].

In addition to these weight and duration factors, “incorrect strapping, over weight backpacks, poor fitness and posture, congenital anomalies, uneven hilly terrain... put the individual at greater risk of injury” (Mansoor et al., 2012).

Conclusions

Based on the reports, backpack palsy is a condition that may occur when users carry loads in excess of 25% to 35% of their body weight, regardless of their physical condition. It is possible to reduce the risk of this condition when loads are kept below or within the aforementioned weight ratio, proper placement of straps, and distribution of weight to the pelvis. Referring back to the areas of interest, removing weight bearing from the shoulders, torso, and spine is the easiest way this can be accomplished.

2C.8.2- Skin and Ulceration: Causes and Significance

A second condition to be aware of for backpacks are decubitus ulcers. Reddy (1986) explains that skin, the largest organ of the human body, is “a three-dimensional network of connective tissue fibers" (p. 220). He continues:

> Spaces between these fibers are filled with interstitial fluid and ground substance. The dermis contains blood and lymphatic vessels, nerve terminals, glands, hair, fibroblasts and other types of cells. Subcutaneous tissue is a continuation of the dermis and is composed of connective tissue and fat cells.

Sometimes the skin and these compositional elements can be the site of injury. One condition in particular are decubitus ulcers. These are "localized areas of cellular necrosis caused by prolonged or excessive mechanical loads on tissue," most commonly associated with spinal cord injury or impaired patients who develop bed sores as a result of prolonged laying in bed (p. 215). Some authorities may argue the various categories that ulceration may fall under, yet for the purposes of this study all the conditions that may result in ulceration will be explored. The trinity of conditions for the development of ulcers in the skin and subcutaneous tissue are direct localized pressure, shear forces, and moisture. For the purposes of this study, pressure and shear forces may be grouped together.

External loads or pressure create "a distribution of compressive and shear stresses that generate gradients of interstitial fluid pressure within the tissue beneath the site of load-application:" in other words, creating a blister (p. 219). The pressures and severity of injury vary; at 75mm Hg on the skin results in reduced blood circulation, and pressures over 105 mm Hg results in irritation and can produce subcutaneous edemas after two hours of exposure (Sumner, 2012, p. 41). As such, damage to the skin and pressure spikes in the tissue may cause an ulcer to develop depending on the degree of force and its duration.

An example where both these forces may cause ulceration is a loose fitting sock binding and rubbing against the foot while a hiker walks for a prolonged time. This is a commonly known fact among hikers, and these effects can and will be compounded with the presence of moisture. The lecture *Moisture Lesions* (Kray, n.d.) explains prolonged or excessive exposure to moisture “causes the skin to become damp, soggy and clammy and eventually saturated. If the skin's permeability is breached, there is an increased risk of a combined lesion, resulting from physical damage” (Kray, n.d.).

Accounting for these three factors, it is possible to develop ulceration with prolonged wearing of backpacks, where excess forces on the skin from load pressure, shear forces from ill-fitted straps, and the moisture trapped between the body and the backpack itself may be present. The visible signs of an ulcer may take “3 to 5 days between load application and external appearance,” meaning once a visible spot develops, significant damage has already taken place (Reddy, 1986, p. 217). All the individual sees is the tip of the iceberg: it is not uncommon for significant invasive treatment to be needed for severe cases, where permanent damage may still result. This is why proactive prevention is critical in the design phase and in use.

2C.8.3- Ruptured Disks: Causes and Significance

Referring to the backpack palsy section, excess loads may also result in ruptured discs of the spinal column. The web article “Prevent Herniated Discs with Back To School Backpack Tips” (2014) states that while younger children are “not usually at risk for serious back injuries from overuse or strain,” older children, teens, and adults by extension are more susceptible to “injuries such as herniated discs or sciatica, that could require minimally invasive surgery at some point down the road." This is due to the greater cushioning effect that young spinal discs provide, which spares them many of the common injuries found in adults due to "exposure to excessive force, impact or overuse from physical activity or lack thereof" (para. 1).

Injury, however, can still result from excessively heavy backpacks. "The journal *Spine* published a 2010 study, which concluded that backpack loads caused back pain in children likely due to spinal disc compression and lumbar asymmetry" (para. 2). This by extension applies to adult users as well. The easiest way to prevent this as well is to "don't overload and take out unnecessary items" and "tighten straps to keep the weight close to... the body, lessening the risk of back strain" (para. 4).

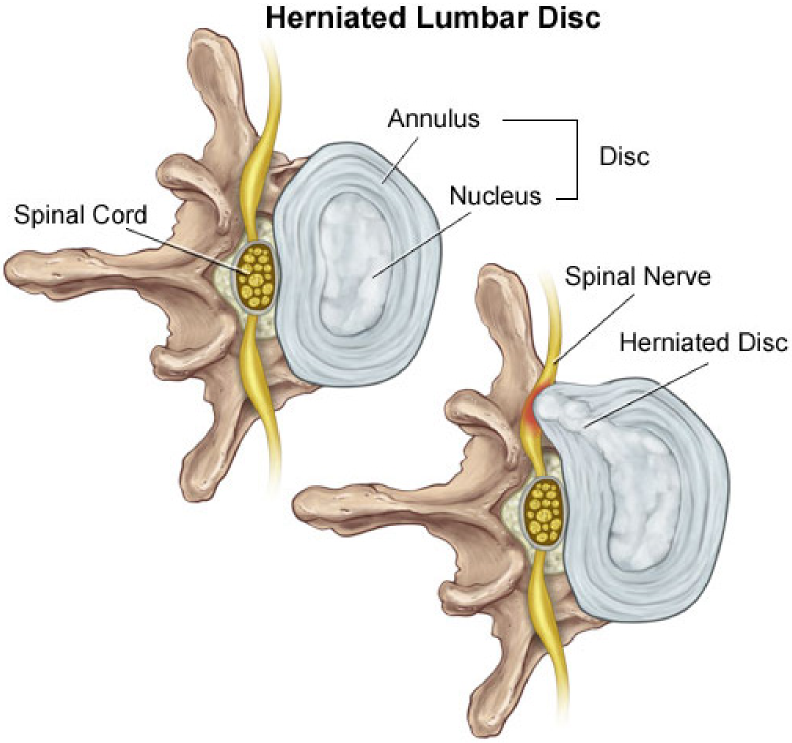


Fig. 2C.25: Herniated Lumbar Disc

2C.8.4- Connective Tissues: Composition and Significance

Connective tissue takes many forms within the human body. “Connective tissues present a great variety of appearances, but can be classified broadly into four types: blood, fibrous connective tissue, cartilage, and bone,” states Hollinshead (1974, p. 13). Fibrous connective tissues in particular are important to the human body in the forms of loose connective tissue, fascia, ligaments, tendons, and shock absorbing elements (p. 14-19).

The different types of fibrous connective tissue have specific roles within the body itself. Loose connective tissue fills “the interstices between organs and serves as padding” and is sometimes known as adipose or ‘fatty’ tissue (p. 14). Fascia is typically “a band or sheet of connective tissue, primarily collagen, beneath the skin that attaches, stabilizes, encloses, and separates muscles and other internal organs” (p. 133). It can be categorized as internal fascia (which lines the two major body cavities) and deep fascia,

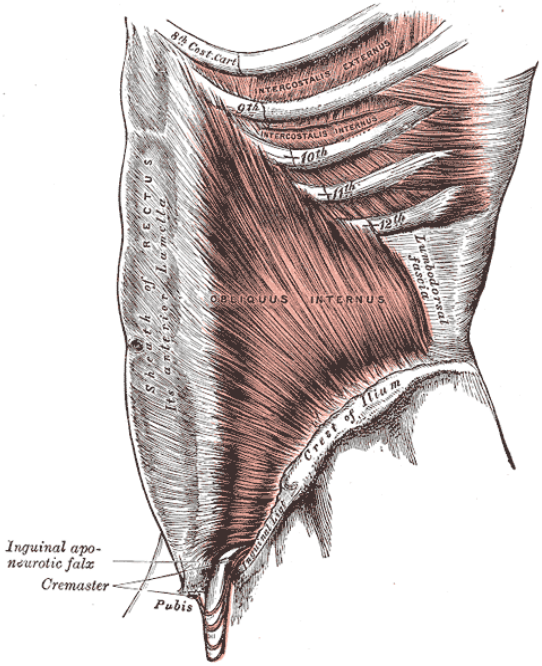


Fig. 2C.26: Plate 395 from Gray’s Anatomy with fascia call-outs

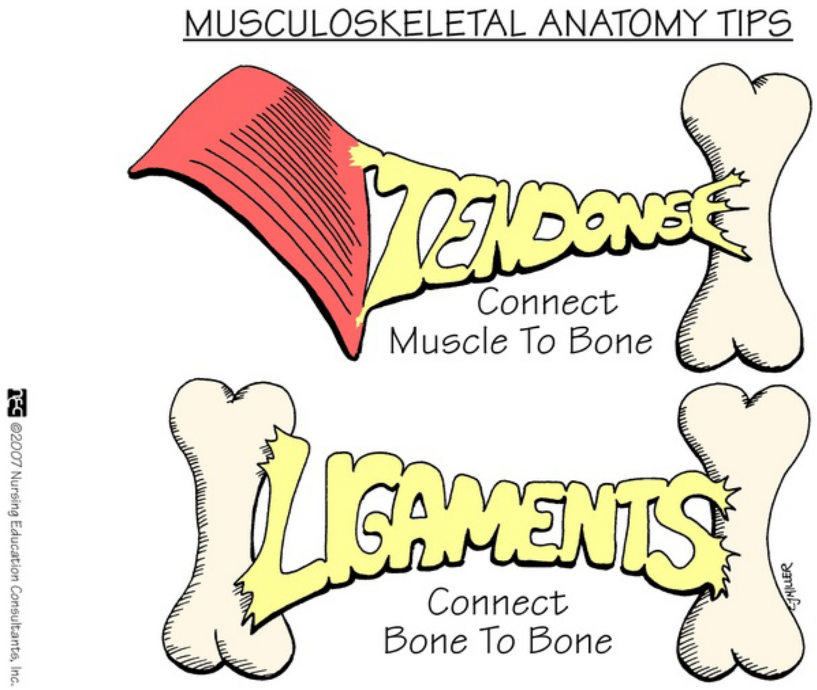
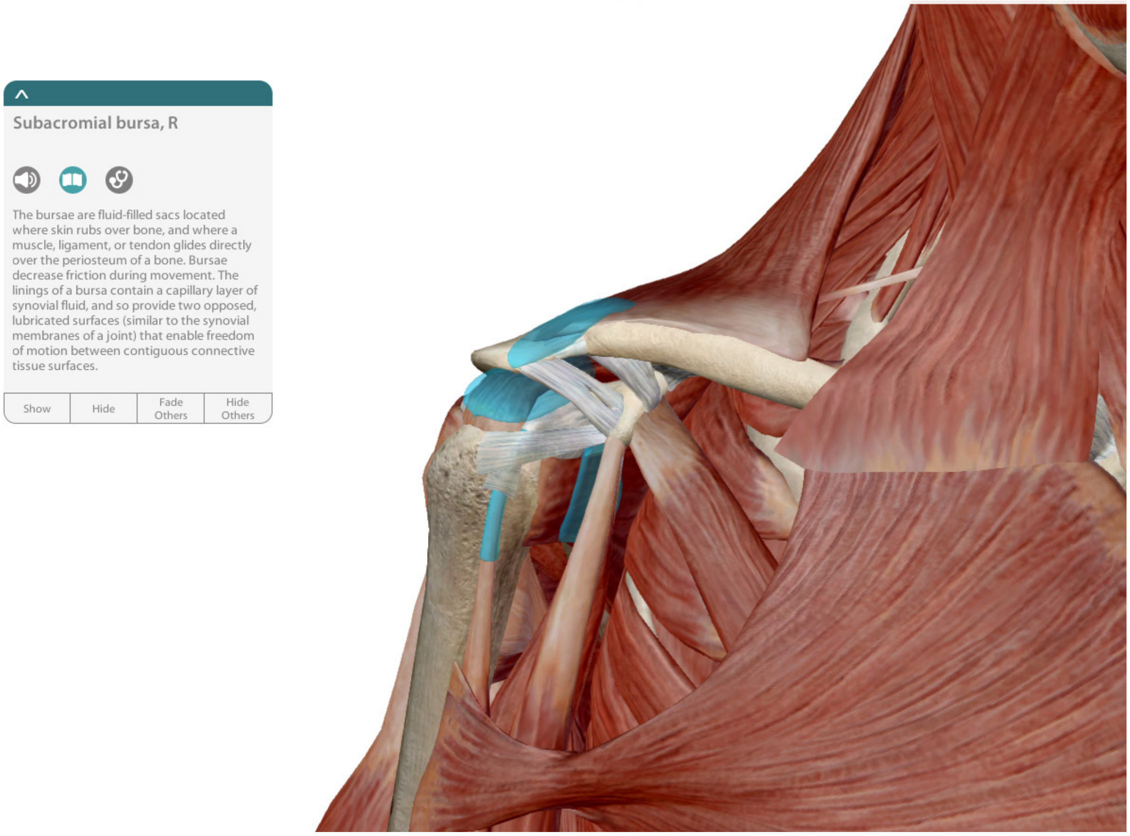


Fig. 2C.27: Quick tips for differentiating tendons and ligaments.

which forms “a thin grayish layer on the surfaces of the muscles, separable from them only by sharp dissection” (p. 15-16). Hollinshead goes into some detail concerning ligaments and tendons. Both are elastic and flexible forms of connective tissues that grow from the periosteum, or outer membrane, of the bones. Ligaments are the more elastic of the two, though the degree of elasticity may be minuscule compared to other features of the body. The main difference is ligaments connect bone to bone/bone like structures, growing close to the respective joints, and whose fibers mostly run in a uniform direction with some variation of cross fibers based on stress forces. Tendons, on the other hand, which “are actually part of muscles... [and] are one type of very dense collagenous tissue,” connect muscle to bone further away from the joints and whose fibers almost run exclusively in one direction: providing a great deal pull-resistant strength at the cost of being fairly easy to shred due to the general lack of cross-fibers (p. 17). Last, there



The bursae are fluid-filled sacs located where skin rubs over bone, and where a muscle, ligament, or tendon glides directly over the periosteum of a bone. Bursae decrease friction during movement. The linings of a bursa contain a capillary layer of synovial fluid, and so provide two opposed, lubricated surfaces (similar to the synovial membranes of a joint) that enable freedom of motion between contiguous connective tissue surfaces.

Fig. 2C.28: Bursae and some tendon sheaths (blue) of the shoulder

are bursae and tendon sheaths, two forms of shock absorbing elements in the human body. Bursae are sacs filled with synovial fluid located wherever movement of muscle, ligament, tendon, or skin glide over one another ("The Human Anatomy Atlas," 2007-2015). They act as shock absorbers for joints in addition to lubricating the surrounding structures for more efficient movement. Hollinshead (1974) finds tendon sheaths very similar to bursae, but take tubular forms that wrap completely around tendon attachments rather than the flat shapes found in bursae (p. 19).

<u>Significance</u>

Concerning connective tissue, men and women are significantly different. Specifically the elasticity properties of the tendons, ligaments, and connective tissue in general is greatly affected by hormonal fluctuation. The articles "Link Found Between Knee Injuries and Estrogen Levels in Women Athletes" (1997) found women during the period of menstruation are more susceptible to injury of the connective tissues caused by the hormonal fluctuations associated with this cycle. What causes this to occur is addressed in the BBC article "Menstrual cycle injury risk link" (2007) and based on the processes involved can be extended to pregnancy. Specifically, this BBC article states:

> Midway through the cycle, the level of the female sex hormone oestrogen, which gives strength to muscles and ligaments, drops dramatically, resulting in sudden weakness. At the end of the cycle levels of another hormone, relaxin, rise. This is to allow the cervix to open so that menstruation can occur, but it also means the ligaments in general are softened. The researchers found that strains and other injuries were more likely at both these stages.... Lead researcher Dr Stephen Sandler, an experienced osteopath, said: 'There was a clear link between hormone levels and laxity of joints, making women more vulnerable to injury' (para. 4-8).

Thus all ligamentous structures of the female body loosen with hormonal changes, especially those which occur during pregnancy. The pelvis has to expand for childbirth, becoming flexible enough for the child to pass through the birth canal ("Pregnancy: Pelvic and Hip Pain," n.d.); it is hoped that these specific connective tissues in the pelvis re-tighten after childbirth, otherwise pelvic dysfunction may occur.

It is also not uncommon for the connective tissues of the feet to loosen during periods and pregnancy, with these tissues not fully re-tightening after the latter. This results in an increased shoe size as the arch of the foot partially or fully collapses. These types of conditions have been well documented within sports medicine journals and the medical field at large, yet are not relevant to this particular study at this time. What should be gleaned is that women are at a significantly increased risk of ligamentous injury to the joints during pregnancy or during the week of menstruation, especially those involved with sports at a likelihood of two to eight times than men (“Link found between knee injuries,” n.d.).

2C.9- Initial Summations Section 2C

Based on the selection of human body information covered in Section 2C, a number of summations can be made. There are specific concepts and features of the body (areas of interest) that are directly interacting with or are impacted through the use of backpacks. Additionally, there are conditions, injuries, and other noteworthy considerations that should be addressed when designing backpacks. Building upon the need addressed in Section 2A, this information is most useful for the designer when it states 1) what needs to be known, and 2) states the significance of this information to the backpack design process.

The choice to use information drawn from the disciplines of anatomy, anthropometry, ergonomics, and biomechanics was well-founded. By tying this combination of data together, the designer can understand what elements of the human body are important for backpack design. Further, the designer can recognize why that information is important and needs to be integrated into the backpack design process. In effect, this information provides the knowledge needed for a new generation of backpacks with improved body-to-pack interfaces to be created.

Based on earlier conclusions, Section 2C addresses half of the goals of this study.

Having identified the information or ‘theory’ needs, there remains the need for a means of application. Just as this section covered the ‘what’ and ‘why’ of importance for human body information, a similar format is needed for use by designers. To do this, a series of design guidelines are recommended. Recognizing there is not a ‘one-size-fits-all’ approach to design, any practical use of human body information for backpack design needs to be flexible. The guidelines format should provide this flexibility, allowing for a repeatable means of design that can be adapted to the project based on the information or constraints at hand.

2D- Concepts & Formats for Human Body Design Guidelines for Backpacks

2D.1- The Need for Design Guidelines for Backpack Designers

Based on the initial summations of previous sections, there is a clear need for a reference guide communicating anatomy, anthropometry, ergonomics, and biomechanics of the human body at the conceptual level for backpack designers. From the industrial designer's standpoint, the material indicated in Section 2C is only half of the equation (i.e. only knowledge thereof). Knowledge of a subject is only of use if there is a technique or process through which it can be applied. For the purposes of this study, a series of guidelines will be created for the creation of backpacks and related soft goods using the aforementioned reference guide. This section will identify some of the major differences between men and women to consider in backpack design, as well as elements of existing backpacks that accommodate the areas of interests of Section 2C.

2D.2- Guidelines as an Ideal Format for Designers

Guidelines exist in many forms and varieties. What is potentially misleading about guidelines or 'guides' as they are sometimes referred to is the actual format they comprise. Guidelines are typically "a rule about how something should be done" (Merriam-Webster, n.d.). Procedures by comparison are "a series of actions that are done in a certain way or order: an established or accepted way of doing something" (Merriam-Webster, n.d.). Where the confusion arises is when these definitions are interchanged to describe what guidelines are. To better communicate the best format of guidelines for designers, a selection of government testing documents for softgoods and personal military equipment and the 4th Edition American Medical Association *Guides to the Evaluation of Permanent Impairment* (1993) were examined. This proved valuable for this study by determining how the guidelines for backpack design would be formated and developed.

(ADA423072) Tests of Combat Uniforms and Protective Clothing

For the purposes of creating a set of guidelines and considerations for civilian soft goods, the document *General Performance Tests of Combat Uniforms and Protective Clothing* (Army Test and Evaluation Command, 2004) is a valuable resource as it includes the methodology through which most wearable soft goods are evaluated and tested for the U.S. Armed Services. This document is also referred to by its accession number ADA423072. This source (Army Test and Evaluation Command, 2004) provides:

> [g]uidance for planning performance and durability tests of combat uniforms, nuclear, biological, chemical (NBC) protective clothing, and other types of clothing worn by the soldier. Items covered include, but are not limited to, uniforms, caps, undergarments, over garments, clothing liners, hoods, masks, gloves, socks and boots" (p. 2).

When broken down, ADA423072 consists of a cover page, table of contents, the scope of the procedures as mentioned above, facilities and instrumentation requirements for the evaluations, the testing conditions required for the evaluations, and the testing procedures themselves in addition to an appendix. A detailed analysis of ADA423072 may be found in Appendix A of this study.

(ADA566201) Tests of Personal Protective Equipment

General Tests of Personal Protective Equipment (Non-ballistic) - Soft Armor (U.S. DOD, 2012) – accession number ADA566201- addresses the “test methodology for nonballistic (NB) testing of soft body armor (SBA) personal protective equipment (PPE), and includes the requirements for First Article Tests (FATs) and Lot Acceptance Tests (LATs)” (p. 2). The layout and content of this document is very similar to ADA432072 in that it includes a scope, facilities and instrumentation requirements, test conditions, and the testing procedures in addition to an appendix.

One way in which ADA566201 stands out from the other document is its inclusion of an Overview of Processes section: something which provides in clear terms to the reader what the process entails:

> There are five distinct phases in the overall process for SBA testing: 1) test item receipt and processing, 2) test conduct, 3) data entry and analysis, 4) data reviewing and reporting, and 5) management approval and Versatile Information System Integrated On-Line (VISION) Digital Library System (VDLS) upload (p. 3).

Additional components included within ADA566201 covers the chain of custody of the soft body armor article, the training/certification of the test evaluators, and quality control parameters. These are included specifically since this document covers the testing and evaluating of personal protective gear. These soft goods operate at a very specialized set of regulations because they are a form of life-saving equipment; as such they must be certified by trained professionals, tracked, and proven through a quality control process. Including this is beneficial to the designer of such soft goods because it is an additional component which is required for soft body armor and personal protective gear.

The inspection and evaluation requirements described in ADA566201 covers a much more specific range of criteria than the clothing evaluation of ADA423072. A detailed analysis of ADA423072 may be found in Appendix B of this study.

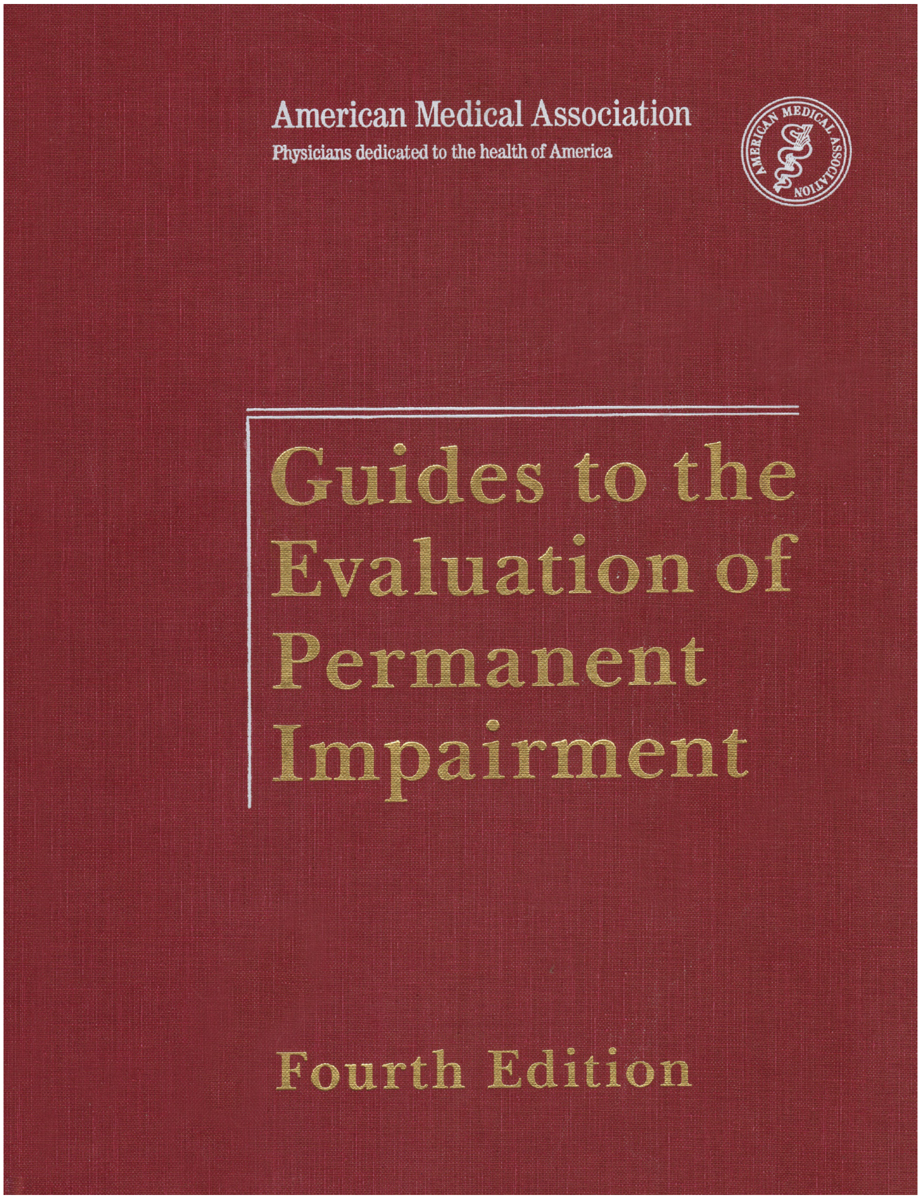
Government Guidelines Summation

Referencing the definitions of guideline and procedure introduced earlier, the two documents examined fall somewhere between guideline and procedure. This can be said as the exact format and chain of events are not rigid and open to modification. That said, at the same time these reference documents outline steps and processes to a more specific degree than a generalized rule or piece of advice.

Initial examination of these two military/federal documents for the testing of equipment identifies shared commonalities. First, clear concise instructions are established to permit repeatable testing to be conducted (as complies with the scientific method). This way, should inconsistencies arise, it is possible to determine if it the inconsistencies were one-time occurrences or indicators of larger issues. Secondly, variations of the instructions are included to permit specialized testing for the particular artifact being tested. This layout of repeatable steps with wiggle room for modification, however, muddies the category into which these documents fall.

Guides to the Evaluation of Permanent Impairment, 4th Edition

A significant resource for this study is the American Medical Association's (AMA) *Guides to the Evaluation of Permanent Impairment*. First developed to address



American Medical Association
Physicians dedicated to the health of America

Guides to the Evaluation of Permanent Impairment

Fourth Edition

Fig. 2D.1: 4th Edition AMA Guides to the Evaluation of Permanent Impairment

whether the “estimates of the severity of human impairments” could be improved for a variety of instances such as worker’s compensation and Social Security, the first edition was published in 1971 (American Medical Association, 1993, p. 1/1). Subsequent editions have been released, most notably the 4th and 6th editions. The 4th edition (1993) includes a number of charts for identifying the degree of impairment based upon objective documentation at the time of evaluation and the normative ranges of motion for various body parts and areas. It also contains a number of the range of motion charts that were omitted or condensed in later versions yet of use for this study in Section 2C.

The AMA *Guides* is more medical-legal resource than true anatomical range and accuracy database. In practice, it is typically used by a physician or health care professional to determine an impairment rating for a patient. As such, its contents need to provide a baseline of information with built-in factors of safety for what is considered average of the human body. This is a significant since impairment is described as:

> [c]onditions that interfere with an individual's "activities of daily living…" include[ing], but are not limited to, self-care and personal hygiene; eating and preparing food… maintaining one's posture, standing, and sitting… walking, traveling, and moving about; recreational and social activities (American Medical Association, p. 1).

The *Guides* go on to clarify that 'disability' as a legal aspect relating to economic loss of income, whereas 'impairment' is considered the degree to which the physical body has been injured or damaged in relation to the state of normal. 'Normal' by comparison is not considered an absolute point or concept: it is a "range or a zone, as with vision and hearing. The normal can vary with age, sex, and other factors…. What is normal must be determined by sufficient studies of representative populations carried out with valid methods" (American Medical Association, p. 2). For many of the various systems of the human body existing "medically accepted and scientifically derived data on normal functioning" is included and referenced to establish what is considered normal (p. 3).

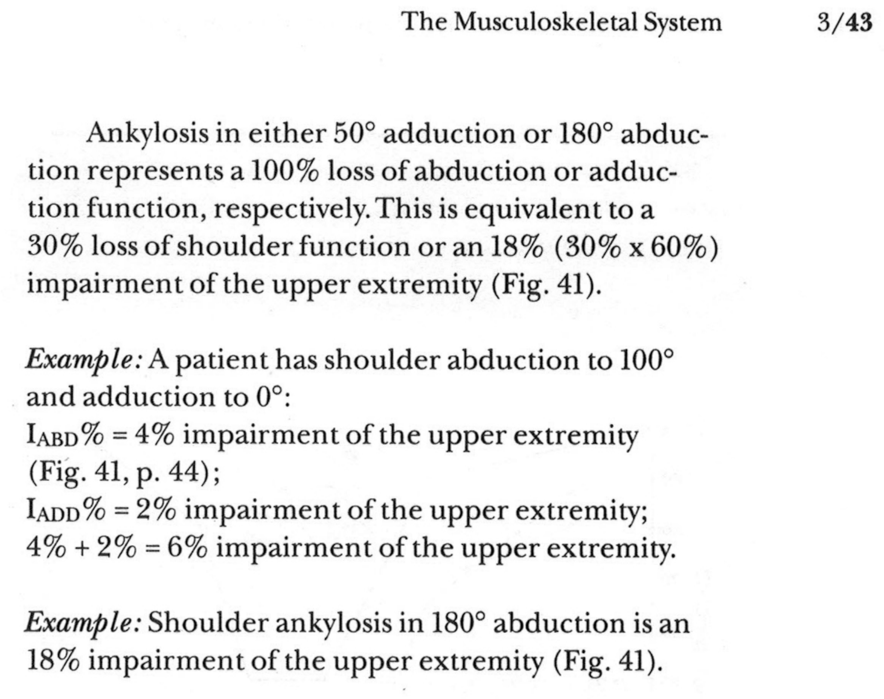
This is important for the designer for two reasons: 1) reducing impairment of the user is paramount, and 2) the range of normal found in the *Guides* can be used as a baseline from which to start designing. However, limitations to the *Guides* and its use do exist. Due to the infinite and constantly changing considerations for the human body and the conditions it can experience "it should be understood that the *Guides* does not and cannot provide answers about every type and degree of impairment" (p. 3). Most importantly for the designer and the focus of this study is a statement at the end of 1.3 in the *Guides*:

> The physician's judgment and his or her experience, training, skill, and thoroughness in examining the patient and applying the findings to the *Guides* criteria will be factors in estimating the degree of the patient's impairment.... other considerations will also apply, such as the sensitivity, specificity, accuracy, reproducibility, and interpretation of laboratory tests and clinical procedures, and variability among observers' interpretations of the tests and procedures (p. 3).

Conclusion of Guides Analysis

Interchanging of words such as 'physician' with 'designer' and 'patient' with 'artifact,' one essentially has the definition of the designer's role. Not only that, the essence of what a series of guidelines should be are explained with a relevant example. For the purposes of a physician, the *Guides* provide a cursory collection of criteria and relevant information to be used in assessing an impairment rating. For a designer, a series of guidelines should include a similar cursory collection of criteria and relevant information for application to a design process (in the case of this study, backpack design).

The overall format of the AMA *Guides* (1993) lends itself well to the development



The Musculoskeletal System 3/**43**

Ankylosis in either 50° adduction or 180° abduction represents a 100% loss of abduction or adduction function, respectively. This is equivalent to a 30% loss of shoulder function or an 18% (30% x 60%) impairment of the upper extremity (Fig. 41).

Example: A patient has shoulder abduction to 100° and adduction to 0°:
$I_{ABD}\% = 4\%$ impairment of the upper extremity (Fig. 41, p. 44);
$I_{ADD}\% = 2\%$ impairment of the upper extremity;
$4\% + 2\% = 6\%$ impairment of the upper extremity.

Example: Shoulder ankylosis in 180° abduction is an 18% impairment of the upper extremity (Fig. 41).

Fig. 2D.2: 4th Edition AMA Guides, Page 43- application example

of design guidelines. Following an introductory statement or page, the *Guides* will typically break down the overall system at hand into smaller, more manageable portions before providing examples of the subject at hand. Concluding the basic format and style used in the AMA *Guides* are the application portions. Specific procedure steps or case examples to fully communicate how to apply the guidelines outlined in the first two elements are present. For more detail, sample pages from the *Guides* that describe elements of the muscular-skeletal system and showcase the writing style are included in Appendix D of this study.

2D.3- Backpack Components and Factors to Consider for Guidelines

Though a brief history of backpack evolution is addressed in Section 2A, there is a need to address some of the more specific features common to backpacks. Up to this point this study has identified a writing style appropriate for the design guidelines to be created, and the information needed to generate them. All that remains are examples from current backpacks that demonstrate that information in practice.

Fig. 2D.3: Parts of a backpack

In their most basic form, backpacks involved a sack with lengths of rope to hold it to the user. Based upon patent documents and a review by Brianna Valorosi (2015), the most common elements of a modern backpack include contoured shoulder straps with sternum strap, a hip/ SI joint belt with lumbar pad, and stabilizing or load-lifting straps as common features to improve the pack-to-user interface. These components, as well as some key differences between the male and female bodies to consider when designing backpacks, will be addressed herein. Additional information concerning the common parts and setup of backpacks may be found in the “Backpack Fitting Guide” (n.d.), located in Appendix C of this study.

2D.3.1- Important Differences Between Men and Women for Backpacks

Men and women are physically, anatomically, and physiologically different. Williams (2014) sums these differences as "men are taller and broader, built to carry and lift," while women are slimmer and "more inclined to use muscular strength for tasks related to flexibility, coordination and balance." When it comes to addressing these differences, Valorosi (2015) notes two major concerns for the design of backpacks involve the overall size of the pack compared to the body and accommodating for the differing body types between men and women. When speaking about women's models, Valorosi (2015) identifies some of the specific accommodations made in women's backpacks. It is fortunate this description also distinguishes some of the major differences between men and women:

> Women's models are sized specifically for a woman's torso, the shoulder straps and back panels are narrower, the harness/ hip belts are curved or molded for contoured bodies, and adjustment options are within the range of a woman's size. A woman's center of gravity varies from a man's, and women's specific designs are intended to optimize load carrying. Women's packs are typically ounces lighter, largely due to this decreased size. These fit and sizing changes often make a women's specific model more comfortable and better fitting than a men's or unisex model, which will make a big difference as you log miles wearing the pack... Some women with larger frames and broader shoulders may prefer men's or unisex models, while most women will find the features of a women's specific pack to be most suitable (paras. 6-7).

Valorosi (2015), however, does not address the anatomical difference with breasts in women versus men. Sumner (2012) also summarizes the significant difference between men and women is that women have less muscle mass than men, have a wider pelvis that is not usually compatible with the “narrow lumbar belts found in most rucksacks or hiking packs,” and are generally smaller in size compared to men (pp. 24-25). This is significant when designing for women since their smaller size creates an “increased load mass relative to the body mass that must be carried” (p. 25).

Recognizing these differences in the male and female body make it easier to accommodate the needs of each in backpack designs. Tying in with the areas of interest information accumulated in Section 2C, it is now possible to describe how the needs of the human body are currently addressed.

2D.3.2- Suspension Systems

“Generally speaking, the lighter the weight of an empty pack, the more comfortably it caries a lighter load of gear, and the heavier a pack, the more comfortably it will carry a heavy load” (Valorosi, 2015, para. 9). This statement identifies the fact that for a backpack, while there may be some variations of use, there is always an intended activity and load capacity. A major factor enabling a backpack to meet these needs are the suspension elements: the shoulder straps, the hip belt, and the frame components of the pack.

The framing system of a backpack can take the form of an internal or external frame. To improve the level of comfort for the user and reduce moisture buildup, the frame may comprise a series of back panels to permit better fitting to the user’s back and ventilation. “Mesh incorporated into the panels creates pockets of space for breathability.

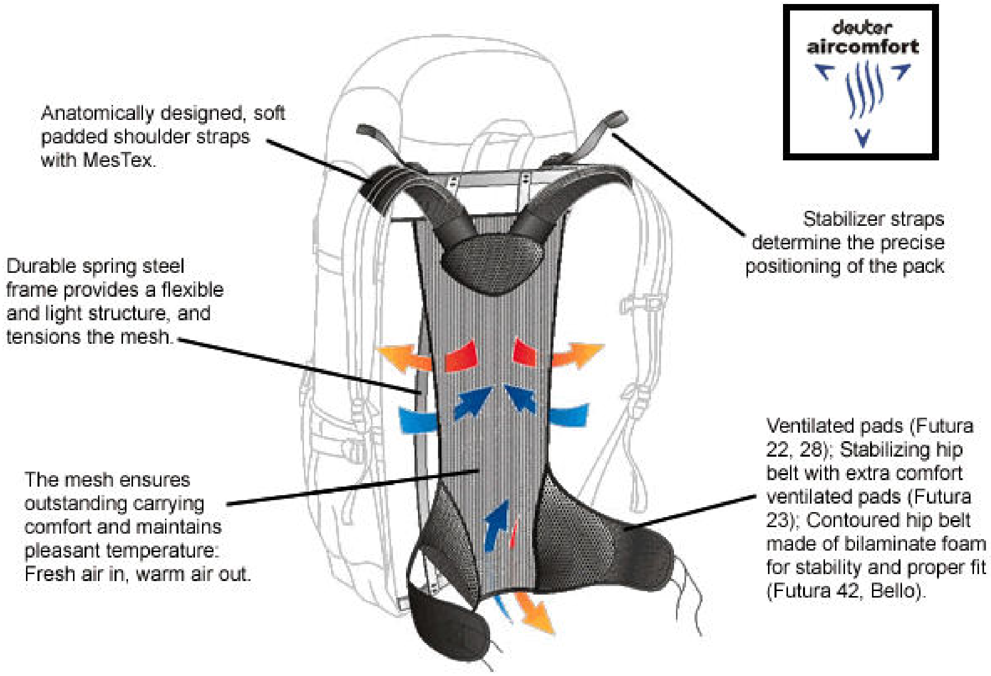


Fig. 2D.4: Deuter AirComfort

A puddle of sweat against your back isn't comfortable" (Valorosi, 2015, para. 12).

Valorosi (2015) identifies more modern means backpack suspension. "Some companies use a newer hinging system at the lower back that is attached to the hip belt and allows the pack to remain stable in the shoulders with synchronized movements in the hips" (para. 16). A second way is to have individually pivoting hip pads; both of which create a more stable and evenly distributed weight suspension. Another suspension design mentioned by Valorosi (2015) involves a swing arm shoulder strap system where the straps "distinctly separates your hip rotation and movement from your shoulder sway. It allows the pack to be carried in a more natural way- one movement doesn't pull the rest of your body" (para. 17). This is important as straps will move medially and laterally as the shoulders raise and lower. Valorosi states this allows for normal ranges of motion for the user, but can cause some issues with overall stability of the pack and user. These suspension means are of direct benefit to backpacks as they transmit the weight of the

Fig. 2D.5: Example of pivoting hip belt

Fig. 2D.6: Example of pivoting shoulder straps pack to the pelvis while permitting a more natural range of motion for the upper body.

An additional means of suspension that aims to remove weight from the shoulder are known as load-lifting straps. These straps "slightly lift the shoulder straps from the shoulders" (Backpack Fitting Guide, n.d.). Their purpose is to "pull the shoulder straps smoothly away from the shoulders, transferring the load to the hip belt while maintaining stability of the upper part of the pack," but additional benefits include a slightly closer fit of the pack to the user's back. These do not and should not be used to compensate for a poor frame to body interface, and must be used in conjunction with a hip belt with slightly looser shoulder straps for the best benefit.

Fig. 2D.7: Load-lifting straps

Regarding the back panel design, Valorosi (2015) states this area is of particular importance for the overall comfort of the user. "The space between the body and the main compartment doesn't compromise any stability except with very heavy pack loads. The closer the pack is to the body, the better it will contribute to stability under heavy weight" (para. 18).

> Most of the packs we evaluated are designed to allow for airflow between the hiker’s back and the pack itself. This is accomplished with a curved frame design so that the pack rests on the shoulder blades and lower hips while opposing the natural curve of the back in the center... which is why packs that were intended for heavier carrying capacity rest closely against the back, incorporating ventilation into the padding (para. 18).

Fig. 2D.8: Osprey backpack with breathable back panel

Significance

The suspension systems of a backpack are responsible for decreasing the pressure of backpack load on the shoulders and upper body. Major considerations for the suspension systems of a backpack include:

- breathable, form fitting back panels
- permitting the body to move while keeping the load stationary
- elements of the shoulder straps that help pull the load off the shoulders.

Specific examples of these considerations are seen in the breathable panels of external frame packs which fit the form of the body and permit airflow, the pivot points for the individual straps and belt components, and load-lifting straps. Padding in the areas of the shoulder straps and hip belt is especially important “for avoiding chaffing and allowing for all-day comfort” (Valorosi, 2015, para. 11). Together, these elements form the basis of the interface between the human body and backpack.

2D.3.3- Shoulder and Sternum Straps

Fig. 2D.9: Replacement shoulder strap set

When it comes to the upper body there are two accepted truths: men have more muscle mass in the upper body (particularly the trapezius muscles) compared to women, and that women have breasts. These are two important concepts to remember when considering accommodations for backpack shoulder straps. In backpacks, the shoulder straps of a backpack come into direct contact with the combined shoulder/shoulder girdle and the torso of the user. More specifically, they come into contact with trapezius and associated muscles of the upper extremity that create the visual profile of the shoulder and neck regions.

Based on muscle density differences between men and women, the visual angle created by the trapezius when viewed from the frontal plane is greater in men than in women. This necessitates the angle shoulder straps attached to the backpack and crossing the upper body be different for men and women. The major difference in shoulder straps for men's and women's backpack versions comes down to a matter of shape.

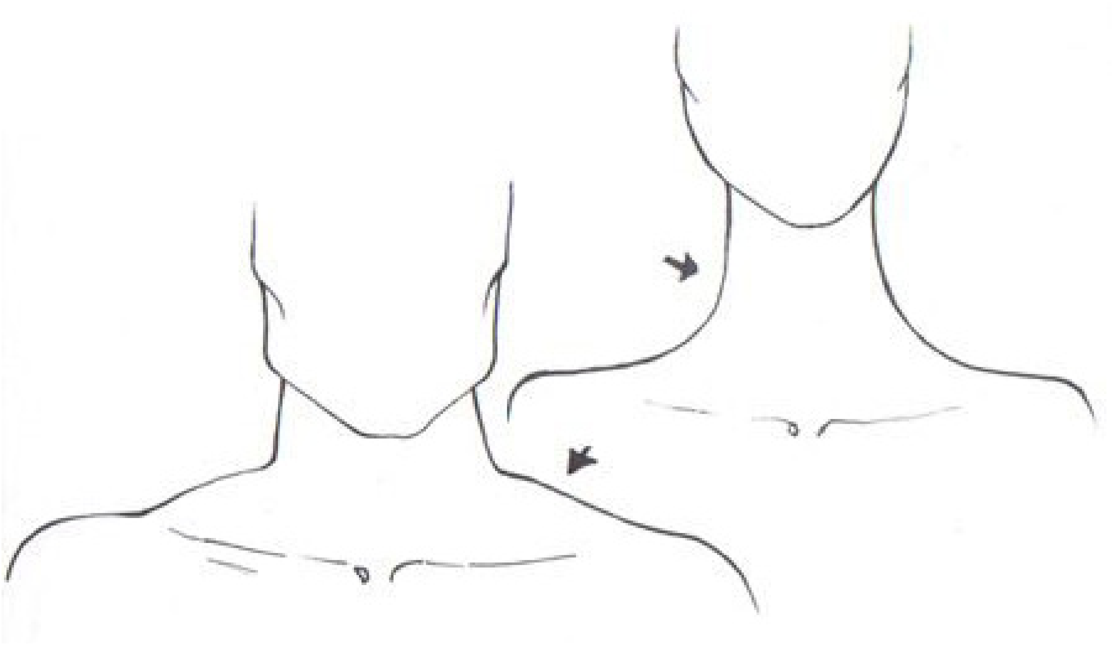


Fig. 2D.10: Profile of the upper body in men (left) and women (right)

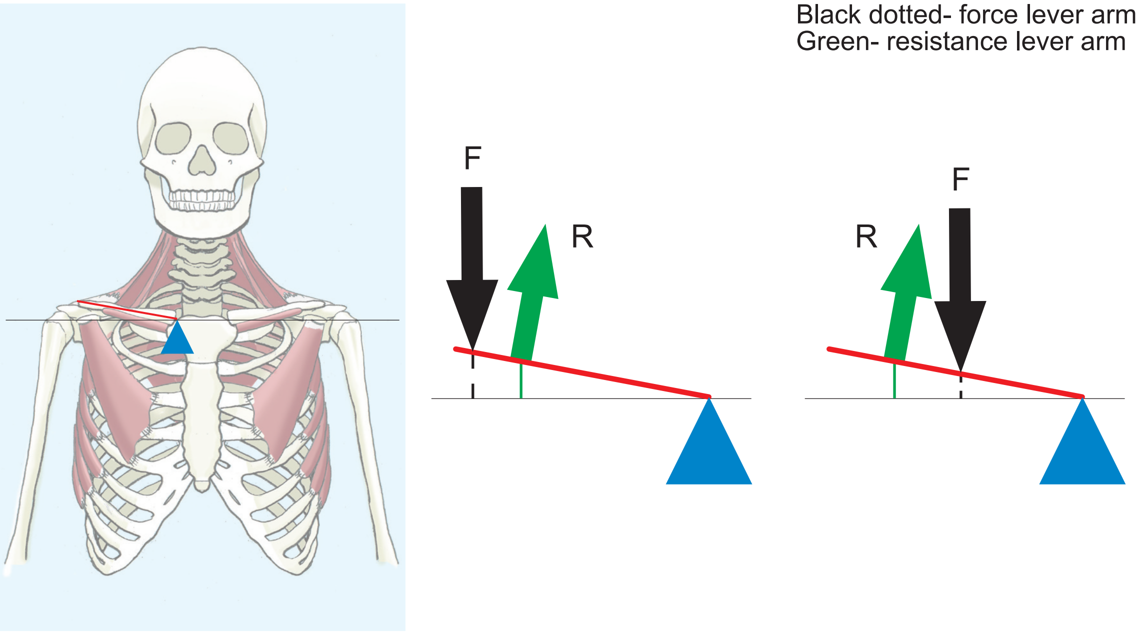
The current cut and shape of shoulder straps in male packs account for the more triangular trapezius muscles and generally flat pectorals of male users; essentially a

C-curved strap. Almost the exact opposite is the case with female variants of backpacks, where the shoulder straps take on more of an S-curve to accommodate the breasts. Without this form accommodation, women may encounter issues when wearing men's or unisex packs. The first option is to loosen the shoulder/sternum strap settings for a better fit across the chest and cause a looser pack-to-body fit overall; the second is to tighten down the shoulder straps and potentially place undue restriction and compression on the chest and breasts of the female user, causing breathing trouble.

Fig. 2D.11: Shoulder straps- Men's Gregory (note C-curve to straps)

Fig. 2D.12: Shoulder straps- Women's North Face (note S-curve straps)

A common addition to backpack shoulder straps is the sternum strap (“Backpack Fitting Guide”, n.d.). Typically an adjustable strap and buckle combination capable of sliding up and down the shoulder straps, the sternum strap is responsible for easing “the tension on the shoulder muscles that no longer have to keep the backpack from slipping off. It also keeps the backpack in the proper position so that your posture is not adversely affected” (Winger, 2016). In use, this strap can be used to comfortably pull the shoulder straps towards the medial plane of the body. Not only does this help keep the pack in place as stated by Winger, but it puts the straps in a position where they have reduced effect from a lever-arm standpoint. With shoulder straps taking the place of the force (F) and the muscles the resistance (R), the lever being moved is the clavicle with its fulcrum (A) at the sternoclavicular joint. Having the shoulder straps closer to the neck decreases the force moment arm on the clavicle, reducing the muscle energy needed to keep the clavicle from depressing and causing injury.



Normal (at rest

Load placement (lateral)

Load placement (medial)

Fig. 2D.13: Shoulder strap effects on the clavicle

Significance

There are different needs for male and female users when it comes to shoulder straps. To address these needs, the straps will vary in width and shape based (Valorosi, 2015). Additionally, the angle the straps are placed on the pack and cross the upper body may differ based on the end-user. To be most effective, “shoulder straps should completely wrap around your shoulders, with no gap between your shoulder blades and the shoulder harness” (Maxwell, n.d.). For the best fit, the point the shoulder straps connect to the pack “should begin about 2” below your C7 or the top of your shoulders” (Maxwell, n.d.). The use of a sternum strap is beneficial for reducing the leverage forces placed on the clavicle and combined shoulder/shoulder girdle, and preventing injury to those structures and the brachial plexus. Further, it helps keep the pack from moving, reducing the negative effects this could have to the user’s posture.

Fig. 2D.14: How backpack shoulder straps should fit

2D.3.4- Waist/Hip/Pelvic Belt

Trying to remove weight from the shoulders of backpack wearers is by no means a new or revolutionary concept. Two of the earlier document examples of a backpack with a hip component may be found in Henry C. Merriam’s United States Patent No. 204,066 (1878) and its subsequent improvement United States Patent No. 362,302. The major downside of this particular designs is the lack of a belt component to secure the 'hip strap' in place, leaving the shoulder straps as the only means of securing the pack to the user (1887, para. 'In Fig. '5').

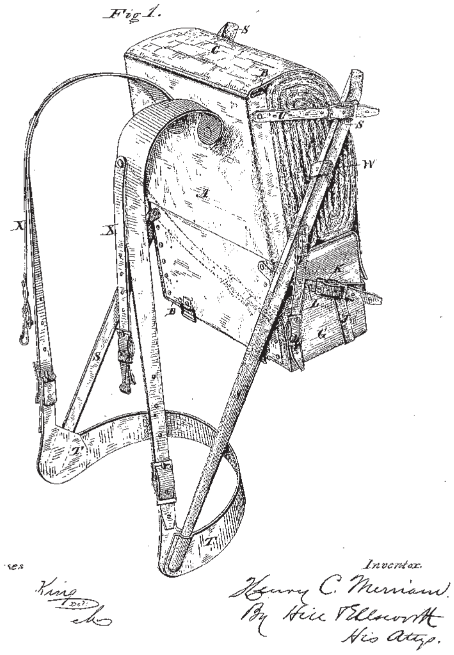


Fig. 2D.15: Figure 1- No. 204,066

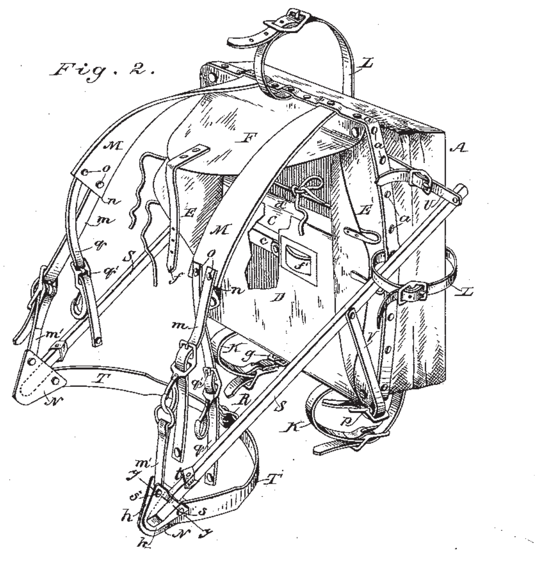


Fig. 2D.16: Figure 1- No. 362,302

Two notable improvements upon this in American service would be the WWII-era J.Q.D. 88B rucksack for mountain and ski troops ("The Rucksack," n.d.), and the Vietnam era ALICE pack and frame. These designs include some padding for the sacrum and posterior pelvis and a simple belt-strap secured by knot (WWII) or quick-release buckle (Vietnam). While this last feature helps secure the packs in place with a third point of contact (waist and shoulder straps), these designs do little to remove weight from the shoulders since the packs are vertically supported by only a thin strap of cotton or nylon based webbing.

Hip belts in modern packs by comparison contain a much higher degree of padding and contact with the user's pelvis. The primary benefit of a proper hip (ideally

Fig. 2D.17: US WWII mountain rucksack

Fig. 2D.18: US A.L.I.C.E. pack (1973 est.)

pelvic belt) that interfaces with the iliac crests is reducing the weight placed on the sacrum. Recalling the spinal column and pelvis areas of interest, all the weight of the upper body is transmitted to the sacrum and the SI joints. According to the website for the

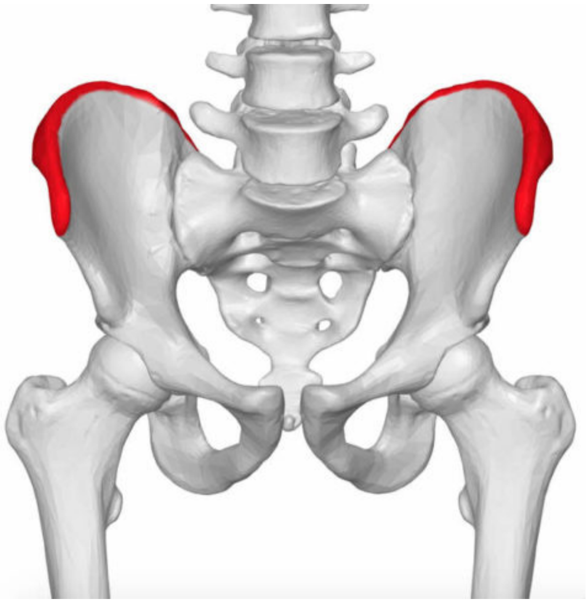


Fig. 2D.19: Brim of the pelvis: the iliac crest

Chiropractic Belt™ (How It Works, n.d.) on the function of an SI joint belt:

> During normal activities, lifting a heavy object, vigorous repetitive body motion, and prolonged sitting or prolonged standing, muscles in the lower back may become fatigued. The ligaments of the sacroiliac joint are vulnerable to stretching and tearing due to fatigue or injury. Ligaments which stretch or tear can cause a separation in the sacroiliac joint. Typically, sacroiliac joint dysfunction causes a dull ache, which is located at the base of the spine on the affected side(s). This pain may worsen during daily activities at any age... correct placement and pressure of the side tension straps, will help resolve many of the symptoms associated with sacroiliac joint dysfunction.

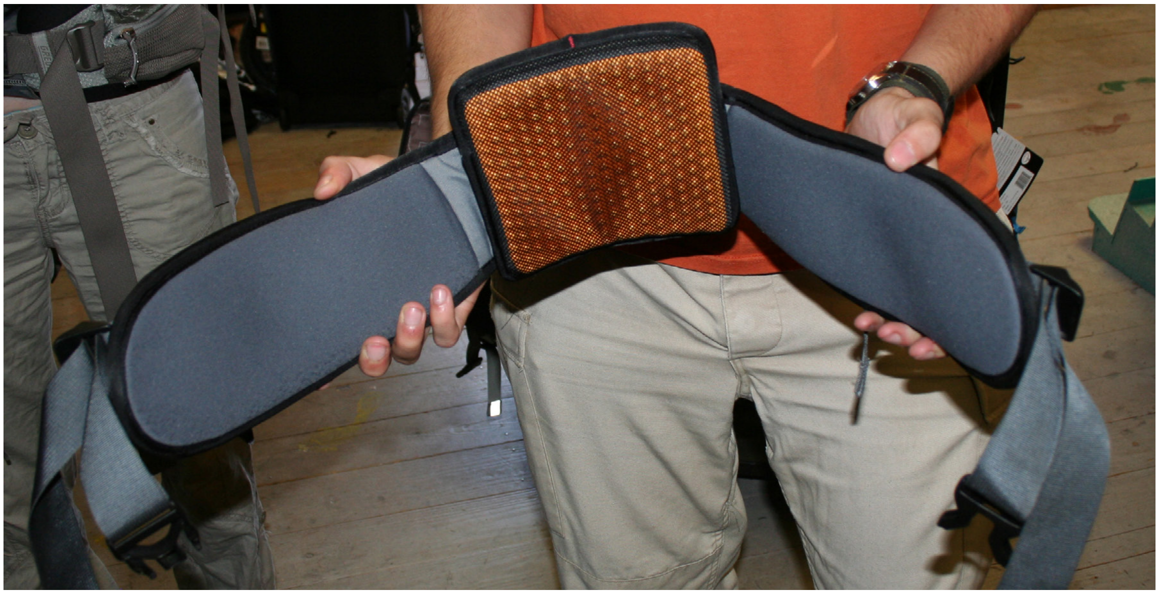


Fig. 2D.20: Heat-moldable hip belt for backpack

Fig. 2D.21: Interchangeable Osprey Bioform CM X Men's Hipbelt

In effect, an SI joint belt helps to keep weight off the sacrum and on the pelvic bones, which, as was addressed earlier, are responsible for load-bearing to the hip joints. Additionally, the compression provides a level of support to keep the SI joints from moving in excess. nic

Subsequently there has been an increase in the use of hip belts with backpacks over the more recent decades, as the hip belt provides a similar service to an SI joint belt. Valorosi (2015) finds "most packs are sized based on the hip belt and torso length," and a number of them offer customizable hip belt options (para. 23). Heat moldable hip belts from Osprey, pivoting hip belts, and detachable options are but a few ways a user can fit a hip belt to their personal build for use with a backpack.

<u>*Significance*</u>

There is a great deal of justification that lumbar and pelvic belts significantly remove pressure and load from the shoulders and spine of the human body (Mansoor et al., 2012; Martin & Hooper, 2000; Öz et al., 2010, Sumner, 2012). These belts take the form of simple straps, foam padding, plastic reinforcing panels, and any combination of those materials. It was determined by Martin and Hooper (2000) that hip belts with plastic reinforcement reduced pressures on the shoulders from 39% to 48%. This greatly supports the need to include a lumbar or pelvic belt that places the load of the pack onto the iliac crests of the pelvis.

When designing a hip belt, the padding for the belt should have no less than three inches in contact with the iliac crest ("Backpack Fitting Guide," n.d). Having more of the belt in contact with the pelvis and tightening it to exert roughly five pounds of force on the pelvis can help stabilize the SI joints (Visnic, 2014). During prolonged backpack use, this is helpful as it can mitigate some low back issues.

Fig. 2D.22: Minimal coverage of the pelvis by a hip belt

While there are no major differences between men's and women's backpacks from a structural frame standpoint, there is a difference in the shoulder straps and the hip belt "Backpack Fitting Guide" (n.d.). This is primarily due to the differences in the shoulders (as previously addressed) and in the hips and waist of the male and female. Because of the differences in the pelvis:

Most women require slightly more flare (angle at which the belt sits on the hips),

> and, generally there is slightly less distance between the lower ribs and hips in women. Therefore, the womens [sic] hipbelt is slightly narrower than the mens to prevent pressure in the area of the lower ribs in shorterwaisted [sic] women and is thermoformed to have a greater angle over the hips (p. 9)

Fig. 2D.23: How backpack shoulder straps should fit

2D.3.5- The Backpack's Compartment

The compartment and body of the backpack is removed from the immediate interface sites with the body, but the effect of this backpack part on the body is significant. This is due to the load effects shifting the center of gravity of the user, which causes postural adaptations that can put undue stress on the shoulders, the spine, and other elements of the body. To that end, there a recommended loading method of a backpack ("Backpack Fitting Guide," n.d.; "How to Pack," 2017). This includes placing bulky yet light items that do not require quick access at the bottom, the heavy items close to the body in the small of the back at the core, and for the lightest items to go on top of the core section and to the outside of the bulky items in the core area.

The rational for placing the heavy items above the pelvis and in the middle of the pack is "packing heavy items here helps create a stable center of gravity and directs the load downward rather than backward. Placed too low, heavy gear causes a pack to sag; placed too high, it makes a pack feel tippy" ("How to Pack," 2017). From a biomechanics and lever-arms standpoint, this reduces the influence the backpack on the body by balancing out the rearward swing of the center of gravity for the combined backpack and body system by producing a small forward lean. This means the backpack and not the body is producing the lean, thus reducing the overall muscle force needed for the balancing act and limiting the postural adaptation of the body. To further limit the rearward pull effects are compression straps, which help limit load shifting and pulls the loaded backpack closer to the body of the user ("How to Pack," 2017). For more information on the proper fitting, loading, and adjusting of a backpack to the user's body, the "Backpack Fitting Guide" (n.d.) is attached in Appendix C of this study.

Fig. 2D.24: Load stowage for a backpack

2D.4- Initial Summary of Section 2D

Building upon the human body information addressed in Section 2C, there is a need for a series of design guidelines for backpacks based on that information. This section reviewed a sample of different guideline formats and came to an initial conclusion. For guidelines to be effective for designers, they must:

1. Contain a breadth of information regarding to the field of application so as to be useful. In other words, they must address the majority of baseline information in a general level.
2. Leave room open for adaptability. Guidelines by nature cannot address every possible scenario. The baseline range of recommendations they provide are to help the reader with the decision process: accordingly, it is ultimately up to the experience, training, skill, thoroughness in work, and judgment of the individual(s) using the guides to decide what elements of the guidelines must be applied to the task at hand.
3. Be repeatable. When the steps taken by the individual(s) applying the guidelines are documented, it becomes possible to repeat the outcome or have similar results if conducted by a secondary group (understanding variation of results is to be expected).

As for an actual format of the guides, it was determined they should include:

1. The statement of the guideline.
2. A description of the guideline and its significance.
3. Provide both ideal (and if possible, unideal) examples so the application of the guideline is clear.

The last point was primarily explored in Section 2D. Since Section 2C explored the important human body information, this section identified the elements of backpack design that make up the human body-to-backpack interface and their significance. Further, examples of design considerations for those elements in current practice were identified. Effectively, this provides the ‘how’ application missing from the ‘what’ and ‘why’ of human body information explored earlier.

2E- Summary of Literature Review

Considering the current state of the backpack design process and the findings of this research, this study can produce a number of conclusions. Regarding backpacks, this study has found backpacks are a specific product family that has evolved and adapted to meet specific use and application requirements. They belong to a continuously growing and lucrative market, as suggested by available resources. Second, the human body is bought into direct contact with a backpack during its use, and as such can be greatly influenced and affected by the backpack system and its load(s). Third, to develop backpacks with a more positive body-to-backpack interface, there is a need for designers to take into consideration the dynamic forms and functions of the human body. As such, a collection of such information catered specifically to the designer's needs must be established. Finally, a series of design guidelines based on that human body information must be established so designers can create backpacks that produce an improved and positive body-to-backpack interface compared to existing product designs.

Regarding human body information catered to the designer, the designer must have a layman's level of practical knowledge for the human body. To that end, the disciplines of study most relevant to the application-based needs of the designer include basic anatomy and physiology of the human body, anthropometry, biomechanics, and ergonomics. Basic principles and critical concepts that could impact the design decisions for backpacks from these respective disciplines should be addressed, as the designer does not require an in-depth understanding of the body. However, because the designer does not belong to one of the sciences mentioned, a selection of the common descriptive terms and orientation material are required.

Regarding the specific anatomy, anthropometry, biomechanics, and ergonomics information knowledge base, there are numerous areas of interest to consider when designing backpacks and their interface with the human body. By addressing the important anatomical, anthropometric, biomechanical, and ergonomic data for each of these areas of interest, a cursory yet well-rounded understanding of each area of interest is established. This enables the designer to learn what is important about those areas and why they are important for backpack design. Further, common injuries and dysfunctional conditions common to backpacks are described, as well as the significance of how those conditions develop and can be prevented.

Finally, regarding the creation of human body design guidelines for backpacks, a guideline format that communicates 1) the guideline, 2) a description of what and why it is important, and 3) ideal and unideal application examples of the guideline to communicate how to use the guide is recommended. In addition, the elements of backpacks that interface with the body were explored and the significance of their design and integration addressed. This information provides examples of application: the ‘how to’ element critical for guidelines building upon the human body information of section 2C.

Based on this literature review, there is a need for an information resource and design guidelines for backpacks based on human body information. It is this study’s conclusion these human body resources can be developed for use by the designer. Further, these resources lay the product semantics framework for designers to create backpacks that have a more positive interface with the human body than current designs.

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3. METHODOLOGY FOR GUIDELINES

A significant percentage of this study involved locating, translating, and compiling a body of useful and relevant human body data. Based on those efforts, it was quickly determined to attempt a complete series of guidelines package for the human body across numerous product design applications is far outside the scope of the study at hand. This is due to the varying degrees of complexity inherent to the human body subject matter. Specifically, the literary review identified two needs for backpack design: (1) there is a clear need for design guidelines for the human body, and (2) there is a clear need for the supporting resources of reference materials needed to communicate the significance of key features and data for those guidelines.

Based on these issues, this study seeks to identify if such reference and guidelines packages can be created to address specific design project applications. Specifically, the primary focus of the development stage was to determine the best format and organization of the collected research information should take so as to be a useful design tool. This chapter in particular will address the methods and practices used by the researcher to create a best fit proposal of a design guidelines and references package for the creation of backpacks with improved human body interfaces.

3.1- Determining Scope and Focus of Information

Given the scope and breadth of the subject matter, the reference material accumulated in Chapter 2 is but a cursory introduction to design implications and requirements for backpacks. For the purposes of this study, the various concepts, principles, terms, and factors addressed in Chapter 2 form the baseline body of information such guide and reference packages would need to address. From this perspective, a large portion of the work needed for a guidelines and reference information package has been completed, leaving formatting and illustration of the information as the final design hurdle. Different formats and levels of content inclusion are indicated depending upon the resource type and its end use. Accordingly, the content needs will be addressed herein.

3.2- Anatomy, Biomechanics, and Ergonomics for Backpack Design

Primarily drawing from the Literary Review Section 2B and 2C, the scope of the included information addresses basics of general terminology and principles of anatomy, biomechanics, and ergonomics for the combined neuromuscular-skeletal system of the human body. In some instances specific areas of research or principles were advised by the study's committee members and subsequently addressed within the literary research.

In order to produce the most benefit for the designer and other disciplines, the general format of the Anatomy, Biomechanics, and Ergonomics for Backpack Design package will specifically address the following:

1. Introductory information:
    - Anatomical position.
    - Anatomical principles and terminology of reference and direction in space.
    - Anatomical principles and terminology for movement in space.
2. Human Body Areas of Interest (multiple areas with similar format):
    - Composition.
    - Ranges of motion.
    - Significance of area as relates to backpacks.
3. Additional concepts of importance:
    - Anatomical differences between adult male and female.
    - Common conditions to prevent in backpack designs.

3.2.1- Style of Writing and Format

As covered in Section 2B, *Gray's Anatomy* (1974) succeeded in part because of its simple descriptions. With this in mind, the content of the resource packages will use as simple and basic a writing style as possible given the complexity of the concepts and principles at hand. Comparing the style of *Gray's* and the *Anatomy Flash Paks*, an emphasis will be placed on introducing the definitions and terminology preemptively within the resources more so than a reveal-as-the-reader-progresses approach as is typically used.

In practice, this may take the form of a glossary of terms at the beginning of each section. This will be done to ensure the more complex terms and definitions are clearly understood by the reader before more conceptual or detailed information is introduced, thus reducing the overall likelihood of confusion.

3.2.2- Anticipated Outcome

It can be expected (though research and testing is indicated based on informal word of mouth accounts) that the anatomy, biomechanics, and ergonomics for Backpack Design may be used by individuals in disciplines other than industrial design. Some disciplines that this generalized reference package may be useful for include biomechanics, kinesiology, anatomy, general medicine, and their related educational departments for the students of those fields. As such, the reference package may be used as an introductory resource to help translate the various principles, terms of definition, and practices to those not skilled in the related arts.

3.3- Human Body Guidelines for Backpack Design Package

In a similar manner to the human body information package, the human body guidelines for backpacks resource will draw primarily from the information addressed in the literary review, specifically Section 2D. Accordingly, the human body guidelines for backpacks will address basic elements inherent to backpack design: specific anatomical, biomechanical, and/or ergonomic considerations needed for backpack designs with positive interfaces with the body. Additionally, factors or conditions to prevent or reduce based on the aforementioned human body information will be included. The main focus of this particular resource package is to clearly communicate the relevant basic principles, features information, and terminology in addition to identification of critical concepts, their significance, and means of practical application within a design. In some instances, specific areas of research or principles were advised by the study's committee members and subsequently addressed within the literary research conducted for Section 2D.

In order to produce the most benefit for the designer and other disciplines, the Human Body Guidelines for Backpack Design package will specifically address the following:

1. Introductory information:
    - Overview of backpack and related product field.
    - Common components of backpacks.
    - Purposes of the guides.
2. Generalized guidelines when designing for the human body:
    - Statement of the guide.
    - Explanation of its significance with the human body. Will address overarching needs of the body as a whole as addressed in the anatomy, biomechanics, and ergonomics for Backpack Design package.
    - Examples from existing designs illustrating how to apply the specific guide in practice, if applicable.
3. Specific design guidelines for backpacks:
    - Statement of the guide.
    - Explanation of its significance with the human body. Will address overarching needs the specific areas of interest as addressed in the anatomy, biomechanics, and ergonomics for Backpack Design package. Elements of these guidelines will tie in with and build upon the generalized guidelines.

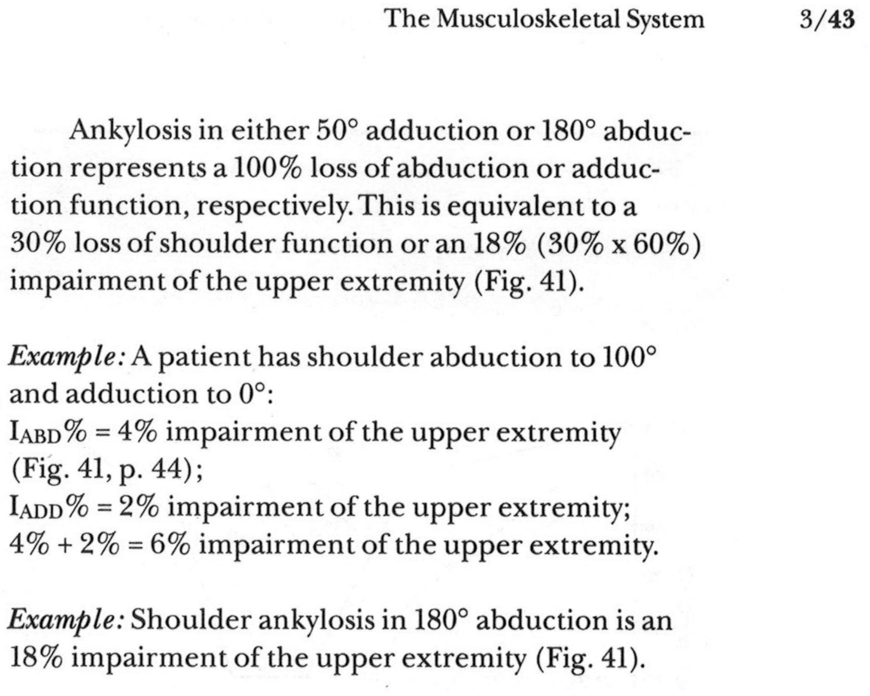
- Examples from existing designs illustrating how to apply the specific guide in practice.

3.3.1- Style of Writing and Format

The writing style for the Human Body Guidelines for Backpack Design package will be separated into two sections: reference material and guidelines. The reference portion of the design guidelines package will be the same as with the Anatomy, Biomechanics, and Ergonomics for Backpack Design: informative, simple in format, emphasizing clear communication of definitions, terms, concepts, and features.

The guidelines portion will utilize a style similar to that found in the 4th Edition *AMA Guides* (1993). This format may be best described as procedural, and is best illustrated on numerous pages from the 4th Edition (See Appendix D for the pages in question). Following an introductory statement or page the *Guides* will typically break down the overall system at hand into smaller, more manageable portions before providing examples of the subject at hand. The following description summarizes the basic format and flow of information as found in the AMA *Guides*.

With the pages included in Appendix D, the muscular-skeletal system is described. A chapter introduction addresses the general composition of its material as it relates to the body system being described. Typically these are the most basic and general of the chapter parts, addressing the material in its broadest strokes. Specifically, Chapter 3 begins by stating "this chapter includes sections on the upper extremity, the lower extremity, the spine, and the pelvis. The sections describe and recommend methods and techniques... also included are tables with impairment estimates" (p. 13). Most



The Musculoskeletal System 3/43

Ankylosis in either 50° adduction or 180° abduction represents a 100% loss of abduction or adduction function, respectively. This is equivalent to a 30% loss of shoulder function or an 18% (30% x 60%) impairment of the upper extremity (Fig. 41).

Example: A patient has shoulder abduction to 100° and adduction to 0°:
$I_{ABD}\%$ = 4% impairment of the upper extremity (Fig. 41, p. 44);
$I_{ADD}\%$ = 2% impairment of the upper extremity;
4% + 2% = 6% impairment of the upper extremity.

Example: Shoulder ankylosis in 180° abduction is an 18% impairment of the upper extremity (Fig. 41).

Fig. 3.1: 4th Edition AMA Guides, Page 43- application example

importantly, the 4th Edition's chapter intro states "each section describes appropriate methods and considers issues applicable to that section" (p. 13).

Next come the section descriptions, which break down the elements noted in the chapter introduction. Generally speaking, the material addressed is more specific.

> Methods for evaluating... the upper extremity may be described as having anatomic, cosmetic, or functional bases. The physical examination is based on a detailed examination of the patient and the upper extremity and is necessary to determine anatomic aspects of the impairment. (p. 15)

Additionally, significant concepts or factors relating to the format and explanation of the section component are communicated:

> The most practical and useful approach to evaluating impairment of a digit is to compare it with the loss of function resulting from amputation. Total loss of

> motion and sensation of a digit, or ankylosis with severe malpositon that renders that digit essentially useless, is considered to be about the same as amputation of the part... Impairment due to total sensory loss only is considered to be 50% of that due to amputation. (p. 15)

Concluding the basic format and style used in the AMA *Guides* are the application portions. Specific procedure steps or case examples to fully communicate how to apply the guidelines outlined in the first two elements are present, and are most notable on page forty-three of the *Guides* (Fig. 3.1).

Based on this generalized format, any guidelines developed for this study will utilize a similar arrangement:

1. Statement of the guideline in its broadest form.
2. Expanded guideline description and its significance to the reader/designer.
3. Possible case examples of how to apply the guide in practice, either in procedural steps, current or prior design practices, or existing product features.

3.3.3- Anticipated Outcome

It is anticipated that the Human Body Guidelines for Backpack Design Package will form a practical resource of conceptual information and functional guidelines for the designer. Further research and testing is indicated to determine the actual level of effectiveness this guide possesses or to what degree additional information will need to be integrated, though that is neither required nor the focus of this study.

As stated previously, other disciplines than industrial design may find the information the design guidelines contain both useful and desirable. Some of those disciplines may include biomechanics, kinesiology, anatomy, general medicine, and their related educational departments for the students of those fields. As such the reference package may be used as an introductory resource to help translate the various principles, terms of definition, and practices to those not skilled in the related arts.

3.4- Backpack Design Charts

As an additional design tool, a document of charts condensing the information for the various backpack components will be created. This document will help tabulate the different considerations to make in the design process based on the demographics of the end-user and the use application for the backpack being created.

3.5- Closing Statement for Methods of Illustration and Guide Development

In closing, use of the methodology outlined above for guideline and human body illustration development set the criteria and process for the end resources of human body information and design guidelines created by this study.

These guidelines and resources will fill the clear and present information gap generated by existing sources and discipline practices by creating resources that communicate in the simplest manner possible the concepts, definitions, and practices needed to understand the human body at the conceptual level. These resources, as determined by the literature review, are needed by more than just the discipline of industrial design: as such, the methods of creation outlined in this chapter were developed to make the most-encompassing body of information possible.

Additionally, the human body design guidelines case study forms a practical design tool: clearly communicating critical concepts the designer must be aware of, aiding in the design process for more practical, human-body friendly designs. Collectively, the resource packages generated by this study bring the functional aspects and design considerations for the human body to light, permitting the designer to not just design for manufacturing, sustainability, or end-user needs, but to implement design practices which complement the human body itself, the considerations and benefits of the end-user as an individual, and the field of design in general.

4. HUMAN BODY DESIGN GUIDELINES AND RESOURCES

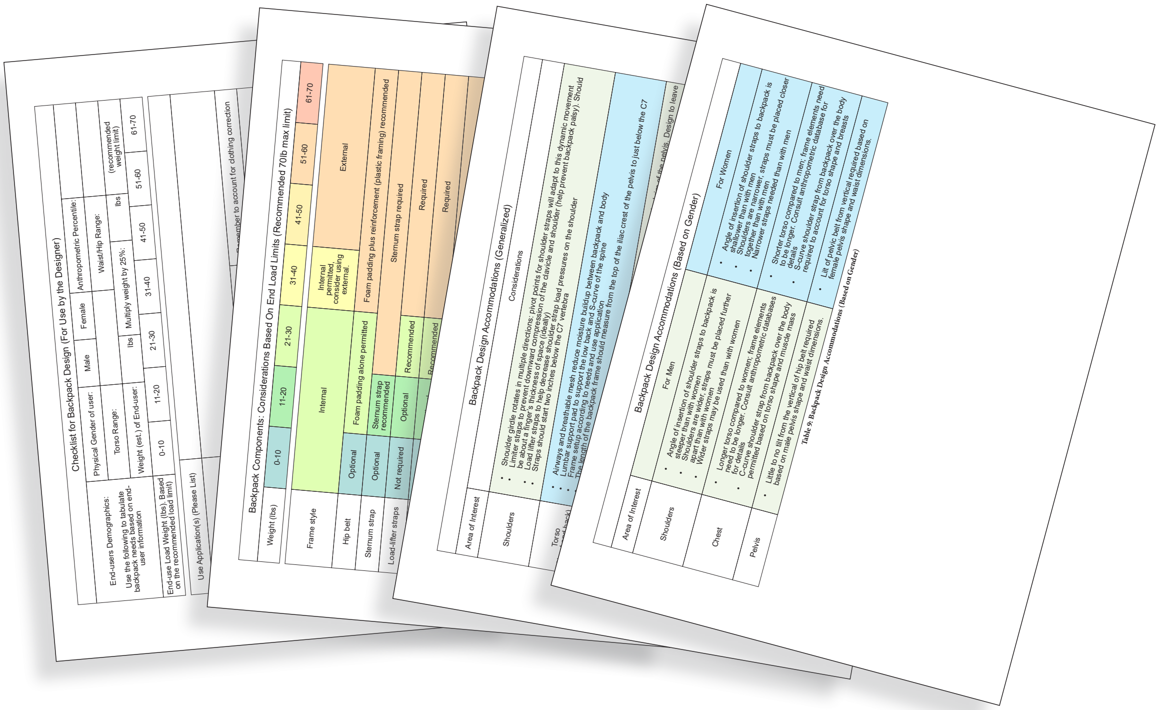


Table 2: Human Body Design Forms

The design resources for backpack creation are described in this chapter.

Section 4A will describe design guidelines for developing and designing backpacks to positively interact with the human body.

Section 4B will cover the basic material needed to describe the human body. Additionally, the important anatomical sites and concepts to be aware of when designing for positive interfaces between human body and backpack are addressed.

Lastly, Section 4C will include design forms for backpack and positive backpack interface creation.

4A- Human Body Guidelines for Backpack Design

The following guidelines are broken into two groups. First are general design guidelines to use when dealing with the human body, with backpacks as the example of application. The second group of design guidelines are specifically for use in developing and designing backpacks. It should be noted that there is a significant degree of overlap between the guidelines described herein. Each guideline is important in its own right, and the guidelines as a whole are most effective when used together.

4A.1- General Guidelines when Designing for the Human Body

When designing products to be compatible with the human body, the following guidelines are recommended.

4A.1.1- Design for the Local Requirements and Consider Global Effects when Dealing with the Body

The human body is complex, dynamic, and interconnected. Typically, the various elements of the body rotate to translate; often movement results from a chain of elements moving sequentially to favor greater speed or range of motion, or simultaneously to favor force production. To do this, muscles have at least two attachment points in various locations on the skeleton to permit movement. Minor changes in the functionality of one muscle segment can cascade up and down the chain of elements to cause pain or instability in areas far removed from the initial change site. Because of this, designing for the human body may be considered a “wicked problem,” which explains why traditional design approaches typically fall short when considering human body compatibility.

To address the needs of the product and the user, one should design for the component elements and parts directly interacting with the body, and for the body as a whole. This is important for two main reasons: 1) ensuring the anatomical, ergonomic, and biomechanical needs of the individual areas of interest are met, and 2) the cascade effects of the product on the body are accounted for while meeting the overarching system needs of the body as a whole.

Significance

- Address the needs of the individual parts of the body. The shoulder, the chest, the spine, and the pelvis all have specific functions that must not be hindered if the mobility and functions of the body are to be preserved. Focus on addressing these needs to the best possible degree.
- Recognize a change in one spot will affect another. These changes may be ideal, and they may be unideal. Be thoughtful and deliberate when making design decisions. The effects will compound upon one another to effect the body as a whole, and the combined system of user's body and backpack.

Example(s)

- Hip belts help keep the pelvis stable. They also can reduce 39% to 48% of the pressure a backpack can place on the shoulders and brachial plexus (Martin & Hooper, 2000). While structurally not needed for a backpack to function, having one balances the load placed on the body. It also decreases the pressure on the shoulders and the spine.

Fig. 4A.1: Backpack without belt

Fig. 4A.2: Backpack with waist belt

4A.1.2- Identify the Task(s) or Purpose(s) Being Designed for

Given size and form differences between men and women, identify the main task being designed for. If a product is designed to perform a specific task, unintended use may result in a cascade of unforeseen effects on the body.

Ideally, design for one or two specific tasks or applications. Multi-task or multi-purpose products should be designed to meet those needs from inception, and identifying how that product can limit the negative impacts on the body while in the various use configurations/applications.

Significance

- Identify what the backpack is being designed to do. A light-duty backpack for use as a book bag has structural and interface considerations very different from a heavy-load hiking backpack and a satchel.

Fig. 4A.3: Messenger bag

Fig. 4A.4: 3-Day assault pack

- Identify where the backpack is intended to be used. This may alter the form of the backpack's interface to account for clothing correction.

Fig. 4A.5: High altitude mountain climbing

Fig. 4A.6: Hiking pack in the Painted Desert

<u>*Example(s)*</u>

- Build in limits to keep the backpack at hand within the specification of the design brief. If it is a multi-purpose design, consider the multiple applications the backpack might face.

Fig. 4A.7: Mystery Ranch Overload- full expansion

Fig. 4A.8: Mystery Ranch Overload- minor expansion

- Consider how the backpack will be used, misused, or adapted beyond the original intent of design. Design the main compartments and accessory storage sites to limit the amount and type of material that can be carried based on the end application.

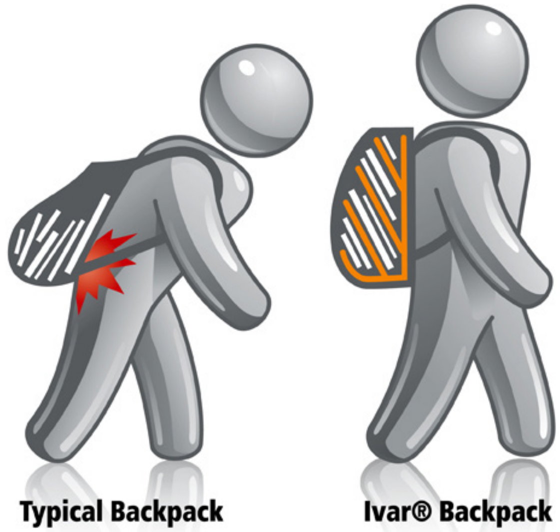


Fig. 4A.9: Ivar backpack design

Fig. 4A.10: Naneu 217F Sahara

4A.1.3- Design Versions for Men and for Women, not Unisex

Anatomical differences exist between men and women. For example, typically men are physically larger with wider shoulders, whereas women are more slender by comparison yet have wider hips. Numerous other structural and hormonal differences specific to each gender directly affect connective tissue stability and other structures, resulting in certain injuries becoming more likely to occur in one gender over the other. As such, special considerations need to be accounted for when designing for men and for women.

Example(s)

- The shoulder straps for men and women's backpacks are different. Men's are commonly C-shaped to accommodate the male torso and attach to the backpack at a steeper angle because of the larger trapezius muscle. Women's shoulder straps are S-shaped to accommodate the female torso and breasts, and attach to the backpack at a shallower angle than with men.

Fig. 4A.11: Male shoulder straps

Fig. 4A.12: Female shoulder straps

- The male pelvis is narrow with relatively no 'waist;' the female pelvis is wider with a larger brim, with noticable differences in waist and hip circumferences. This means an angled hip belt to better fit the curves of the female body, while very little angle is needed for the male body.

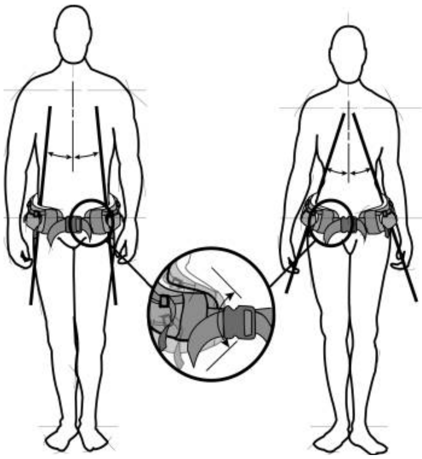


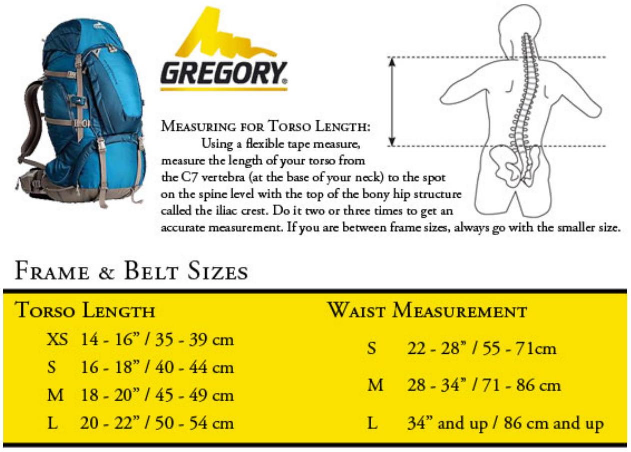
Fig. 4A.13: Hipbelt Differences and Angle Adjustments

4A.1.4- Design for “Multiple Sizes Fit Most,” not “One Size Fits All”

The human body comes in all manner of different shapes and sizes. Most importantly, it is not a simple matter of scale: a single individual may belong to a variety of different anthropometric percentiles based on their measurements between body parts and their personal build (i.e. a person may belong to the 92nd percentile for overall height but have a 55th percentile lower limb length paired with a 75th percentile upper body length). Ideally, any design created to interact with the human body should be adapted to accommodate as wide a user body percentile range as possible without hindering the body, or sacrificing the aesthetics or function of the designed artifacts.

Significance

Designing a series of backpacks versus a ‘one-size-fits-all’ design will allow users to find a size option that best fits their own personal measurements.



Measuring for Torso Length:
Using a flexible tape measure, measure the length of your torso from the C7 vertebra (at the base of your neck) to the spot on the spine level with the top of the bony hip structure called the iliac crest. Do it two or three times to get an accurate measurement. If you are between frame sizes, always go with the smaller size.

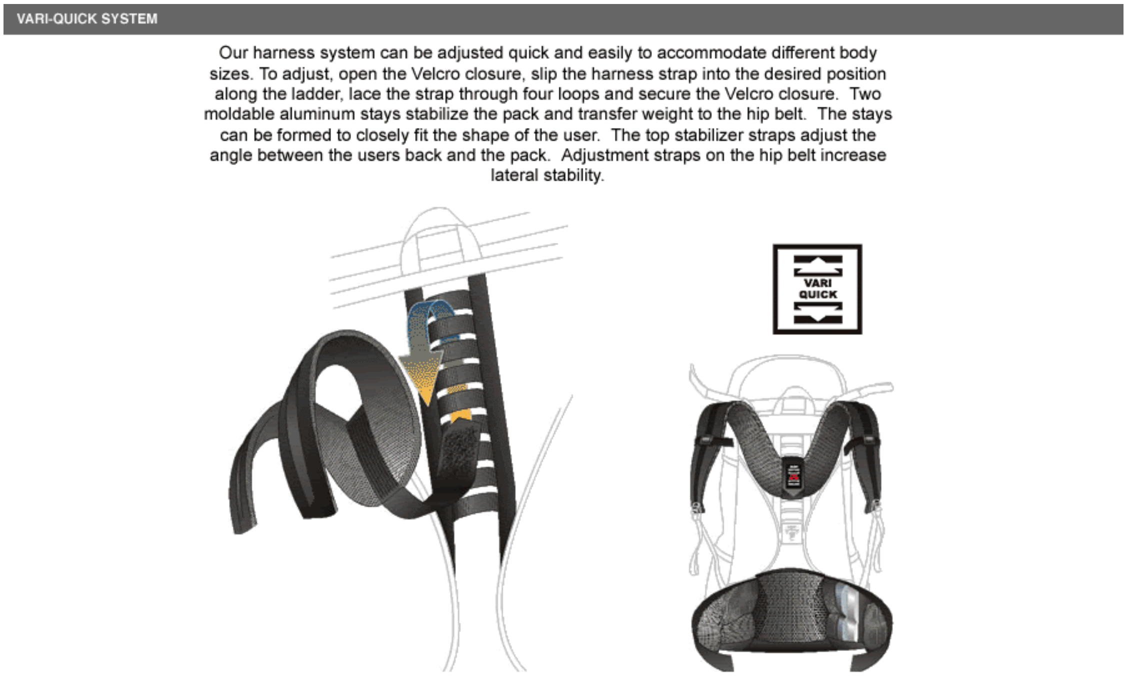
Frame & Belt Sizes

Torso Length		Waist Measurement	
XS	14 - 16” / 35 - 39 cm	S	22 - 28” / 55 - 71cm
S	16 - 18” / 40 - 44 cm	M	28 - 34” / 71 - 86 cm
M	18 - 20” / 45 - 49 cm	L	34” and up / 86 cm and up
L	20 - 22” / 50 - 54 cm		

Fig. 4A.14: Backpack size ranges and measurements

Example(s)

- If designing for ideal adjustability, include different sizes and have adjustment for the torso.



VARI-QUICK SYSTEM

Our harness system can be adjusted quick and easily to accommodate different body sizes. To adjust, open the Velcro closure, slip the harness strap into the desired position along the ladder, lace the strap through four loops and secure the Velcro closure. Two moldable aluminum stays stabilize the pack and transfer weight to the hip belt. The stays can be formed to closely fit the shape of the user. The top stabilizer straps adjust the angle between the users back and the pack. Adjustment straps on the hip belt increase lateral stability.

Fig. 4A.15: Hipbelt Differences and Angle Adjustments

4A.1.5- Anticipate Dynamic Movement While Eliminating Excess Pressure, Shear Force, and Exposure to Moisture

A majority of anthropometric and biomechanical range of motion/reach studies are typically conducted in a static environment. Based on this, movement of the human body in relation to the product and the environment of use will be different in actual use than in a test environment. Anticipate and accommodate these dynamic movements. Testing of the design in the intended use environment is recommended to ensure the human body is not hindered.

Additionally (and barring accidents and freak incidents), most dysfunction or injuries are preventable. Design features that reduce pressure points by dispersing weight more evenly, prohibit frictional shear forces to occur, and are breathable to reduce moisture build up should be of top priority.

Example(s)

- To permit dynamic movement response in the backpack, consider having pivot points on the straps and the hip belt. This will allow the straps to move in response to the body moving, but will still disperse the weight of the pack through the pins into those straps.

Fig. 4A.16: Example of pivoting hip/waist belt

Fig. 4A.17: Example of pivoting shoulder straps

- Consider breathable mesh/fabrics for keeping moisture levels low. Explore structural elements for the interface elements to open up air channels while supporting the body.

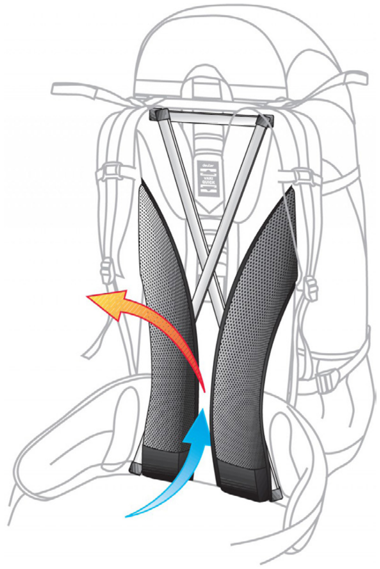


Fig. 4A.18: Deuter Aircontact Lite System: lumbar support and air channels

- Integrate support elements for load stabilization. Keep the backpack from pushing body parts, such as the shoulder, beyond normal ranges of motion.

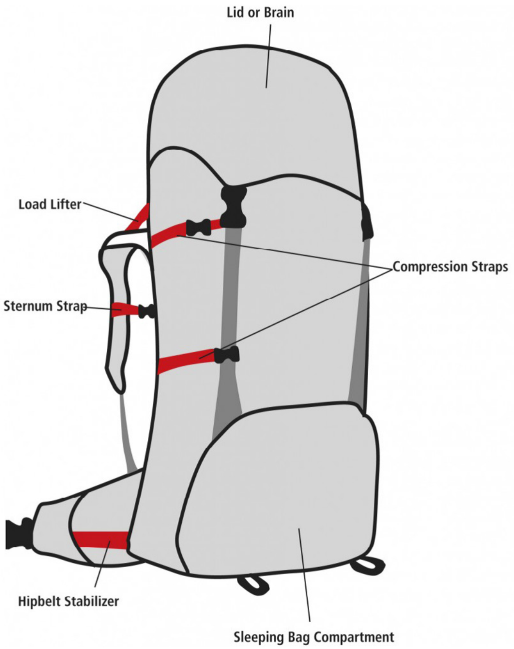


Fig. 4A.19: Common support elements on a backpack

- Not using a hip belt can not only pull/compress elements of the shoulders and place undue pressure on the spinal discs from forward postural adaptations, but also place excess stress on the ligamentous structures of the SI joints in the pelvis. This can lead to shearing of the ligaments, resulting in serious dysfunction or injury for the user. Thus, consider using a hip belt to place the weight of the pack onto the pelvis, and not leave the majority of the load on the shoulders and spine (especially for load-applications greater than 10lbs).

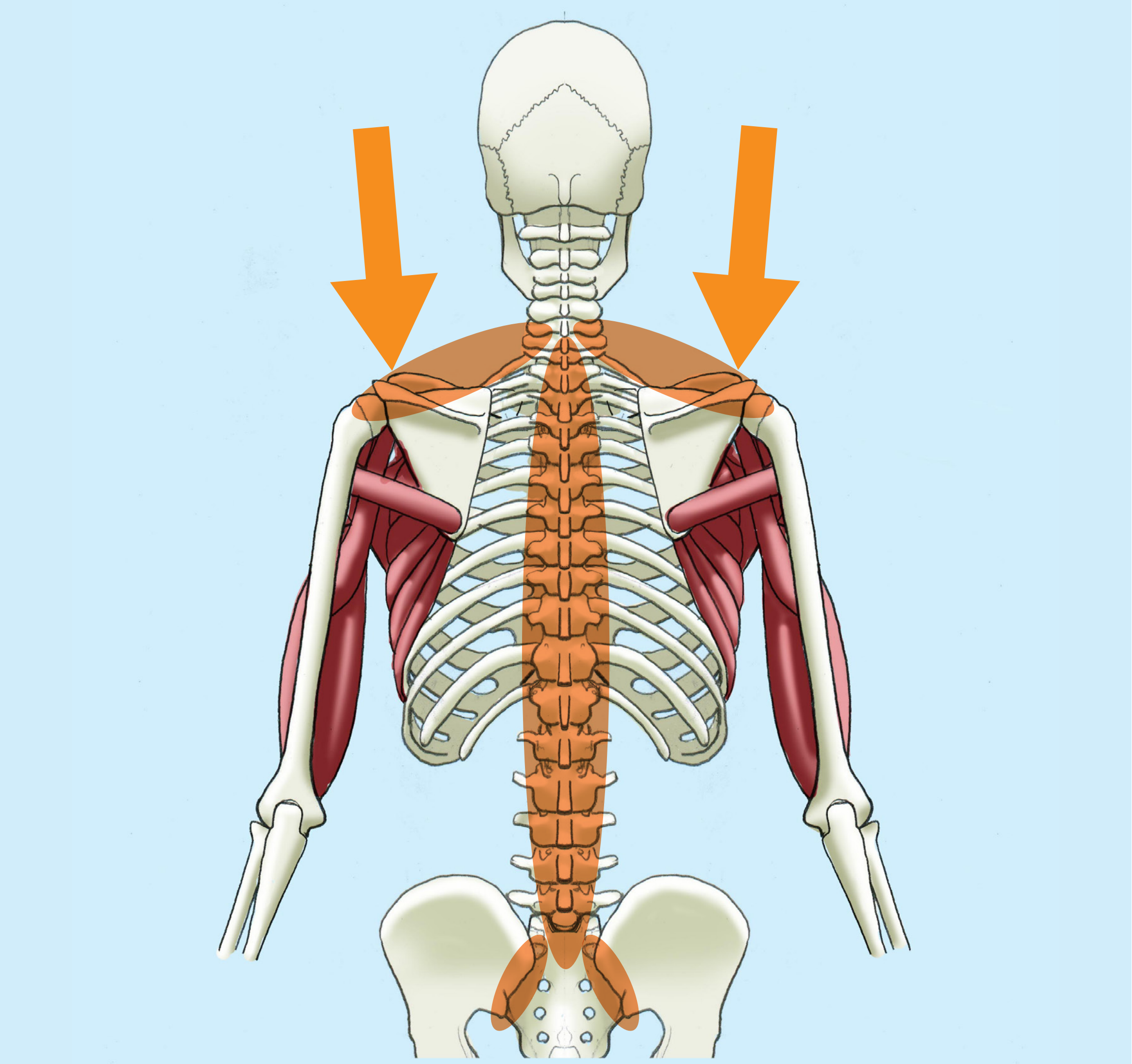


Fig. 4A.20: Common injury site w/o hip belt
Arrows indicate locations of load application;
orange highlights indicates sites of dysfunction and/or injury

4A.2- Human Body Design Guidelines for Backpacks

The following human body design guidelines are for use when designing backpacks. Compared to the generalized guides of Section 4.1, these guidelines are specific for backpacks and backpack-style products.

4A.2.1- Recognize and Reduce Postural Adaptations While Promoting Movement

The body is designed to move. Elements of the human body move and may change shape as the body moves.

Postural adaptations of the body in response to external loads are to be expected. From a biomechanical standpoint, it will be next to impossible with a backpack alone to maintain the normal posture of the unloaded body. With this understanding in mind, try to reduce instances of extreme postural adaptation by balancing backpack loads and removing weight from the shoulders and spine. Factor how different placements and arrangements of the backpacks's components will affect both the global interaction between the backpack and the body as a whole and the local elements of the body directly impacted by the backpack.

Remember the body should move in as unrestricted a manner as possible. Restricting body parts/regions (and even forcing them past their normal operating parameters) not only hinders natural movements and functions of the body, but can place undue force and pressure on critical anatomical features and lead to both sudden and gradual onset injuries.

Significance

The center of gravity of an individual will always move based on posture. When an external load is placed on the body, the center of gravity will swing in the direction of the load and the body will adapt in the opposite direction. This occurs so the individual does not fall over in the direction the load is pulling the body.

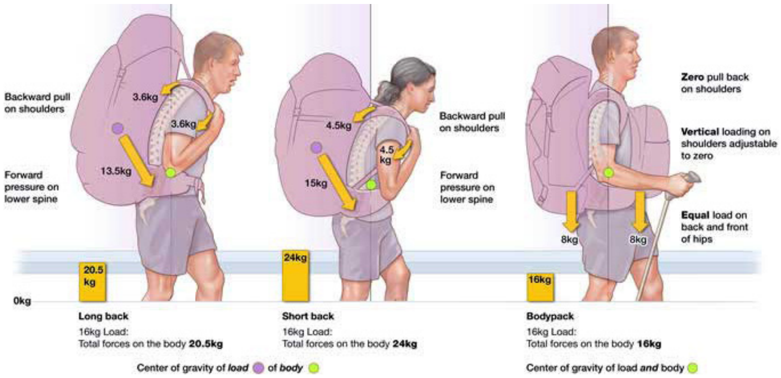
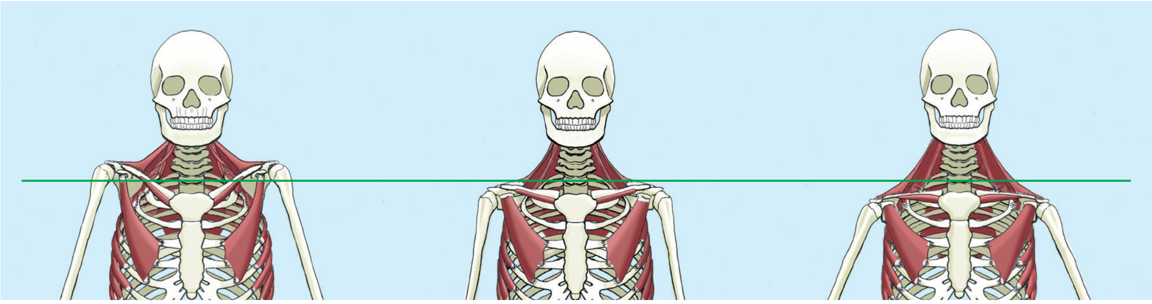


Fig. 4A.21: Backpack load effects on the body

Example(s)

- Keep heavy backpack items and loads close to the center of gravity of the body. Consider balancing loads on the front as well as the back to keep the pendulum swing of the center of gravity as small as possible.
- Identify the final load limit for the backpack. Recognize the effects this will have on influencing changes with the body's center of gravity when fully loaded, and when it is not loaded to capacity.
- Use a hip belt any time the load exceeds 10lbs. Utilize a plastic or rigid reinforced hip belt when loads start exceeding 20lbs. This way the pressure on the shoulders can be reduced by 39-48%, leaving the remaining pressure to be divided across the two shoulders. This will help reduce forward lean of the body and help prevent shoulder injury.



Anterior, Elevated Anterior, Normal (at rest) Anterior, Depressed

Fig. 4A.22: Comparison of motion, Shoulder girdle elevation and depression

- Muscles such as the trapezius will change shape and length with different movements. Based on this, the surface of the body in areas of the shoulder will change shape as well. Accordingly, design features such as pivoting shoulder straps will compliment this change in surface form by letting the body move more normally than a set of fixed shoulder straps.

Fig. 4A.23: Proteam backpack pivoting harness

Fig. 4A.24: Proteam harness pivot point on vacuum

- Frame components do not just have to be a box. Explore and test different forms for the support structure that will allow the body to move.

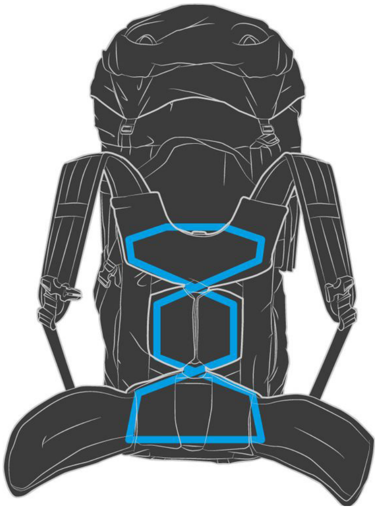


Fig. 4A.26: Bergans flexible internal frame: U.S. Patent No. US 20140061263

Fig. 4A.26: Movements of the Bergans carrier frame

4A.2.2- If the Intended Use Load Exceeds 30lbs, Consider an External Frame; Over 40lbs, External Frames Required

Backpacks by nature are task-specific, load-bearing structures. The lighter the pack itself, the more comfortable it is for a lighter load; the heavier the pack, the better and more comfortable it is for heavy loads. Internal frames by nature of their design are lighter and therefore ideal for lighter load-applications. External frames by nature of their design are initially heavier and therefore ideal for heavy load-carrying applications.

Significance

Design for the task and its specific load capacity: if it is for light loads, an internal frame may be utilized. When a load is greater than 30lbs an internal frame can be used, but begin considering use of an external frame structure. Anytime the load of the packed backpack exceeds 40lbs, especially if the end load requirements exceeds the 25% body weight ratio, a properly designed external frame for the backpack should be used to maintain proper posture of the user.

Example(s)

- The Bergans Glittertind 55L can support up to a maximum 44lbs due to its unique internal frame (“Glittertind 55L,” n.d.).
- The Kelty Yukon 48 can support up to 50lbs because of its external frame structure (“Kelty Yukon 48.” n.d.).

Fig. 4A.27: Bergans Glittertind 55L Internal Frame

Fig. 4A.28: Kelty Yukon 48 External Frame

4A.2.3- Keep Weight Close to/on the Pelvis and Center of Gravity of the Individual

Biomechanically, simple machines such as levers and pulleys are present in the anatomical makeup of the body. External loads force the body to respond with postural adaptations, which can result in muscle fatigue or soreness after extended periods. Additionally, the center of gravity differs between genders: for men it is more superior (higher) in the body than it is for women. To reduce the degree of muscle force needed to maintain proper posture, keep the weight of a backpack as laterally and frontally close to the spine and center of gravity as possible. Further, ensure the load is anchored onto the pelvis. This will help reduce the muscle force needed to maintain posture, and reduce stress levels on various parts of the body.

Significance

The center of gravity is higher in men than in women (approximately 57% of standing height from the ground in the transverse plane for men, 55% for women), and will shift based on movement and posture (Hamilton, Weimar, & Luttgens, 2008). Keeping the weight of the backpack close to the center of gravity will help reduce its impact on the body and reduce the degree of postural adaptation.

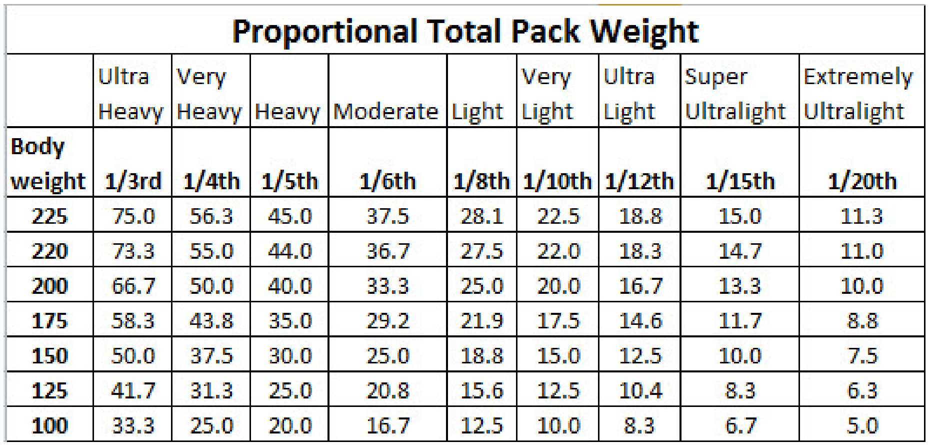
Example(s)

- Integrate compartments to store the load items in an organized manner, keeping that weight close to the body and reducing load shift while moving.

Fig. 4A.29: Ivar backpack concept art

4A.2.4- Try not to Exceed 25% of the User's Body Weight when Anticipating Dynamic Movement in Adults

There is a limit to the load capacity the human body can carry. With the smaller surface area of backpack straps amplifying pressure on the body, the permissible weight for the human body to carry before conditions such as backpack palsy begin to develop is roughly 25% of the user's body weight. Additional efforts need to be made to remove the weight from the shoulders and spine when load limits above this percentage cannot be avoided. This figure is somewhat smaller than the maximum permissible weight of 35%, but that figure comes from static tests (Öz, et al., 2010; Mansoor et al., 2012). Designing for a smaller limit builds an inherit buffer into the system that can account for dynamic movements such as jumps and landings on uneven terrain.



Proportional Total Pack Weight

	Ultra Heavy	Very Heavy	Heavy	Moderate	Light	Very Light	Ultra Light	Super Ultralight	Extremely Ultralight
Body weight	**1/3rd**	**1/4th**	**1/5th**	**1/6th**	**1/8th**	**1/10th**	**1/12th**	**1/15th**	**1/20th**
225	75.0	56.3	45.0	37.5	28.1	22.5	18.8	15.0	11.3
220	73.3	55.0	44.0	36.7	27.5	22.0	18.3	14.7	11.0
200	66.7	50.0	40.0	33.3	25.0	20.0	16.7	13.3	10.0
175	58.3	43.8	35.0	29.2	21.9	17.5	14.6	11.7	8.8
150	50.0	37.5	30.0	25.0	18.8	15.0	12.5	10.0	7.5
125	41.7	31.3	25.0	20.8	15.6	12.5	10.4	8.3	6.3
100	33.3	25.0	20.0	16.7	12.5	10.0	8.3	6.7	5.0

Fig. 4A.30: Proportional Total Pack Weight

Significance

Communicate the maximum permissible weight a backpack is capable of carrying. Ideally, have this on the backpack itself in some fashion so the figure of max weight is not lost. Further, design the main compartment of the backpack to only carry so much capacity (typically measured in liters).

Examples

- The size of the main compartment can greatly determine the overall load-carrying capabilities of a backpack. Design the main compartment's volume to not exceed the maximum permissable weight of the end-user.


Fig. 4A.31: 10L backpack


Fig. 4A.32: 50L backpack


Fig. 4A.33: 100L backpack

4A.2.5- Protect Anatomical Structures from Undue Strain and Stress

The main areas of anatomical interest when it comes to backpacks are those directly in contact or impacted by the backpack, comprising the shoulder complexes, the spine and chest, and the pelvis. Accordingly, any design feature of a backpack that serves to protect an area of interest or decrease the backpack's impact on those areas is vital and of great benefit to the end-user.

<u>*Significance*</u>

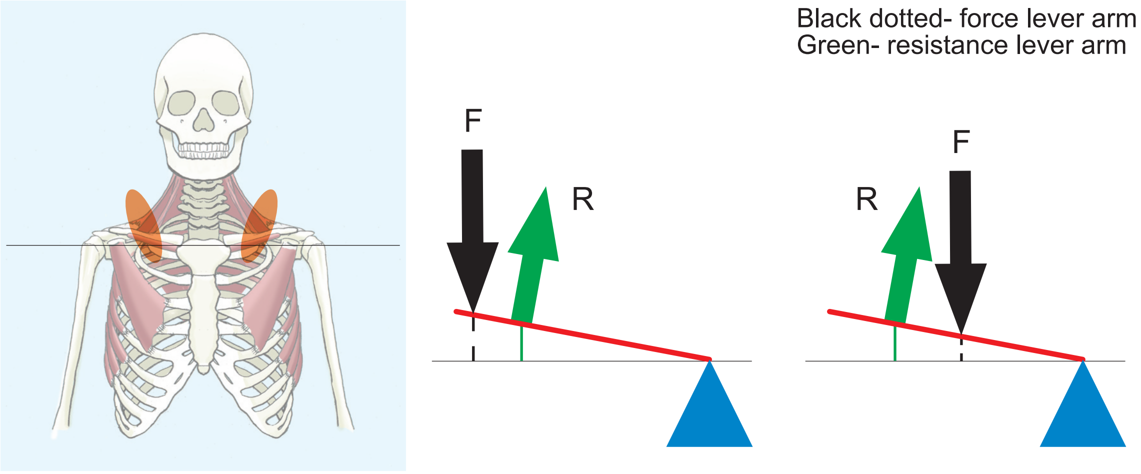
Structural elements should not be placed anywhere that direct contact on the body is possible; provide appropriate padding to interface components (shoulder straps, lumbar pads, hip belts, etc.) and ensure no pressure or 'hot spots' are created. Account for the normal ranges of motion for the body and the various areas of interest: build in limiters to the design so parts of the body are not pushed or pulled into abnormal ranges or positions.

Example(s)

- Contour the low back of the pack with a lumbar pad to support the S-curve of the spine. This padding and form can hide the attachment points of the hip belt to ensure continuous contact with the pelvis of the body without exposing the body to hardware fasteners or structural elements.

Fig. 4A.34: Lumbar support and waist belt components

- When designing packs without load-lifter straps, the shoulder straps should be adjustable to fit around the neck and shoulders of the user. Ideally, shoulder straps should be close to the neck, but not touching (ReviewOutdoorGear, 2012). When straps are placed too far out onto the shoulders, moment-arms of the load force are greater compared to the muscle resistance force. This can push shoulder depression past the normal range, increasing the likelihood of stretching and shearing of the muscles and brachial plexus. Pulling the shoulder straps medially towards the neck decreases the backpack load force moment arms, decreasing likelihood of the shoulder girdle and related parts being compressed past the normal ranges of motion.



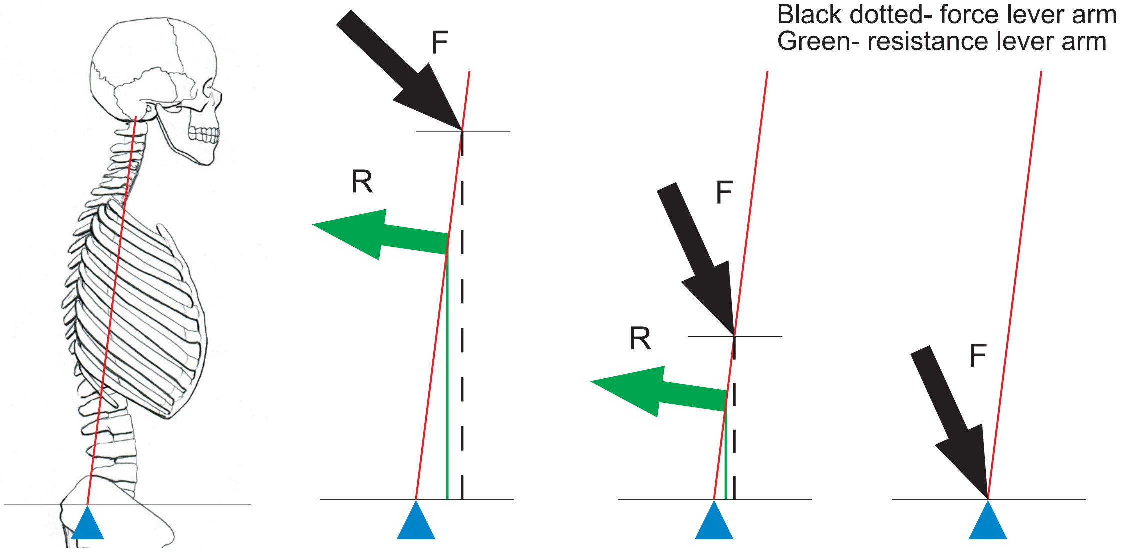
Ideal Strap Placement (male)　Load placement (lateral)　Load placement (medial)

Fig. 4A.35: Ideal location for shoulder strap placement

- For heavy loads, consider using load-lifter straps to help pull the weight of the backpack closer to the body. This transfers the main force holding the backpack up and close to the body across the chest, and not downward on the shoulders. About a finger's width of space should be between the strap and the body (ReviewOutdoorGear, 2012).

Fig. 4A.36: Load-lifter straps adjusted correctly: about a finger's space

- In addition to the contact area on the brim of the pelvis, design hip belts to have at least a third to half of the belt above the brim of the pelvis on the iliac crest. This way 80-90% of the weight of the backpack can be transferred to the pelvis (“Sizing & Fitting,” n.d.). Using a hip belt will help decrease the negative postural adaptations of the upper body and decrease the pressure placed on the shoulders.



Normal (at rest

High Load Placement

Low Load Placement

Load on Pelvis

Fig. 4A.37: Lever arms of pelvis with backpack

- Keep pressure off rotating or moving body parts as much as possible. The excess pressure and friction across the skin’s surface can result in shear injuries and may lead to ulceration. Such a site is the cervical spine, which exhibits more rotation than the thoracic spine (which is relatively less mobile to serve as the site for rib attachments). This is why existing backpacks measure to C7 and do not pass above it.

Fig. 4A.38: Osprey backpack measurements for torso and pack size

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4B- Anatomy, Biomechanics, and Ergonomics for Backpack Design

The guidelines addressed in 4.1 and 4.2 address the major considerations and practices needed to ensure a positive interface between the human body and a backpack system. This subsection includes an orientation portion addressing the basic and common terminologies used to describe the human body in space and movement. Further, it addresses a cursory overview of the important parts of the body relating to backpacks, providing specifics for important angles and ranges of motion and anatomical makeup alluded to within the guidelines.

4B.1- Anatomical Neutral

When describing the human body, the most typical position is anatomical neutral. There are two schools of thought depending upon the location. In Western medicine the body is standing upright with the arms down and palms facing forward (Crafts, 1979). In

Fig. 4B.1: Western or 'Standard' anatomical position

Eastern medicine, the arms are raised above the head with palms facing forward (Helms, 1995). In design projects with international collaboration, be sure to establish which one is considered the norm for all parties so confusion and misunderstanding can be reduced.

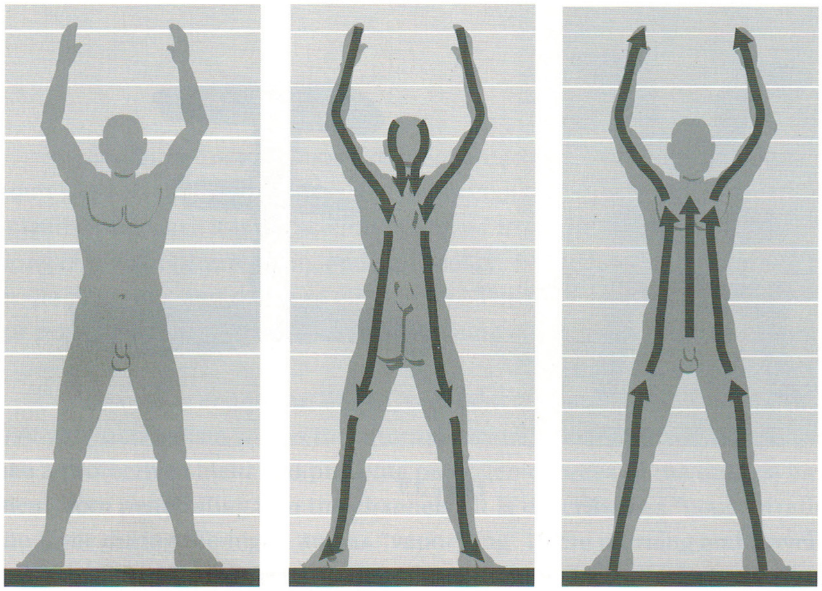

Figure 3.11 *Figure 3.12* *Figure 3.13*

Fig. 4B.2: TCM or "Eastern" anatomical position

4B.2- Reference Planes (Anatomical Planes)

Most if not all computer aided design programs common to the design process have a series of origin and reference planes from which a model or design is constructed.

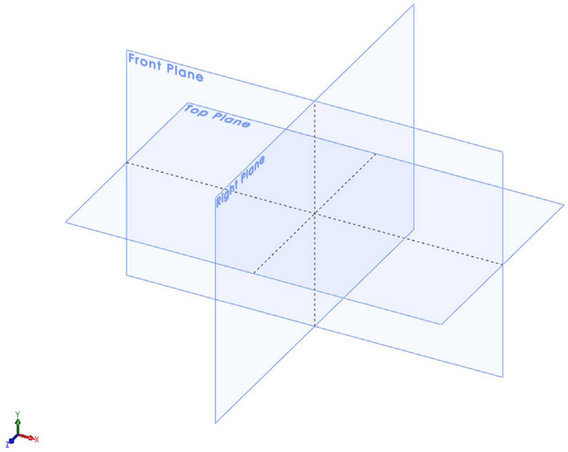

Fig. 4B.3: Reference planes in Solidworks 2015

The same can be said of the human body, which also has a series of reference planes that infinitely intersect the body.

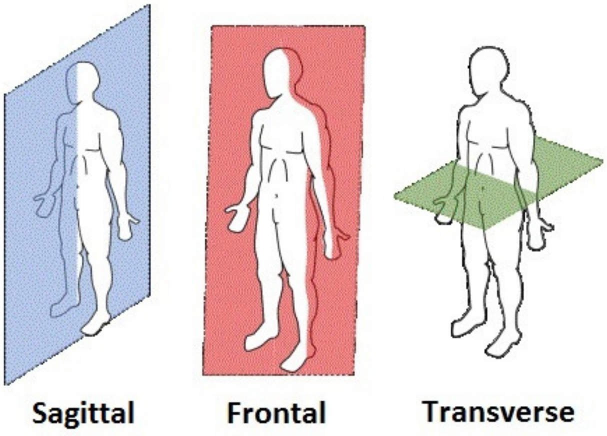

Fig. 4B.4: Main anatomical planes

Definitions of Anatomical Planes (relating to CAD reference planes)
Sagittal plane: divides the body along its long Y-axis and its Z-axis (or right plane) to create the left and right sections (or parts) of the body.
Frontal plane: divides the body along the X- and Y-axes (or front plane) to create the into anterior (frontward) and posterior (rearward) sections. Perpendicular to the sagittal.
Transverse plane: horizontal plane that divides the body across the X- and Z-axes (or top plane) to create the superior (upper) and inferior (lower) body sections. Perpendicular to both the sagittal and the frontal planes.
'Mid' prefix to planes: used to describe any anatomical plane positioned along the respective medians or midlines of the body, bisects into halves that are relatively equal.
'Para' prefix to planes: used to describe any anatomical plane parallel to a median plane but not coincident with it, bisects the body into sections that are not equal in proportion.

Table 3: Definitions of Anatomical Planes

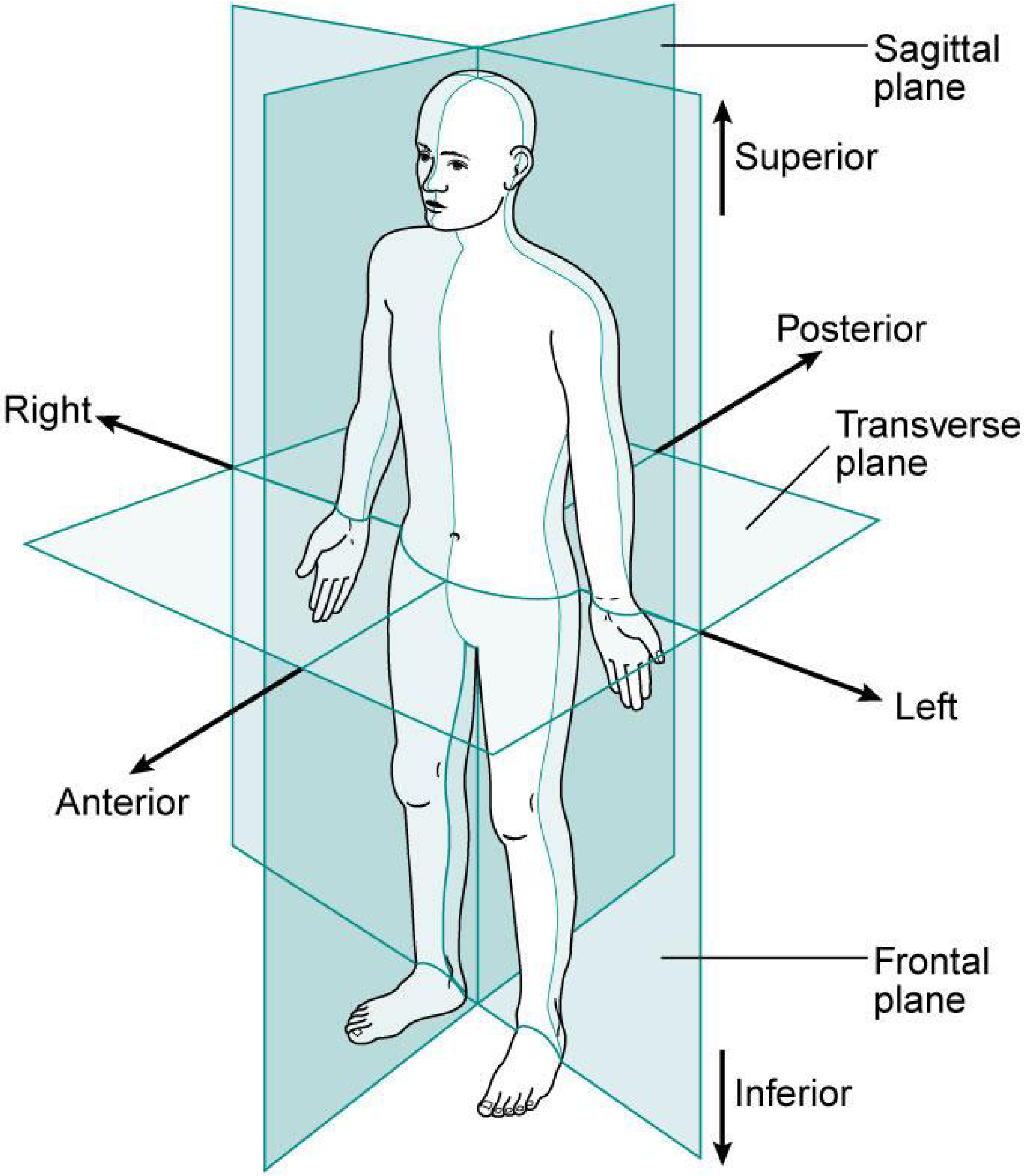

Fig. 4B.5: Anatomical body planes of the body

4B.3- Anatomical Terms of Direction

There are specific terms of direction to use when describing features of the body in relation to one another and the anatomical planes. These terms are used specifically in reference to position in relation to the body in space, and not describing the particular act of motion as the next subsection will address.

Anatomical Terms of Direction:

Superior: towards the head along the long Y- Axis of the body.

Inferior: towards the feet along the long Y- Axis of the body.

Anterior: towards the front of the body, usually associated with a frontal plane. Can also be known as ‘ventral.’

Posterior: towards the back of the body, usually associated with a frontal plane. Can also be known as ‘dorsal.’

Medial: towards the mid-sagittal (median) plane of the body.

Lateral: away from the mid-sagittal (median) plane of the body.

Internal: Ttowards the inside of the body, typically used to describe rotation.

External: towards the outside of the body, typically used to describe rotation.

Proximal: relation to attachment points such as a limb closer to the center of the body.

Distal: relation to attachment points such as a limb away from the center of the body.

Superficial: closer to the skin of the body and surface of the body: choose the reference plane and structure from which the term is being used to avoid confusion.

Deep: further away from the skin of the body and surface of the body: choose the reference plane and structure from which the term is being used to avoid confusion.

Radial: relation towards the radial bone.

Ulnar: relation towards the ulnar bone.

Tibial: relation towards the tibia bone.

Fibular: relation towards the fibula bone.

Frontal (hand and feet): anterior surfaces or ‘top’ of the foot or the hand.

Dorsal (hand and feet): posterior surfaces or ‘bottom’ of the foot or hand.
Palmar: relation towards the palm of the hand.
Plantar: relation towards the sole or bottom surface of the foot.

Table 4: Anatomical Terms of Direction

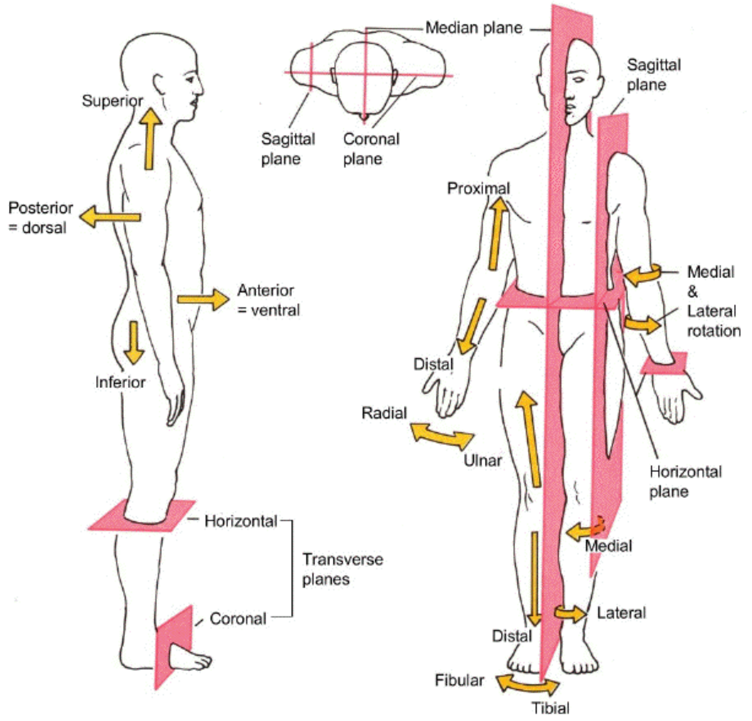

Fig. 4B.6: Anatomical position terms and planes of the body

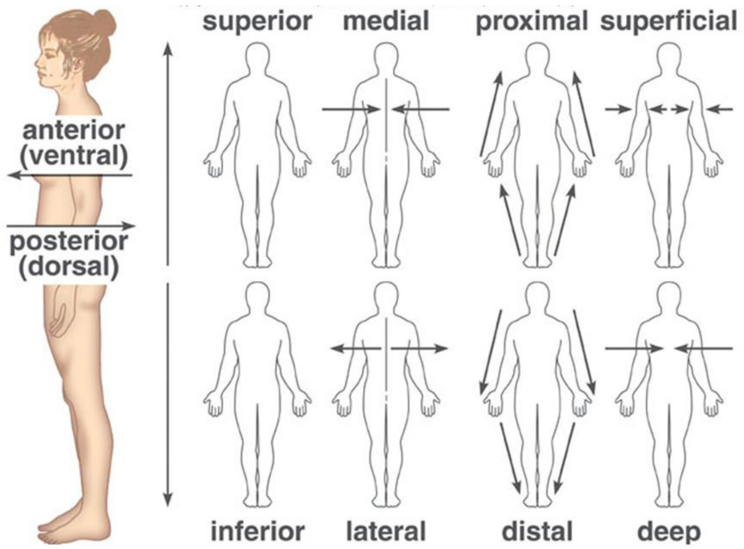

Fig. 4B.7: Body planes and anatomical position

4B.4- Anatomical Terms of Movement

When it comes to describing movement of the body, the reference planes mentioned earlier and axes of rotation are typically involved. Each plane has a respective axis that is perpendicular to it, about which elements of the body rotate. A bilateral axis runs infinitely perpendicular to the sagittal plane from left to right and vice versa. Anterior-posterior axes are infinitely perpendicular to the frontal/coronal plane and can be inferred through the keywords anterior-posterior. Lastly are polar (vertical) axes that are infinitely perpendicular to the transverse plane. The main polar axis intersecting the mid-sagittal and mid-frontal planes is the longitudinal axis.

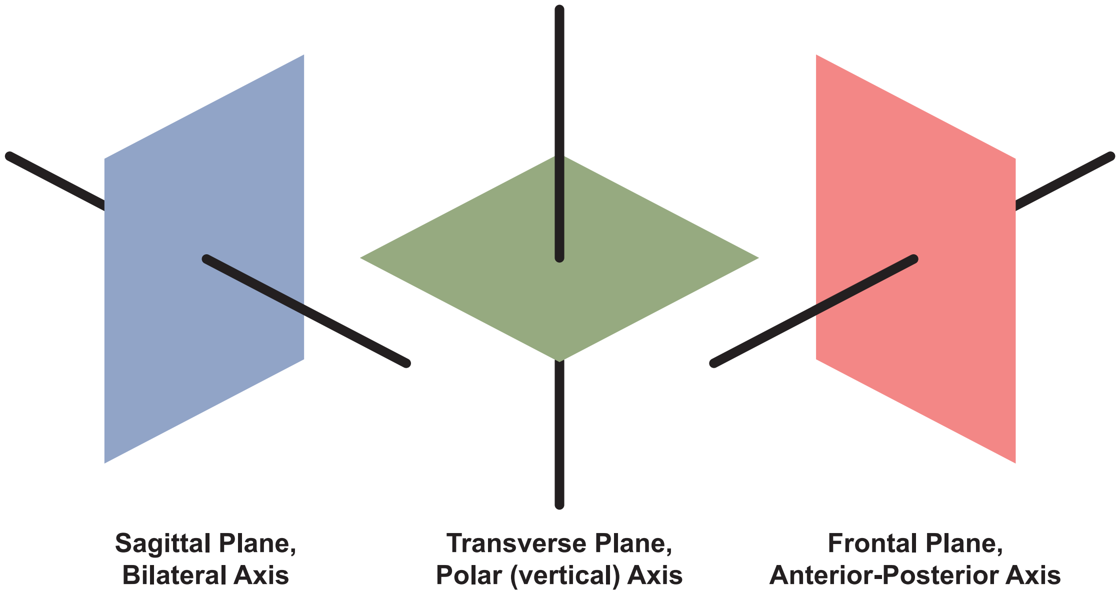

Fig. 4B.8: Anatomical planes and related axes of rotation

These rotations and movements, depending on the plane and the axis pair, are described accordingly:

Main Anatomical Terms of Motion
Flexion: a decrease in the angle between two segments (such as bending).
Extension: an increase in the angle between two segments (such as stretching).
Abduction: movement away from the midline of the body or the body part.
Adduction: movement towards the midline of the body or the body part.
Rotation: a motion in which all parts of the system are not displaced by a similar amount (pivoting or rotary motion).
Circumduction: circular movement (a circumferential movement).

Table 5: Main Anatomical Terms of Movement

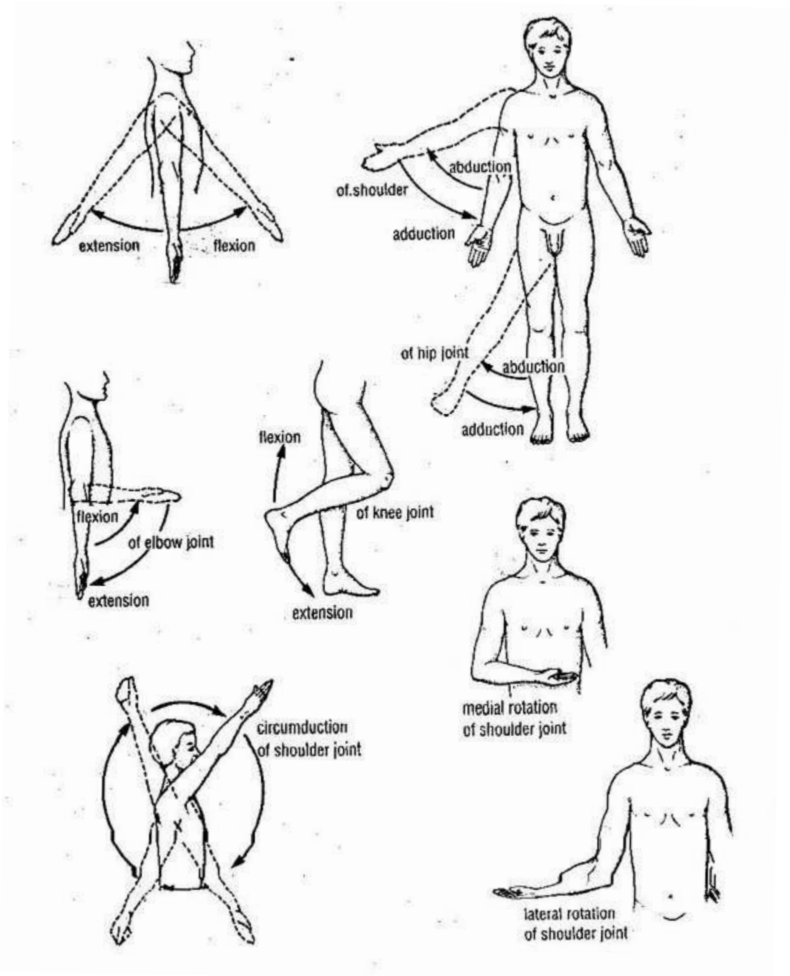

Fig. 4B.9: Movements of the limb

Special Anatomical Terms of Motion: Torso

Clockwise rotation: rotating the thorax/pelvis left to right about the longitudinal axis. The 12 o’clock position is placed anteriorly to the body on the mid-sagittal plane.

Counter-clockwise rotation: rotating the thorax/pelvis right to left about the longitudinal axis. The opposite of clockwise rotation.

Lateral flexion: side bending where the upper body bends towards one side and the spine curves convexly towards the opposite side of the body.

Special Anatomical Terms of Motion: Foot

Dorsiflexion: ankle joint extension, towards the dorsal or posterior face of the body.

Plantar flexion: ankle joint flexion, towards the anterior face of the body.

Eversion: combination of foot pronation and forefoot abduction.

Inversion: combination of foot supination and forefoot adduction.

Foot pronation: sole of the foot rotates outwards (standing on inner side of the foot).

Foot supination: sole of the foot rotates inward (standing on outer side of the foot).

Special Anatomical Terms of Motion: Pelvis

Tilt: Movement of the pelvis about various axes. Specifically:

Anterior pelvic tilt: when the anterior-superior spines of the pelvis are moved anterior to the main vertical plane that passes through the symphysis pubis.

Posterior pelvic tilt: when the anterior-superior spines of the pelvis are moved posterior to the main vertical plane that passes through the symphysis pubis.

Lateral pelvic tilt: one pelvic ilium crest is higher than the other in the frontal plane.

Special Anatomical Terms of Motion: Arms
Forearm pronation: from medical neutral, the palmar surface rotates to face posteriorly.
Forearm supination: the palmar surface rotates to face anteriorly as in medical neutral.
Lateral (external) rotation: rotating anterior surfaces away from the body’s midline.
Medial (internal) rotation: rotating anterior surfaces towards the body’s midline.
Horizontal abduction: abduction in a transverse plane away from the mid-sagittal plane.
Horizontal adduction: adduction in a transverse plane towards the mid-sagittal plane.
Horizontal flexion: flexion of the arms in a horizontal (transverse) plane.
Horizontal extension: extension of the arms in a horizontal (transverse plane.

Table 6: Chart of special anatomical motions

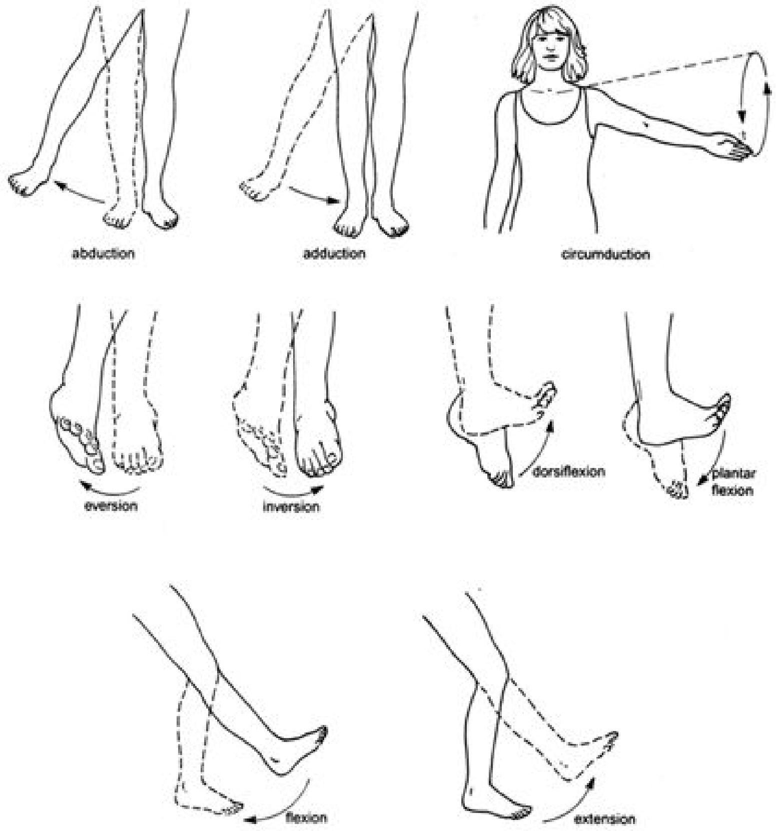

Fig. 4B.10: Additional motions of the human body

4B.5- Anatomical Areas of Interest for Backpacks: The Shoulder Complex

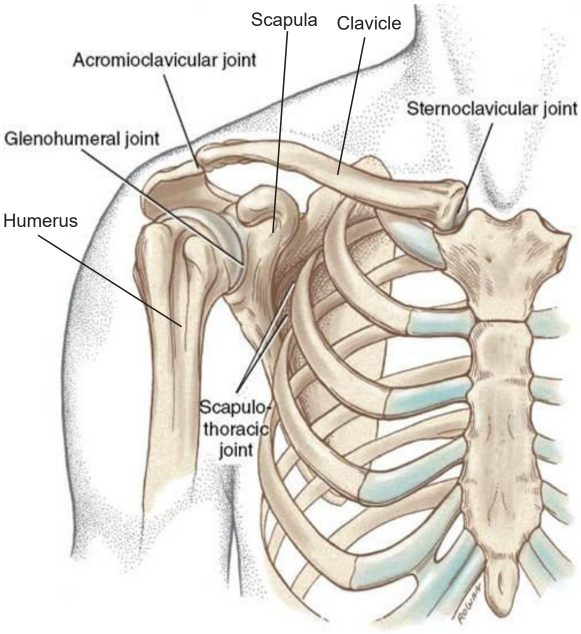

Fig. 4B.11: Shoulder complex

Composition

The shoulder complex comprises the shoulder joint and the shoulder girdle. This comprises the humerus, the scapula, and the clavicle bones, and the synovial glenohumeral, acromioclavicular (AC), and the sternoclavicular joint. A non-synovial scapulothoracic joint. For muscles and nerves, see the *Manual of Structural Kinesiology* (Floyd, 2012)

Ranges of Motion

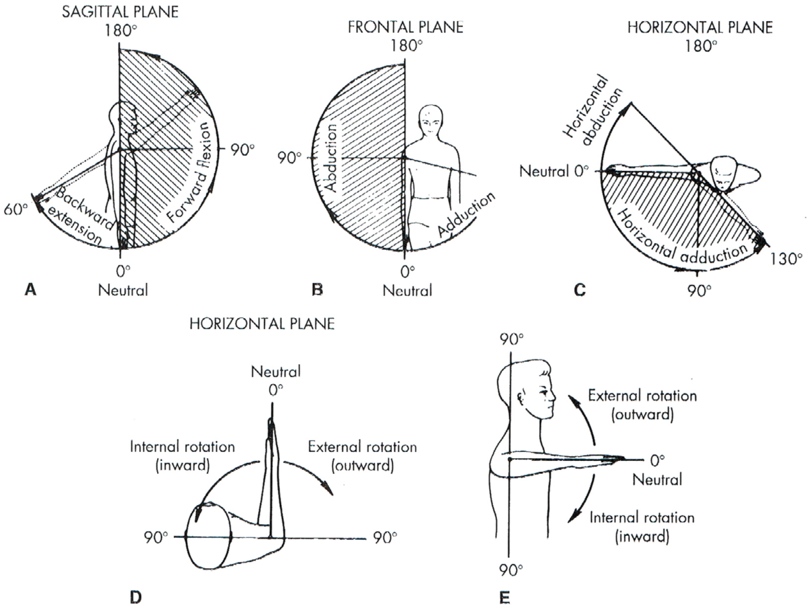

FIG. 5.6 ● Range of motion of the shoulder. **A,** Flexion and extension; **B,** Abduction and adduction; **C,** Horizontal abduction and adduction; **D,** Internal and external rotation with the arm at the side of the body; **E,** Internal and external rotation with the arm abducted to 90 degrees.

Fig. 4B.12: Shoulder ranges of motion- Floyd, 2012, p 113

The first thirty degrees of shoulder joint motion is purely from motion in the glenohumeral joint. After that, for every 2 degrees of shoulder flexion or abduction that occurs, the scapula must upwardly rotate 1 degree. This 2:1 ratio is known as scapulohumeral rhythm (Lippert, 2011, p. 120).

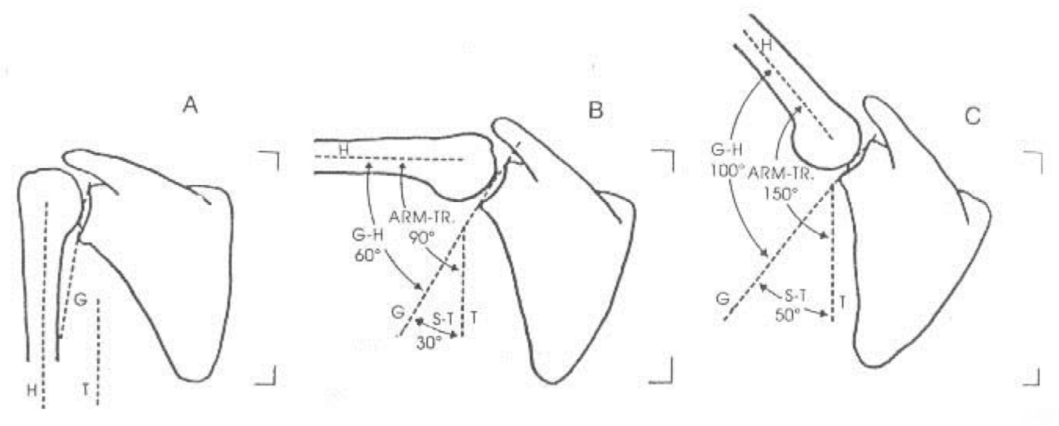

Fig. 4B.13: Scapulohumeral rhythm

<u>Significance</u>

The shoulder complex and its various muscles are responsible for not only for movement of the upper limb, but the muscles and bones it comprises provide the physical form of the upper body. The sternoclavicular joint is significant as it is the only physical hard point of attachment between the axial skeleton and the bones of the upper extremity. These structures are directly interacting with and influenced by the straps of backpacks; as such understanding of this area of interest is critical for designing backpacks. Injury to these structures can severely limit the normal ranges of motion for the shoulder complex, and cause injury to the nerves, muscles, and other anatomical features that are a part of or pass through the upper extremity.

4B.6- Anatomical Areas of Interest for Backpacks: Brachial Plexus

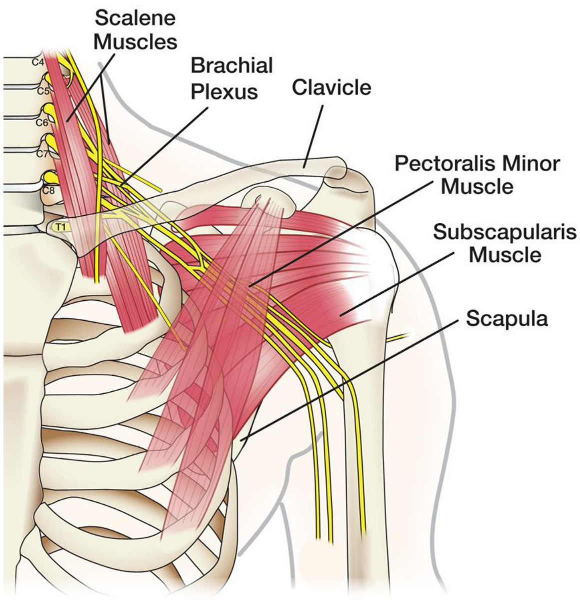

Fig. 4B.13: Brachial plexus

Composition

The brachial plexus is one of the intersecting nerve branches present in the peripheral nervous system, and the one that innervates the shoulder and upper limb (Floyd, 2012, p. 95). In effect it is a complex wiring schematic. This intricate bundle weaves and interweaves its way through the upper body to the shoulder and the upper limb.

Significance

Injuries to this plexus and the related nerves that continue from it can result in mild numbness through loss of functionality depending on the degree of the injury and its location. In the case of a total brachial plexus injury, the end results can include “flail arm, paralysis of a muscles of the hand, and the absence of sensation” (Floyd, 2012, p. 52). Backpack or ‘rucksack’ palsy is one of the more serious conditions that can develop with the shoulder and the brachial plexus.

Based on the 4th Edition AMA *Guides to the evaluation of permanent impairment* (1993), an injury to the brachial plexus as a whole relates to a sixty-percent whole body impairment rating. This is a significant reason to protect this area of interest in backpacks by preventing abnormal compression on the clavicle from loading and excess pressure.

4B.7- Anatomical Areas of Interest for Backpacks: Spine

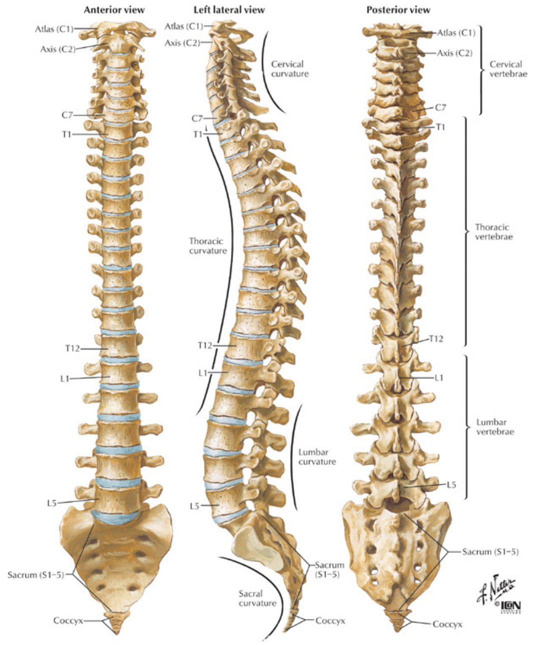

Fig. 4B.14: The human spinal column

Composition

The spinal column comprises twenty-four articulating vertebrae, nine non-articulating vertebrae, thirty-one pairs of spinal nerves, and a number of intervertebral discs Floyd, 2012, p. 327; p. 332). A flexible load-bearing structure with shock absorbing elements, it protects/ houses the spinal cord, and supports the upper body (University of Maryland Medical Center, n.d.).

Ranges of Motion

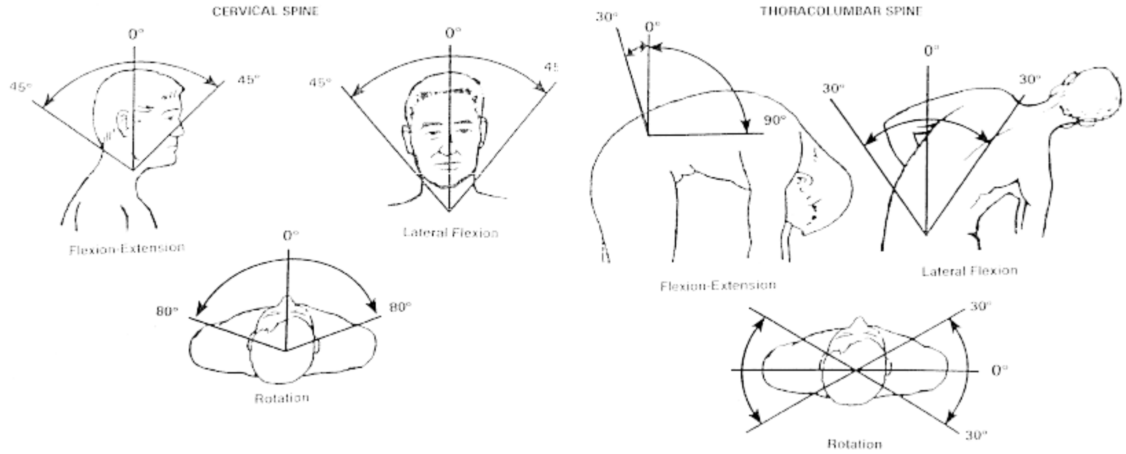

Fig. 4B.15: Ranges of motion of the spine

When it comes to the spine, the degree of rotation is somewhere between three to seven degrees between any two vertebrae. The motions of flexion and extension occur primarily in the cervical and lumbar spine (Kahle et al., 1992).

Significance

The load-bearing nature of the spinal column favors flexibility and support of the upper body, not external loads. Injury to it can prohibit normal movement and range of motion, paralysis, or a combination of all due to its complexity. The more flexible regions of the spinal column are more likely to encounter injury or dysfunction from over-strain. This is partly why backpack interface panels for the back stop below the C7 vertebra, since the thoracic vertebrae which serve as attachment points for the ribs are less mobile.

Biomechanically, the spine serves as the lever for the upper body with its fulcrum at the pelvis. Placing external loads on the back of the body will force a postural adaptation that requires muscle force and energy. The higher up the back the load is placed, a more significant forward flexion of the body will develop and more muscle force is expended to balance this movement. This increases strain on the body and increases disc pressures. Taking the load of a backpack and mounting it to the pelvis will greatly reduce the forward flexion of the upper body and decrease the amount of pressure on the shoulders, the spine, and the intervertebral discs.

4B.7- Anatomical Areas of Interest for Backpacks: Thorax

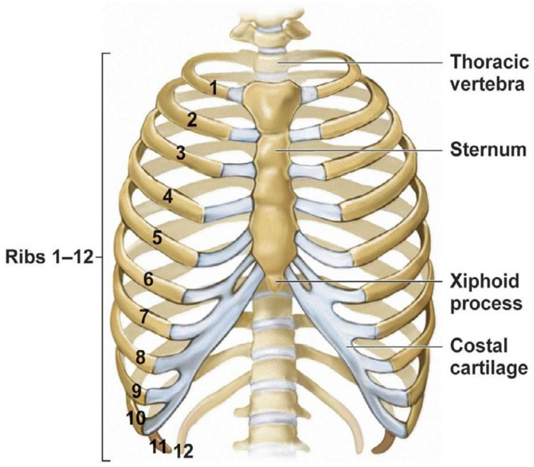

Fig. 4B.16: The human rib cage

Composition

The trunk, or thorax, is the bony structure that provides protective space for vital organs and the attachment means of the shoulder complex/upper limb to the spinal column (Floyd, 2012, p. 328). It provides the skeletal points for the shoulder complex and upper limb to attach to the axial skeleton. It is a dynamic structure since it expands and contracts to allow for respiration.

Breathing

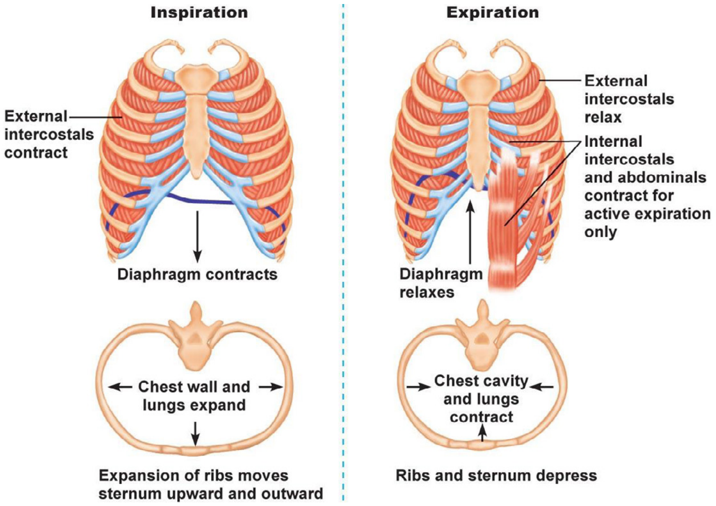

Fig. 4B.17: Movement in the chest from breathing

Significance

Restrictive or over tightening of straps limits maximal inspiration and cause breathing issues.

4B.8- Anatomical Areas of Interest for Backpacks: Pelvic Girdle and Hip

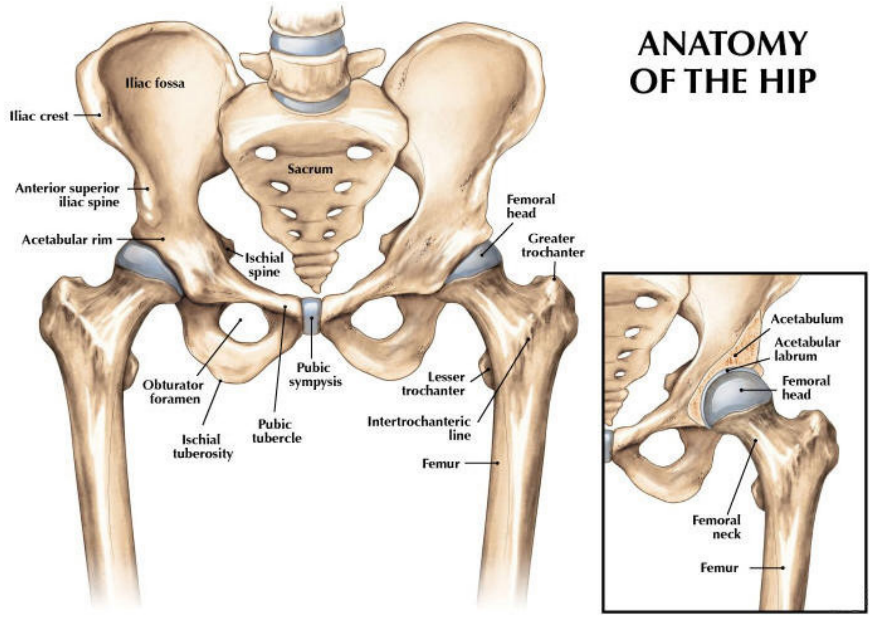

Fig. 4B.18: Pelvic girdle

<u>Composition</u>

The pelvic girdle comprises the left and right pelvic bones, the sacrum, the coccyx, and obturator foramen. It is held together by three joints: the symphysis pubis in the front and two sacroiliac or SI joints between the sacrum and the two pelvic bones. Of special note are the SI joints themselves, which are shell-shaped joints with an extensive ligamentous structure that help hold the pelvis and the sacrum together. The concave surfaces of the acetabulums of the pelvis are the sites of the acetabular femoral or hip joint. For muscles and nervous elements, which are numerous, please see *Manual of Structural Kinesiology* (Floyd, 2012, pp. 237-264).

Ranges of Motion

FIG. 9.8 ● Active motion of the hip. **A,** Flexion is measured in degrees from a supine position; the knee can be extended or flexed; **B,** Extension or hyperextension is normally measured with the knee extended; **C,** Abduction can be measured in a supine or side-lying position; adduction is best measured with the subject lying supine; **D,** Internal and external rotation can be evaluated in either a supine or a prone position.

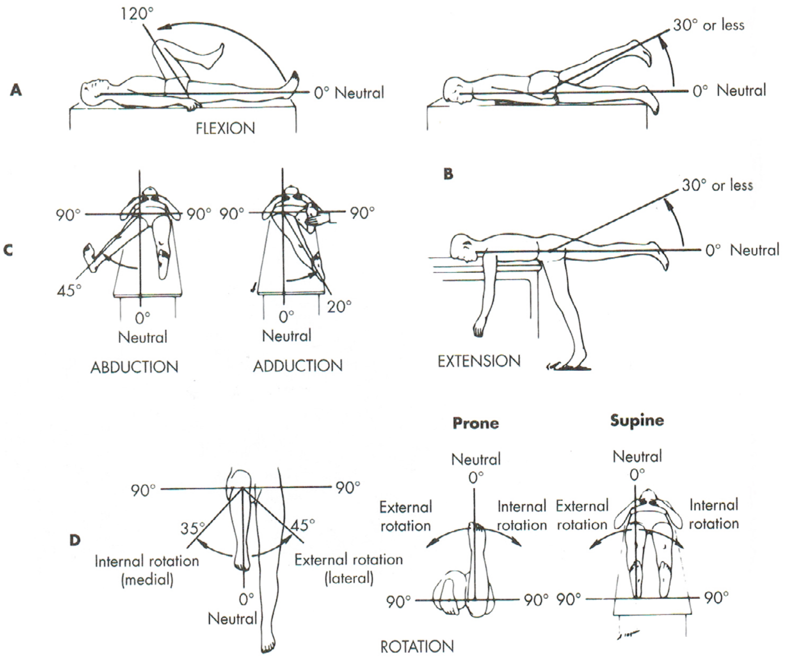

Fig. 4B.19: Ranges of motion of the hip- Floyd, 2012, p. 232

Significance

In addition to being site of the load-bearing joints for the lower limb, the pelvic girdle is ideal for weight bearing of backpacks through a waist or pelvic belt since it is a stable platform. The pelvic bones then communicate loads down through the leg and relieve loads from the spinal column. The spine and sacrum are not ideal for load-bearing by comparison. The SI joints facilitate a small degree of dynamic axial rotational gliding between the sacrum and the pelvic bones (where more movement occurs superiorly than inferiorly where the point of rotation may be found). Any forces or loads placed on the spine (especially in the vertical planes) will translate to bear on the SI joints and the numerous ligamentous structures that support it. Any such injury resulting in a shear tear of the ligaments will greatly affect the entire structure

4B.9- Anatomical Areas of Interest for Backpacks: Lower Limb

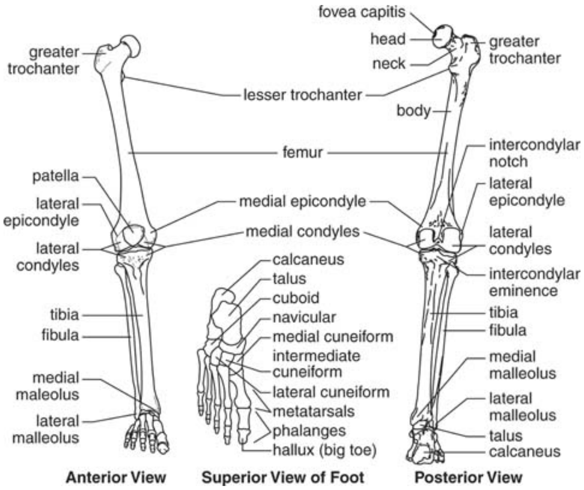

Fig. 4B.20: Shoulder complex

Composition

The lower limb comprises the femurs, fibula and tibula bones, the patela, and the various bones of the feet. For more specifics on these structures, the musculature involved, and the innervating nerves, see *Manual of Structural Kinesiology* (Floyd, 2012).

Significance

When loads such as backpacks are placed on the body, the gait pattern of the body is altered. The most significant of these adaptations of the body due to posterior loading include a decrease in the length of stride, an increase in stride frequency and step width, decreased pelvic girdle rotation, and a decrease in balance (Sumner, 2012).

4B.10- Anatomical Areas of Interest for Backpacks: Center of Gravity

Definition(s)

The center of gravity can be described different ways: 1) "the point representing the weight center of an object," 2) "point in the body about which all parts exactly balance each other," and 3) "the point at which the entire weight of the body may be considered concentrated" (Hamilton, Weimar, & Luttgens, 2008, pp. 32-33).

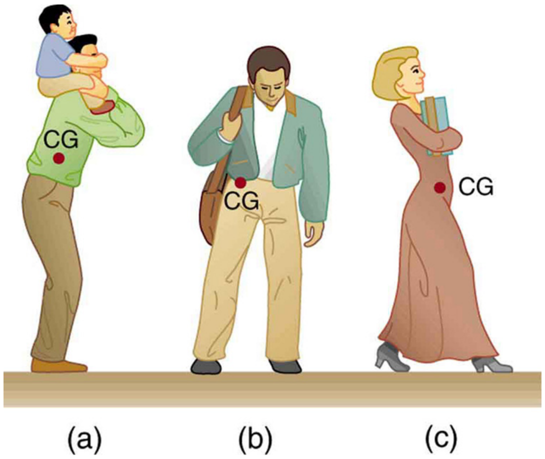

Fig. 4B.21: Center of gravity location with external loads

Significance

The center of gravity is typically located anterior to the sacrum at about 55% of the standing height of women and about 57% of the standing height in men in anatomical neutral. It is a moving point, different for each person. It is influenced by the posture of the individual at a given time and all external loads placed on the body.

With external loads, the CoG will move towards the load. The body will exert energy to adapt its posture opposite the load pull to bring the CoG of the system closer to the position of anatomical neutral. With loads on the back, the body will lean forward (A); with loads on the side, the body will lean to the opposite side (B); with loads on the front, the body will lean back (C). Otherwise, the individual will fall over in the direction of the load. Overloading/excessive postural adaption may result in dysfunction or injury.

4B.11- Backpack-Related Anatomical Differences Between Men and Women

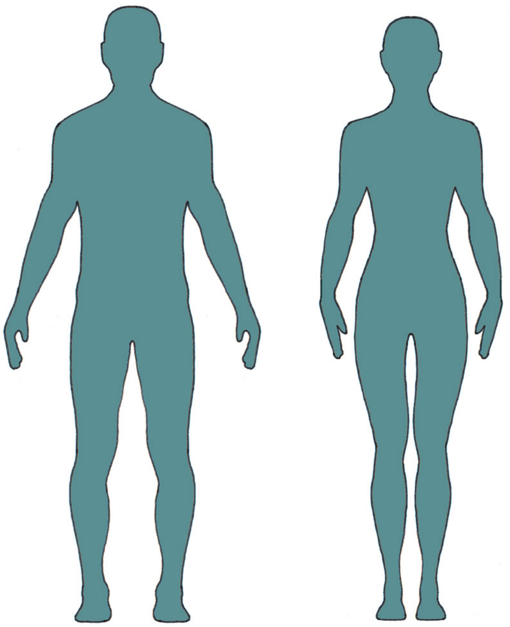

Fig. 4B.22: General outline of the male and female body

Significance

The male and female bodies are significantly different from a form standpoint and from a function standpoint. Recognizing these differences is valuable for the backpack designer, since design considerations and accommodations for the male human body may not work or benefit the female human body

---

Overall

Adult males "have 150% of the lean body mass of the average female and twice the number of muscle cells" (Rogol, Roemmich, & Clark, 2002, p. 196). This is primarily due to the levels of testosterone in males and estrogen in females. The effect of those hormones during puberty also leads to "differential growth of the shoulders and hips and differences in lean tissue accrual between males and females" (p. 196).

Shoulders

A significant site of anatomical interest for backpacks are the shoulders. A major difference between the shoulders of the male and female bodies are as follows. Male shoulders are typically broader in size compared to females, with significantly more mass in muscles such as the trapezius. Female shoulders are typically less broad in size compared to males, with significantly less muscle mass in the upper body muscles. This results in a difference the angle the muscles of the upper extremity create; thus male and female body require a different angle for the shoulder straps to cross the body.

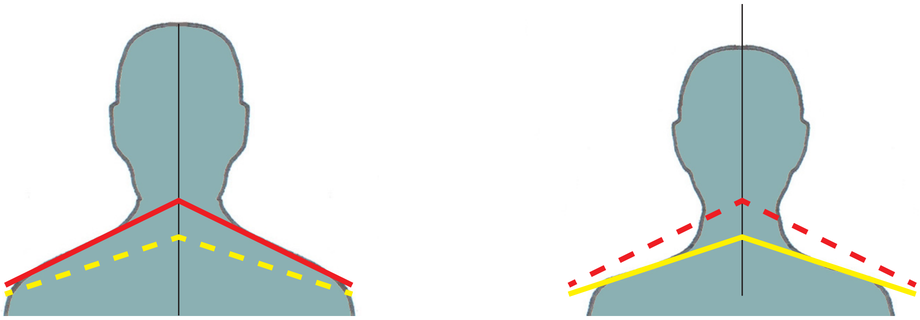

Fig. 4B.23: Comparison of shoulder slope (male and female)

Thorax

The major difference in this area of interest for the male and the female body are the female breasts. This anatomical feature of the female body dictates the use of a different shoulder strap shape than the type used for men. Otherwise, women may experience improper fitting of the shoulder straps, undue compression of the chest and breasts from an effort to properly fit the shoulder straps, and difficulty breathing.

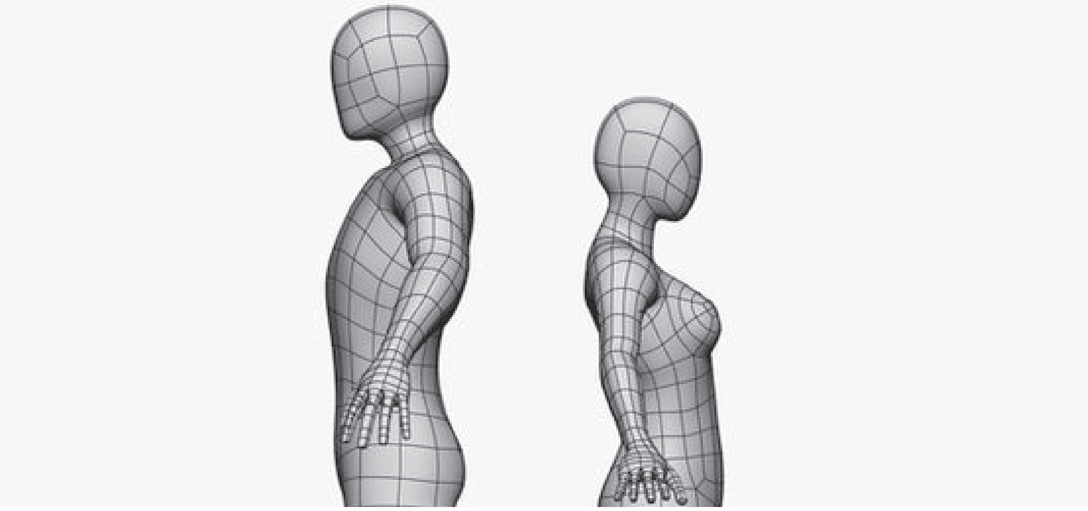

Fig. 4B.24: Comparison of the chest (male and female)

Pelvis

The male and female pelvis differs in shape, size, and angle. With the male pelvis, the brim of the pelvis is smaller, the pubic arch angle is less than 90 degrees, and there is a narrower pelvic outlet. With the female pelvis, the brim of the pelvis is much wider than for men, the pubic arch angle greater than 90 degrees, and the pelvic outlet is much larger (Skeleton Premium, 2015).

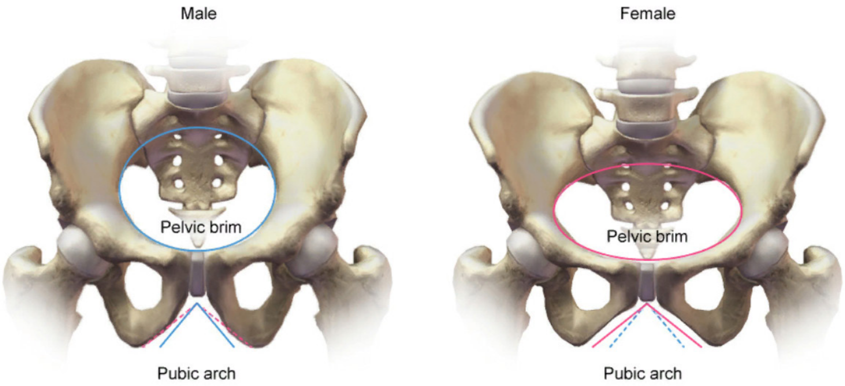

Fig. 4B.25: Comparison of the pelvis (male and female)

Lower Limb

Because of the wider pelvis in females, the Q-angle of the lower limb is much larger than it is in women. This increases the stress placed on the knees, correlating to the increased chance of women sustaining ACL injuries compared to men (Fields, 2012).

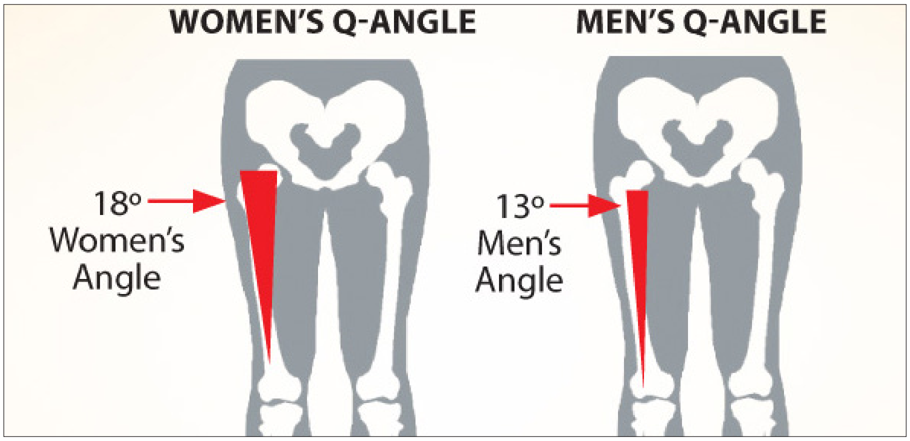

Fig. 4B.26: Comparison of the Q-angle (male and female)

Accordingly, it is recommended (when external loading of the body is concerned) that female backpack-users utilize knee braces as a preventative measure.

Center of Gravity

The center of gravity differs for the male and female body as well. Measured from the ground in the transverse plane the center of gravity is located approximately at the 55 percent of the standing height, while for men the center of gravity is approximately at 57 percent of the standing height (Hamilton, Weimar, & Luttgens, 2008).

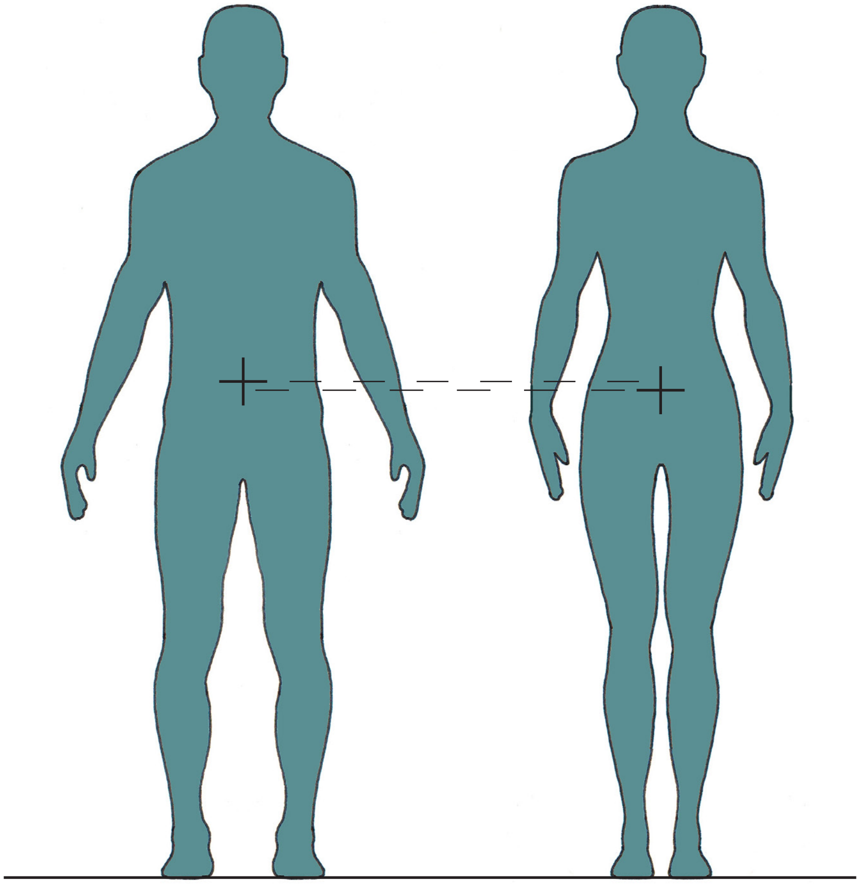

Fig. 4B.22: General outline of the male and female body

4C- Backpack Design Guideline Checklist

Following the writing and information formats found in the 4th Edition AMA *Guides* (1993), the following charts condense some of the more critical informations to consider when designing backpacks. These may be used by the designer to tabulate critical information such as the maximum recommended load-carrying limits; backpack features based on the end-use, use environment, and load-carrying capacity; and basic dimensions of those features.

<table>
<tr><th colspan="8">Checklist for Backpack Design (For Use by the Designer)</th></tr>
<tr><td rowspan="3">End-users Demographics:
Use the following to tabulate backpack needs based on end-user information</td><td colspan="2">Physical Gender of user:</td><td>Male</td><td>Female</td><td>Anthropometric Percentile:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Torso Range:</td><td colspan="2"></td><td>Waist/Hip Range:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Weight (est.) of End-user:</td><td>lbs</td><td>Multiply weight by 25%:</td><td>lbs</td><td colspan="2">(recommended weight limit)</td></tr>
<tr><td>End-use Load Weight (lbs). Based on the recommended load limit)</td><td>0-10</td><td>11-20</td><td>21-30</td><td>31-40</td><td>41-50</td><td>51-60</td><td>61-70</td></tr>
</table>

<table>
<tr><td>Use Application(s) (Please List)</td><td colspan="4"></td></tr>
<tr><td>Anticipated Use Environment(s)</td><td colspan="4"></td></tr>
<tr><td>Does the use environment require specific clothing?</td><td>Yes</td><td>No</td><td>Maybe</td><td>Remember to account for clothing correction</td></tr>
<tr><td colspan="5">What types of clothing will be used with this backpack?:</td></tr>
</table>

<table>
<tr><td>User Size Chart*†</td><td>XS</td><td>S</td><td>M</td><td>L</td><td>XL</td><td rowspan="2">NOTE: These measurements are general ranges: consult anthropometric databases for specifics. Recognize that there are intermediate sizes that may overlap the standard ones listed here.</td></tr>
<tr><td>Torso (Generalized)</td><td>≤ 17”</td><td>16” - 19”</td><td>18” - 21”</td><td>20” - 23”</td><td>22” - 26”</td></tr>
<tr><td>Waist (Men)</td><td>N/A</td><td>≤ 31”</td><td>30” - 34”</td><td>33” - 37”</td><td>≥ 36”</td><td rowspan="2">* https://www.ospreypacks.com/pe/en/fitting-learning/size-fit
† https://www.hiking.com.au/assets/images/osprey-2013-sizing-chart.jpg</td></tr>
<tr><td>Waist (Women)</td><td>≤ 28”</td><td>27” - 31”</td><td>30” - 34”</td><td>≥ 33”</td><td>N/A</td></tr>
</table>

Table 7: Checklist for Backpack Design (For Use by the Designer)

Backpack Components: Considerations Based On End Load Limits (Recommended 70lb max limit)							
Weight (lbs)	0-10	11-20	21-30	31-40	41-50	51-60	61-70
Frame style	Internal			Internal permitted, consider using external.	External		
Hip belt	Optional	Foam padding alone permitted		Foam padding plus reinforcement (plastic framing) recommended			
Sternum strap	Optional	Sternum strap recommended	Sternum strap required				
Load-lifter straps	Not required	Optional	Recommended	Required			
Frame extensions for load lifter straps	Not required	Optional	Recommended	Required			
Compression straps	Not required	Recommended	Required				

Table 8: Backpack Components: Considerations Based On End Load Limits

Backpack Design Accommodations (Generalized)	
Area of Interest	Considerations
Shoulders	• Shoulder girdle rotates in multiple directions: pivot points for shoulder straps will adapt to this dynamic movement • Limiter straps to prevent downward compression of the clavicle and shoulder (help prevent backpack palsy). Should be about a finger's thickness of space (ideally) • Load lifter straps to help decrease shoulder strap load pressures on the shoulder • Straps should start two inches below the C7 vertebra
Torso (Chest and back)	• Airways and breathable mesh reduce moisture buildup between backpack and body • Lumbar support pad to support the low back and S-curve of the spine • Frame setup according to needs and use application • The length of the backpack frame should measure from the top of the iliac crest of the pelvis to just below the C7 vertebra
Pelvis	• Hip/waist/pelvic belt should have at least three inches of the belt interacting with the brim of the pelvis. Design to leave three inches (minimum) of space between the two ends of the belt when buckled and fitted to the user • Plastic reinforced belts placed on the iliac crests of the pelvis can help reduce up to 48% of the pressure placed on the shoulders • Proper fitting of a hip belt can help stabilize the SI joints, reducing some referred pain into the low back from the pelvis

Table 9: Backpack Design Accommodations (Generalized)

Backpack Design Accommodations (Based on Gender)		
Area of Interest	For Men	For Women
Shoulders	• Angle of insertion of shoulder straps to backpack is steeper than with women • Shoulders are wider, straps must be placed further apart than with women • Wider straps may be used than with women	• Angle of insertion of shoulder straps to backpack is shallower than with men • Shoulders are narrower, straps must be placed closer together than with men • Narrower straps needed than with men
Chest	• Longer torso compared to women; frame elements need to be longer. Consult anthropometric databases for details • C-curve shoulder strap from backpack over the body permitted based on torso shape and muscle mass	• Shorter torso compared to men; frame elements need to be longer. Consult anthropometric database for details • S-curve shoulder strap from backpack over the body required to account for torso shape and breasts
Pelvis	• Little to no tilt from the vertical of hip belt required based on male pelvis shape and waist dimensions.	• Lilt of pelvic belt from vertical required based on female pelvis shape and waist dimensions.

Table 10: Backpack Design Accommodations (Based on Gender)

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5. DEMONSTRATION OF HUMAN BODY DESIGN GUIDELINES

5.1- Introduction

Within Chapter 4, this study has developed a series of design guidelines, reference materials, and design charts. This chapter will focus on demonstrating these various design resources with a conceptual backpack design. To achieve this, the design forms were filled out to identify which backpack elements were needed within the design. With that accomplished, some reference material was collected to inspire specific features and the overall form of the conceptual backpack design. Then, an initial Solidworks CAD model was created to generate the backpack design. It should be reiterated this design is purely for communicating application of the design guidelines. As such, features such as end-use buckles, hardware fasteners, fine sewing detail, and a refined backpack compartment aesthetic were omitted.

5.2- Tabulated Design Guideline Charts

Over the next pages, the tabulation charts have been filled out to address a specific backpack design brief. Based on the design brief requirements filled out in 5.2 the end-user is a 92nd percentile male, whose backpack measurements are for a large torso with a large or extra large waist belt depending on the user’s preference. The end use is for a medium-duty backpack whose anticipated load capacity is over the 40lb mark. Based on the anticipated use as a school backpack and dual-purpose camping/hiking backpack in the southern USA, no special clothing correction is anticipated, though ventilation would

<table>
<tr><th colspan="8">Checklist for Backpack Design (For Use by the Designer)</th></tr>
<tr><td rowspan="3">End-users Demographics:
Use the following to tabulate backpack needs based on end-user information</td><td>Physical Gender of user:</td><td>[✓ Male]</td><td>Female</td><td colspan="2">Anthropometric Percentile:</td><td colspan="2">92nd % (est.)</td></tr>
<tr><td>Torso Range:</td><td colspan="2">22” - 22.5”</td><td colspan="2">Waist/Hip Range:</td><td colspan="2">36”</td></tr>
<tr><td>Weight (est.) of End-user:</td><td colspan="2">225 lbs</td><td>Multiply weight by 25%:</td><td>56.25 lbs</td><td colspan="2">(recommended weight limit)</td></tr>
<tr><td>End-use Load Weight (lbs). Based on the recommended load limit)</td><td>0-10</td><td>11-20</td><td>21-30</td><td>31-40</td><td>[✓ 41-50]</td><td>51-60</td><td>~~61-70~~</td></tr>
</table>

<table>
<tr><td>Use Application(s) (Please List)</td><td colspan="4">Light Backpacking, light camping, predominantly for carrying books & school supplies (est. 45lbs max)</td></tr>
<tr><td>Anticipated Use Environment(s)</td><td colspan="4">Southern USA: Tropical to Semi-tropical. Harsh sun, high humidity.</td></tr>
<tr><td>Does the use environment require specific clothing?</td><td>Yes</td><td>No</td><td>[✓ Maybe]</td><td>Remember to account for clothing correction</td></tr>
<tr><td colspan="5">What types of clothing will be used with this backpack?: Single layer, casual clothing, specialized athletic wicking clothing, etc. No correction.</td></tr>
</table>

<table>
<tr><td>User Size Chart*†</td><td>XS</td><td>S</td><td>M</td><td>L</td><td>XL</td><td rowspan="2">NOTE: These measurements are general ranges: consult anthropometric databases for specifics. Recognize that there are intermediate sizes that may overlap the standard ones listed here.</td></tr>
<tr><td>Torso (Generalized)</td><td>≤ 17”</td><td>16” - 19”</td><td>18” - 21”</td><td>[✓ 20” - 23”]</td><td>22” - 26”</td></tr>
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† https://www.hiking.com.au/assets/images/osprey-2013-sizing-chart.jpg</td></tr>
<tr><td>Waist (Women)</td><td>≤ 28”</td><td>27” - 31”</td><td>30” - 34”</td><td>≥ 33”</td><td>N/A</td></tr>
</table>

Table 11: Checklist for Backpack Design Form Demonstration

Backpack Components: Considerations Based On End Load Limits (Recommended 70lb max limit)

Weight (lbs)	0-10	11-20	21-30	31-40	41-50	51-60	61-70
Frame style	Internal			Internal permitted, consider using external.	External		
Hip belt	Optional	Foam padding alone permitted		Foam padding plus reinforcement (plastic framing) recommended			
Sternum strap	Optional	Sternum strap recommended	Sternum strap required				
Load-lifter straps	Not required	Optional	Recommended	Required			
Frame extensions for load lifter straps	Not required	Optional	Recommended	Required			
Compression straps	Not required	Recommended	Required				

Table 12: Backpack Components: Considerations Form Demonstration

be a major consideration. The Backpack Components flow-chart quickly formulates the parts requirements for the backpack design. Since the design will operate at some point above 40lbs, an external frame is required, as are compression straps, load-lifter straps, sternum straps, frame extensions, and a reinforced hip-belt.

5.3- Initial Reference Materials

Given the load-carrying application, the initial design concept involved taking the rigidity and weight-carrying ability of an external frame and mixing it with elements from internal frame backpacks such as the back and lumbar support. Balancing these two together was a focus on keeping the load from shifting during use, and to keep the design breathable to overcome the shortfalls inherit to internal frame designs.

Fig. 5.1: US MOLLE rucksack frame

Fig. 5.2: Gregory back and lumbar support pad

5.4- Human Body Design Guidelines-Based Backpack Concept

Fig. 5.3: The Crossover hybrid frame backpack system

5.4.1- Orthographic Views and Technical Figures

Fig. 5.4: Front View

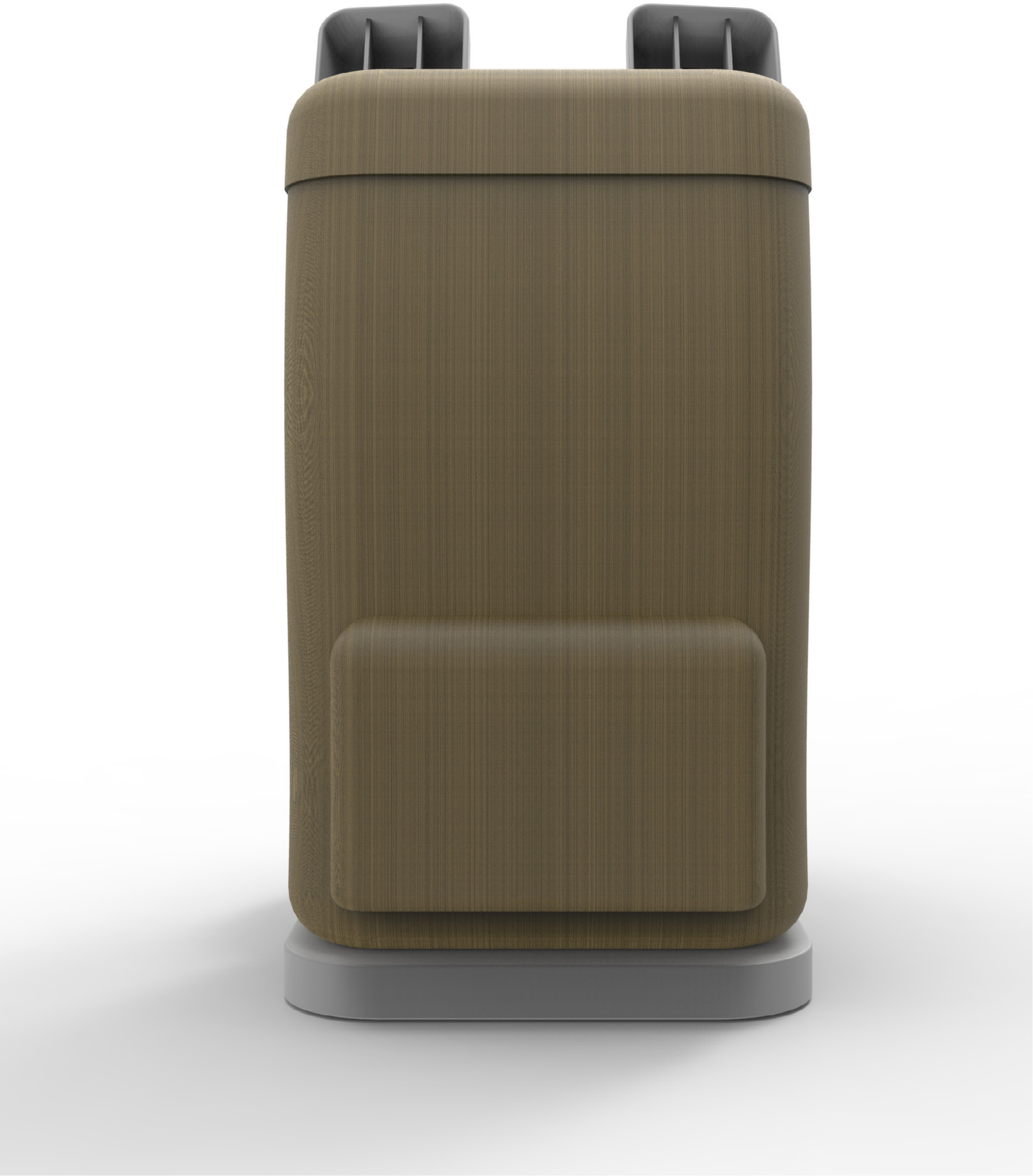

Fig. 5.5: Rear View

Fig. 5.6: Left Side View

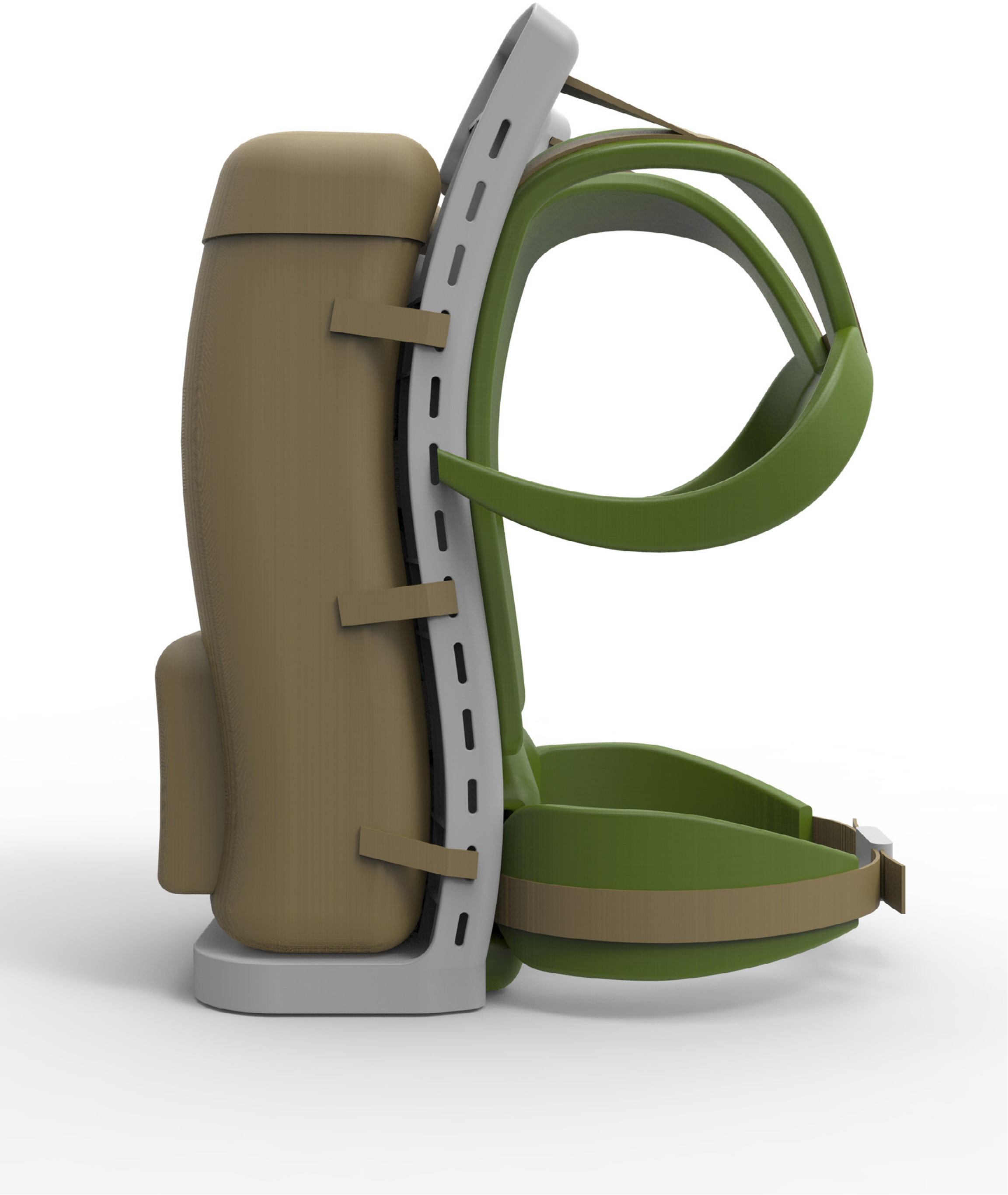

Fig. 5.7: Right Side View

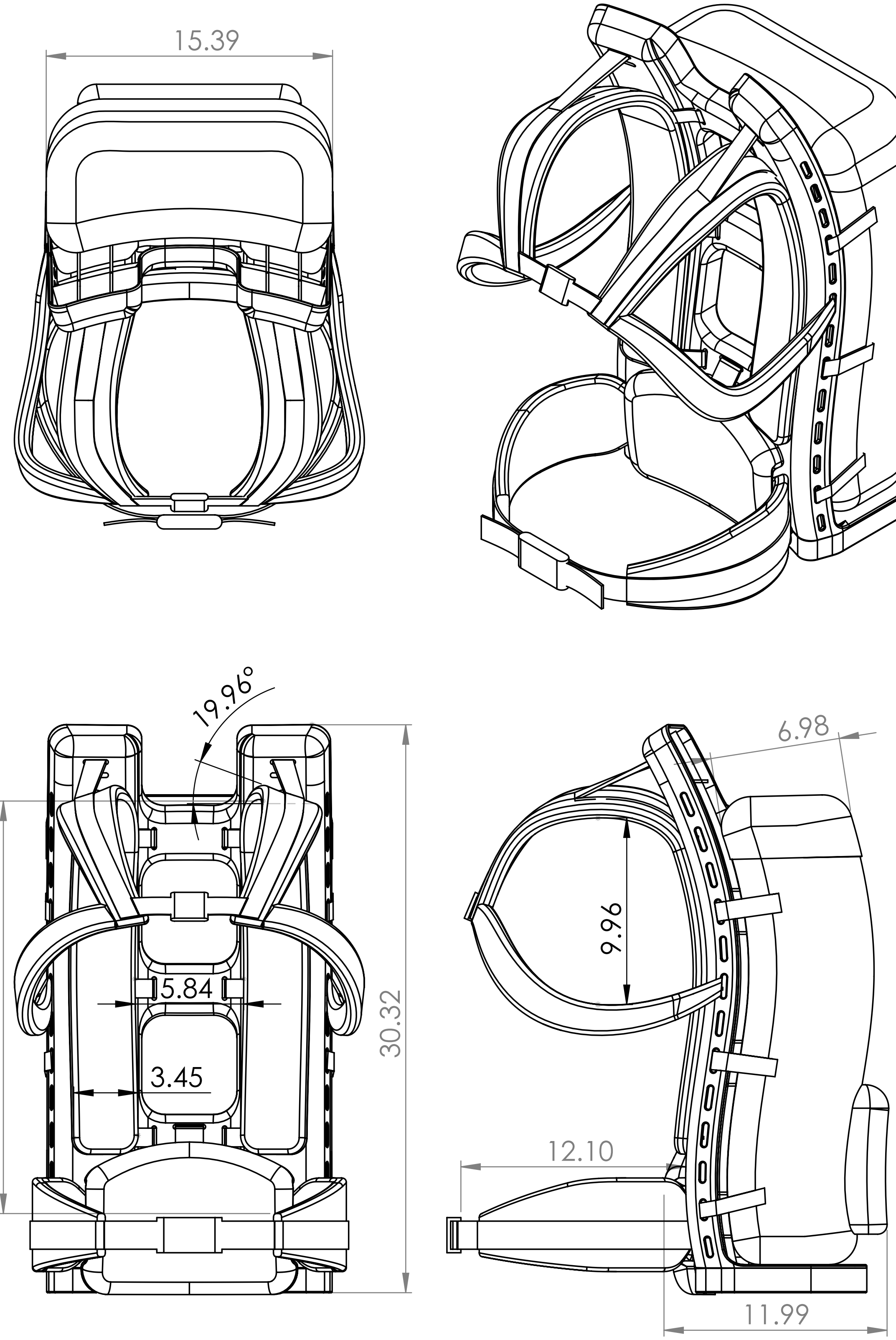

Fig. 5.8: Crossover Technical Drawings: Rough measurements in inches

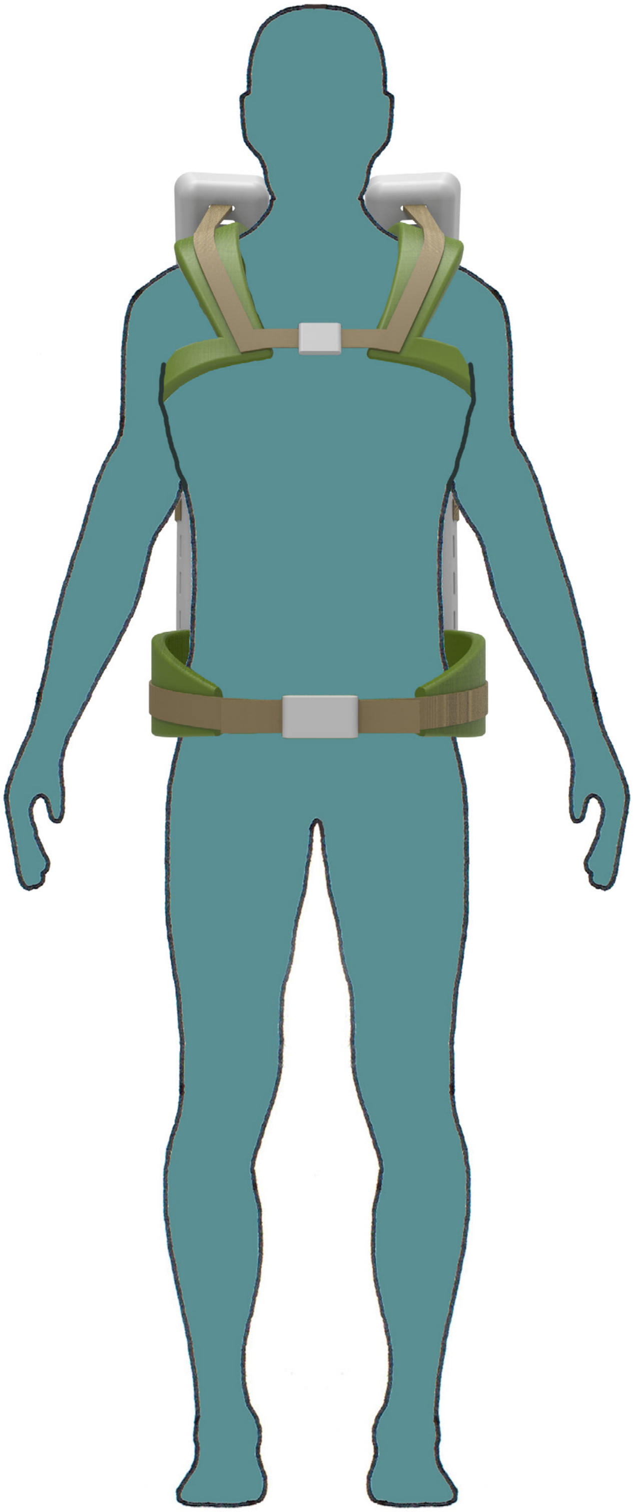

Fig. 5.9: Crossover frame pack (early context exploration)

5.4.2- Backpack Concept Details

1) X-Harness:

- Helps keep placement of straps consistent on the clavicle and shoulder.
- May permit more natural movement by mimicking the clavicle and sternoclavicular joint of the body, with fine adjustment from the sternum strap.
- Full contact shoulder strap provides ample cushioning support for the back without becoming a heat/sweat trap.
- Lumbar support covers the pivot points for the pelvic belt.

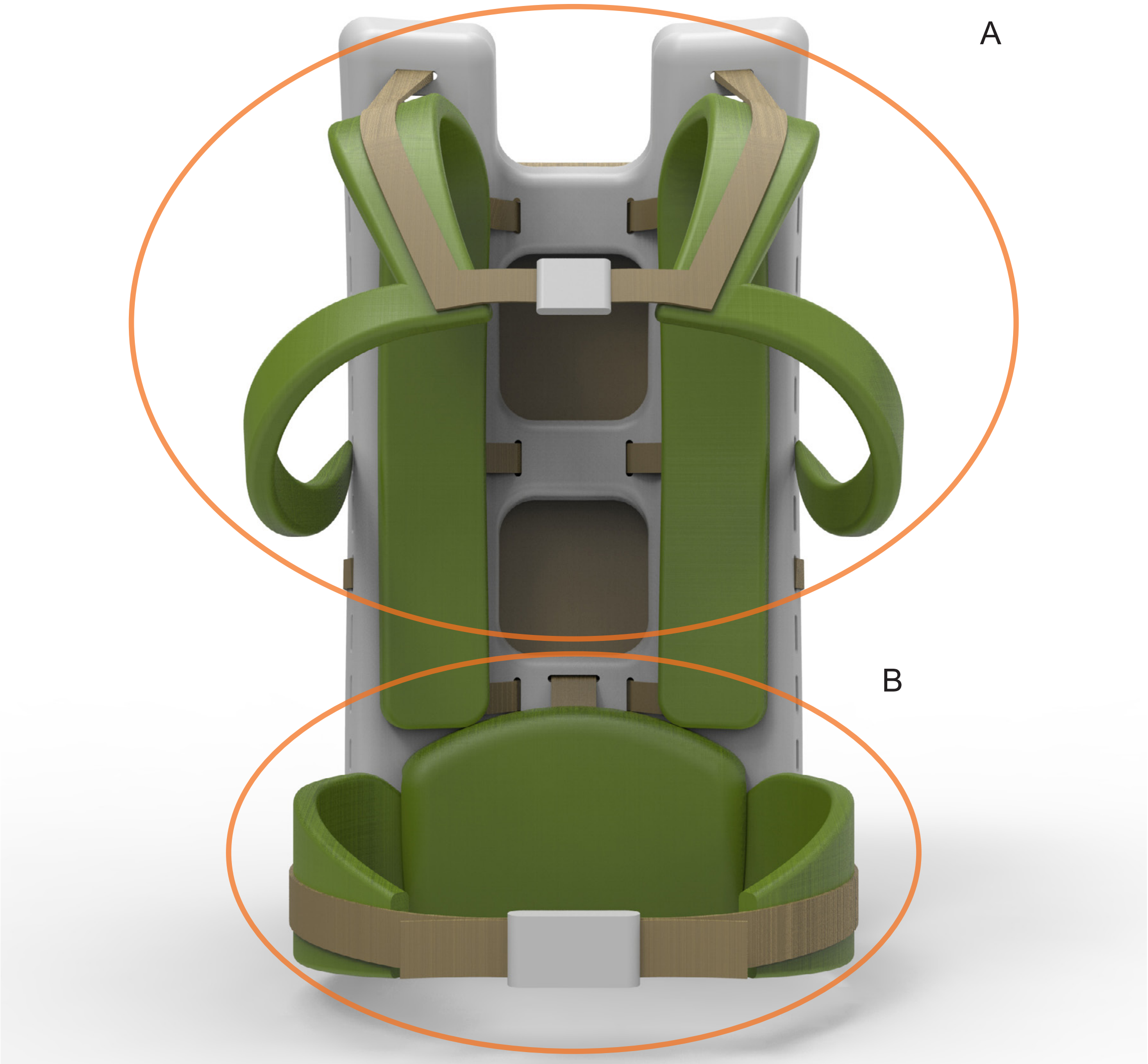

Fig. 5.10: X-Harness (A) and lumbar support/hip belt (B)

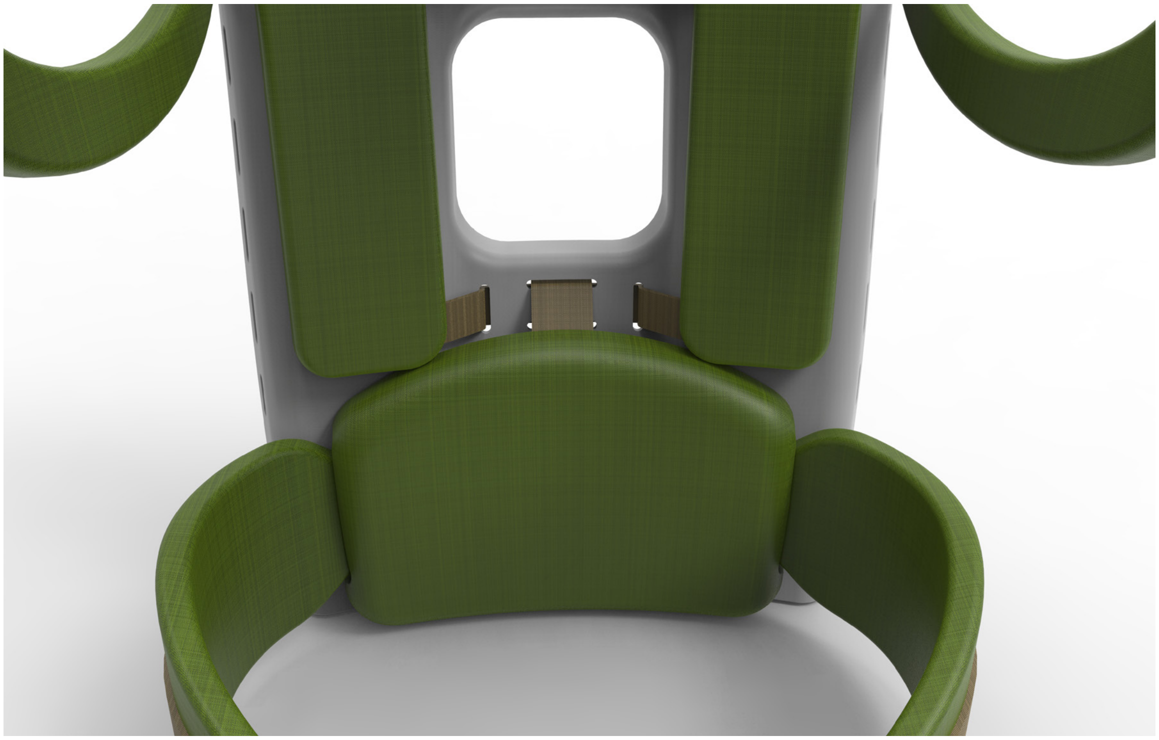

Fig. 5.11: Hip belt and lumbar support (lumbar pad on)

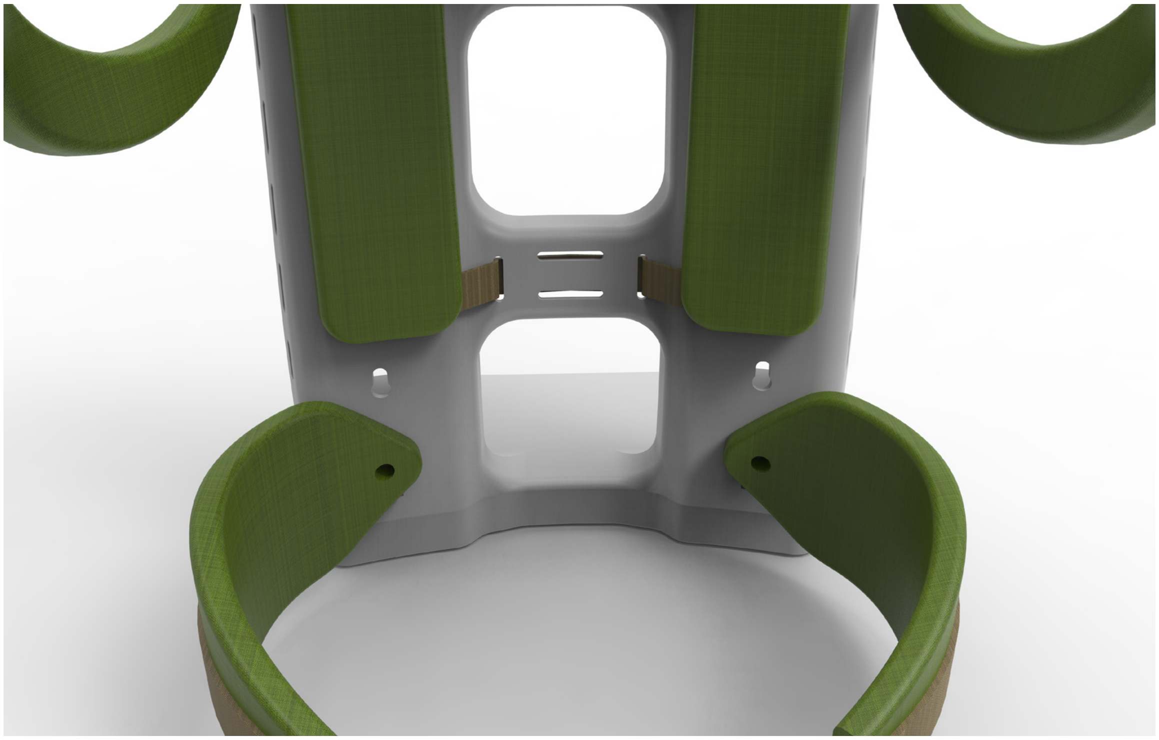

Fig. 5.12: Lumbar pad and pivoting hip belt anchor points

2) Crossover Frame (injection or roto-molded component):

- Gives the structural support of an external frame with the S-curve and back support padding of an internal frame design.
- Mid-back slot permits unrestricted airflow without compromising frame strength.
- Keyslots in the frame are mounting points for the shoulder straps, and provide a degree of customization ability for the shoulder pads/straps placement.
- Secondary strap slots for the shoulder padding helps keep shoulder straps in place.
- Load tray keeps backpack compartment from drooping and shifting the center of gravity.

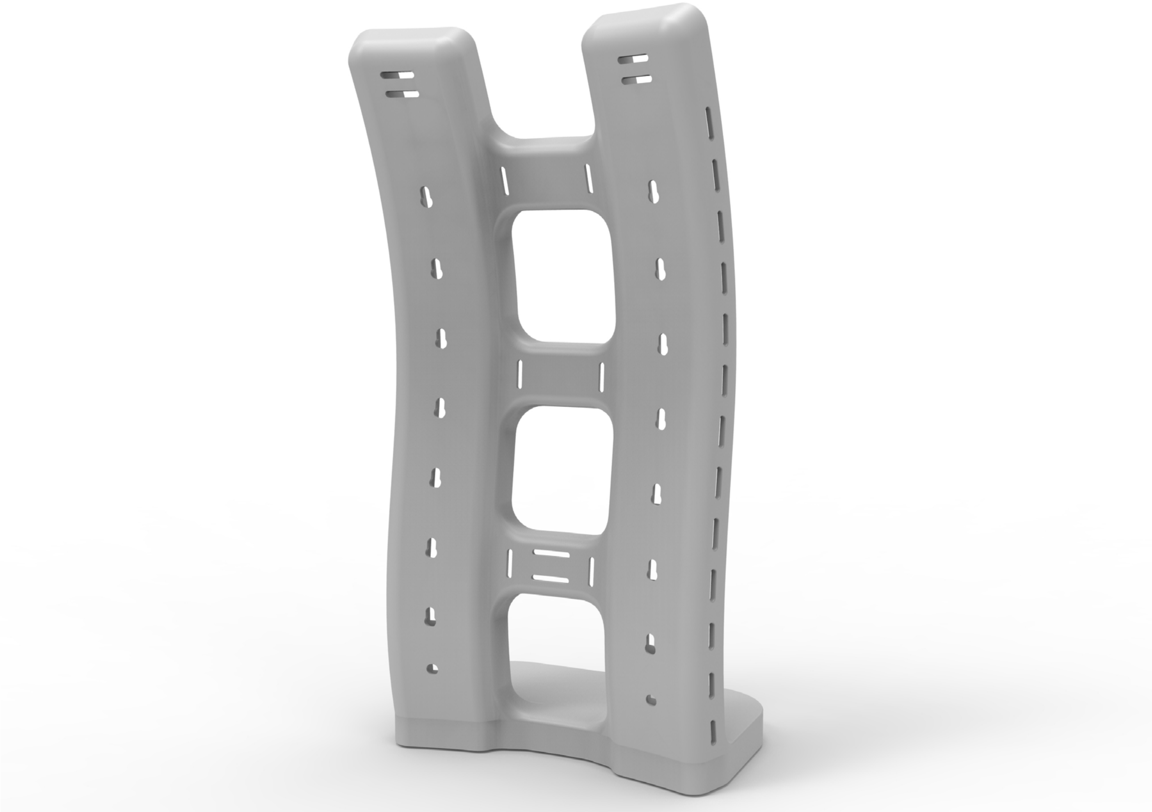

Fig. 5.13: Crossover frame (no harness from front)

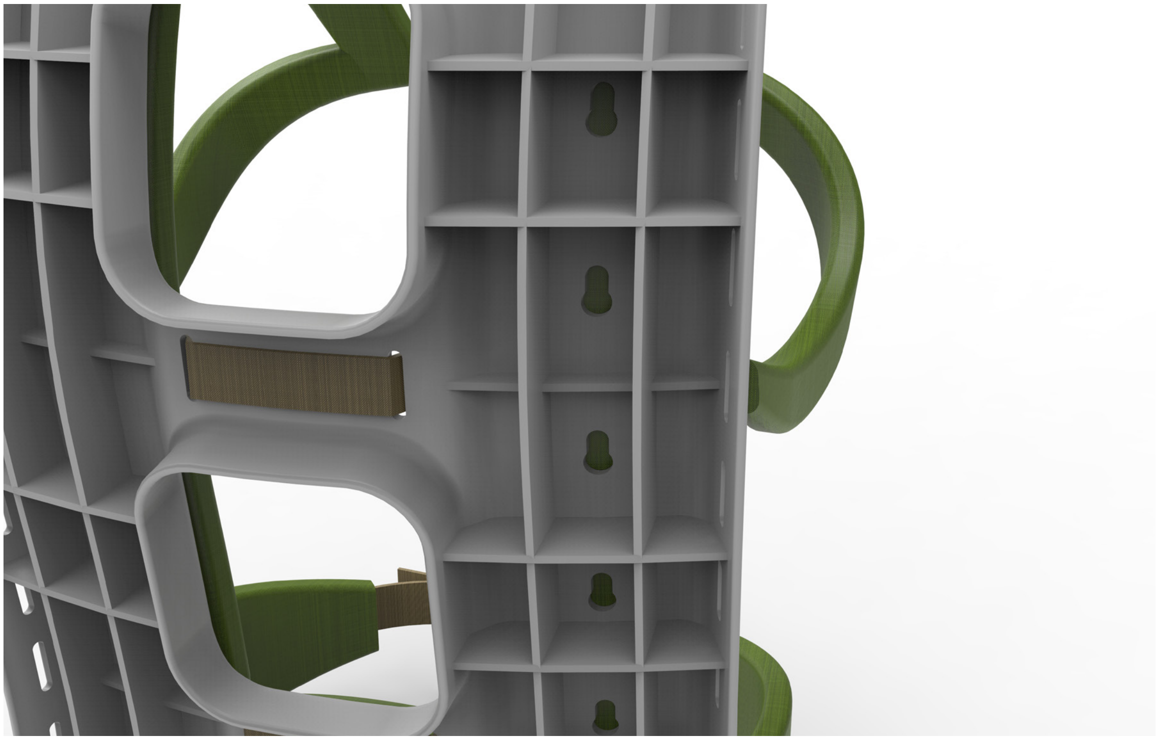

Fig. 5.14: Shoulder strap: Primary (key-slot) and secondary anchor points

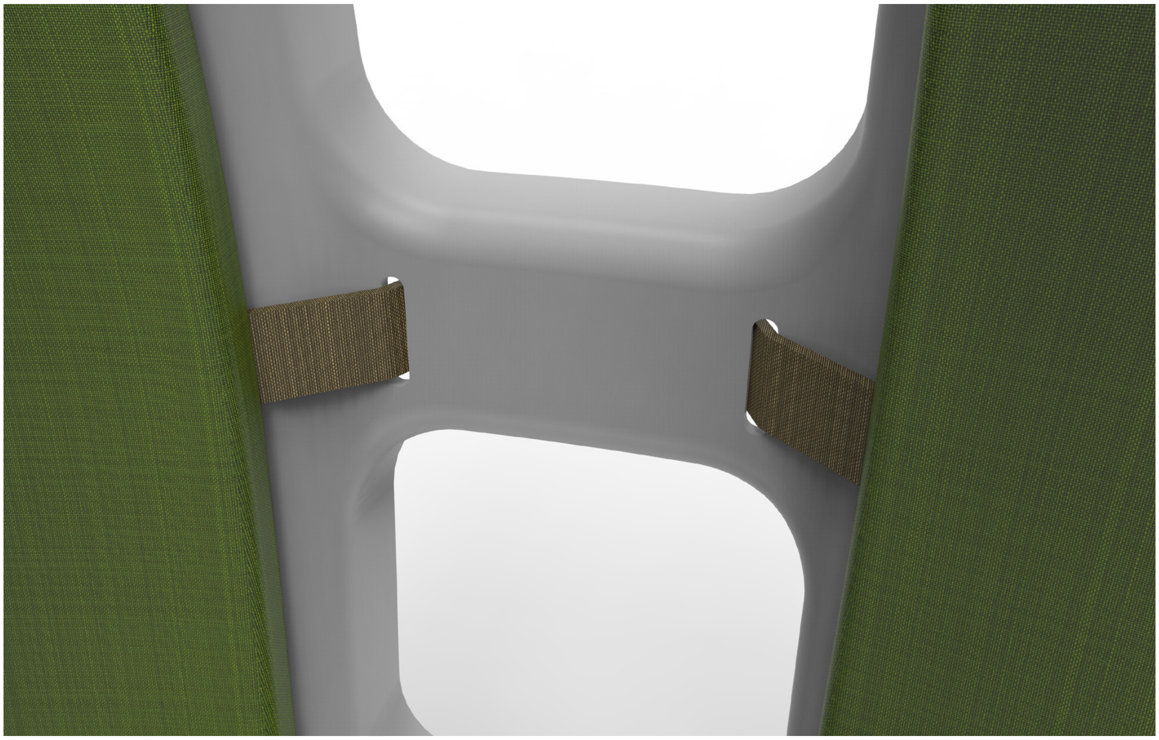

Fig. 5.15: Shoulder strap secondary anchor points (front)

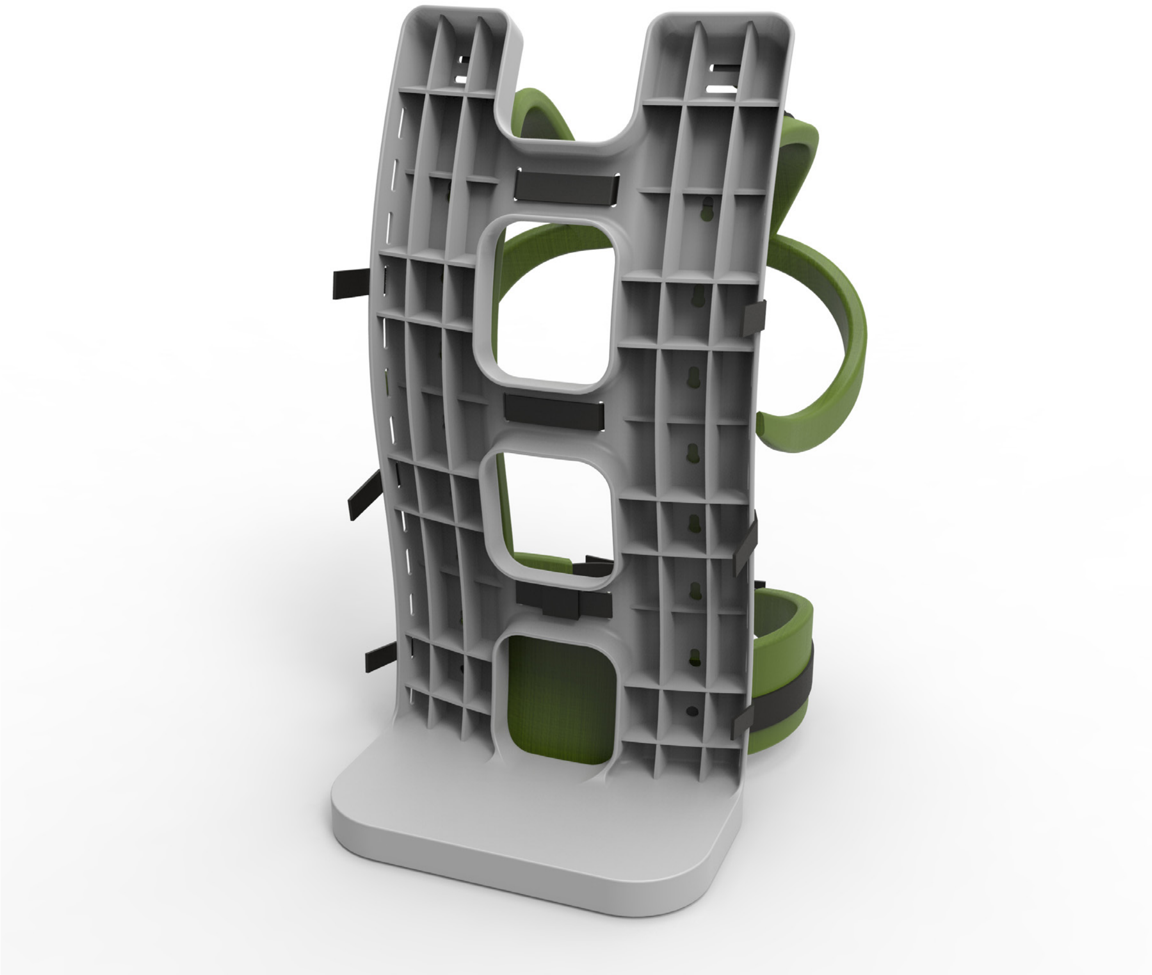

Fig. 5.16: Crossover frame with harness (note the load tray)

5.5- Initial Design Guidelines Evaluation

The Crossover hybrid external frame backpack concept is intended to be a injection-molded frame for carrying loads up to 50lbs, which is well within the 25% BMI to pack-load ratio for the anticipated user identified in Section 5.2. The design forms helped identify the component parts needed for a backpack in this line of application, yet the question remains: does the Crossover concept backpack meet the needs of the body as laid out in the Human Body Guidelines for Backpack Design? To answer this, a brief analysis to determine how the Crossover backpack addressed the guidelines will be conducted.

Design for the Local Requirements and Consider Global Effects when Dealing with the Body

The Crossover was designed to meet the needs of the user's torso, shoulders, and waist. Specific examples include having a twenty to twenty-five degree slope in the shoulder straps to accommodate the male upper extremity and body, and the individual length of the torso based on the user's pack size. The pack aimed to keep the load as close to the body as possible and utilized a load tray on the bottom of the frame to keep the loaded backpack compartment from sagging.

Identify the Task(s) or Purpose(s) Being Designed for

The Crossover was designed to address a minimum of multi-tasking. Since the anticipated roles were similar in potential load-capacity and impact, the frame and compartment would enable to user to conduct these activities with little to no adjustment needed. Utilizing this backpack for roles outside of light camping, hiking, or potential heavy school books is not within the design parameters due to shifts in load and effects on the body as a whole.

Design Versions for Men and for Women, not Unisex

This particular version of the Crossover was designed specifically for the male body. Changes in shoulder strap angles and the S-curve of the frame, and resizing of the padding components may be needed for a female body-friendly version.

Design for "Multiple Sizes Fit Most," not "One Size Fits All"

The Crossover in this configuration is built to address the needs of ‘Large’ sized users. Some minor adjustments in the strap placements are possible because of the keyhole anchor points on the frame.

Anticipate Dynamic Movement While Eliminating Excess Pressure, Shear Force, and Exposure to Moisture

The Crossover’s X-harness anticipates upper extremity movement by trying to mimic the clavicle and sternoclavicular joints. This will potentially permit the upper strap (crossing the shoulder) to pivot with the clavicle with upper arm movement. Further, this design feature keeps the shoulder straps medially closer to the neck, decreasing the backpack load’s compressive effect on the clavicle and upper extremity. Potentially, this may help reduce the likelihood of backpack palsy and other common upper extremity conditions. Also, the open air design of the central back channel and extended shoulder strap padding for the torso should help improve the wicking and air-flow of the backpack compared to traditional internal or external frame designs.

Recognize and Reduce Postural Adaptations While Promoting Movement

By designing the harness (body interface components) to allow the body to move while keeping the load and elements of the backpack as stationary as possible, the body’s natural ranges of motions may be less impeded. Further, by keeping the load closer to the body and utilizing a load tray in the frame, the center of gravity of the combined user and backpack will be less likely to move. More importantly, by supporting the S-curve of the spine and keeping the load of the backpack anchored to the pelvic bones, the degree of negative postural adaptations may be reduced.

If the Intended Use Load Exceeds 30lbs, Consider an External Frame; Over 40lbs, External Frames Required

The Crossover is specifically designed with a 50lb maximum load use in mind. Therefore, an external frame is standard and obligatory.

Keep Weight Close to/on the Pelvis and Center of Gravity of the Individual

The Crossover's use of a hip belt keeps the load of the backpack off the shoulders and the spine. This element would make use of a plastic reinforcement panel to ensure the maximum of pressure reduction for the shoulders is achieved. Further, the design of the backpack aims to keep the load as close to the body as possible, reducing the degree of center of gravity swings and subsequent postural adaptations.

Try not to Exceed 25% of the User's Body Weight when Anticipating Dynamic Movement in Adults

The maximum 50lb load-limit is well within the safety range identified in Section 5.2 with the design forms.

Protect Anatomical Structures from Undue Strain and Stress

The ample padding of the waist belt, shoulder straps, and lumbar pad provide a protective barrier between the human body and the hardware/hard points of the backpack's frame. Further, by utilizing a waist belt and load-lifter straps in addition to supporting the natural curve of the spine, the degree of strain and impact the backpack will have on the human body should be significantly lower than with standard external frame backpacks.

5.6- Potential Refinements

Given the conceptual nature of this demonstration, the backpack design is still very early in the actual design process. As such, there are a number of items for improving the backpack concept:

- Confirm measurements of the frame curve to ensure the most positive body to backpack interface.
- Consider increasing the width of the shoulder/back straps that come into contact with the user's back. If the straps are a breathable wicking material, this would increase the surface area of the straps on the body, decreasing any potential pressure spots.
- More in-depth exploration of the final backpack compartment design, to develop a more refined aesthetic for the overall design. This applies to the shoulder straps, the waist belt, and refinement of the frame to bring the various elements together.
- Streamline the frame design to ensure injection-molding compatibility. Test whether the frame extensions are long enough for the recommended 45 degree angle needed between load-lifer straps and the shoulder straps.
- Potentially increase key-slot column for the shoulder/torso straps from one to two per side (testing needed to ensure the strength of one column versus two).

- Test/identify the ideal placement of the straps and padding to ensure user comfort without sacrificing or compromising the structural/interface elements.
- Consider telescoping elements on the frame to better fit the backpack to the human body (providing a wider range of micro-adjustment for the user).
- Consider rigid framing elements for the backpack compartment itself to limit the load-storage/types.
- Limit the degree of adjustability so that the backpack and its features/options remain within the scope of the guidelines (i.e. reduce the number of slide slot options for the X-harness attachment points).

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6. CONCLUSION

6.1- Summary of Project

This thesis project began by identifying a problem inherent to the discipline of Industrial Design, which is designers have very little working knowledge or background dealing with the physical human body of the end-user. To try and tackle a comprehensive gathering and distilling of the human body for designers is a monumental challenge. As such, a specific case study of improving the interface between the human body and backpack-type load-carrying systems was selected due to the role and degree of backpacks in everyday life.

Within Chapter Two, the bulk of this study focused on identifying critical concepts and information needed to create backpack design guidelines. The research in particular identified basic information needed to describe the human body common to a number of disciplines related to the human body. Specifically, the disciplines of anatomy/physiology, anthropometry, biomechanics, and ergonomics were identified as the most useful fields of study to draw from. This stems primarily from the practical application "what needs to be known and how does one use it" mentality and need of the industrial design discipline at large. This study also identified the important areas of interest in the human body that directly relate to the backpack interface with the body. Lastly, examples of how those areas of interest in the body are accommodated by current backpacks were identified. This laid the groundwork for the two end-resources produced by this study. First, a practical guidelines package to be used when designing backpacks with a positive interface with the body. Second, the anatomical, ergonomic, and biomechanical reference material packaged for use by the designer to support the guidelines.

Chapter Three outlines the methods of organizing the material researched in Chapter Two into the deliverable components of human body reference guide and backpack interface design guidelines. This chapter in particular was influenced by the formatting and writing styles of the 4th Edition AMA *Guides* (1993), so that the design resource package could 1) identify critical concepts to address when designing backpacks, 2) the significance of that concept in practice, 3) identify examples of that guideline in current use, and 4) package additional information in a plug-and-play manner so the designer can quickly and efficiently formulate a backpack's composition according to application of use and the end-user's body type.

Chapter Four details the design guidelines created by this study as well as the support information needed to create a well-rounded resource package for the Industrial Designer. The generalized and specialized design guidelines created by this study were addressed through the lens of backpack design. Reduced to a singular point, these guidelines identify there cannot be a one-size-fits-all solution for backpack design, due to the numerous variables that need to be addressed based on the user's physical gender and build, the biomechanical effects of externally loading the human body, and the end use application of the backpack itself. To communicate and address these variables, quick-reference sheets detailing the anatomical and biomechanical areas of interest within the body and the differences between the male and female human body were developed to aid the designer and justify the design guidelines. To further aid the designer, a collection of charts were developed to quickly help formulate backpack design requirements based on the body-type of the end-user and application, streamlining the workflow to determine the features needed for specific backpack design projects.

Finally, Chapter Five demonstrates the use of the design guidelines and resource materials with a conceptual backpack design. This design concept is represented with illustrations and a preliminary Solidworks CAD mode to demonstrate the design guidelines in practice.

6.2- Implications and Applications of Study

The design guidelines and reference material package was created for use by industrial designers developing backpack and backpack-type load-carrying systems. In particular, the resources were developed for designers that have little to no background or familiarity with the human body. By focusing on information from four disciplines pertaining to the human body, collecting design-critical information and concepts, and packaging/translating it for use by the designer, this particular information and knowledge gap can be bridged insofar that backpacks are concerned. Further, by packaging this information together for the designer, a series of design guidelines were produced to provide the means of application for that information within the design process.

It is the author's intent that this study and the resources created from it will be the first step to reorienting the design process to address the physical needs of the end-user's human body in addition to the numerous other variables. To that end, it is anticipated by the author that this study will lay the framework for a new generation of backpacks with a more positive interface with the human body. It is also anticipated this study will lead to the development of new resources of human body information for the design process, so designers can better address human body needs throughout various product categories and applications.

6.3- Recommendations for Future Study

Areas for further research are indicated based on the scope and duration of the present study. Further research indicated based on the resources produced by this study includes but is not limited to:

- Independent review of human body information package. If needed, refinements for this resource are indicated based on peer review.
- Independent review of human body design guidelines for backpacks. If needed, refinements for this resource are indicated based on peer review.
- Potential prototyping and testing of the conceptual backpack design produced for this study.
- Testing and evaluation of the design guidelines in existing backpack designs.
- Testing and evaluating backpack designs created using these guidelines compared to those designed without.
- Anthropometric research to identify common angles of the human body's surface as would relate to harness or backpack interfaces (including the visible slope of the shoulder in men compared to women based on musculature, the common hip to waist angles for backpack waist belts, etc).

Further research indicated based on the limits of this study includes but is not limited to:

- Researching and developing specific backpack application material and guidelines for children, teenagers, ADA-compliance, and geriatrics.

- Researching the degree of adjustability that is permissible to keep a backpack within the scope of the guidelines based on user-type and use application.
- Developing a sub-set of human body guidelines addressing issues of comfort rather than direct human body needs or considerations (placement of straps, types of material, etc.).
- The impact of obesity will have on these design guidelines and reference materials for each user age-grouping.
- The impact of different diseases and conditions typical to each age-group on the body as would relate to backpack design.

Further research indicated based on the initial problems of human body knowledge and information gaps for designers includes but is not limited to:

- Researching and creating human body information and design guidelines packages for various product applications (such as power drills, seats and chairs, vacuum cleaners, assistive technology, wearable technology, personal protective gear systems, etc.).
- More in-depth analysis of the human body information disciplines to create definitive semantic resource collections to be used within the product design process.

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APPENDIX A

ADA423072- Cover Sheet

The cover page is a purely documentation-based inclusion: it records the data of the test and its particulars as well as any security or archival information which is pertinent to the specific tests in question.

ADA423072- Facilities and Instrumentation

The Facilities and Instrumentation section references to portions of the appendix; covering the facilities in which the soft good will be tested, it covers the course layout to which the evaluators will subject the wearable article and the types of obstacles the course will include. Titled as Accelerated Wear Test Courses, the purpose of this section outlines the types of courses and obstacle tests in which the evaluations will:

> Compress anticipated service life/time of an item or a material into shorter testing periods. Testing is characterized by judicious repetition of use under conditions approximating or stressing beyond normal conditions. Several characteristics are evaluated simultaneously (e.g., abrasion resistance, snag resistance, wear pattern, and water repellence). Comparative performance and correlation with expected field use are possible through study of wear effects (p. C-1).

This concept of accelerated wear testing is familiar to those of a product design background— it is a proven method of evaluation to ensure the end product is structurally sound and durable enough to meet the end-user's needs, and meets the other criteria specific to the end product. The specific facilities in which most of these tests are conducted are Standard Mobility/Transportability Courses, a standardized series of physical obstacles located on the majority of military installations and training centers which may bring to mind images of the stereotypical boot camp course with cargo nets, barbed wire belly crawl slots, and ladders over a long, muddy body of water. "A typical test course design consists of seven events selected to adequately evaluate the clothing being tested. The course is designed so that the end point of one event is the starting point of the next" (p. C-1). The benefit of these standardized facilities is that product/equipment evaluations can take place wherever these facilities exist.

The purpose ADA423072 (Army Test and Evaluation Command, 2004) states for exposing the tested product to these conditions is to "provide a field performance course to measure the durability of the garment, the effect of personal clothing and equipment, and military personnel's ability to maneuver, i.e., run, jump, crawl or climb as might be required under realistic operational scenarios" (p. C-1). During the testing "garment wear times, traversed times along with instances of difficulties should be documented" (p. C-1). The section also states that should specific testing evaluation be required, that specially selected obstacles may be chosen to ensure those results are obtained (p. C-1).

ADA423072- Required Test Conditions

The Required Test Conditions section of ADA423072 walks the reader through all the steps leading up to the actual testing. This is methodology critical to both the manufacturer and the designer: these steps set forth a standardized and scientifically orientated evaluation scenario; the documentation of which enables follow-up testing to establish the results are consistent should the need arise.

The first component specifies the required documentation for the testing to occur such as:

> Test and Evaluation Master Plan (TEMP), System Evaluation Plan (SEP), Event Design Plan (EDP), Operational Requirements Document (ORD), and specifications as available and appropriate, and background information such as references from preceding development and test phases and similar studies which required selection of appropriate samples, methods, test sequences, facilities, and test equipment (p. 2).

Further, it goes into fine details such as safety procedures, proper briefing of the test participants to ensure their safety and training for the specific testing procedures, and documentation of variables such as the test participants anthropometric data, their medical history, the issue of Test Item Control Numbers (TICNs) to record the status and data of the tester and the items assigned to him/her from beginning to end in Test Incident Reports (TIRs), and the physical examination and measurements of the tested items to the nearest 1/8th of an inch (p. 2-5).

Once this baseline data and procedures are established, the actual testing of the garments/ soft-goods may begin.

ADA423072- Test Procedures

The bulk of the ADA423072 document consists of the test procedures related to the testing of combat uniforms and protective clothing. Again, the methodology for testing and result recording is approached in a scientific manner. Safety is the first concern to be mentioned.

Next comes the sizing and re-measuring of the clothing or soft goods for the individual test participant. Once again this brings forth the emphasis on anthropometry: “Combat and protective clothing components have labels attached, which indicate fitting of garment sizes by range of body measurements (anthropometrics)” (p. 5). This ensures the most appropriate fitting for the tester is obtained for testing: having a larger or smaller garment or soft good on a particular test participant can and may skew the results of the evaluation. After proper fitting, donning (the act of putting on) and doffing (the act of removing) the soft good are evaluated. ADA423072states:

> The objective is to evaluate the ease with which the test item can be donned and doffed and to determine the time required to don and doff the system. Doffing shall be analyzed in terms of emergency doffing as well as doffing for body

> eliminations. Closures shall be analyzed with respect to the ease of opening and closing with bare hands and while wearing appropriate handwear, and during daytime and darkness. The potential of the closures to degrade the protective characteristics of the ensemble should be considered. Multiple series of donning and doffing tests may be necessary to address multiple configurations. When testing multi-layer items characterize each step of the donning and doffing process (p. 6).

This component of the evaluation may provide critical data to both designer and evaluator: both accelerated wear testing and the donning/doffing testing can determine what specific types of construction and combinations of fastener are most appropriate for a particular design, whether or not the design and assembled components is sound, and if the design contains any form of hindrance which may prove impairing or dangerous in an emergency situation.

Further testing procedures cover particulars such as leakage, water proofing, electro-static discharge/decay, launderability, storage of the item, water immersion, as well as transportation and handling (p. 7-13). These may or may not seem of particular importance, but this combination of testing helps cover a consistent range of variables that may not spring to the mind of the designer/manufacturers immediately. By comparison, test procedures 4.11 through 4.14 do cover what may be considered to be the important tests: human factors engineering (HFE) for range of motion tests which “can be done in conjunction with the accelerated wear tests, field use, and other tests in which test participants use the items,” mission performance/suitability to test or find how appropriate the soft good may be for specific purposes, and durability testing (p. 13). Durability testing occurs in two forms. The document describes these two types of durability:

> One is to obtain controlled durability data in terms of traversals of stations in a wear course for quantitative comparisons. A common procedure has been to use a sample size of eight to twelve military personnel to characterize performance on structured durability wear courses. The second method is field durability testing in which test items are worn by military personnel in mission scenarios while the developmental test team tracks all wear hours and histories of each item. A sample size of one platoon (25 to 30 test participants) has been commonly used in this type of testing (p. 14).

It also states:

> Both types of tests can be used to compare candidates to each other and to standard items and should include the standard items tested side by side whenever possible. The relative durability courses can also address mobility over obstacles and timed traversals for quantitative performance comparisons. These tests are usually run to failure. The field durability testing is particularly important for items which are required to provide chemical or ballistic protection after wear.

> The field durability test is run for a set number of cumulative wear hours at which time the items are withdrawn and provided to DT laboratories for further testing. Formulating an appropriate database to track all durability data and wear histories is critical to support the follow on DT laboratory testing (p. 14).

Once again proper recording of all data is stressed, as is the degree to which the testing should progress and the manner in which the testing will occur (mentioned in the Appendixes and referenced in the Required Test Conditions section).

ADA423072- Appendix

The appendix component provides useful, relevant data to both designer and evaluator.

Appendix A includes charts displaying sizing data for both upper and lower torso, and over garment information for sizing of soft goods which are worn over an additional uniform or set of clothing (pp. A1 – A3).

Appendix B displays how a donning/doffing test's results are to be displayed. Of note is that the test includes considerations for the tester's use of bare hands and gloves for both hot-weather and cold-weather soft goods (p. B1).Including this helps ensure that the end-user wastes no more time and energy than is necessary to put on and take off the tested soft good.

Appendix C covers information related to the establishing of test courses and the relevant data for those courses. This enables consistent testing of a soft good across multiple locations, since the description and components of a course can be recorded and duplicated by follow-up evaluations (pp. C1 – C3).

The last component, Appendix D, covers any course and testing criteria required for hand wear. A sub-market of soft good, the human factors and human interaction of hand wear can be more specialized than other soft goods due to the fact that the hand is a complex part of human anatomy. Because of this, related hand wear may need to perform according to different criteria than other soft goods (pp. D1- D5).

* * *

APPENDIX B

ADA566201- Visual Inspection Testing.

The Visual Inspection Testing section outlines, as the name suggests, the protocol for visual inspection of a wearable soft body armor or personal protective gear item. For the designer, this holds significance since the quality control requirements for soft body armor demand stringent adherence to established construction guidelines.

The first section of the Visual Inspection Testing section covers inspection of the bartack— which the Glossary of Military Clothing Fabrication Terms (U.S. DOD, 1995) defines as “a compact group of stitches made on an automatic barracking machine or by hand. It consists of a number of parallel or superimposed stitches with cover stitches. It is used to reinforce points of strain” (p. 2). These are inspected to “ensure that each bartack is present, properly constructed and that no operation has been omitted” (U.S. DOD, 2012, p. 5). If any deficiencies or missing components are noted, they are documented and photographed for later reference.

Component and Assembly Inspection is the second step in the visual inspection. This step may be considered a general inspection of the garment, focusing on all components of the design, whether they are present, if there any misaligned seams, quality of the construction and whether there are any defects such as holes in the fabric

(U.S. DOD, 2012, p. 5).

Construction and Design inspection are the following sections: these cover evaluation criteria for the inspection of the whether the overall garment's construction practices meet established guidelines and whether the design of the end garment match the intended design (p. 6). Following these two sections include inspection criteria for the emergency release mechanisms, the functional integration and interaction of all parts in the garment's assembly, whether any physical hardware such as zippers or side-release buckles are intact and acceptable from a visual perspective, proper verbiage and typeface requirements of the garment's labels, weight of the garment, and overall quality of the seams and edges. This can be broken down into the stiches in regards to overall stitch count, stitch type, and stitch tension; and whether any raw edges are present, loose thread ends, or open seams are present in the garment to be tested (p. 6-12).

By understanding the visual inspection requirements for certain soft goods such as soft body armors or personal protective garments, the designer can include from the beginning of the project which seam types and related criteria need to be included to ensure the end product meets or exceeds existing testing procedure requirements.

ADA566201- Materials Inspection Testing

This next section arguably is not within the designer's scope; one could argue this is more within the realm of the manufacturer. However, the inspection requirements defined within this section provides insights into material demands the designer can work into or recommend be included in a designed soft good rather than hope the manufacturer selects the appropriate materials and the measurements of standardized features.

Listed within are steps to measure the weight of the ballistic filler weight to check it is within the set criteria for weight. Additionally, ballistic panel subcomponents are tested to ensure they fit easily and snuggly into the appropriate carrier compartments and whether they cover the minimal ballistic area coverage requirements. Further, steps are included to test the strength of the aforementioned bartacks; record the various dimensions such as the length of and distance between one bartack and another, distances between horizontal webbing strips, button hole lengths and positions, as well as the length and width of the overall garment (pp. 12-15).

Mechanical testing is the emphasis of article 4.3.10 and 4.3.11. Within, the steps for the testing of the drag strap— a standard feature on certain combat gear that allows a soldier to pull a wounded fellow via the strap attached to the back— and the Emergency Release Anchor Webbing components are described (pp. 16-17).

The last components of the Mechanical Inspection Testing covers inspection of the garments with reference to the pattern pieces that were used to make it. This helps ensure accuracy within the parts of the garment with regards to their size and the sizing of the end garment. This also includes inspection of the material used to make up the garment, its plycount, and the vertical alignment of bartack stitches (pp. 17-18).

ADA566201- Appendixes

Also included within the ADA566021 is a large section of appendixes: a treasure trove of information to the designer, the manufacturer, and testing evaluator. Within and described in detail are lists of locations for individual testing procedures, descriptions and photographs of the testing equipment necessary for the evaluation of soft body armor; example photographs and descriptions detailing failed work samples, documentation, and testing thereof. Lastly, included are charts relating to sizing data, a glossary of relevant terms, and references to any and all related testing procedures or standards (pp. A1-J2).

This wealth of knowledge provides visual insight into the testing procedures used to evaluate some soft good products, examples of passing and failing features, and a source of reference material for particular testing components.

* * *

APPENDIX C

Backpack Fitting Guide.

The following pages include the “Backpack Fitting Guide” (n.d.).

Some pages have been adjusted to fit this document.

A

Choosing and Fitting a Pack

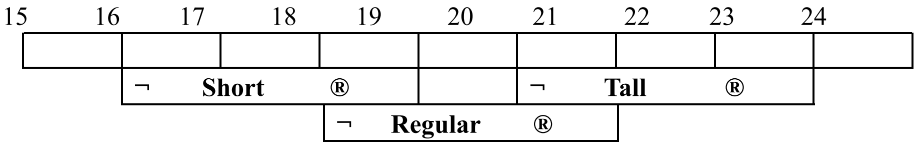
A) PACK FRAME SIZE

To measure back length ;

i) Locate the point on the spine that is at the same level as the crest of the hip bone. The crest is the point at which the hip bone can be felt at the side sticking out.

ii) Locate the 7th Cervical vartebrae. This is the first prominent vartebrae felt as a finger is run downward from the base of the skull.

iii) Stand relaxed, with hands at your sides, and have someone measure along the contours of the spine between the level of the hip crest and the 7th Cervical vartebrae. This measurement in inches corresponds to the following pack sizes;



This section does not apply to the packs that are available only in a single frame size

- **Sebring**
- **Miura**
- **Snoyo**
- **Yoyo**

Please note: The **Bora 30** and **Khamsin 38** are available in only 2 frame sizes ***(Regular*** and ***Tall).*** These have a single frame stay but do not have a structured hip belt and are therefore able to span a wider range of back lengths in a given frame size. These are not considered to be "fully suspended" packs.

All Other Packs

- **Bora 40**
- **Khamsin 50**
- **Bora 60**
- **Bora 65**
- **Bora 70**
- **Bora 80**
- **Bora 90**
- **Bora 95**
- **Nozone**
- **Borea**

These are available in 3 different frame sizes. We have used the designations ***Short, Regular*** and ***Tall*** for these 3 sizes. Each model has published volumes for each given frame size. Quite often, a customer will select a frame size based on its stated volume (“I need the extra 200 cubic inches a Tall will give me”). It is important to choose the correct frame size for a given back length. Correct, comfortable fit cannot be achieved with the incorrect size. DO NOT CHOOSE A FRAME SIZE BASED ON STATED VOLUME. We consider our pack volume measurements to be conservative. If possible, try to see an example of the model you are interested in stuffed to it's capacity.

In some cases, a measurement may fall between 2 sizes (in the 1" overlap area between the sizes). In this

case, a judgement must be made using a loaded pack with the frame stays adjusted. ***In almost all cases, it wil be better to go with the smaller of the two sizes and then size and adjust the shoulder straps and hip belt appropriately***. In the case of the **B40, K50, Nozone** and **Borea** where the shoulder straps are sewn directly to the main bag, careful sizing is necessary, as changing the straps is not an option. Choosing the larger of two sizes in question often results in the shoulder straps not making contact at the back of the shoulder, even with the frame stays properly adjusted (**see Fig. 4b**)
Check to ensure that the exit point of the shoulder straps is correct (**see Fig. 4a**) and that the load lifters are still angled downward to the shoulder straps to join the shoulder straps slightly to the front of the top of the shoulder (**Fig. 4a**). On larger packs, the position of the occipital cavity can be used as a **guide** to correct size. On some of the smaller volume packs (e.g. Bora 40), the load lifter straps will not form an angle with the shoulder straps. On these packs, the load lifter straps perform a stabilizing function rather than a load transfer and stabilizing function. Shoulder straps and hip belts are interchangeable. A pack is normally supplied with the sizes of components and frame matched (small with small, etc.), but any combination can be set up or ordered by a dealer.

B) HIP BELT

The hip belt size is based on a measurement around the hips at a position 2" below the point at which you would measure waist size (or approximately around the hip crest). The measurements correspond to the following sizes (in inches);

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
	¬		**S**		®		¬		**M**		®	¬		**L**		®	

· When the hipbelt is properly positioned (centered on the hip crest) and tightened, the ends of the pads should extend at least 3 inches past the hip crest. This is to ensure even weight distribution around the entire pelvic structure. It is not unusual to have a hipbelt fit so that there is very little extra webbing between each pad and the buckle. This is okay as long as the hipbelt is properly positioned and tensioned.
· Two special fit considerations should be noted;

1) If trying on a pack for winter use, you should try bulkier clothing with the hipbelt to ensure it still falls within the range of a proper fit.
2) If planning a long hike and you have not trained extensively for it, you may lose considerable weight during the hike, causing the hipbelt to become too large.

· If in doubt, try another size of hipbelt and take into consideration all of the information you can think of. It is possible that 2 hipbelts may be needed, one for winter expedition use and one for summer use (only in exceptional cases).

CAREFUL MEASUREMENT IS AT BEST ONLY A GUIDE TO DETERMINE A STARTING POINT FOR THE FIT PROCESS

-
-

C) SHOULDER STRAPS

With the correct frame size established, the correct shoulder straps may be chosen. It is extremely important that the frame stays be correctly shaped first (**see section on bending the frame stays**). If the frame does not properly match the contours of the back, some space may exist at the top of the back between the frame and the back, even with the shoulder straps properly tightened. This can have 2 effects on the fit. First, the perception may be that the shoulder straps are the correct size when, in fact, they are too long. Second, when tensioning the shoulder straps, the pack gets deformed toward the back and an increased amount of tension is required to make the pack feel snug against the back. This tension pulls the shoulders backward and pain will be the result after only a short distance.

When properly fitted and installed, the shoulder straps should contour smoothly from their point of contact with the upper back to the front under the armpit. They should also be in contact throughout the entire length of the shoulder strap padding.

DO NOT TRY TO EVALUATE THE FIT OF THE SHOULDER STRAPS BY MEASURING THE DISTANCE BETWEEN THE TOP OF THE SHOULDER AND THE POINT OF CONTACT BETWEEN THE SHOULDER STRAP WITH THE BACK. THIS MEASUREMENT CAN BE HIGHLY INDIVIDUAL.

- The adjustment buckle at the lower end of the shoulder strap should be positioned roughly even with a line drawn downward from the center of the armpit.

- If there is no further adjustment possible in the webbing strap attaching the lower part of the shoulder strap, a switch to a smaller size set of shoulder straps should be tried.

- Heavily muscled men sometimes require a set of shoulder straps one size up from the main bag size. Use your judgement. ***Do not go up a size in the frame for the sake of the shoulder strap size.***

As a final adjustment, the shoulder straps can be raised relative to the frame sheet approximately 2.5 inches, effectively lengthening the frame slightly (**See Fig. 3 for attachment**).

(APPLIES TO B60 to B95 ONLY)

i) Undo the Velcro tabs running from the bottom corners of the main back pad to behind the frame sheet (**1**)

ii) Undo the Velcro strip at the top of the lumbar pad and swing the lumbar pad downward. (**2**)

iii) Slide your hand palm upward underneath the moulded back pad and locate the bottom edge of the plastic sheet the shoulder straps are sewn to. (**A**)

iv) Separate the Velcro securing this sheet to the soft loop side Velcro of the frame sheet.(**A & C**)

v) With your other hand, move the shoulder straps upward or downward as desired, ensuring they are positioned evenly and allow the Velcro to re-attach itself. (**4**)

- The above procedure should be performed to achieve the correct, even contact of the shoulder straps along their entire length and should be considered especially if your back measurement fell into the overlap area between two sizes (smaller of the two sizes chosen).

The quality of this fit may be evaluated by slowly tensioning the load lifter straps and watching the effect on the shape of the shoulder strap curve (**see Fig. 4a**). The weight of the pack should slowly be lifted from the shoulder straps, effectively transferring it to the hip belt. If any kinking or other deformation of the shoulder strap exists behind the shoulder;

i) Check to make sure the shoulder straps themselves are properly tensioned. There should only be a minimum of tension in the shoulder straps when the load lifters are operated as ***the purpose of the load lifters is to slightly lift the shoulder straps from the shoulders, not to bring the pack in against the back.*** Load lifters will bring the pack a bit closer to the body and help snug it in to the back, but they should not be used to compensate for a poor frame stay fit. When tensioned, the load lifters will pull the shoulder straps smoothly away from the shoulders, transferring the load to the hip belt while maintaining stability of the upper part of the pack. When tensioning the load lifters, the shoulder straps themselves should be loosened very slightly.

ii) If the shoulder straps are properly tensioned, and deformation still exists, re-insert the shoulder straps slightly into the frame sheet. Several small adjustments may be necessary to achieve the final, correct fit. It is possible that at this stage a switch to a smaller frame size may be necessary.

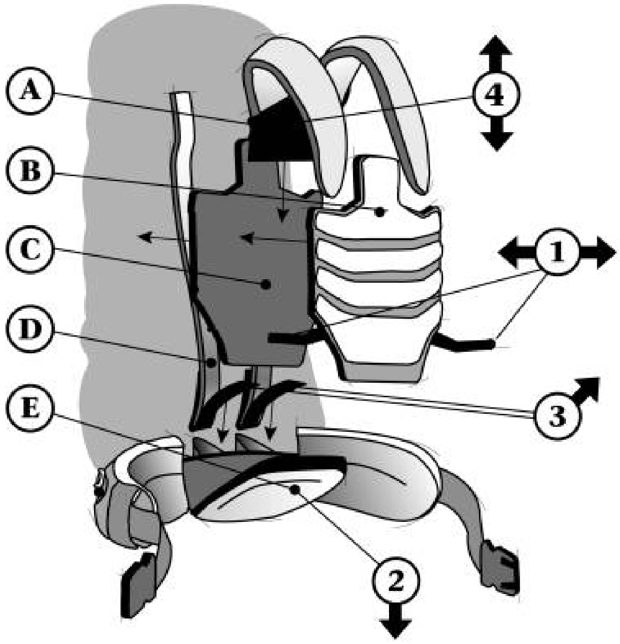


Figure 3- Component Attachment

A) Shoulder strap assembly
B) Moulded back pad (sewn in place)
C) Frame sheet (removable)
D) Aluminum frame stay
E) Lumbar pad

1) Velcro tabs to secure corners of back pad
2) Lumbar pad swings down
3) Pockets in back of hip belt for stays
4) Shoulder straps move up or down

ANY TENSION IN SHOULDER STRAPS OR LOAD LIFTER STRAPS ENDS UP BEING BALANCED BY MUSCULAR EFFORT SOMEWHERE IN THE SHOULDER AREA. MINIMUM TENSION IS REQUIRED FOR EACH STRAP TO DO ITS JOB IF THE PACK IS CORRECTLY ADJUSTED. EXCESS TENSION=PAIN

The ideal angle for the load lifter straps is 45 degrees. This angle minimizes the tension required in the strap to achieve the two functions of these straps (load transfer and stabilization). In practice however, an angle of 30 to 60 degrees is quite acceptable.

Bending the Frame Stays

THIS IS THE SINGLE MOST IMPORTANT ADJUSTMENT TO ACHIEVE A COMFORTABLE FIT. FINE TUNING OF THE OTHER ADJUSTMENTS IS FUTILE UNTIL THIS STEP IS PERFORMED CORRECTLY.

A rudimentary curve is given to the stays at the factory. In practice, this curve does not fit many people well. The reason for this is that the curve of the frame stays must conform exactly to the person's back to achieve a good fit and every back is slightly different.

ACCESS TO FRAME STAYS

Miura, B30, B40, K38, K50, Snoyo, Borea, Nozone - Access is via a flap inside the main bag on

the frame side. Separate the Velcro securing the flap to expose a piece of webbing covering the stay. Withdraw the stay from its sleeve. When replacing the stay, ensure that the protective webbing is in place over the end of the stay.

Bora 60 , 65, 70, 80, 90, 95 - (refer to **Fig. 3 - component attachment** for steps 1, 2)

1) Access the frame stays by flipping the lumbar pad downward and sliding the hipbelt downward off the ends of the frame stays. The B90 and 95 have a protective piece of webbing covering the lower ends of the stays. Release the Velcro securing this webbing to the frame sheet to expose the stays.

2) Slide the frame stays from the pack. Keep their orientation correct by placing them alongside the pack.

BENDING THE FRAME STAYS

Refer to **Fig. 6** for steps 3 - 6

3) Stand relaxed, with hands at your sides and bent forward slightly at the waist in the same manner as when measuring.

4) Have a helper place the stay against the your back in the same position it would be within the pack when worn. For single stay packs, you must position the stay across the shoulder blade area to determine proper curve. This is because the backpad straddles the shoulder blades and the frame stay gives the backpad its shape. Note that on packs with 2 stays, the stays are splayed outward at the top across the area of the shoulder blade. Try placing the frame stay in the pocket on the hipbelt and wearing the hipbelt. This will help establish more precisely the positioning to be used for bending. (remove hipbelt before bending). When doing this, make sure the hipbelt is settled on the hips properly before having your helper mark the stay position against your back.

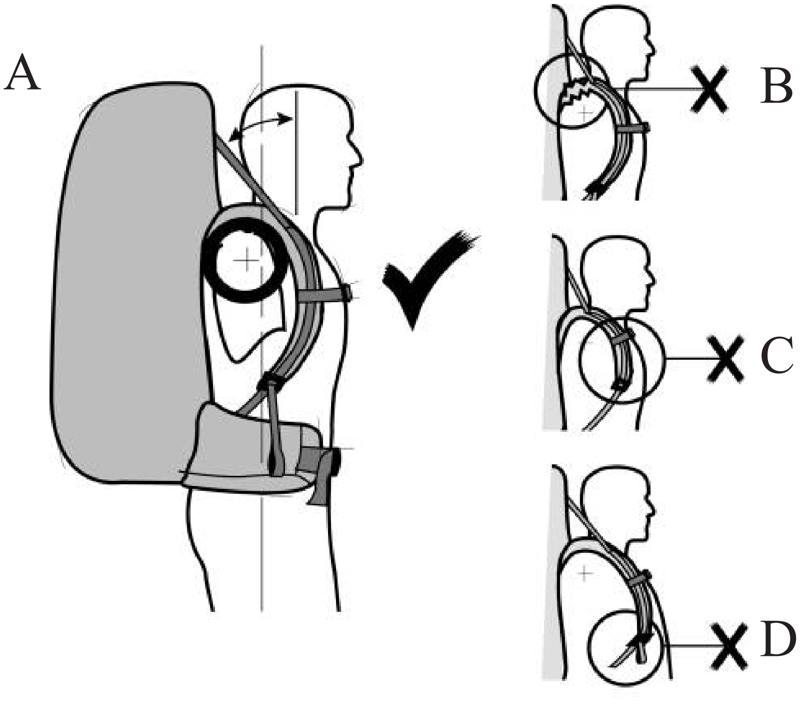
5) Beginning at the bottom of the frame stay, have your helper bend it a bit at a time to match the contours of the your back. The upper portion of a leg makes a good anvil for bending. If using a form to aid bending, avoid placing your hands too far apart when bending. While making for easier bending, this will create very sharp bends rather than a smooth curve. Note that there is one sharp bend at the top of the stays on some larger packs. This is for occipital cavity clearance and may be emphasized slightly after the stay has been bent to the back shape. In some cases, the stay will take on a very dramatic "S" shape. This is normal and you have probably done the job correctly.

6) Bend the second stay (if applicable) to the same shape as the first. Placing both on a flat surface will help you see how your work is progressing.

7) Re-insert the frame stays into the pack. On packs with an occipital cavity, some difficulty may be experienced about 3" from the top of the stay pocket. ***Do not force it!*** Make sure that the pocket is flat, loosen the load lifter and gently wiggle the stay into position. Reposition the hipbelt and fasten all Velcro.

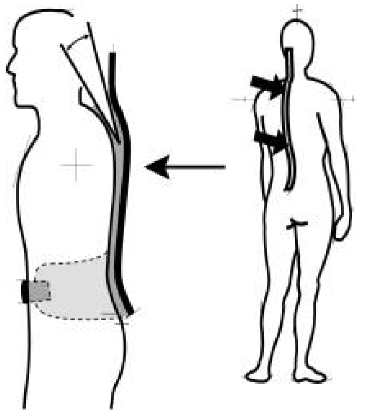
HINT: When the desired curve is achieved in the lumbar area, try rocking the frame stay in the lumbar area of the person's back. Excessive curve of the frame stay will result in the creation of a fulcrum in this area, and when the shoulder straps are relaxed, the pack will tend to swing away from the upper back (undesirable). If the frame stay can be rocked (watch the upper end), back off on the curvature a bit at a time until the stay remains relatively stable.

FIG.4 - Correct Shoulder Strap Fit

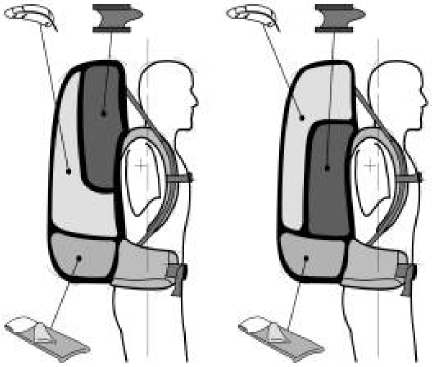


A) Correct - smooth fit of shoulder strap (constant contact)
B) Incorrect - Bunching or kinking behind shoulder caused by;
  1) shoulder straps too long
  2) frame size too large
  3) shoulder straps raised on frame sheet too far
C) Incorrect - Shoulder straps need to be raised slightly
D) Incorrect - Shoulder straps too small for person - try next size up

Fig. 6 - Contours and Placement of Frame Stays



Correct Loading of a Pack



a) preferable for moderate terrain **b) more stable for uneven terrain**

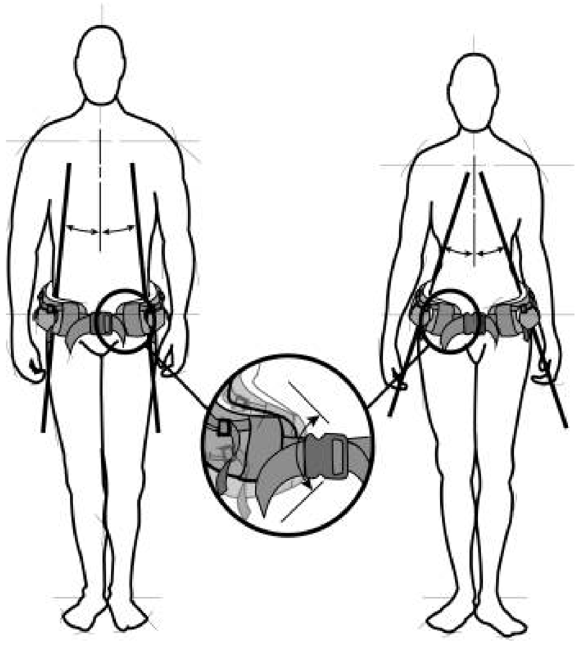
· Items with the greatest density should be placed as close to the frame of the pack as possible and above the lower compartment.

· Items of lower density such as sleeping bags and spare clothing should be used to pad out the load and prevent shifting.

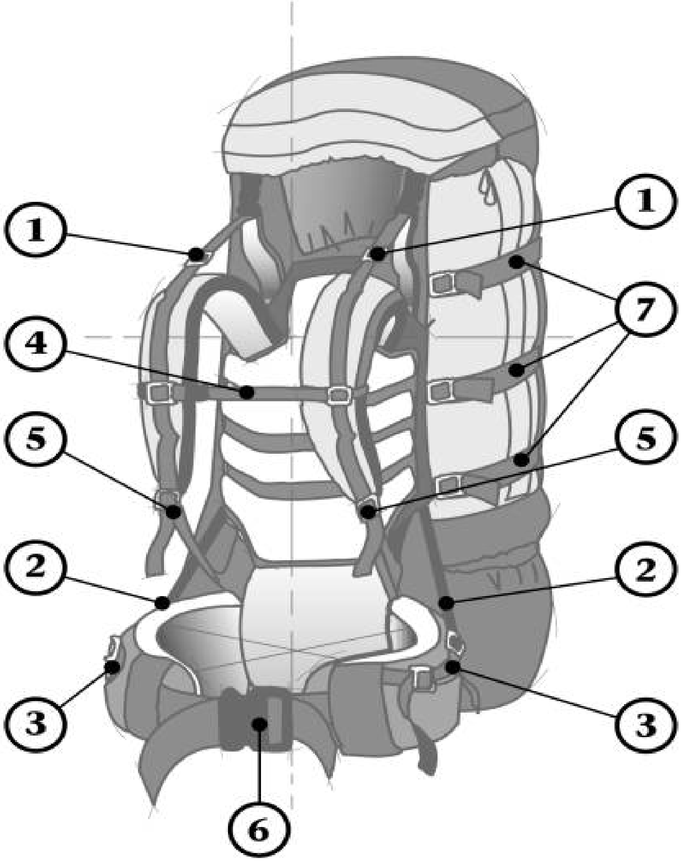
Women’s Packs vs. Men’s Packs

There is no difference in the main bag or it’s frame measurement between the womens and mens packs. The only thing that makes a pack a woman’s model is the components (hip belt and shoulder straps) fitted to it. There is also no difference in size measurement between a mens and womens hip belt. The difference is shown in **Fig. 5.** Most women require slightly more flare (angle at which the belt sits on the hips) , and, generally there is slightly less distance between the lower ribs and hips in women. Therefore, the womens hipbelt is slightly narrower than the mens to prevent pressure in the area of the lower ribs in shorter-waisted women and is thermoformed to have a greater angle over the hips. However, it is not true that **all** women require womens hip belts and shoulder straps. Final choice should be determined by fit and comfort. On all structured hipbelts (**B40 through B95**), fine tuning of the angle of flare is possible by adjusting the angle at which the 2” webbing exits the front of the padding (see **Fig. 5**). Tilting the webbing upward tensions the top of the hipbelt more, causing a flaring of the bottom of the belt. Conversely, tilting the webbing downward slightly will cause the hipbelt to take on a more straight appearance and could alleviate problems with pressure along the top of the belt.

FIG. 5 - Hipbelt Differences and Angle Adjustment



The Parts of a Pack



1) load lifter straps
2) load distribution adjusters (gray strap-applies to B90, B95 only)
3) load stabilizers
4) sternum strap
5) shoulder strap adjusters
6) hipbelt buckle
7) compression straps

APPENDIX D

Examples of Writing and Formatting, *AMA Guides,* 4th Edition

The following pages are included as reference for the writing style and general layout/format of information within the 4th Edition American Medical Association *Guides to the Evaluation of Permanent Impairment* (1993).

The Musculoskeletal System

This chapter includes sections on the upper extremity, the lower extremity, the spine, and the pelvis. The sections describe and recommend methods and techniques of determining impairments due to amputation, restriction of motion or ankylosis, sensory or motor deficits, peripheral nerve disorders, and peripheral vascular diseases. Also included are tables with impairment estimates relating to specific disorders of the upper extremity, lower extremity, and spine. Each section describes appropriate methods and considers issues applicable to that section.

In general, the impairment percents shown in this chapter make allowance for the pain that may accompany the musculoskeletal system impairments. The chapter also considers pain related to peripheral nerve disorders. Chronic pain and the chronic pain syndrome are evaluated as described in the *Guides* chapter on pain (p. 303).

Description: The upper extremity, the lower extremity, the spine, and the pelvis are each to be considered a unit of the whole person. The upper extremity has four parts: hand, wrist, elbow, and shoulder. The normal hand has five digits: the thumb and the index, middle, ring, and little fingers (Figs. 1 through 3, pp. 16 through 18). The thumb has three joints: the interphalangeal (IP), metacarpophalangeal (MP), and carpometacarpal (CMC) joints. Each finger has three joints: the distal interphalangeal (DIP), proximal interphalangeal (PIP), and MP joints.

The lower extremity has six sections: the foot, the hindfoot, the ankle, the leg, the knee, and the hip. The foot has five digits: the great toe and the second, third, fourth, and fifth toes. The great toe has two joints: the interphalangeal (IP) and the metatarsophalangeal (MTP) joints. The second, third, fourth, and fifth toes all have three joints: the DIP, PIP, and MTP joints.

Normally the spine has 24 vertebrae. The cervical region has seven vertebrae, C 1 through C 7; the thoracic region has 12 vertebrae, T 1 through T 12; and the lumbar region has five vertebrae, L 1 through L 5.

The pelvis is composed of the pubis, ischium, and ilium, which form its side and front, and the sacrum and coccyx, which form its posterior portion.

Examinations for determining musculoskeletal system impairments are based on traditional approaches for recording the medical history and performing the physical examination. The impairment examination and report should not be separated from the generally accepted principles of medical practice or the consensus of medical knowledge and experience.

The measurement techniques recommended in this chapter are current and are as simple, practical, and scientifically sound as possible. The tests should be done accurately and precisely. For evaluating ranges of motion of the upper and lower extremities, small and large goniometers are needed. For evaluating the spine, either two mechanical inclinometers

3.1 The Hand and Upper Extremity

3.1a Evaluation

Methods for evaluating impairments of the upper extremity may be described as having anatomic, cosmetic, or functional bases. The *physical evaluation* is based on a detailed examination of the patient and the upper extremity and is necessary to determine anatomic aspects of the impairment. The *cosmetic evaluation* concerns the patient's and society's reaction to the impairment or the results of surgical treatment. The *functional evaluation* is a measure of the individual's ability to carry out an expected function or task within a set time frame. Evaluation of anatomic impairment is considered to be the most reproducible and reliable system and is the approach recommended in this section. Using a combination of these approaches would be ideal.

A system for evaluating impairment of the hand and upper extremity due to amputation, sensory loss, abnormal motion, and ankylosis was developed and approved by the International Federation of Societies for Surgery of the Hand in association with the American Society for Surgery of the Hand. That approach forms the basis of the tests and procedures recommended in the *Guides* for evaluating the hand and upper extremity.

The most practical and useful approach to evaluating impairment of a digit is to compare it with the loss of function resulting from amputation. Total loss of motion and sensation of a digit, or ankylosis with severe malposition that renders the digit essentially useless, is considered to be about the same as amputation of the part. Ankylosis of the digit or joint in the optimal functional position is given the least impairment. Impairment due to total sensory loss only is considered to be 50% of that due to amputation.

In evaluation of restriction of motion of the hand and upper extremity, the full range possible of *active* motion should be carried out by the subject and measured by the examiner. Several repetitions may be performed to obtain reliable results. The examiner may check the range of *passive* motion by applying moderate pressure to the joint. However, in the *Guides*, the range of *active* motion takes precedence. If a joint cannot be moved actively by the subject or passively by the examiner, the position of ankylosis should be recorded.

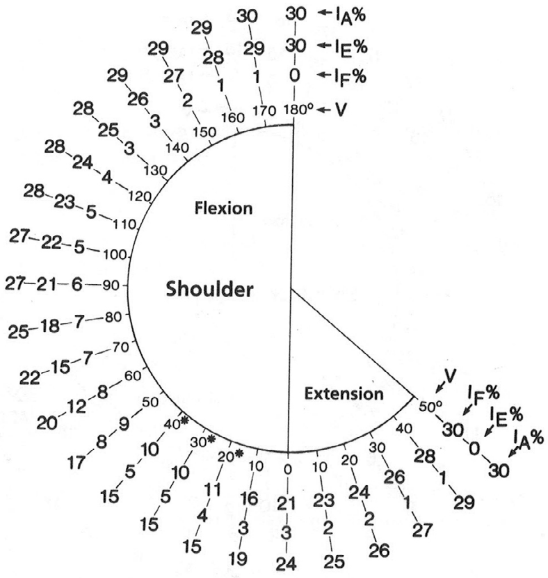
In general, range of motion measurements are rounded to the nearest 10°. The measurements are converted to impairment estimates by referring to the appropriate tables.

For accurate impairment evaluation, a complete and detailed examination of the upper extremity is necessary. This is facilitated by the use of a printed chart or figure that lists the various tests and measurements in an orderly fashion, such as the Upper Extremity Impairment Evaluation Record, Fig. 1 (pp. 16 and 17).

Part 1 of Fig. 1 (p. 16) has been designed to assist evaluation of hand impairment due to abnormal motion, amputation, sensory loss, and other disorders. Part 2 (p. 17) has been designed to assist evaluation of wrist, elbow, and shoulder impairment due to abnormal motion, amputation, and other disorders, and upper extremity impairments related to the peripheral nerve system, the peripheral vascular system, and other disorders that are not included in regional impairments. As Fig. 1 indicates, the hand, wrist, elbow, and shoulder impairments are *combined* using the Combined Values Chart (p. 322) to determine the total upper extremity impairment. The latter is converted to a whole-person impairment using Table 3 (p. 20).

The hand and upper extremity section considers evaluation of the thumb, finger, wrist, elbow, and shoulder regions. Each part considers techniques of measurement and includes values for impairments due to amputation, sensory loss, and abnormal motion. In addition, impairments of the upper extremity due to peripheral nerve, brachial plexus and spinal nerve lesions, vascular problems, loss of strength, and other conditions receive consideration in this section. Also, combining two or more impairments and relating them to the individual as a whole ("the whole person") is illustrated.

Figure 38. Upper Extremity Impairments Due to Lack of Flexion and Extension of Shoulder. Relative value of this functional unit to upper extremity impairment is 30%.†



$I_A\%$ = Impairment due to ankylosis
$I_E\%$ = Impairment due to loss of extension
$I_F\%$ = Impairment due to loss of flexion
V = Measured angles of motion
* = Positions of function

†Data from Swanson, AB, Goran-Hagert, C, de Groot Swanson, G[31], p. 66, Fig. 4-28.

Abduction and Adduction of Shoulder

1. Measure the maximum abduction and adduction and record the goniometer readings (Fig. 39, at right). Round the figures to the nearest 10°. The normal range of motion is considered to be from 180° abduction to 50° adduction. The position of function is from 50° abduction to 20° abduction.

2. Using Fig. 41 (p. 44), match the measured abduction and adduction angles (V) to their corresponding impairments of abduction (row headed $I_{ABD}\%$) and adduction (row headed $I_{ADD}\%$).

3. *Add* the impairments for loss of abduction and adduction to obtain the upper extremity impairment.

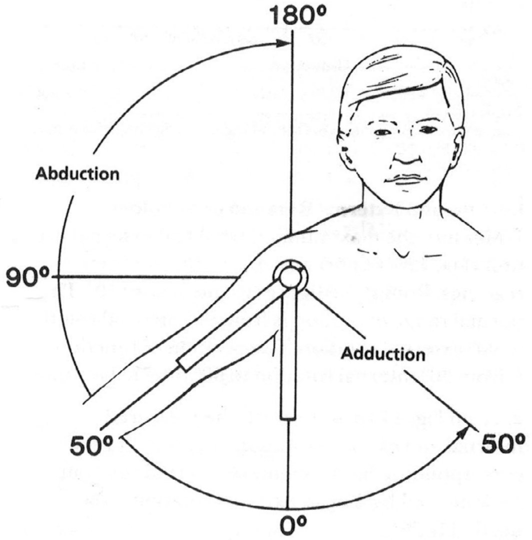
4. If the shoulder is ankylosed, measure the position and match the angle (V) to the corresponding ankylosis impairment (row headed $I_A\%$) in Fig. 41. Ankyloses in functional positions (50° abduction to 20° abduction) are given the lowest impairment percent, 9% impairment of the upper extremity.

Ankylosis in either 50° adduction or 180° abduction represents a 100% loss of abduction or adduction function, respectively. This is equivalent to a 30% loss of shoulder function or an 18% (30% x 60%) impairment of the upper extremity (Fig. 41).

Example: A patient has shoulder abduction to 100° and adduction to 0°:
$I_{ABD}\%$ = 4% impairment of the upper extremity (Fig. 41, p. 44);
$I_{ADD}\%$ = 2% impairment of the upper extremity;
4% + 2% = 6% impairment of the upper extremity.

Example: Shoulder ankylosis in 180° abduction is an 18% impairment of the upper extremity (Fig. 41).

Figure 39. Shoulder Abduction and Adduction.



FOOTNOTES

[1] For the reader hesitant to accept this particular anatomical position and its relative importance, some contextual consideration is necessary. Acupuncture and Eastern medicine are proven methods of treatment which are at times as old as recorded civilization: a graph of the chronology of acupuncture indicates that there are records of acupuncture in the Xia Dynasty— time stamping its practice between 2000 and 1500 B.C. (Helms, 1995, p. 16). Additionally, Helms is a definitive authority on the subject. A graduate of Johns Hopkins University and UCLA, he is a practicing physician who has taught over 5,000 physicians acupuncture through collaborative courses with the medical divisions of Stanford and the UCLA Schools of Medicine (Welcome to Acupuncture Professor). All considered, Eastern medicine and acupuncture are not gimmicks seeking attention in the spotlight as some preconceived notions may infer, but proven methods of treatment.

[2] An area for further research exists with the vertical load capabilities of this ligamentous structures and SI joints: how much movement is associated with static and dynamic vertical loading of the spine through the SI joint structure of the pelvis, ideally to determine specific ranges of tolerance. Considerations would need to be made for men, women, children, hormonal changes, and individual variability.

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