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# The development of a performance hand wear and tools product innovation framework

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## Abstract

Humans wear products and use tools that interface with their hands to provide abrasion resistance, impact protection, grip, thermal comfort, and detailed maneuvers. The skills needed to design new and innovative products for the hand are multi-faceted. Academic programs in the US typically focus on soft goods (textile and apparel) or hard goods (industrial and product design/engineering) based design. Therefore, students often do not learn all of the available skills and technologies needed to design hand wear performance products because of the pedagogical split between the different academic disciplines. This case study outlines a three-phase innovation framework, for use by designers throughout the product creation process, specifically for creating performance products and tools for the hand. The phases include strategies for: (1) understanding the hand wear and tool project background, (2) defining the user's 3D and 2D hand and (3) hand wear and tool product innovation. The paper will also demonstrate how the framework was implemented by students in a graduate level design studio, to create new gloves for athletes. The framework could also be used by students and professionals to design innovative products for other users and to improve safety and overall performance.

**Keywords:** Innovation framework, Hand wear, Gloves, Tools, Design

## Introduction

Humans wear products and use tools that interface with their hands to provide abrasion resistance, impact protection, grip, thermal comfort, and detailed maneuvers. Some product examples include mitts, gloves, wraps, braces, scalpels, mallets and saws. The skills needed to design innovative products for the hand are multi-faceted, including the knowledge of soft and hard goods design tools, state-of-the-art and artifact analysis, business and marketing, user perceptual needs, anatomy, physiology, biomechanics, anthropometry, manufacturing, materials science, fit/sizing, engineering and validation methods. However, since academic programs in the US typically focus on soft goods (textile and apparel) or hard goods (industrial and product design/engineering), design students often do not learn all of the available skills and technologies to design performance products for the hand (Sokolowski 2019). Because of the pedagogical split between different academic disciplines, there is an opportunity to build a framework of

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strategies to help designers improve their success in developing new, innovative technologies for products specifically for the hand.

This case study outlines a three-phase innovation framework, with strategies for designers to use when creating new performance products and tools for the hand. The paper also demonstrates how the framework was implemented by students in a graduate level design studio to create gloves for athletes. The framework could also be used by other students and professionals to design innovative products beyond athletes, specifically to improve safety and overall performance.

## Case description: performance hand wear and tools product innovation framework

The *Performance Hand Wear and Tools Innovation Framework* was developed to provide designers with opportunities during the product creation process, to ideate better products for users who need abrasion resistance, impact protection, optimal grip, thermal comfort, and accuracy in performing fine detailed maneuvers with their hands. The framework includes three phases with multiple strategies to use throughout the product creation process. It is important to note that the framework is not a design process. The framework is integrated within the design process, where the strategies allow creators multiple ways to ideate products for the hand. Literature in both the apparel and industrial/product design fields have explored and described design strategies for specific product genres or technologies, but none have specifically described strategies for hand wear and tools design. Some examples in the apparel field include Lee and Jirousek's (2015) pilot work on developing design ideas in the early apparel design process, Min et al. (2015) work on the phenomenon of *flow* and Parsons and Campbell's (2004) work placing new technologies in the design process. Examples in the industrial and product design fields include Childs and Tsai's paper (2010) on creativity methods for turbomachinery design and Hsiao and Chou's work on developing a creativity tool (2004).

It important to note that not all strategies must be completed in the *Performance Hand Wear and Tools Product Innovation Framework*. However, when a designer applies all or most of the strategies, robust innovation opportunities will result. As summarized in Table 1, the phases include: understanding the hand wear and tool project background, defining the user's 3D and 2D hand dimensions, and hand wear and tool product innovation.

### Phase one: strategies for understanding the performance hand wear and tool project background

The first phase of the framework includes strategies to understand the background of the hand wear or tool design project. The designer can conduct research about historical or existing products the user may interface with, and how those products are built, the components and technologies involved, materials used, and method of make. Market landscape and user-specific needs can be realized. In typical design processes, this work is conducted during problem identification (LaBat and Sokolowski 1999).

**Table 1 Performance hand wear and tools product innovation framework**

| Phase one<br>Strategies for understanding the hand wear and tool project background | Phase two<br>Strategies for defining the user's 3D and 2D hand | Phase three<br>Strategies for hand wear and tool product innovation |
|---|---|---|
| Historical and state-of-the-art product anatomy<br>Technology landscape<br>Market landscape<br>User needs | Hand anatomy<br>Hand physiology/biomechanics<br>User injuries<br>Hand landmarking<br>3D hand scanning<br>3D hand scan processing<br>Hand anthropometry<br>3D hand forms<br>2D hand croquis | Ideation drawing<br>Materials identification<br>Product prototyping<br>Product patterning and form<br>Product tech drawings<br>Fitting and modeling on the 3D hand<br>Product validation |

### *Historical and state-of-the-art product anatomy*

Understanding historical and state-of-the-art products for the hand are important to the designer, as it enables an understanding of the silhouettes, patterning, components, materials, and construction involved to help inform new design and innovation. This knowledge identifies how other manufacturers address hand coverage/interface, manufacturing techniques, and resources. This work can be conducted by many methods, including analyzing packaging, searching online, at retail, visiting museums and archives, and analyzing worn or purchased artifacts (including disassembly).

### *Technology landscape*

From the identified historical and state-of-the-art products, the designer can further investigate existing performance technologies to (1) understand how they are designed and integrated and (2) develop a point of view of where technology gaps occur that limit new innovation. This work can be conducted through analyzing packaging, worn or bought artifacts, and by searching online/retail.

### *Market landscape*

From the historical and state-of-the-art products, it is also important to understand how market competitors communicate user features and benefits, define line plans, and costs. This information can also identify technology gaps and help define line plans and methods of product communication to the user.

### *User needs*

Understanding directly from the user why they need new hand wear or tools, and their performance expectations assists in uncovering information that the physical product, technology or market landscape findings cannot communicate. Users provide a unique perspective because they intimately interface with a product. This work may be conducted through observing the user interfacing with existing products, collecting basic data (e.g., pressure patterns, flex and high wear zones), surveys, focus groups, analyzing used products and consumer returns.

The information gathered in Phase One helps to further identify the problems to be solved, along with technology and innovation gaps for future product innovation development.

#### Phase two: strategies for defining the user's 3D and 2D hand

With the development of more accessible 3D body scanning tools and scan file processing software, this phase of the framework provides designers with strategies to capture, process and define the user's 3D hand to understand relevant anthropometric measurements, hand shapes, forms for prototyping and 2D croquis to use as the basis for design. The phase also includes strategies for understanding hand anatomy, physiology and biomechanics related to the new product. In the traditional design process, this work is conducted during problem identification.

##### *Hand anatomy*

The human hand is one of the most complex parts of the body. As a part of the upper limb, it has an intricate assembly of bones, ligaments, joints, muscles, tendons, nerves, veins, skin and nails, to allow for a wide array of tasks (Sokolowski et al. 2018). The hand is comprised 27 bones, 123 ligaments, 29 joints and 34 muscles (Sokolowski et al. 2018; Wilhelmi et al. 2016). Anatomically, the 27 bones provide support and basic shape. They are segmented into three categories: carpals (wrist), metacarpals (palm) and phalanges (fingers) (LaBat and Ryan 2019; Sokolowski et al. 2018). The bones are connected by ligaments that make up the joints, which provide flexibility in-between the bones (Sokolowski et al. 2018). The hand's 34 muscles behave like elastic bands and are connected to the bones through tendons which in unison assist with mobility and grip strength (Sokolowski et al. 2018). The nerves stem from three major branches: median, ulnar and radial (LaBat and Ryan 2019; Sokolowski et al. 2018). Because the hand is the terminal portion of the upper limb, it has an elaborate vascular network (arteries and veins) where blood is transported in and out of the hand (Sokolowski et al. 2018). The skin and nails provide protection and is the surface from where anthropometric data can be collected (Sokolowski et al. 2018).

For users who rely on hand wear and hand tools for performance purposes, there are often conflicting design challenges, like thermal protection and flexibility or dexterity and impact protection. By understanding the underlying structure that the product must interface with, it allows for accurate mapping of design features, so attributes are designed as efficiently as possible. This information can come from studying anatomical literature, x-rays and working with medical clinicians and physical/occupational therapists. In some cases when the user has a disability or a condition affecting their anatomy (e.g., amputation), it may be pertinent to work with the user, medical specialist or caregiver to understand anatomical differences and needs.

##### *Hand physiology/biomechanics*

For users who rely on performance hand wear and tools, it is also important for the designer to know how the human hand functions physiologically and biomechanically. As an example, the back of the hand physiologically has an important venous exchange that helps the body thermoregulate through vasodilation or vasoconstriction.

Vasodilation is where blood vessels widen to assist with cooling, where with vasoconstriction the vessels constrict to maintain heat (Watkins and Dunne 2015). In some cases, there are physiological conditions like Raynaud's disease or neuropathy where the hand has a difficult time thermoregulating in cold environments, so it is important to understand how users may need to be accommodated with materials selection and pattern coverage.

Biomechanically, the hand can grasp, pull, abduct, adduct, touch, push and catch (Sokolowski et al. 2018). When a product is worn on or interfaces with the hand, it is likely that movements will be impaired, even if just slightly due to material thickness and product shape/patterning. Some examples of how biomechanical data can be collected are with high speed videography, motion capture and grip strength. By understanding biomechanics, the designer can make informed patterning, material and construction choices when ideating.

#### *User injuries*

Injury information may be collected from two points of view. The first may include understanding how the product reduces the risk of injury. There are a variety of injuries one may withstand. Table 2 outlines common hand injuries and causes.

To illustrate, a boxer would wear hand wraps and gloves to reduce the risk of knuckle impact injury. Without these products, the boxer could seriously bruise and fracture his/

**Table 2 Common hand injuries and causes**

| Injury | Description and cause |
|---|---|
| Amputation of finger(s)/hand(s) | Complete removal of the finger(s) or hand(s) due to traumatic injury, frostbite, infection or surgery |
| Broken bone or fracture | Break or crack of a bone(s) caused by a direct blow or crushing injury |
| Carpal/cubital/radial tunnel syndrome | Numbness or tingling sensation in the hands and fingers, caused by compressed nerves |
| Chaffing/blistering/calluses | Damage and/or hardening of the skin caused by chemicals, freezing, friction or pressure overtime to the hand/fingers |
| Cuts or lacerations | Open wound through the skin caused by cutting or blunt impact |
| First/second/third degree or chemical/electrical burns | Burning of the epidermis and dermis caused by heat, chemicals or electricity |
| Frostbite or frost nip | Damage to the skin surface and in worse cases muscles, nerves and blood vessels due to extreme or prolonged exposure to the cold |
| Impact injury or bruising | Bruising or swelling of the hand due to the collision of the hand with a stationary or moving object |
| Neuropathy | Weakness, numbness and pain to the hands, caused by damage to nerves outside of the brain and spinal cord |
| Skin infection | Invasion and multiplication of viruses, bacteria and parasites that are not normally present in the body. Typically caused by cuts and lacerations, where viruses, bacteria and parasites can enter because the skin is not intact |
| Strain or sprains | Stretching or tearing of muscles/tendons (strains) or ligaments (sprains) caused by high velocity forces |
| Tendinitis | Inflammation, injury or damaged tendons in the hands, fingers or wrist. Caused by repetitive motion or high intensity activities |
| Trigger finger | When fingers get stuck in a bent position. Caused by repetitive gripping actions |

| Crease # | Crease Name | Diagram of Hand Creases |
|---|---|---|
| 1 | Transverse Wrist Creases | |
| 2 | Longitudinal Palmar Creases | |
| 3 | Transverse Palmar Creases | |
| 4 | Proximal Phalangeal Creases | |
| 5 | Interphalangeal Creases | |
| 6 | Proximal Digital Creases | |
| 7 | Medial Digital Creases | |
| 8 | Distal Digital Creases | |


**Fig. 1** Hand crease landmarks (palmer view) (Sokolowski et al. 2019)

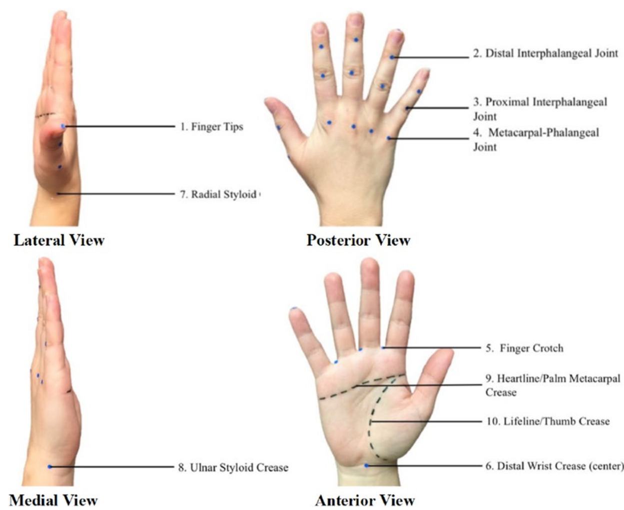


**Fig. 2** Hand anatomical landmarks (all views) (Sokolowski et al. 2019)

her hands. The task of the designer in this case may be to invent a new way to combine the wrap and glove into one product to decrease weight, while providing protection.

The second perspective is to understand the type of injuries that a product can inflict upon the user. An example of this is hand numbing due to vibration of a power tool while wearing a glove primarily designed for cold weather. Although the user may be protected from the cold, there is still an opportunity to reduce numbness by designing a product with better shock absorption. Injury information can be collected from literature, industry safety reports, users and medical clinicians.

### *Hand landmarking*

Through hand surface anatomy and skin creases, it is possible to measure and determine where functional design attributes (e.g., padding, abrasion protection, touch points) should be located on the product (Sokolowski et al. 2019). To do this, as seen in Figs. 1 and 2, landmarks are typically applied to the user's hand with contrast colored stickers or marking pen (washable/non-washable) (Griffin et al. 2019a). Certain landmark colors are preferred, especially when 3D scanning is used to collect information from users with different skin colors.

#### *3D hand scanning*

With the development of 3D body scanning technology that can capture small objects, it is possible for designers to quickly and conveniently collect hand data. Scans can be collected with a variety of tools, ranging from portable hand-held devices to stationary foot scanners (Sokolowski et al. 2018). Service agencies can also provide scan collection. 3D scans can be used to collect anthropometric measurements, provide underlays for sketching, develop hand forms for physical prototyping, create 3D CAD componentry and digital fit. Scans may be taken in a variety of "working positions" to understand the range of a user's hand positions that must be accommodated by a product (Griffin et al. 2019a).

#### *3D hand scan processing*

Many designers do not realize that 3D scans files are not "perfect" in the initial "captured" state. This is especially the case with hand scans because it is difficult to capture data between the fingers where a surface may be occluded by an opposing finger. Holes in the scans will often need to be "patched" so the file can be useful for collecting anthropometric measurements, creating hand forms, developing 3D CAD componentry and facilitating digital fitting. Depending on the software, different processes may be used (see Figs. 3 and 4). Software programs related to anthropometric measuring (e.g.,

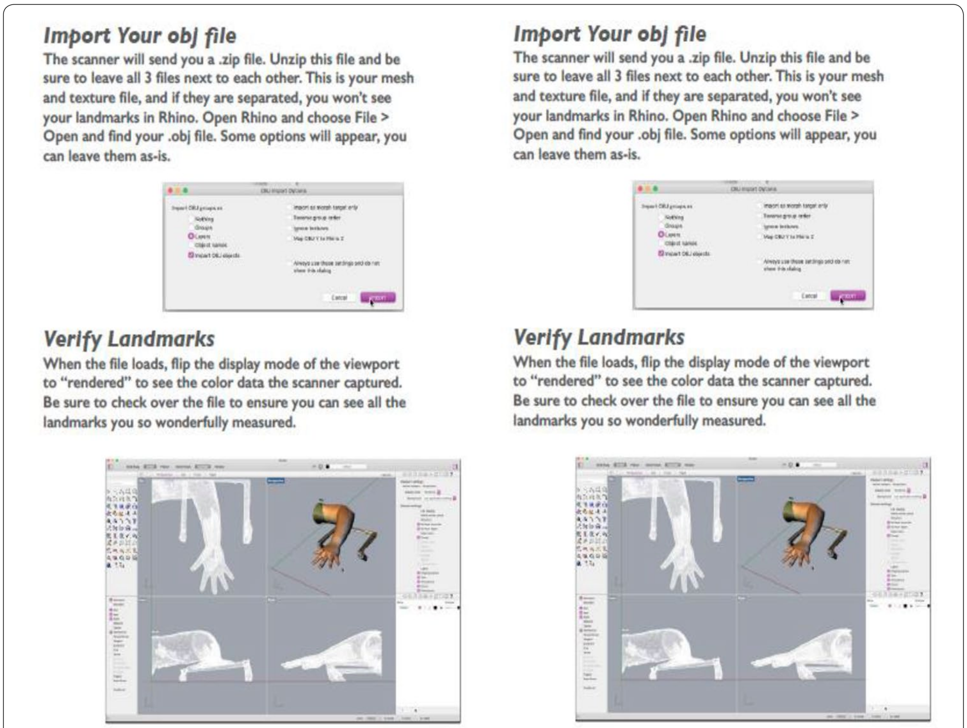


**Fig. 3** Example of 3D hand scan processing in Rhino software (Sokolowski and Corr 2018)

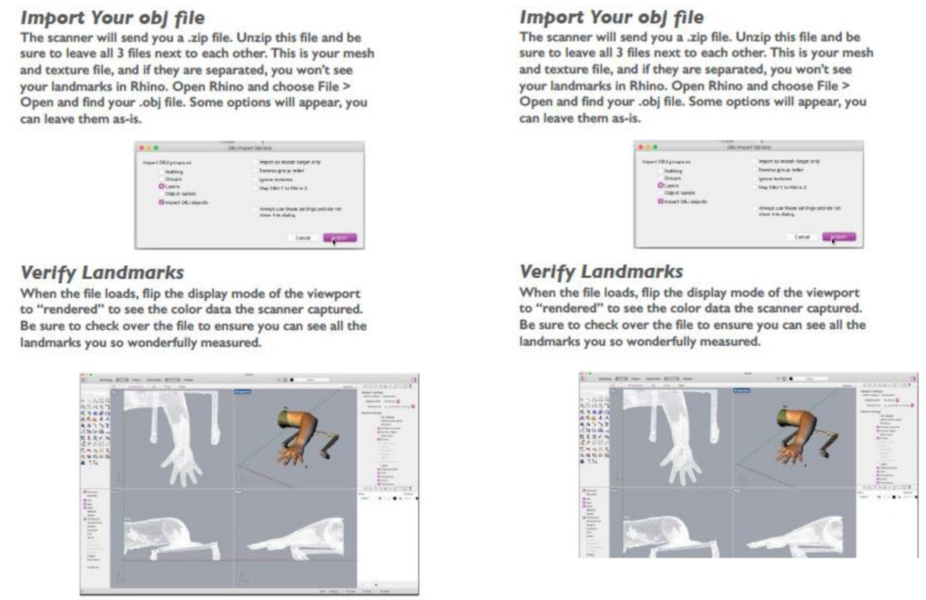


**Fig. 4** Example of 3D hand scan processing in Rhino software and Stand Development (Sokolowski and Corr 2018)

**Table 3 Hand measurement examples (Griffin et al. 2019a)**

| Measurement | Description |
|---|---|
| Hand circumference | Circumference of the hand, around the palm, at the level of the palm metacarpal crease |
| Palmar spread | Surface distance from the side of the 2nd digit's metacarpal-phalangeal joint crease to the side of the 5th digit's metacarpal-phalangeal joint |
| Total hand length—dorsal | Perpendicular distance on the surface of the hand, from the finger tip of the 3rd digit to the base wrist crease landmark |
| Total hand length—palmar | Perpendicular distance on the surface of the hand, from the finger tip of the 3rd digit to the distal wrist crease landmark |
| Metacarpal–phalangeal joint spread | Distance between the 1st digit's metacarpal-phalangeal joint and the 5th digit's metacarpal-phalangeal joint |
| Phalange spread | Distance between the finger tip of 1st digit to the finger tip of the 5th digit |

*AnthroScan*) can often fill holes automatically, where 3D CAD design programs (e.g., *Rhino*) need to follow a more complex procedure to clean the scan (Sokolowski and Corr 2018).

### *Hand anthropometry*

Three methods have been used historically to collect hand anthropometric data (see Table 3). They include measurements taken directly from: the landmarked hand (with a tape measure or caliper), a 2D photo/photocopy of the landmarked hand (with tape measure or caliper), or a 3D hand scan (landmarked and measured with software such as *Geomagic* or *AnthroScan*) (Sokolowski et al. 2019). Measures are important because they can inform materials selection and placement, pattern development, fit and sizing. What is important for hand wear and tool design is that the anthropometric measurements are relevant to the product being designed. For example, if the user will grip while using the

**Fig. 5.** 3D hand print and form (Sokolowski 2019)

**Fig. 6** Assembled 3D hand print and form (Sokolowski 2019)

product, then finger length in a gripped position is important to measure, because the length will change compared to fingers in a splayed position (Griffin et al. 2019a).

### *3D hand forms*

3D printing technology now makes it possible to print processed 3D hand scans, to make hand forms for glove prototyping. Specialized resin formulations make it possible to print semi-flexible hand parts. To save print time, files can be split into four to five sections, as seen in Fig. 5. The multiple sections allow the hand form to break apart to aid with prototype donning and doffing (see Fig. 6). Hand forms can also be printed at different scales to help designers work through patterning challenges or 3D sketch ideation.

### *2D hand croquis*

In pilot research conducted by the author, methods used to develop hand croquis (sketch underlays) for ideation were found to be inaccurate (Sokolowski et al. 2019). The methods were based on proportions identified by artists to teach figure drawing (Hogarth 1988). It is important for designers to ideate using accurate hand croquis so that product proportions, placement of technology, and fit and sizing are appropriate for the user. By using 3D hand scans and anthropometric measurements, better croquis can be devised for ideation purposes.

### Phase three: strategies for hand wear and tool product innovation

By completing the strategies outlined in Phase One and Two, innovation applied to products for the hand can be based on more accurate and relevant information. In Phase Three, designers are then able to ideate, prototype, identify materials, pattern/model, develop tech drawings, fit and validate new ideas in a lab using instrumentation and/or on a user, all while referencing the actual 3D and 2D user's hand and background information.

#### Ideation drawing

Ideation is the most common method used by designers to generate ideas, however with the tools developed in Phase Two, ideation can be more accurately derived and conducted with 2D methods (e.g., pen, pencil, marker) or digitally in 3D (e.g., drawing tablet, *Illustrator*, *Rhino, Photoshop*, *KeyShot*). No matter what ideation method is used, it should be easy to facilitate, so the designer can quickly document ideas and explore different options uncovered in Phase One.

#### Materials identification

Once ideas are refined, the designer can select materials that are appropriate to physical prototyping. In many cases the designer will use materials that are similar to what will be required for the final product concept, as it is likely that finalized materials have not been fully developed. Product performance requirements should drive materials selection. Some performance requirement examples include stretch, insulation, grip, support, impact protection and rigidity. Materials can be sourced from a vendor or retail store.

#### Product prototyping

After materials selection, viable ideas can be prototyped, at a 1:1 scale. There are many prototyping tools available for designers including: cutting and sewing, vacuum forming, laser cutting, heat pressing, molding, sculpting, 3D CAD and 3D printing. Ideal prototypes can be held in the user's hand(s) and initially evaluated to determine viability.

#### Product patterning and form

Once ideas are refined to the final concept(s) for product development, it is important to start building blueprints (patterns) for accuracy and replication. In some cases, the prototype should be drafted in 3D CAD and through that process, exact measurements can be referenced from Phase Two to develop drawings. Another method is to drape patterns on the hand forms, then scan and digitize the shapes into patternmaking or *Illustrator* software. The work must be precise and accurate so that it can be referenced for future work.

#### Product technical drawings

From the selected concept(s), Phase Two information is used to develop technical drawings drawing to scale to accurately convey the design. These drawings are typically done on the computer in *Illustrator* software. The drawings should include key views of the product: front, back and ¾ view. These drawings will be used and modified throughout the development process to communicate all of the design details.

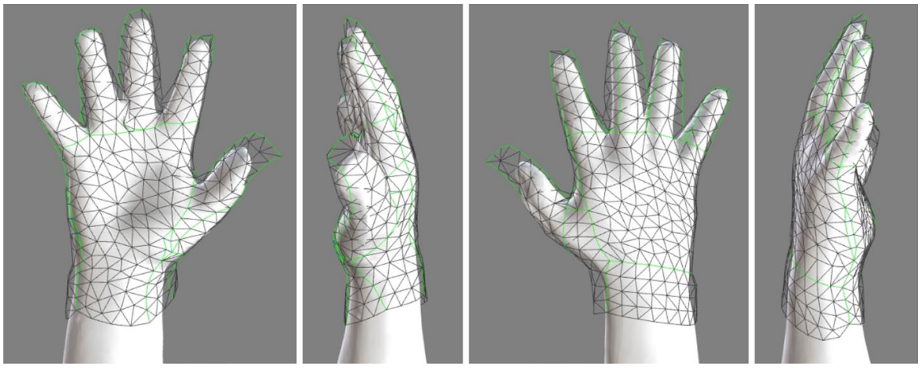

**Fig. 7** Glove draping in *Optitex* (Griffin et al. 2019b)

**Table 4 Commonly used ASTM standardized tests to evaluate materials, components and whole products**

| Standard | Test name |
|---|---|
| ASTM D3822/D3822M | Standard test method for tensile properties of single textile fibers |
| ASTM F2675/F2675M | Standard test method for determining arc ratings of hand protective products developed and used for electrical arc flash protection |
| ASTM F1930 | Standard test method for evaluation of flame-resistant clothing for protection against fire simulations using an instrumented manikin |
| ASTM D3884 | Standard guide for abrasion resistance of textile fabrics (rotary platform, double-head method) |
| ASTM F2992 | Cut test method |

### *Fitting and modeling on the 3D hand*

The design concept can also be modeled using the 3D hand scan described in Phase Two, to check proportion and fit. Typically two methods are used. The most common is to model the glove design or components in 3D CAD, using programs like *Rhino* or *Blender* (see Fig. 7). With this method, the designer will work from the technical drawing. More recently, *Optitex* apparel design software has been explored, with glove patterns digitally draped onto a 3D hand scan (Griffin et al. 2019b).

### *Product validation*

For performance hand wear and tools, it is especially important that product concepts are tested and validated for use. Validation can be done in a lab setting, where individual materials, components or products can be tested (e.g., durability or flame retardancy). Table 4 presents commonly used ASTM standardized tests, however depending on end use other tests may be used.

Depending on risk, testing could also be conducted in-vivo or through wear testing, where users can go through a battery of standardized tests (e.g., dexterity or grip strength) or the product can be tested in a real-life use scenario to provide feedback.


**Fig. 8** Historical overview of tactical combat gloves (Echols 2018b)


**Fig. 9** State-of-the-art cycling glove (Sokolowski and Hoegsted 2019)

## Performance hand wear and tools innovation framework: application and evaluation

The *Performance Hand Wear and Tools Innovation Framework* was used to teach a graduate level sports equipment design studio. Students in the course were tasked with designing gloves for specific users. This section will review the student work that used the framework.

### Application of phase one: strategies for understanding the performance hand wear and tool project background

In teaching design, it is always important for students to understand how a product was initially designed and evolved over time. By conducting historical research, students are able to learn dates of creation, materials, silhouette, features and benefits of products from the past, related to their project area. Figure 8 provides a historical overview of tactical combat gloves (Echols 2018b).

It is also important for students to learn about state-of-the-art products. Figures 9 and 10 show a road cycling glove that was referenced by a student for a project, along with a

**Fig. 10** Anatomy of a state-of-the-art cycling glove (Sokolowski and Hoegsted 2019)


**Fig. 11** Market and technology landscape for women's clay pigeon shooting gloves (Echols 2018a)

product dissection to understand all of the pattern pieces and components involved with designing the state-of-the-art product.

Figure 11 provides an example of a market and technology landscape for women's clay pigeon shooting gloves. The analysis highlights key competitors, product silhouette, price points, features and benefits.

By studying the three handlebar holds and grip patterns used by cyclists (Fig. 12), the student was able to get an understanding of padding needs for a new glove. The study

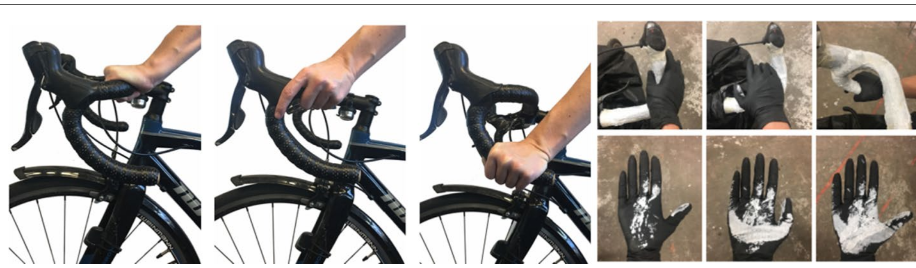

**Fig. 12** Road cyclist user needs (Sokolowski and Hoegsted 2019)

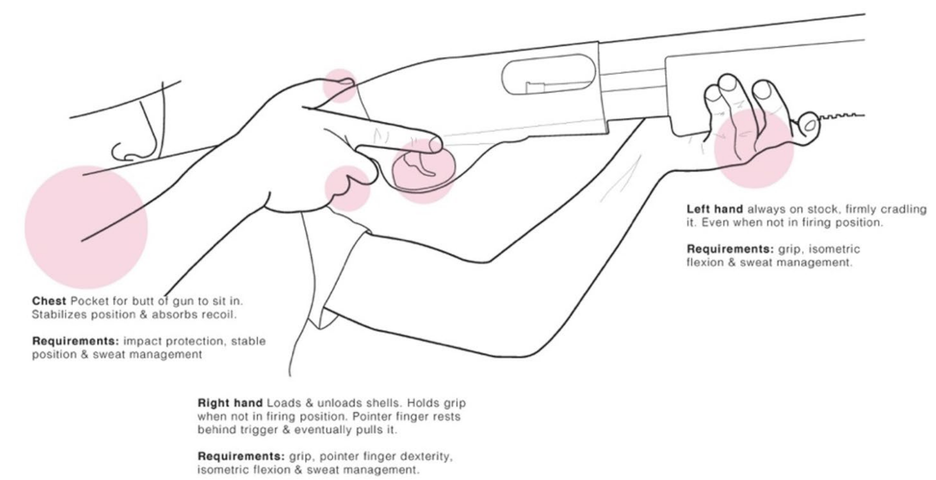


**Fig. 13** Clay pigeon shooter physiological and biomechanical needs (Echols 2018a)

was conducted by painting taped bike handlebars white, so the grip contact surface could be transferred onto black rubber gloves. The white paint transferred to the black glove helped to identify exactly where palm protection should be placed for the new cycling glove (Sokolowski and Hoegsted 2019).

#### Application of phase two: strategies for defining the user's 3D and 2D hand

Depending on sport focus, the students used strategies described in Phase Two to understand their user's hand anatomy, physiology, biomechanics and injuries related to the product they were designing. Figure 13 shows how a student documented physiological and biomechanical needs for female clay pigeons shooters.

Through the same landmarking, 3D scanning and scan processing methods described in the framework; students were able to create 3D hand forms for their design work. They used an *Occipital Structure Sensor* (mounted to an *iPad*) and *Skanect* software to capture the 3D hand scan. The forms also provided a mechanism for the students to collect anthropometric measurements, establish hand croquis for ideation, and develop prototypes.

#### Application of phase three: strategies for hand wear and tool product innovation

Once the user's 3D and 2D hand dimensions were defined, students were able to commence the ideation process. Pencil sketches were created, along with the development of physical prototypes to address palm cushioning, fit, mobility and thermal comfort (Figs. 14, 15, 16, 17) (Sokolowski and Hoegsted 2019).

Once students finalized their design direction, final patterns were drafted to fabricate the final product concept. Figure 18 shows patterns for the women's clay pigeon glove and harness. Technical drawings for the products were also created (Fig. 19).

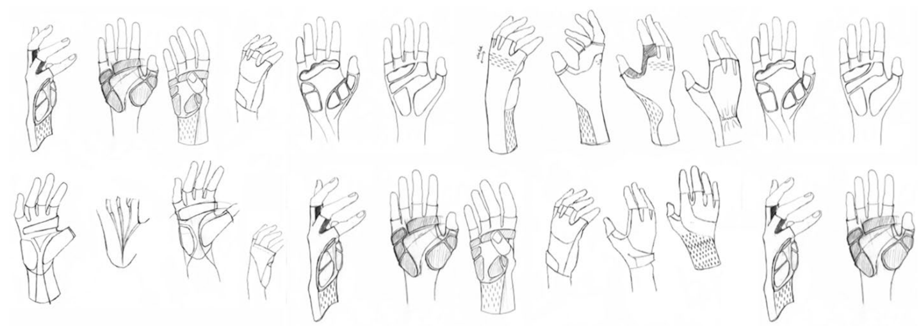

**Fig. 14** Cycling glove sketch ideation (Sokolowski and Hoegsted 2019)

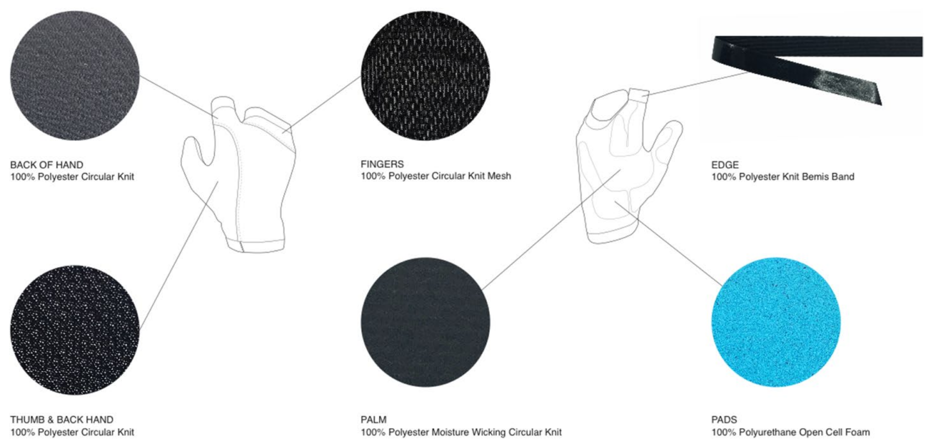


**Fig. 15** Cycling glove materials identification (Sokolowski and Hoegsted 2019)

**Fig. 16** Cycling glove palm cushioning prototypes (Sokolowski and Hoegsted 2019)

As seen in Fig. 20, for the cycling glove project, the final concept was fitted on the user's hand and evaluated in the three road cycling handlebar positions for grip comfort, fit, mobility and thermal comfort (Sokolowski and Hoegsted 2019).

**Fig. 17** Cycling glove prototypes (Sokolowski and Hoegsted 2019)

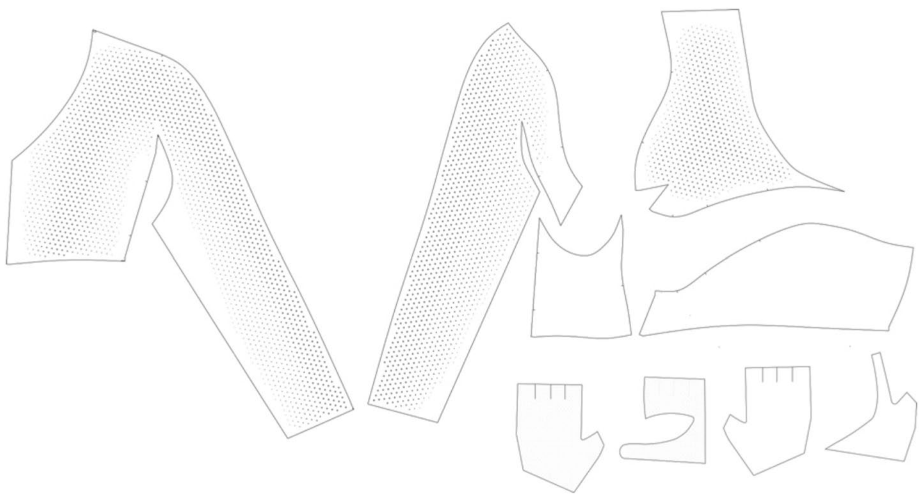

**Fig. 18** Clay pigeon glove and harness product patterning (Echols 2018a)

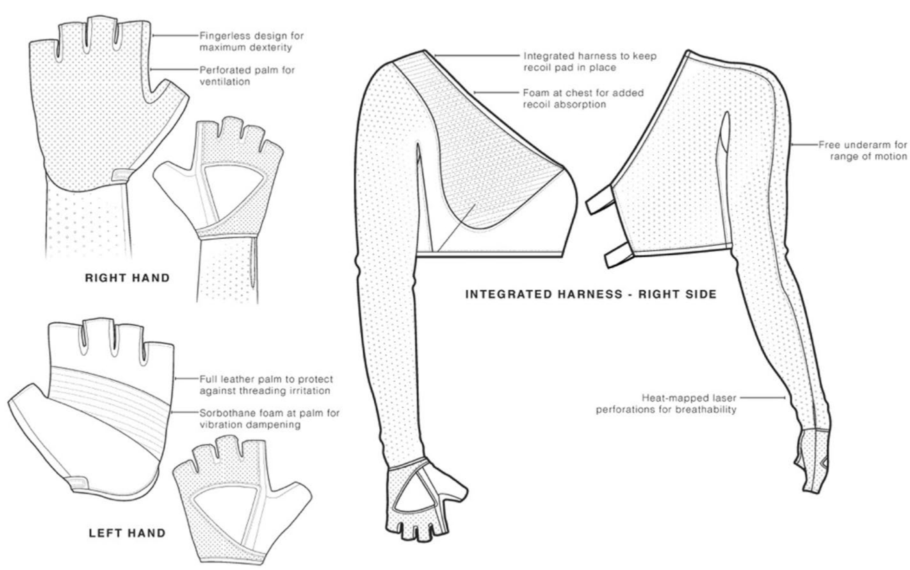


**Fig. 19** Clay pigeon glove and harness product tech drawings (Echols 2018a)


**Fig. 20** Cycling glove fit and validation (Sokolowski and Hoegsted 2019)

### Evaluation of the framework

Innovating performance products for the hand can be a complex process. By applying the *Performance Hand Wear and Tools Product Innovation Framework*, students were able to use the strategies presented throughout the design process, to facilitate new ideas for sport gloves. Through the success of the class project, students have been able to share their work at international sport conferences and design competitions. It is anticipated that other students and professionals interested in hand wear and tool design could implement this framework to guide their work.

## Conclusion

By using the *Performance Hand Wear and Tools Innovation Framework*, students and design professionals can create new and innovative products through a variety of strategies to explore design challenges. Each phase of the framework aids designers in garnering a better understanding of user needs, and 3D and 2D hand characteristics, in order to ideate and prototype new products. As technologies develop in 3D scanning, CAD, generative design and machine learning – the end results of using the framework may change but the strategies should hold true as they are broad in nature. Through more creatives using the framework, it is possible for certain combinations of strategies to more successful, for designers with similar backgrounds (e.g., apparel versus product designers). The goal for future work is to use the framework in designing products for military personal, surgeons, construction and fire service workers.

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**Author's contributions**
SS developed the *Performance Hand Wear and Tools Innovation Framework*. SS has also taught the framework to graduate students in the Sports Product Design Program at the University of Oregon. OE and CTH shared their design work for this paper. SS wrote the entire paper. The author read and approved the final manuscript.

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SS is the Founding Director and Associate Professor of the Sports Product Design Graduate Program, at the University of Oregon. She has over 25 years of performance footwear, apparel and equipment design experience; working at Nike, Burton Snowboards, Fila and the US Department of Defense. Her work is holistic in nature, where consideration of the athlete's body form, performance, psychology, sport, materials and styling are addressed to develop game-changing innovation solutions. She is specifically focused on issues surrounding design of products for special populations, including women and disabled athletes. SS holds over 35 utility patents in the space and has been recognized internationally. A motivational coach and mentor, SS is committed to inspiring students in product design, development and business.

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The author declares no competing interests.

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