Breathable Splint Design for Carpal Tunnel Syndrome

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Abstract

In the current market for carpal tunnel syndrome (CTS) splints, the need for a splint that is breathable, comfortable, and effective, and therefore user-compliant, leaves room for innovation. It is hypothesized that a device that is more breathable (i.e. contacting the body in fewer locations), will be preferred for patients with CTS. We propose a novel wrist splint to vary breathability using gloves of varying levels of coverage. CTS patient surveys are used to evaluate the desirability of each splint-glove combination, along with efficacy and comfort. For minimal wrist-loading tasks, it is expected that participants will prefer a glove with low coverage. From these results, we may form a recommendation for coverage to best promote breathability and compliance in splint-design. Therefore, we expect that survey results will indicate preference for breathable wrist splints.

I. Introduction

Approximately 3-6% of adults in the United States suffer from Carpal Tunnel Syndrome (CTS) [1]. CTS is a condition caused by compression of the median nerve at the wrist. This causes pain, numbness, and tingling of the hand and arm. Any forceful repetitive hand movement that causes the median nerve to swell can cause CTS [2]. This may include risk factors such as workplace tasks [3], playing video games, or playing a musical instrument. CTS symptoms may also be caused by high computer usage, a task very relevant in college students. As students are constantly using and sharing laptops without practicing stress-relieving activities, they are put at risk for developing CTS [4].

There are several forms of treatment for CTS, both surgical and non-surgical. It is recommended to use a non-surgical form of treatment, such as a hand brace, to prevent undergoing surgery. However, splints have limitations such as induced perspiration, odor, and discomfort which may lead to decreased user compliance [5]. Since compliance is directly tied to treatment effectiveness [6], exploring the CTS splint design space is crucial.

A. Background

CTS can be diagnosed through clinical symptoms, signs, and nerve conduction [7]. In addition, the development of touchscreen tablet games has made CTS screening more accessible [8]. Also, the implementation of self-administered questionnaires, such as the Boston Carpal Tunnel Questionnaire, can help patients monitor their dynamic CTS experience [7]. Aside from wrist splints, when considering conservative, or non-surgical, treatment of CTS some options include oral therapies, local injections, and therapeutic exercises. However, wrist splints have repeatedly shown to be practical for promoting recovery and improving symptoms and function [9], [10]. In addition, splints are most effective when worn full time which implies that user compliance issues should be addressed [6]. More examples of splint user compliance concerns include difficulty to keep the device clean and dry, poor aesthetics, weight, and compromised performance of daily activities [5].

The purpose of wrist splints is to relieve pressure on the median nerve and restrict wrist movement to prevent carpal tunnel pressure elevations. As a CTS patient, there are many considerations to make when buying a wrist support such as duration of wear and level of wrist extension [10]. In addition, product options include soft or rigid devices and can be prefabricated or custom made. Prefabricated canvas splints with adjustable metal inserts risk losing rigidity and may invite unprescribed angle changes. Some prefabricated wrist supports include beanbag-like cushions to support the user's palm or a hard and flat support that extends the length of the fingers, as in the case of the Manu(®) soft hand brace [7]. Meanwhile, non-adjustable custom thermoplastic splints are often deemed more comfortable than prefabricated ones. Though more expensive, the added comfort in custom splints may increase user compliance [6].

Since this study focuses on CTS in relation to low wrist-loading activities, and especially computer usage, we anticipate that concerns include sweaty palms and lack of ventilation [5]. With computer usage, it can be assumed that these issues are amplified due to heat radiation from the computer. Moreover, wrist supports that are bulky at the palm or that inhibit the movement of the fingers are not practical. In fact, user compliance can be particularly problematic if the splint interferes with one's job [6]. Notably, some feats in the space of human-computer interaction include a glove that controls a cursor on a screen [11]. This device however encloses the hand in a glove and must require the user to not rest their hand/arm.

With many CTS relief products on the market, choosing a product is likely a confusing decision to make. On Amazon.com, there exists devices that claim to be a CTS support and pain relief device such as wristbands, hot/cold therapy gloves, compression gloves, gel gloves, and wrist bracelet supporters. The treatment effectiveness that some of these supports claim to provide is misleading since wearing a flexible wrist device can limit the range of wrist motion but has no significant effect on carpal tunnel pressure [12]. However, we acknowledge the possibility that users might primarily choose to use these devices simply for temporary, targeted pain relief. Furthermore, although not specific to CTS splints, Paterson et al. suggests that 3D-printing could lead to opportunities in the field of occupational therapy [5].

With regard to the aforementioned literature and market, the absence of a wrist splint that is breathable, comfortable, and effective clearly points toward potential innovation. This study facilitates the development and testing of a device to address this clear gap. By exploring these seemingly conflicting needs of breathability and comfort, our results may provide CTS patients with a desirable and novel CTS treatment option. Accordingly, the potential increase in user compliance will make a large impact on CTS symptoms including pain [5], [10].

B. Overview

From literature and current devices on the market we know that there is a lack of breathable splints that have been systematically tested. We hypothesize that a device that is more breathable, in this case, contacting the body in fewer locations, will be more desirable for patients with carpal tunnel syndrome. *Section II* discusses a preliminary interview with a person with CTS. The results from this interview support the idea that lack of breathability in a splint is a relevant user compliance issue [5]. In *Section III*, we present a wrist splint design that utilizes a splint frame and glove to enable the evaluation of breathability while maintaining wrist support. As suggested in *Section IV*, obtaining data from real CTS patients may impact academic and industry splint research for the design of user-compliant splints. The use of this study is not limited to orthotics, but may also be relevant for wearable device studies. In addition, *Section V* discusses how this study may ultimately influence conservative treatment for CTS patients.

II. Preliminary Results

Given our interest in splint-use as a conservative treatment for CTS, we assume that full-time students with part-time jobs are spending many hours of their time doing low wrist-loading tasks at the computer. Therefore, we chose a college student with CTS who owns wrist-splints as the interviewee for this study.

We used the interview method known as contextual inquiry. This method establishes a master and apprentice relationship between the interviewee and interviewers, respectively. Using this method allows for the interviewee to expand on their experiences and workarounds they were not previously aware of. For our interview, our explicit openness to learn allowed the conversation to branch out into meaningful insights and helped us find primary user needs. There were two interviewers and one note-taker. “Interviewer 1” started the interview and recording while “Interviewer 2” redirected the questions to the interview list. Both engaged in the conversation with the interviewee and helped her feel welcomed and important.

As a diligent student, she constantly has to write and use her laptop while working on assignments. Throughout the week, she typically studies, attends classes, works for her internship, leads academic extracurriculars, and works in a desk setting for a majority of her day (10 to 12 hours). She expressed that these time demanding activities worsen her CTS symptoms. Based on her experiences with CTS, we created a long list of user needs from the interviewee’s personal anecdotes and daily routines. Our team truncated the user needs chart to four customer statements that guided our design decisions for our project (Fig. 1).

As aligned with literature, the interviewee expressed how washing the splint often is an inconvenience for her and that she tries her best to prevent it from smelling as much as possible. Therefore, she discussed how she must take off her splint every thirty minutes while doing workplace tasks due to its lack of breathability. Without doing so, she mentioned the issue of sweat and how the splint will eventually begin to smell. Removing the splint so often also decreases her work efficiency. Thus, breathability became an important need in our design.

The interviewee described how the metal insert sometimes pokes into her forearm, creating pain and discomfort. While she is able to complete computer tasks without having this pain, she is unable to wear the splint while doing housework. She experiences wrist pain while vacuuming, but she cannot wear her splint because the vacuuming motion digs the metal insert into her skin. The interviewee therefore has to deal with her wrist pain while completing chores around the house. We wanted to consider the pain caused by the metal insert because it’s an important problem for the interviewee. In addition, this user compliance issue is a common concern for patients as stated in literature [5]. Despite the pain caused by CTS, she isn’t able to comfortably wear her splint since it causes additional pain during certain activities.

As the interviewee wears her splint when working on her assignments, she appreciates that she doesn’t have to worry about keeping her wrist posture in the correct ergonomic position. She stated, “So what I like about my wrist splint is that I don’t have to keep track of my posture. I can just type without worrying that it’s going to hurt later, because my arms, wrist, and my hands are already in the right position.” This allows her to continue focusing on her work instead of her CTS pain. We therefore wanted to consider a design that is not only breathable and comfortable, but also automatically keeps the wrist in an ergonomic position.

III. Methods

This neutral wrist splint provides support for the wrist by preventing unwanted flexion and extension while enabling breathability (Fig. 2). On the palmar and dorsal sides, the rigid splint frames are made of metal and conform to the hand. To promote breathability, the frame has minimal contact points which consist of supportive, vertical, hand-conforming rods, therefore creating vertical open windows. On the dorsal side, a similar, yet smaller, frame prevents the wrist from extension. This side has two rods, creating one open rectangular window. On the far left and right rods of the palmar and dorsal frames, an elastic cord is threaded through holes in the frames. This holds the two rigid parts of the device together, therefore promoting stability. In addition, the cord is able to be slightly stretched in order to slip the device over the fingers and knuckles. To provide stability and security there is a velcro strap at the wrist that holds all pieces together.

Customer Statement	Interpreted Need
"I don't like that the brace is not breathable."	The product allows air circulation/is breathable.
"It [the splint] kind of pokes you so it's uncomfortable."	The product has comfortable attachment points to the body.
I need to work for long periods of time.	The product is comfortable even with hours of wear.
"What I like about my wrist brace is that I don't have to keep track of my posture"	The product automatically keeps the wrist in an ergonomic position

Fig. 1. This truncated user needs chart shows which customer statements and product requirements that motivate the design of this device.

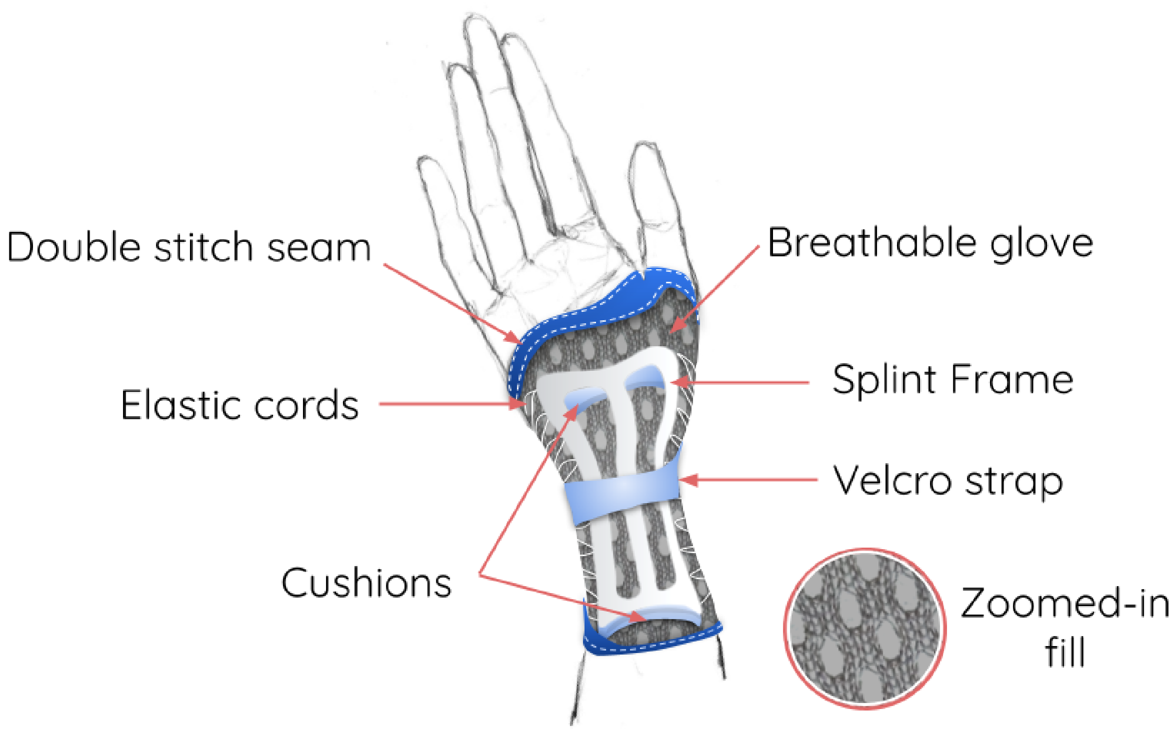

Fig. 2. Description of our wrist splint with arrows pointing toward various components of the device.

Past studies have measured breathability as the moisture vapor transmission rate or the "quantity of moisture vapor through a fabric during a specified time period" [13]. In this study however, we define breathability in relation to the amount of contact the device makes with the body. Therefore, the fewer locations of body contact, the more breathable the device is because more water vapor can escape. By using this definition of breathability rather than the quantity of moisture vapor, we will gain personalized and relevant data on breathability without excessive sensor setups for experiments. In our prototype, the rigid, windowed, frame serves as a means of moderating breathability with various gloves and as a support structure. Therefore, this frame enables testing of the desirability of different gloves by varying breathability and obtaining user input from surveys.

We will determine an optimal breathable design by varying the area of contact of the inner glove of the splint. In each participant, we will inquire about the desirability of 1) a glove with 100% coverage (i.e. no holes), 2) one with 50% coverage, and 3) one with either 25% or 75% coverage (Fig. 3). The level of coverage in the third round will depend on the participant's response to our second round. By increasing and decreasing the fill of holes in the glove, we will be able to vary the area of contact, and therefore breathability in a systematic way. Desirability of each glove will be determined by a phone survey. This survey will include questions around their experiences such as discomfort from poking, frequency of use, breathability or perspiration, and interference during low wrist-loading tasks, such as computer use. In addition, by using interactive upper-arm diagrams, participants can identify and select areas where splint-induced irritation occurred. To guide the construction of the surveys, we will reference the work by Sinkowitz-Cochran et al. [14]. Surveys for each group will be conducted using the same questions after a certain amount of time of wearing the splint. Also, to inform future studies using our splint design, participants will answer the Boston Carpal Tunnel Questionnaire to determine splint effectiveness for reducing CTS symptoms [15].

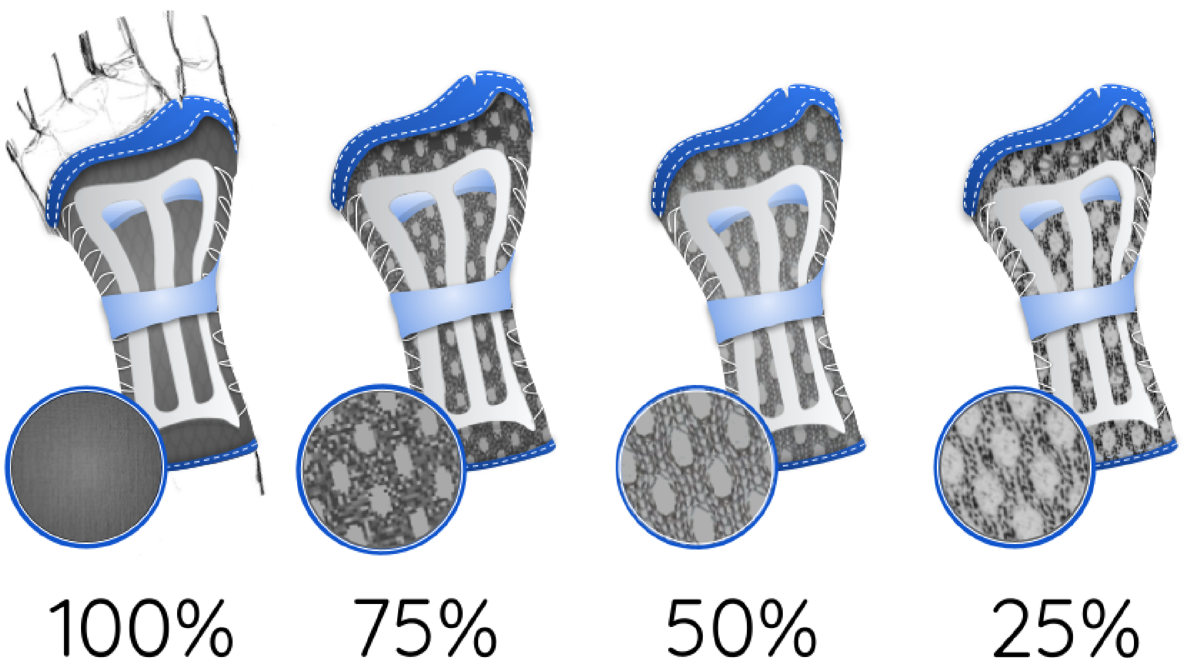

Fig. 3. Each splint uses fabric with a different percentage of coverage to change the breathability. All users will try out the 100% coverage splint and the 50% splint afterwards. Lastly, they will choose to try the 25% or 75% coverage splint before ranking their final preferences in our survey.

While more coverage may be desired for high strain activities (causing prodding from metal insert), we expect that users will prefer a lower coverage for tasks where the wrist is not repeatedly loaded and unloaded. Therefore from our survey results, we expect participants to prefer a glove with 25% coverage for minimal wrist-loading tasks. With lower coverage, we expect that users will enjoy more airflow while not compromising optimal splint support. Once the optimal coverage is determined, we can further explore the implications and effects of varying variables such as the glove thickness and material (e.g. organic fiber or synthetic plasticky fiber). Our final coverage recommendation is the average of final coverage preferences per person. This will become the minimum coverage prescribed for the material. From this, several other recommendations can be derived and used to prototype a new glove:

1) Given the same thickness, it is not recommended to choose a material that is weaker than the glove material used in this study.
2) Given the same coverage, it is not recommended to choose a material that is less sweat-wicking than the glove material used in this study.

If the thickness of the glove is increased, a weaker material could potentially be used and if coverage is decreased, a less sweat-wicking material could potentially be used.

IV. Intellectual Merit

In this study, we will obtain qualitative results from real CTS patient experiences using our novel splint design. Notably, this will address the current gap in wrist splints on the market and allow for the creation of a recommendation for splint breathability based on real data. This splint frame technology enables breathability and reimagined force loading therefore benefitting the future of orthotic, and wearable, design centered around user compliance. The splint technology, testing, and results may lead to a host of new studies in wrist splint design. This includes information on breathability, materials, as well as our secondary results on comfort and effectiveness with respect to patient insights. In the future, if a device is fully developed in breathability, comfortability, and effectiveness, then it would be a desirable and trusted option to treat CTS.

V. Broader Impact

Many splints in the current market will claim to be breathable, however, they are rarely accompanied by relevant studies to prove their breathability. Our results and testing methodology may influence companies in either using our recommendations or testing their devices. Additionally, the final tested device may give doctors more confidence in recommending it to patients with compliance issues due to lack of breathability. CTS patients themselves may find the device more desirable to take on-the-go since it's more breathable and, therefore, less odorous. This is particularly relevant for students, who are constantly working in non-ergonomic settings throughout the day: a park bench, cafe, or lecture hall [4]. With an increase in confidence in breathability, CTS patients may be encouraged to wear their splint more often, thus decreasing pain caused by CTS.

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