PneuExtensio: Designing Pneumatic-based Bodily Extensions to Facilitate Embodiment across Everyday Life Experiences

Aryan Saini
aryan@exertiongameslab.org
Exertion Games Lab, Department of Human-Centred Computing
Exertion Games Lab, Department of Human-Centred Computing, Monash University
Melbourne, Australia

Elise van den Hoven
elise.vandenhoven@uts.edu.au
University of Technology Sydney
Sydney, Australia
Eindhoven University of Technology
Eindhoven, Netherlands

Florian 'Floyd' Mueller
floyd@exertiongameslab.org
Exertion Games Lab, Department of Human-Centred Computing
Exertion Games Lab, Department of Human-Centred Computing, Monash University
Melbourne, Australia

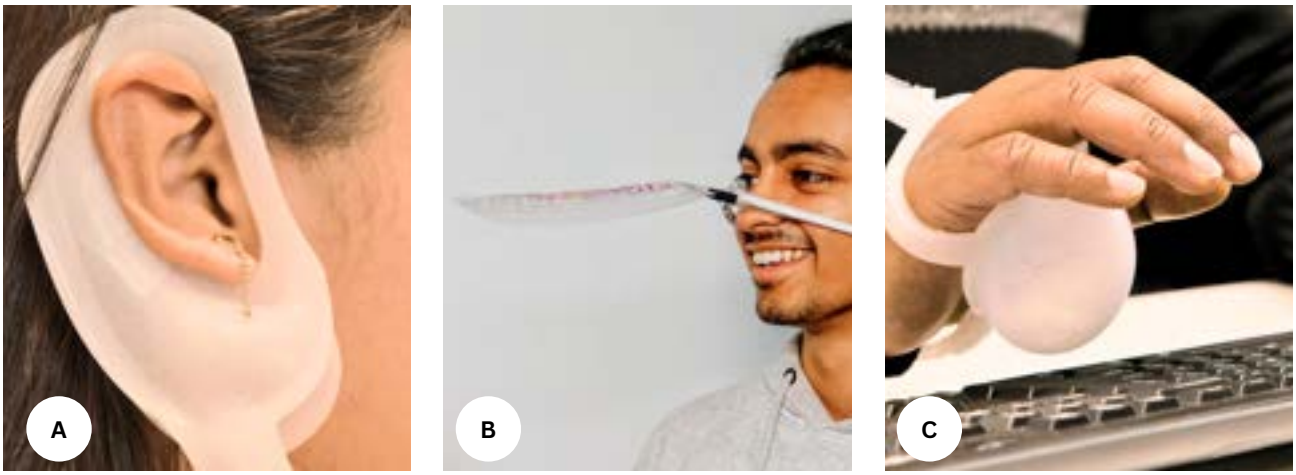

Figure 1: Bodily extensions enabled by PneuExtensio: A) "Pardon" that moves the ear forward when the user says, "Beg your pardon?"; B) Pneunocchio that extends the nose whenever the user lies, and C) "Take a break" that pushes the user's hand away from the keyboard to help facilitate taking a break from work.

ABSTRACT

Bodily augmentations have been increasingly investigated by HCI researchers due to the associated benefits, such as accessibility, offering novel input space, and sensing environment. Most of these investigations have adopted a utilitarian perspective, providing impairment, mobility, and rehabilitation support. However, more recently a subset called bodily extensions has emerged that appears to also embrace experiential aspects. These bodily extensions physically extend the human body, going beyond traditional sensing and accessibility perspectives. Initial designs were mostly rigid, leading to a focus on short-term use, missing out on the opportunities for these bodily extensions to be integrated into everyday life. In our work, we build soft pneumatic-based bodily extensions that users can incorporate into their everyday lives. We detail the design and rationale behind these bodily extensions, along with the novel scenarios they enable. We share our insights from creating these systems and the associated user experiences from our field study with 48 participants, resulting in a design framework that will hopefully aid future designers in facilitating embodiment across everyday life through bodily extensions.

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CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; Interaction paradigms;

KEYWORDS

bodily extensions, pneumatics, embodied interactions, embodied experiences

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1 INTRODUCTION

Bodily augmentations have recently garnered interest in HCI for example they can offer novel input spaces around the user's body [4], support accessibility [48], and sense environmental cues [23]. While current bodily augmentations appear to take a utilitarian approach [23, 24, 28–31], there have been advances around a subset called "bodily extensions" that physically extend the wearer's body while also embracing experiential aspects [7, 20, 33, 40]. So far, these bodily extensions generally feature a rigid design that limits their potential to support everyday life. We believe if bodily extensions were designed such that they could support everyday life, they could exploit their potential for both instrumental and experiential aspects much more through facilitating embodiment. However, unfortunately, there seems to be only minimal knowledge on how to design these bodily extensions that are more body-conform such that a user can benefit from them in everyday life. In order to begin addressing this gap, we answer the research question: how do we design body-conform bodily extensions to support embodiment across everyday life?

Supporting embodiment in everyday life experiences is important as it can have numerous benefits, such as speech production, memory recall, and temporal perception [10–12, 26, 27, 32]. Hence, we aim to contribute to the knowledge of designing such systems by analyzing the creation of a set of bodily extensions that users can benefit from in their everyday lives and studying the associated user experiences. To support body conformity, we employed a pneumatic-based shape-changing design approach in order to support everyday wearability.

To answer the question above, we conducted two case studies (one focusing on leveraging contextual cues to trigger the bodily extensions, and the other on physiological cues from the user) with a series of bodily extensions discussed in section 3.

2 RELATED WORK

In this section, we discuss relevant prior work on embodied interaction, bodily augmentations, and pneumatic interfaces.

2.1 Embodied Interaction

While previous research indicates that there are various lenses on the application of embodied theory [14, 22, 44], in our work, we aim to explore the role of technology in an attempt to facilitate embodiment in everyday life scenarios. As a result, we talk about creations primarily centred around leveraging or eliciting bodily movement [2, 27, 45], similar to the tangible interfaces field that also aims to leverage or elicit bodily movements, but does through tangibles (whereas we do this through the body) [44].

2.2 Bodily Augmentations

Bodily augmentations have been explored mostly in the form of prosthetics [8], interactive textiles [43], and shape-changing interfaces [18]. These have been centred around sensing [1, 25] and feedback [3] mechanisms that often leverage the location of a body part to deliver contextual information. We focus on bodily extensions that are catered towards facilitating unusual experiences as a part of the user's body and, hence, learned from prior work that investigated the perception of one's body under the influence of a bodily extension [7].

2.3 Pneumatic Interfaces

Pneumatic interfaces have been increasingly explored due to their soft nature, occupying less space, and being lightweight in comparison to their traditional counterparts in applications such as VR [42], accessibility [48] and haptic feedback [19], however, not in regards to bodily extensions (with a few exceptions [18, 41]). Fortunately, there have been several advances in lowering the threshold for the design of pneumatic interfaces in the form of rapid prototyping techniques [17], toolkits [47] and frameworks [15]. We leveraged this knowledge to create pneumatic-based bodily extensions to facilitate embodiment across everyday life.

3 RESEARCH METHODS

We outline our research methods, starting with iterative design, user elicitation study, field study and semi-structured interviews, and thematic analysis.

Iterative Design. Design researchers have long adopted the iterative approach for prototyping systems [21]. This method allows the designer to reflect on each iteration and improve upon the next one. We employed iterative design as it complemented our rapid prototyping skills.

User Elicitation Study. A user elicitation study offers unique insights into the design of the bodily extensions as well as helps to reaffirm the design methods adopted [13, 16, 46]. This method was employed in the form of a 40-minute session with users to gauge their understanding and perception of the system and offered key insights about how the bodily extensions would be perceived by onlookers lacking the context.

Field Study and Semi-Structured Interviews. Since we wanted to create bodily extensions that can be worn by users across everyday life, we deemed it to be important to evaluate the experience in an unsupervised setting [9, 34]. We conducted four field studies with 12 participants each for a duration of seven days followed by a semi-structured interview [5]. We employed a semi-structured technique to allow users to express their thoughts and gather information about novel situations that have arisen during the field study.

Thematic Analysis. After conducting the semi-structured interviews, we used inductive thematic analysis for analysing the qualitative data [6, 39]. This method enabled us to form themes that assisted in creating a framework and guidelines for designers aiming to facilitate embodiment across everyday life through pneumatic-based bodily extensions.

4 DESIGNING BODILY EXTENSIONS

4.1 Case Study 1: Leveraging contextual cues to support movement across everyday life through bodily extensions

We implemented three unique bodily extensions aiming to support movement as a form of embodiment across the following everyday life scenarios: 1) "Pardon?": Moving a user's ear forward and enlarging it whenever the system senses the words "Beg your pardon?" (through a smartphone's microphone) (Fig 1A); 2) Greetings: Promoting a good-bye gesture by moving the user's hand towards such a gesture if the system senses the words "good-bye"; 3) Take a break: Moving the user's hands away from the keyboard to encourage a break from typing (Fig 1C). We demonstrated two different inputs, speech and an automated timer (user configurable) to leverage the context around a user [35–37].

4.2 Case Study 2: Leveraging physiological cues from the user's body to facilitate bodily awareness across everyday life through bodily extensions

In our first case study, we found that the bodily extensions, while promoting movement, also helped participants become more aware of their bodies. However, this awareness primarily extended outwards, aiding them in understanding their body's response to environmental contexts. In our second case study, we shifted our focus to explore how these bodily extensions affect users when the input transitions from contextual (related to the environment) to physiological cues (related to their own bodies). This shift aims to gain insights into the users' perception of self and the physical construction of their bodies.

Pneunocchio. Pneunocchio's design is inspired by the story of Pinocchio, where the character's nose elongates whenever he lies. In our adaptation, we created a pneumatic nose-based bodily extension that responds to the user's physiological activities indicative of lying using Electrodermal Activity (EDA) and Photoplethysmography (PPG) (Fig 1B). Our design's playfulness is intended to spark discussions about the nature of lying and its physiological indicators, as well as to challenge and transform the user's perception of their body when the nose-based extension inflates [38].

PneuMusculus. PneuMusculus is designed to reflect the activity of specific muscle groups as a result of physical exercise, such as when working out, which is represented through a pneumatic-based bodily extension that resembles (much accelerated) muscle growth. The system measures a muscle's electrical activity and inflates the bodily extension accordingly. PneuMusculus can sense the duration and intensity of electrical activity in the user's biceps and calves. It then inflates the corresponding bodily extension proportionally to this activity in terms of time and size. This bodily extension aims to inform users about their muscular activity and offer a tangible representation of the exertion performed.

PneuBelly. PneuBelly is a bodily extension designed to capture the sound activity in the abdomen, known as stomach rumbling or borborygmus, to promote awareness of the user's abdominal activities throughout the day. It is a pneumatic-based device that users can wear around their stomach. The device inflates in response to the intensity and frequency of sounds emanating from the abdomen. Calibrated to detect sounds as low as 10 dB, PneuBelly aims to provide a tangible representation of the auditory signals, helping users learn about the functioning of their gut.

5 CONTRIBUTION AND BENEFIT

The goal of this PhD is to advance the design of bodily extensions that facilitate embodiment across everyday life. By experimenting with various materials and synthesizing the findings from our two case studies, we plan to develop a set of design strategies for researchers designing similar augmentations. Following these case studies, our aim is to establish a user experience framework informed by field studies involving 48 participants, based on the design of our bodily extensions that respond to contextual and physiological input.

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