Towards a Design Space of Proprioceptive Interaction

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Proprioceptive interfaces allow users both, to acquire information by actuating human bodies and to receive input through captured body movements. While humans as well as most user interfaces mainly rely on vision to receive information, proprioceptive interfaces extend established interface modalities and thus, not only quantitatively increase the information bandwidth but also enrich the information quality. This paper discusses the general concept of providing information through proprioception and gives an overview of previous research. It moreover describes our exemplary implementation of the concept and proposes how possible future work could reduce research gaps in that area, aiming to build a design space of proprioceptive interaction.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**; **Interaction techniques**.

Additional Key Words and Phrases: Proprioception; Exoskeleton; Haptic feedback; Infovis.

ACM Reference Format:

Takashi Goto and Katrin Wolf. 2022. Towards a Design Space of Proprioceptive Interaction. In *Workshop on Visuo-Haptic Interaction, 2022, Rome, Italy*. ACM, New York, NY, USA, 4 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION & BACKGROUND

A variety of technologies helps us to acquire information. However, vision dominates these technologies as well as our perception, using additional modalities can have true benefits for information presentation.

Proprioception is part of haptic sensation and is the perception or awareness of the position and movement of the body. This is realized through the body's ability to sense its location, movements, and, actions [10]. Proprioceptive feedback involves tactile and kinesthetic information. In general, proprioception can support people who are blind or partially sighted [8], but also serve as an additional modality for information exploration.

Proprioceptive interaction is originally proposed by Lopes et al. [4]. They proposed the concept to utilize users' poses to interact with computers, and the interaction design allows users to provide input to and receive output from the computer by actuating their bodies using wearable devices. These devices induce the user's body movements by applying Electrical Muscle Stimulation (EMS). Tamaki et al. developed the EMS device for guiding users to perform physical tasks (i.e., training for a string instrument) [9], they described that the wearable device does not hinder touching physical objects. Even though some mechanical devices were used to proposed for controlling the user's hand, the use of EMS was opened up design space as a way to communicate information through proprioception. Both EMS and exoskeletons have pros and cons for actuating body, but the core value of proprioceptive interaction is the capability of conveying information by actuating human body. Here, we question how effectively we can convey information through body actuation? And how these approaches affect human perception to acquire information?

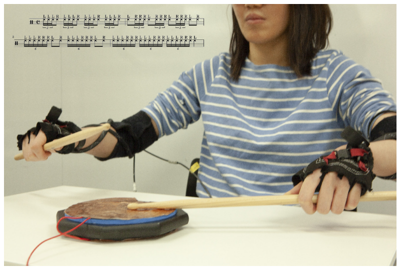

Fig. 1. We created a haptic system that actuates users' wrists to automatically perform complex drumming patterns. The exoskeleton consists out of pneumatic artificial muscles. Two-handed drumming patterns was easier to acquire with our system than using the traditional auditory feedback approach that novice drummers use (musical score and metronome beeps signifying each note and hand).

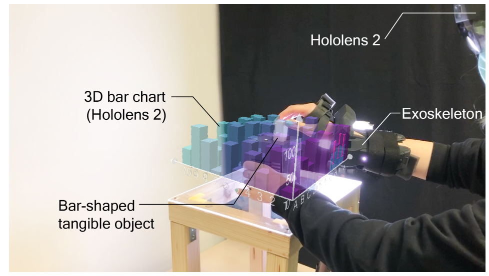

Fig. 2. Our exoskeleton-actuated TUI allows users to edit and to "feel" a 3D bar chart displayed on Hololens 2. They can select a single bar of the chart by moving the bar-shaped tangible object itself and overlaying it with a virtual bar seen through the Hololens. Users can then push/pull the physical bar and hence, realize data input. Their hand can also be moved by the exoskeleton, which serves as output and lets users feel the bars' values.

In our research, we extend the scope of research on proprioceptive interaction, which has been used as input modality so far, through allowing users for both proprioceptive system input and output. Beyond that aim, we will explore how different technologies might influence information quality and quantity. While previous research used electrical muscle stimulation (EMS) [5, 6], we will explore further ways of information presentation. Our here overviewed research intends to extend the applicability of proprioceptive interaction to also make it usable for information presentation of larger bandwidth, such as for music and data exploration.

2 PROPRIOCEPTIVE FOR INFORMATION PRESENTATION

Proprioceptive interaction is interaction design based on human posture, giving input to and receiving output from computers involving body actuation [4]. Lopes et al. almost only used EMS devices because the device does not cover fingertips, and the setup is quite light. While EMS devices are one of the best approaches for proprioceptive interaction, it is hard to use such as difficulty to find the correct positions of electrodes, low control performance, and sometimes very painful stimuli. Here, we would like to emphasize that moving the body by computers is a core part of this concept, so any technologies that are enabled to actuate the human body (e.g., exoskeletons) will also be available for proprioceptive interaction.

However, proprioception interaction is proposed by Lopes et al. for information acquisition, in InfoVis, mainly the graphical approach is used to understand data visually [1]. While these researchers tend to design visual information appearance to increase data exploration efficiency, a promising and novel way to interact with data representation to acquire information could be (additionally) realized by touching the data. Shape-changing interface, for example, were used as kinetic sculptures to show data, which provides various ways for data exploration. When inForce, for example, allows users to explore volumetric data [7], they can intuitively understand what data looks like by touching them and receiving haptic feedback. The use of different modalities of data representation does not always contribute to increasing efficiency, but it may help users to acquire information more intuitively or ease to understand complicated information.

While proprioceptive interaction has the potential for designing intuitive interaction, we still need to explore ways to retrieve quantitative and qualitative data in a beneficial way. Affordace++ is well designed to intuitively teach the use of the tool by actuating human bodies [5], which inspired many other researchers, including us. While EMS was used in the research field of HCI for a variety of applications, the promise of using proprioceptive feedback to actually support skill acquisition and training users is still lacking empirical validation. Our project unveiled how pneumatic artificial muscles impact skill acquisition, using two-handed drumming as an example use case (see Fig. 1) [2]. Proprioceptive feedback was used to demonstrate how to drum and its timing. The interaction design improved participants' correct recall of drumming patterns significantly when compared to auditory training. Participants of a user study in this project were not well trained in musical instruments. Thus, they could not understand the scores designed for the task. Proprioceptive feedback allowed them to understand the score and trained them for the rhythm by directly actuating hands. In comparison, audio feedback only notified the timing, and it made the task harder to understand.

It is well known that haptics, in general, has lower information bandwidth than vision [3]textcolorredadd citation. Hence, proprioceptive feedback as an addition to vision is a more promising information design than using proprioception only. Interaction involving multiple modalities can save our mental effort (multiple resource theory) [11], which makes haptic feedback, including touch and proprioception, a promising candidate to support large data exploration and manipulation in a cognitively ergonomic way. Thus we explore the design of proprioceptive feedback to extend visualizations.

Our project, Exoskeleton-Driven TUI is an interactive system to interact with digital content such as 3D bar charts for data exploration and manipulation (see Fig. 2). The system consists of a commercial exoskeleton and a bar-shaped tangible object. It supports proprioceptive data input/output for 3D bar charts displayed on an AR headset. Proprioceptive input is captured through sensing the hand motion when the user is changing the bar value by pushing or pulling the data representing the tangible bar. Data output using proprioception is realized through activating the bar and letting the user feel the bar growing or shrinking when touching the tangible bar. While the accuracy of reading data through proprioception lacks bandwidth, data manipulation through proprioception is easy and intuitive. Moreover, proprioceptive feedback is capable of providing relative information for data exploration. With this project, we aimed to reduce the gap in using proprioceptive interaction to extend visual data representation. Exoskeleton-Driven TUI provides two types of input (i.e., the position of TUI on a 2D surface and the position of the bar part of TUI) to interact with the visualization, while the exoskeleton also provides two types of output (i.e., continuous force and vibrating). As shown in Fig. 3, Exoskeleton-Driven TUI supports greater input and output bandwidth as well as Affordance++ [5]. Previous projects, which share the concept of proprioceptive interaction, have a different amounts of input and output bandwidth. Proprioceptive interaction with more information bandwidth has the potential to provide a richer experience.

For example, proprioceptive interaction uses input gestures to provide continuous control for a video [4], and it supports greater bandwidth of input and output bandwidth than only on/off commands or other discrete commands. Affordance++ supports several gestures for multiple objects by applying EMS to teach how to use these tools [5], thus it has greater output bandwidth than [4], which is capable only to move the user's hand for flexion/extension as a single gesture. Possessed hand also does not support multiple gestures, but it is capable to move the user's fingers for flexion/extension rather than hand [9]. For an understanding systematic view of proprioceptive interaction, we need to have measures to categorize them, and we focus on information bandwidth. On the other hand, Lopes et al. [6] has smaller input and smaller output bandwidth. While their work renders the weight of objects, it only provides continuous force when the user's hand collides with virtual objects. Goto et al. [2] also have smaller input bandwidth than the others because it only rotates the user's wrist to drum following predefined drumming patterns. It would be worth exploring how also these technologies influence bandwidth.

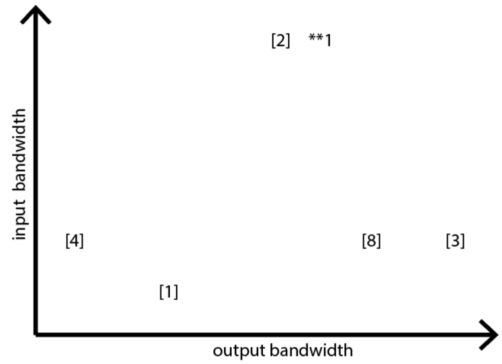

Fig. 3. Previous research addressing the two key aspects of proprioceptive interaction (**1: Exoskeleton-Driven TUI).

3 CONCLUSION

In this paper, we introduce the design space of proprioceptive interaction to acquire information using the two dimensions input and output bandwidth. The design space shows two research gaps: 1) understanding how to systematically increase input as well as output bandwidth for proprioceptive interaction, and 2) understanding how the technology used influences bandwidth. For future work, we will develop a system and conduct user studies to bridge these research gaps. For future work, we will explore proprioceptive interaction more intensively, aiming at reducing the highlighted research gaps.

ACKNOWLEDGMENTS

We thank co-authors for their support and contributions to my research, and the people who helped to conduct experiments. We further acknowledge the financial support provided by Landesforschungsförderung Hamburg (LFF) within the KIMRA project (LFF-WKFP 07-2018)

REFERENCES

[1] Mackinlay Card. 1999. *Readings in information visualization: using vision to think*. Morgan Kaufmann.
[2] Takashi Goto, Swagata Das, Katrin Wolf, Pedro Lopes, Yuichi Kurita, and Kai Kunze. 2020. Accelerating Skill Acquisition of Two-Handed Drumming using Pneumatic Artificial Muscles. In *Proceedings of the Augmented Humans International Conference*. 1–9.
[3] Kenneth J Kokjer. 1987. The information capacity of the human fingertip. *IEEE transactions on systems, man, and cybernetics* 17, 1 (1987), 100–102.
[4] Pedro Lopes, Alexandra Ion, Willi Mueller, Daniel Hoffmann, Patrik Jonell, and Patrick Baudisch. 2015. Proprioceptive interaction. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 939–948.
[5] Pedro Lopes, Patrik Jonell, and Patrick Baudisch. 2015. Affordance++ allowing objects to communicate dynamic use. In *Proceedings of the 33rd annual acm conference on human factors in computing systems*. 2515–2524.
[6] Pedro Lopes, Sijing You, Lung-Pan Cheng, Sebastian Marwecki, and Patrick Baudisch. 2017. Providing haptics to walls & heavy objects in virtual reality by means of electrical muscle stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 1471–1482.
[7] Ken Nakagaki, Daniel Fitzgerald, Zhiyao Ma, Luke Vink, Daniel Levine, and Hiroshi Ishii. 2019. inFORCE: Bi-directionalForce'Shape Display for Haptic Interaction. In *Proceedings of the thirteenth international conference on tangible, embedded, and embodied interaction*. 615–623.
[8] Sabrina Paneels and Jonathan C Roberts. 2009. Review of designs for haptic data visualization. *IEEE Transactions on Haptics* 3, 2 (2009), 119–137.
[9] Emi Tamaki, Takashi Miyaki, and Jun Rekimoto. 2011. PossessedHand: techniques for controlling human hands using electrical muscles stimuli. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 543–552.
[10] John C Tuthill and Eiman Azim. 2018. Proprioception. *Current Biology* 28, 5 (2018), R194–R203.
[11] Christopher D Wickens. 2002. Multiple resources and performance prediction. *Theoretical issues in ergonomics science* 3, 2 (2002), 159–177.