Towards the Next Generation of Extended Reality Wearables

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ABSTRACT

Extended reality (XR) systems are among the most prominent interactive environments of today's entertainment. These systems are often complemented by supportive wearables such as haptic gloves or full–body suits. However, applications are usually limited to tactile feedback and gestural controls while other strong parts of wearables such as the performative, social and interactive features are neglected. To investigate the ways of designing wearables for playful XR environments by drawing upon these strong parts, we conducted five participatory design workshops with 25 participants. Our study resulted in 14 design concepts that were synthesized into three design themes that include 9 sub-themes, namely *Virtual Costumes*, *Modification of Bodily Perception* and *Social Bioadaptivity*. The knowledge created extends the design space of XR wearables and opens new paths for designers and researchers to explore.

CCS CONCEPTS

• **Human-centered computing → Interface design prototyping**; **Ubiquitous and mobile devices**; **Virtual reality**; **Mixed / augmented reality**; **Participatory design**.

KEYWORDS

Wearable, Virtual Reality, Augmented Reality, Participatory Design, Game Design

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1 INTRODUCTION

As Extended Reality (XR) applications become wide-spread, many different types of hardware accompanying head-mounted XR displays got integrated into eco-system. Haptic controllers, tracking systems, 360-degree treadmills, tactile gloves or suits complement these environments for increased immersion and better player experience. Wearable devices are among the most common peripherals frequently proposed for a complete XR experience and besides many research projects that develop wearables [2, 10, 15], even the movies such as "Ready Player One" envisions that different types of wearables from gloves to full-body suits will enhance the XR experience through different interaction modalities.

Although there are remarkable amount of interest in XR wearables, the applications usually remain within the limit of providing enhanced haptic feedback and incorporating body data [9, 15, 17, 20]. Wearables are surely suited for those applications, yet, other strong parts introduced by playful wearables such as 1) their strength in affording social interactions [1], 2) qualities related to self-expression, costuming and character identification [6, 18] and 3) variety of interaction modalities that can be accommodated by wearables [8, 31] are underexplored in the XR field.

There are a few projects that touches upon the above topics. For example, Childhood utilizes a miniature child-hand prop, a waist-worn camera and a non-functional hood for simulating the experience of a child in a VR environment. This project benefits from the transformative power of wearables and costuming qualities to create a sense of embodiment between the user and the child they are impersonating [27]. Another project is FaceDisplay [14] that adds displays and touch areas to VR headsets to create social experiences shaped around asymmetric interaction. These projects are good examples of incorporating wearables in XR environments and draw on strong parts such as transformativity, self-expression or affording social interaction as defined by the design framework for playful wearables [6].

Studies on gaming wearables, not exclusively for XR, exploited the above mentioned strengths of wearables with several in-depth studies. Hotaru [16] and Magia Transformo [18] aimed at enhancing social interaction and performativity; these projects examine design-related qualities of wearables, such as their visual aspects, interface properties and affordances. In addition to embodied modalities, wearables have also been envisioned to adopt tangible and embedded interface modalities that are attached to body [31]. In line with this, another project - WEARPG [8]- is an augmented role-playing game system that examines customisability, tangibility and character identification with wearables. These playful wearable projects show that wearables can increase the connectedness to imaginary worlds and thereby the immersion experience, which is critical for XR experience. These strong points were also further emphasized by the design framework for playful wearables [6] which examines playful wearables in three dimensions: performative, social and interactive. Mentioned strengths of wearables emphasized by previous studies were rarely considered by most XR wearable projects. Thus, contributing to the body of knowledge in this area through in-depth design studies is crucial to extend the design space of XR wearables for creating enhanced embodied experiences that are critical for these environments.

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To fill this gap and extend the design space of XR wearables, we have organized a series of participatory design workshops with 25 participant from different backgrounds and disciplines. We organized five consecutive workshops. The first three, Atom Workshops, repsectively focused on *Bioadaptivity (utilization of body signals in games), Social Interaction and Costume Qualities* of wearables, major strengths of playful wearables according to previous studies [6, 11, 23]. The last two, Synthesis and Fusion workshops, aimed at designing holistic and detailed XR wearable concepts and user scenarios by focusing on interaction modalities. This fragmented atom workshop structure has been used by previous studies as a method for sensitizing participants [32] and creating an informed participatory environment regarding the design topic [7]. In our workshops, participants created XR games incorporating wearables since games afford different types of interactions (i.e., collaboration, competition, role-playing, strategical thinking, fast decision making, etc.) that can produce results adoptable by the broader HCI field. As a result of this process, we extracted three main design themes which includes 9 sub-themes. In this late-braking work, our main contribution is laying out these design themes and provide design recommendations that extends the design space of XR wearables.

2 METHOD

2.1 Participants

Twenty five participants took part in the workshops. Participants had various backgrounds including game design, business administration, bioengineering, interaction design and electronic engineering. 13 participants were graduate students of Tampere University from, HCI (3), game studies (2), IT (2), electric (2), mechanic (2), biomedical engineering (1) and international relations (1). One participant was a quality assurance tester from the game industry. we had 11 undergraduate students and since their domain knowledge were limited compared to other participants, they were evaluated as "players" solely. In participatory design settings, it is critical to involve different stakeholders [4, 22]. We included participants with diverse backgrounds related to wearable development for XR games to benefit from their different perspectives. Three credits were given to students who participated in the workshops. We compensated the travel costs and lunch of the external, non-student participant and granted a gift card with the value of 75€ .

2.2 Procedure

The structure of the first three atom workshops were similar with minor differences depending on the workshop's subject. We started the workshops with a presentation about the topic of the workshop, schedule and the design problems. The creation process started with a *3-12-3 brainstorming session* [13] (3-minute generation of keywords, 12-minute ideation by combining keywords, 3-minute presentation of results). 3-12-3 structure is an effective way to trigger participant to think on the subject in a quick manner and start collaboration among participants to come up with initial ideas. The concepts created in this first stage were extended into a rich variety of ideas with a more *free-form brainstorming* session (45-min) which was moderated by the workshop moderator. The morning session was concluded with a lunch break. After the lunch, we created an *affinity diagram* (30-min) [24] to categorize these ideas into themes. These themes were *voted* by participants (15-min) (each participant had right to use three votes on separate themes). This method has been proposed as an efficient narrowing down method which would also help participants to reflect on the most valuable outcomes by Gray et al. [13]. The most voted three themes (MVTs) were selected to be extended into more concrete gaming concepts by creating *paper prototypes* (30-min) and experiencing them with *bodystorming* (60-min) [25]. Each group in the workshop, then, *presented their ideas by acting* the user-scenarios to others and the ideas were further discussed among participants. After the presentation, participants filled a *questionnaire* which included open-ended questions regarding their opinion about the concepts and themes created in the workshop. Each workshop lasted 7 hours. We asked participants to prepare a *workshop diary* to summarize their experiences so that they can convey their knowledge to their peers when they come together in the Synthesis and Fusion Workshops.

The aim of the first three workshops were to sensitize participants [32] to the strong aspects of playful wearables (as suggested by [6, 11]) through making while the Synthesis and the Fusion Workshop was about using this knowledge to create concrete prototypes and use cases. Synthesis workshop started with a presentation about gaming wearables, brief summaries of Atom Workshops' topics and the MVTs. After, we divided participants into five groups which included 4-5 members. We tried to incorporate participants from different workshops and disciplines in each group. 23 participants were present in the Synthesis and Fusions Workshops. Drawing on each other's knowledge gained in the Atom Workshops, groups worked together in the Synthesis Workshop and created holistic concepts by considering the different facets of XR wearables. After concretizing the concepts in the Synthesis workshop, groups worked on prototypes and immersive video sketches in the Fusion Workshop to finalize their concepts. Both workshops lasted 7 hours and ended with a questionnaire including questions about the concepts and the workshop experience.

2.2.1 *Analysis.*

The author who moderated the workshops (first author) visualized the concepts through sketching and illustrations to familiarize himself with the details of the each concept. In total, 14 concepts (3 from each Atom Workshop and 5 from Fusion Workshop) were illustrated by consulting the videos of the workshops and questionnaires. Afterwards, the first author mapped the MVTs of the Atom Workshops to concepts to understand how they are incorporated. Furthermore, he applied a visual thematic analysis [29] to each concept by iteratively coding the unique features. After, these unique features categorized into broader themes through affinity diagramming [24]. As suggested by thematic analysis method, the researcher who will conduct the analysis should deeply familiarize themselves with the data [5]. In our case, visual thematic analysis is conducted by the first author since he moderated the workshops and could read into the concepts in a more informed way. In the following parts of the paper, we explain these themes by analyzing their relation to selected concepts through an Annotated Portfolio [12], an established way to extract design knowledge in research through design studies [33]. Here, we did not include all the concepts due to the space constraints and elaborated the concepts that comprehensively reflects the extracted themes.

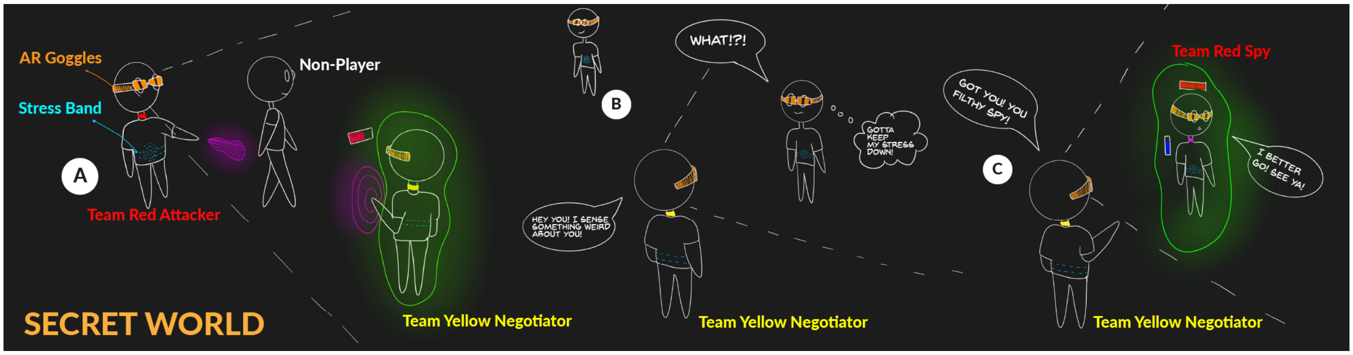

Figure 1: A) Team Red Attacker attacks the Team Yellow Negotiator. Negotiator reflects the attack back with a class-specific shield ability. B) As glasses look like regular glasses, Spy Classes can hide themselves by turning off their auras. However, Yellow Negotiator is suspicious. C) Yellow Negotiator can track Stress Levels (measured by the stress band) of others to reveal the identities of spies.

3 DESIGN THEMES

3.1 Virtual Costumes

Virtual Costumes, prevalent in several projects, refers to complementing a physical artifact with a "virtual" layer to create a costuming experience. While *Virtual Costumes* (**Fig. 3 - Right**) featured a full-body virtual costume, others incorporated partial (*Cyber Bracelet* - **Fig. 2**), hidden (*Secret World* - **Fig. 1**) or interactive (*Pirate Crew* - **Fig. 3**) costumes.

3.1.1 Visibility Level. Secret World is an AR game where players need to spot other "inconspicuous" players in order to beat them. These players can be spotted by their green aura in AR view, however it is hard to realize them in reality because the stress band is worn under the shirt and the AR goggles looks like regular daily glasses. Visibility Level theme suggest that the wearable can be invisible in the real life but visible in the virtual world. As also in Virtual Costumes project, only markers on the body is visible in real life while the rest of the wearable is visible in the virtual environment. *Therefore, interaction between the visibility levels of virtual and real parts of the costume is something that designers can alter for designing different game/interaction mechanics and actions.*

3.1.2 On-Body Partiality. As in *Virtual Costumes* and *Cyber Bracelet*, by placing partial artifacts on the body, interactions which use the body as a platform/surface can be created. For example, in *Virtual Costumes*, the cuff module of the costume can be pulled and pushed through the arm to shoot a projectile. *Therefore, placing physical artefacts on the body can allow diverse set of mappings in the virtual world which can create dynamic interactions on virtual costumes.*

3.1.3 Featured Costumes. In *Pirate Crew* (**Fig. 3-Left**), each wearable has different features and therefore grant different skills to players. For example, captain wears an eye-patch which shows the location of the enemies when looked through, while the musketeer wears a glove which fires rifles with gestural control. *Thus, designers can assign "functional" features which are related to the physical aesthetics of XR wearables and grant specific abilities to players which can increase the sense of embodiment with their fictional characters.*

3.1.4 Balance of Diegesis. While wearables can become costumes, they can also be a part of the game interface. The balance between the diegetic costume and the non-diegetic interface is critical *because while costumes can strengthen the sense of embodiment, a non-diegetic interface bound to the virtual costume can break the*

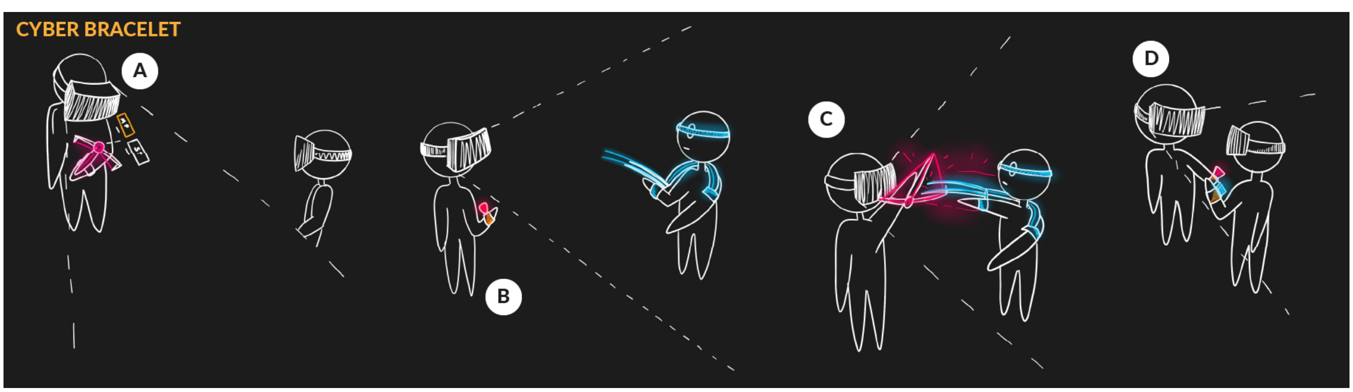

Figure 2: A) The player chooses multiplayer (MP) mode through the wearable-centered interface. Until the MP mode is chosen, the player can't see other players, B) The pink glowing real world tangible part looks like a full weapon in VR environment, C) Two players are fighting, D) Pink player beats the blue player and steals the real tangible part of the wearable representing the virtual weapon.

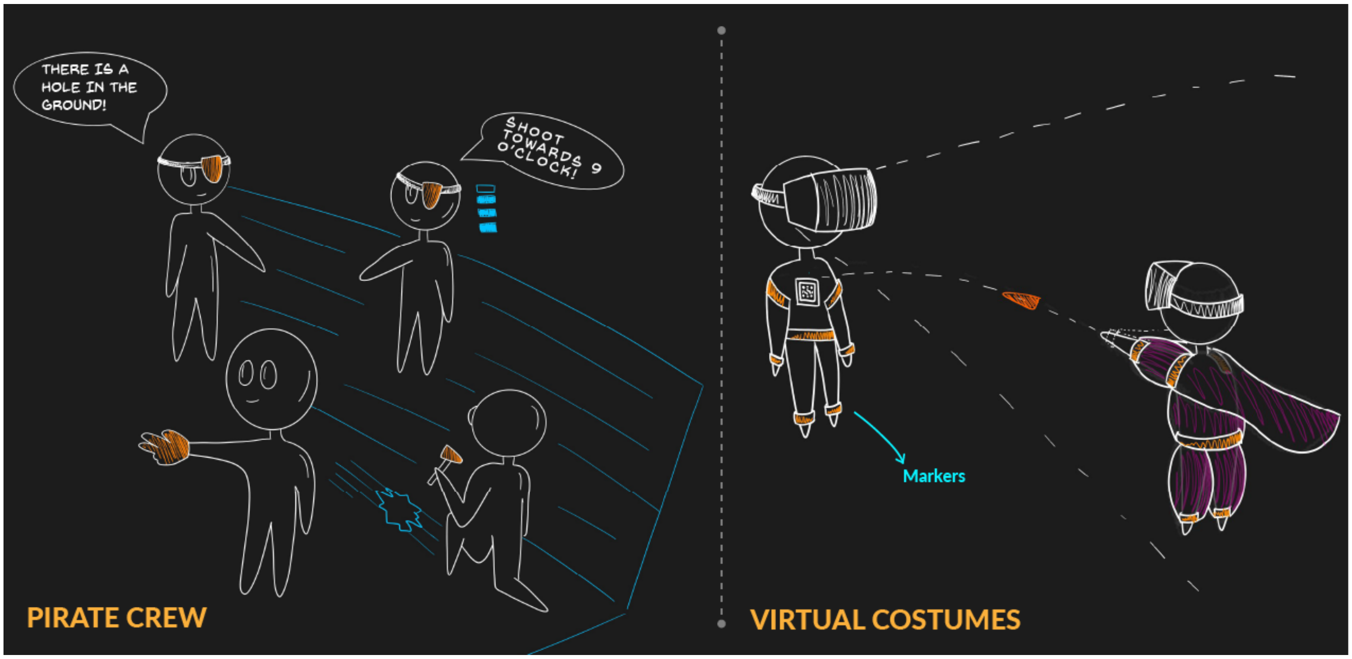

Figure 3: In *Pirate Crew*, players have wearables that grant different abilities bound to the interaction modalities they provide. Players can see the virtual world through eye patches while gesture tracking glove can be used for shooting. *Virtual Costumes*: Wearable pieces form a virtual costume when looked in a virtual environment. It also uses the physical properties of the body for forming game mechanics. For example, the cuff piece can be pulled back and pushed forward to fire a projectile.

illusion. For instance, the interface in *Cyber Bracelet* is centered around the wearable diegetically, but the stress bars in *Secret World* remain disconnected from the story, contrary to the green auras.

3.2 Modification of Bodily Perception

Bodily modification theme refers to using wearables for changing the capabilities, dimensions, affordances or the sensations related to body. *Gravity Chamber* (**Fig 5 - Left**), *Sensory Vest* (**Fig 5 - Right**) and *Blow Bites* (**Fig 4**) are examples of how wearables can change the perception of body in XR environments.

3.2.1 Inducing Physical Effects. Participants proposed changing the bodily perception by inducing physical effects. *Sensory Vest* can change the temperature of the body and measure the stress level while altering the game content to induce a certain level of stress. Designers of this project speculated that certain type of emotions such as "hunger" can be induced by providing changes in body temperature and stress level. Similarly, in *Gravity Chamber*, experiences such as fatigue can be induced by changing the magnetic forces affecting hand and foot-worn wearables. Although creating such "gravity chamber" is costly and unlikely with the extant technology, *these projects envision wearables that can change bodily affordances by altering the sense of embodiment and willing suspension of disbelief through sensory or physical alterations.*

3.2.2 Around-Body Dangling Interfaces. It is also possible to alter the proprioception of the body by developing "extending or dangling" interfaces. In *Glow Bites*, designers envisioned a game which

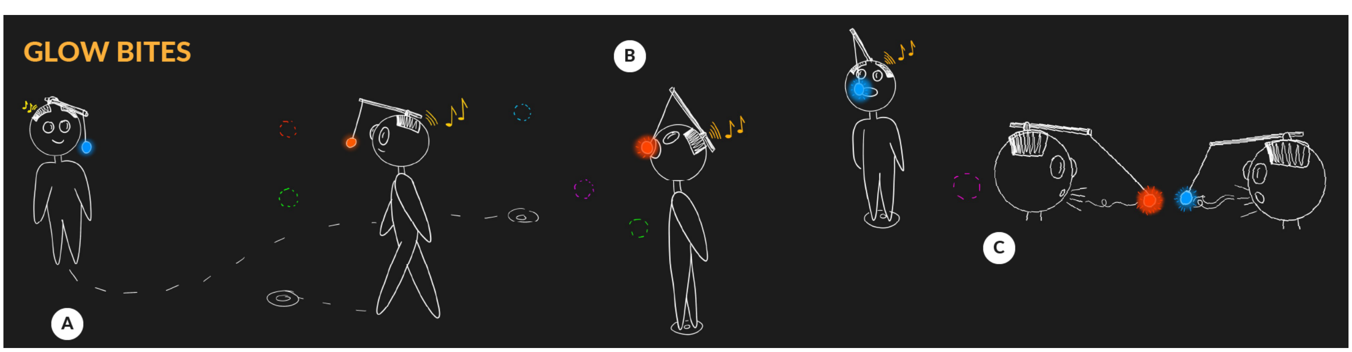

Figure 4: A) Players search for the invisible glowing bites by following the sound and the brightness of the dangling ball B) One Players find Fire and the other finds Ice Bite, C) Players fight by blowing into the bites

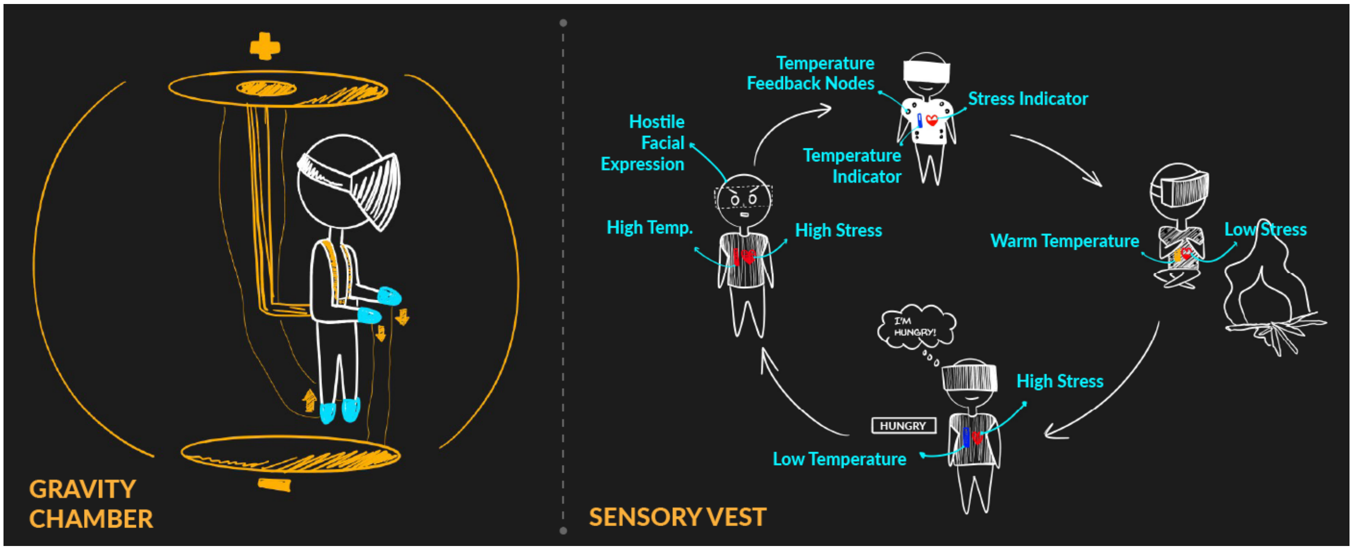

Figure 5: *Gravity Chamber* is a platform that makes players float by creating a magnetic field in which players can move however they want in the game. They also envisioned foot and hand-worn wearables that provides force feedback by changing the magnetic forces upon them to simulate effects such as weight or fatigue *Sensory Vest* allows player to feel the temperature of the Virtual Reality Environment (VRE). It also aims to induce emotions through temperature changes. In one of the scenarios, player's avatar gets hungry and vest lowers the temperature while induces in-game content that would increase the stress of the player which eventually would lead to the feeling of hunger.

is guided by a dangling ball and operated with a blow-based interaction. *By integrating interfaces placed around the body, designers can design means of active tangible interaction while also stimulating bodily movements such as "lifting or bowing" the head to move the dangling interface. Unconventional interaction modalities such as "blowing" can also be used and may result in a heigthened sense of altered body with the augmentations in VRE.*

3.3 Social Bioadaptivity

Social bioadaptivity was also another cetnral theme. Participants of Bioadaptivity workshop voted "Social Bioadaptivity" as one of the important themes while one of the MVTs of Social workshop was "Biosensory Information". Consequently, different ways of using bioadaptive data for social interaction with XR wearables emerged.

3.3.1 Showing or Hiding. One of the mechanics introduced by *Secret World* (**Fig. 1**) was the necessity of hiding the stress level measured by the stress band. In this game, "Spy class" can hide the "green aura" to spy on other teams. However, "Negotiator Class" can sense unusual individuals and reveal their identity. In these cases, biosensory information such as hearth rate should be hidden by the player to avoid detection. *Hence, hiding or showing bodily information can be central to game mechanics and wearable systems should allow alterations in their visibility.*

3.3.2 Extending Biosensory Expressions. Another social mechanic implemented by *Sensory Vest* (**Fig 5-Right**) and *Moody Glove* (**Fig. 6-Right**) was to use the biosensory information for creating bodily or facial expressions. Moody Glove envisioned a glove which has a "face" of which the expression changes with gestures and through bodily data. These projects suggested that *biosensory information can become another way of communication in XR environments and this can also be done in unconventional ways such as mapping a face to the palm instead of showing it in the real face.*

3.3.3 Collective Bio-entity. Designers of *Emoti Ball* (**Fig. 6-Left**) proposed that the bio-signals can have a broader affect on a team performance. Members of the team should try to synchronize their mood and keep the morale high, otherwise game mechanics will induce effects such as fatigue or change the trajectory of the ball. *This project suggests that XR wearables can create a heightened sense of bonding by becoming "biosensory jerseys" for team games.*

4 DISCUSSION AND FURTHER DIRECTIONS

In this paper, we reported a series of five participatory design workshops that we conducted with 25 players to enhance our understanding of the ways for designing XR wearables by drawing on the strong parts of playful wearables highlighted by the previous research [6, 11]. Our investigation resulted in 14 XR game wearable concepts created by participants and yielded 3 design themes and 9 sub-themes prevalent among the envisioned concepts.

Virtual Costumes theme is an example of what XR environments can add to the costume properties of playful wearables which has been recognized by previous work [6, 18]. Previous studies frequently used these costuming qualities as a way to enhance player and character relationship by using wearables as skill bits which improve and alter the in-game characters when different wearables are worn [8, 18, 19]. Addition of the virtual layer can carry the costuming qualities further by introducing different *visibility levels* in virtual or physical world, becoming *partial costumes* that can be interacted in variety of ways by using the body as a platform,

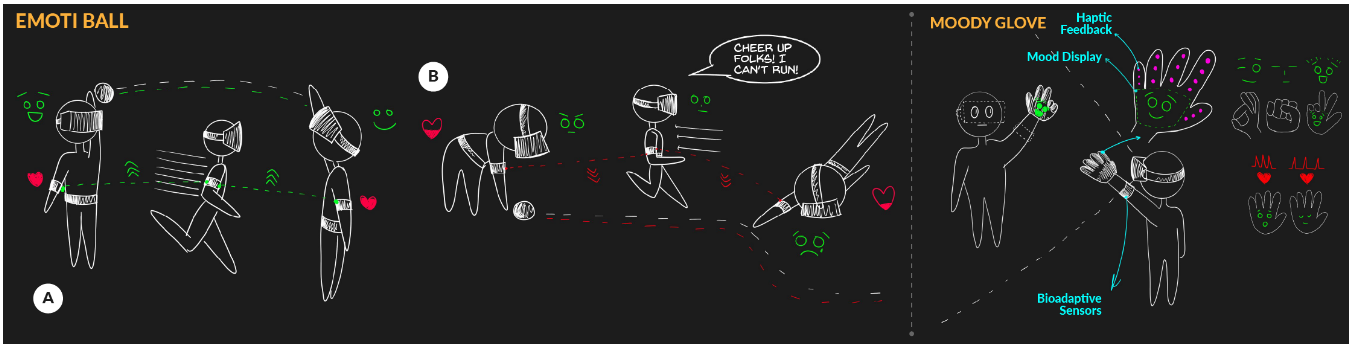

Figure 6: *Emoti Ball:* A) Biosignal Sensors indicate high morale for the team, thus everyone can run faster and ball moves straight, B) Team is demoralized, running is harder and ball does not move as expected. *Moody Glove* is an item that help players communicate. It has a face in its palm area and communicates the mood of the player to others according to gestures performed and also the biosensory information collected through a bracelet.

utilizing wearables as costumes that introduce *features and abilities* originated by their technological capabilities and the recognizing possible shifts between the *diegetic and non-diegetic* interpretations by balancing the costuming and interface qualities.

Modification of Bodily Perception has been studied widely by previous studies. For examples, Svanes & Solheim designed Tails and Ears that alter the proprioception and thereby the perception of the space body covers and how it moves [30]. Body integrated limbs has also been used in game applications as in Arm-a-Dine [26], where players try to feed each other with a robotic limb, guided by their facial expressions. Sub-themes under the *Modification of Bodily Perception* adds to these examples by recognizing the possible ways of inducing emotional and physical alterations to the perception of body which are guided by *physically altered virtuality. Around body interfaces* points towards another opportunity where designers can exploit the periphery of the body by attaching dangling or extended physical interfaces that are augmented in VRE, which can expand the possibilities beyond hand-held controllers [21].

Finally, social bioadaptive cues in VRE has been studied by previous studies in the context of emotional expressions [3], synchronization [20] or interactive performances [28]. Adding to these, our study uncovers that for fostering playful experiences in XR environments, the *visibility of the bioadaptive information* can be a source of game and interaction mechanics. Moreover, although [3] tried unnatural ways of expressing emotion in VR environments (e.g., glowing when excited), concepts in our workshops revealed other ways such as mapping them to different entities, for example limbs or companion animals. Considering biosensory expressions as a concept that can affect a group of people also promises social dynamics that can be altered in variety of ways such as synchronization, group morale boost or group based emotional challenges.

This study is the beginning of a broader investigation of designing wearables for XR environments. We formed these design themes for guiding our design process of XR wearables through a stakeholder oriented participatory method. Our next step is to create streamlines XR wearable concepts by drawing on these design themes and develop prototypes to test with users. The main intention of this paper is to present these preliminary design knowledge to HCI community to inspire and help designers and researchers who work on XR wearables in their design process. This paper contributes to the XR field by revealing ways of designing wearables beyond haptic feedback devices and extends the design space by elaborating on how social, performative and interactive properties of wearables can be leveraged in XR environments. Researcher and designers can further explore the 9 directions we have put forth in the future studies.

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