Flow State Feedback Through Sports Wearables: A Case Study on Tennis

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Abstract
Flow state is a psychological state of optimal performance. To experience flow state, one needs to receive unambiguous feedback. Previous studies have described activities with internalized feedback modalities (e.g. visual). However, they do not offer any appropriate feedback modality for the activities that need external feed-back, such as opponent-based sports. Addressing the issue, we adopted a research through design process and considered tennis as our case, in which there is a clear need of psychophysiological feedback [1]. This pictorial reveals our approach to design 6 wearable device concepts under 3 design themes as future directions for design practitioners and researchers.

Authors Keywords
Flow state; psychophysiology; feedback; sports wearable technology; tennis; research through design

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

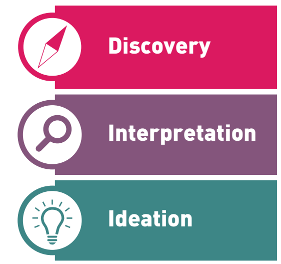
Introduction
Psychophysiology focuses on measuring psychological states and processes such as *emotion*, *attention,* and *stress*, and correlating them with physiological measures like *heart rate variability* (HRV) and *respiration rate* (RR) [2]. A particularly interesting psychological state is the *flow state* [3], which is typically characterized by an

autotelic experience. *Flow* is experienced when the self is fully immersed in an activity which meets the individual's skill level with appropriate challenge, when the individual has clear goals to overcome this challenge and experiences a sense of euphoria in the process that leads up to the optimal performance in that activity. Therefore, adapting flow state to sports, as a psychophysiological measure, creates a huge potential for optimizing performance of sportspeople.

In a previous study, in-depth interviews with 20 professionals revealed that tennis players cannot reach their optimal performance due to the mental load inherent to opponent-based sports [1]. We argue that inducing flow state in players can help them manage this mental load. Moreover, flow state, is commonly referred to as '*the zone*', in tennis [4]. Thus, we considered tennis as a design case, to develop methods and technologies to induce flow state in players.

According to the 9 dimensions of flow state (Figure 5), giving immediate and unambiguous feedback is necessary to induce flow in players [5]. We surveyed the literature for flow state feedback, and found that except games [6] which are designed especially to induce flow, most studies investigated simple activities, such as those performed through mobile or web applications [7]. Furthermore, the activities described in those studies, used internal parameters to give feedback, like speed or the visuals of the task, which is relevant for the experience of flow state [6, 8]. However, there are no fixed internal parameters in the case of tennis, since the variables of the activity are unpredictable, such as the interference of the opponent. In such cases, flow state feedback may become ambiguous. We argue that activities like tennis can benefit from external feedback modalities, which would help to provide unambiguous feedback. To the best of our knowledge, there is no information in the literature to design external feedback modalities in such activities. We speculate that in tennis, wearable technology has a potential in exploring external feedback modalities to induce flow state.

This pictorial reveals our early 5 step *research through design approach* to explore feedback modalities that can induce flow state for tennis: (1) we interviewed 6 elite coaches to learn about flow in tennis, (2) observed 2 tennis players' flow state in a game, (3) reviewed 26 related papers for important indications and (4) the appropriate modalities to induce flow state, and (5) designed 6 wearable device concepts under 3 design themes (Figure 1).



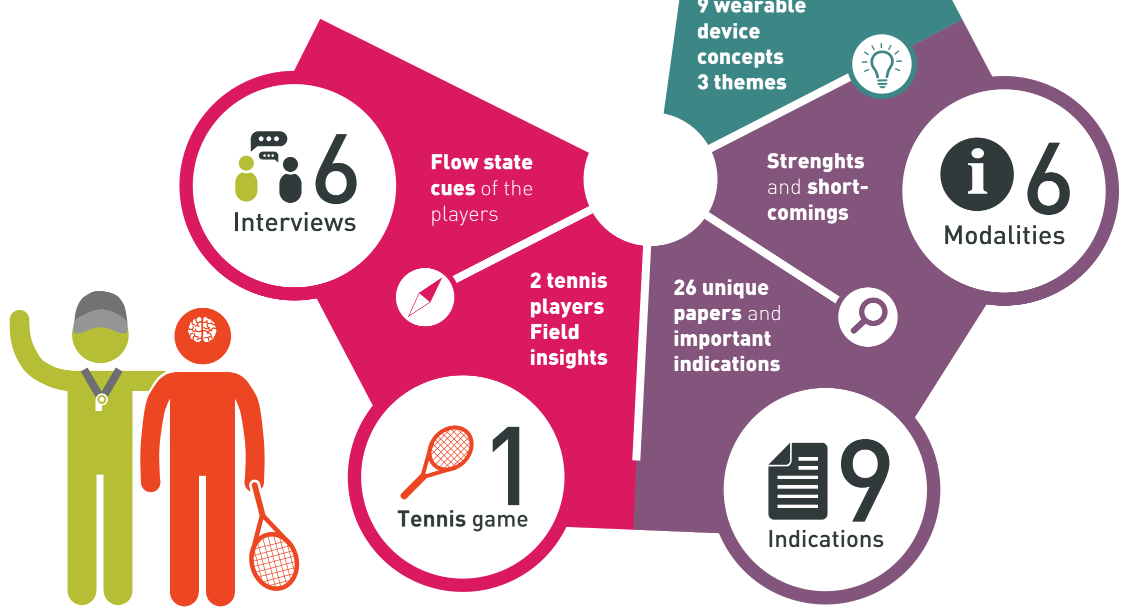


Figure 1. Flow chart, summarizing our 5 step RtD process.

Step 1. Interviews with Coaches

For initial exploration of the flow state phenomenon in tennis, we interviewed 6 *elite* coaches collaborating with Tennis Federation of [Author's country] [9] (Figure 2). We identified that tennis specific cues of flow state are mostly relevant to *body language, posture, activity* and *rituals* of the players (Figure 3). In addition, these cues are also observable to their coaches, which enables observers to identify the flow state of tennis players.

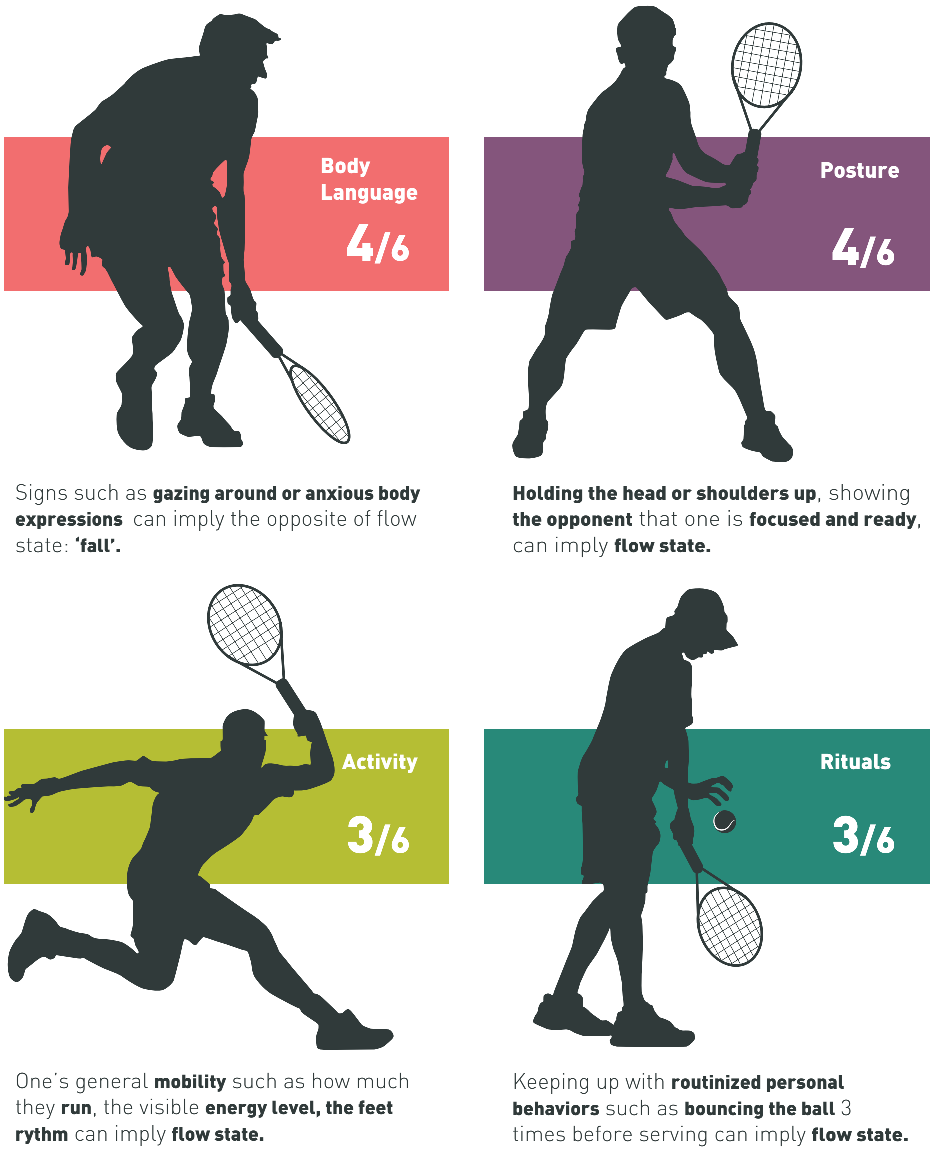


Figure 3. Tennis specific cues of flow state.

Figure 2. Our interviews with 6 elite coaches.

Step 2. Tennis Game

We observed 2 professional players' tennis game while their coach commented on their flow states. We gathered field insights for both the flow state and its opposite, the 'fall' (Figure 4).

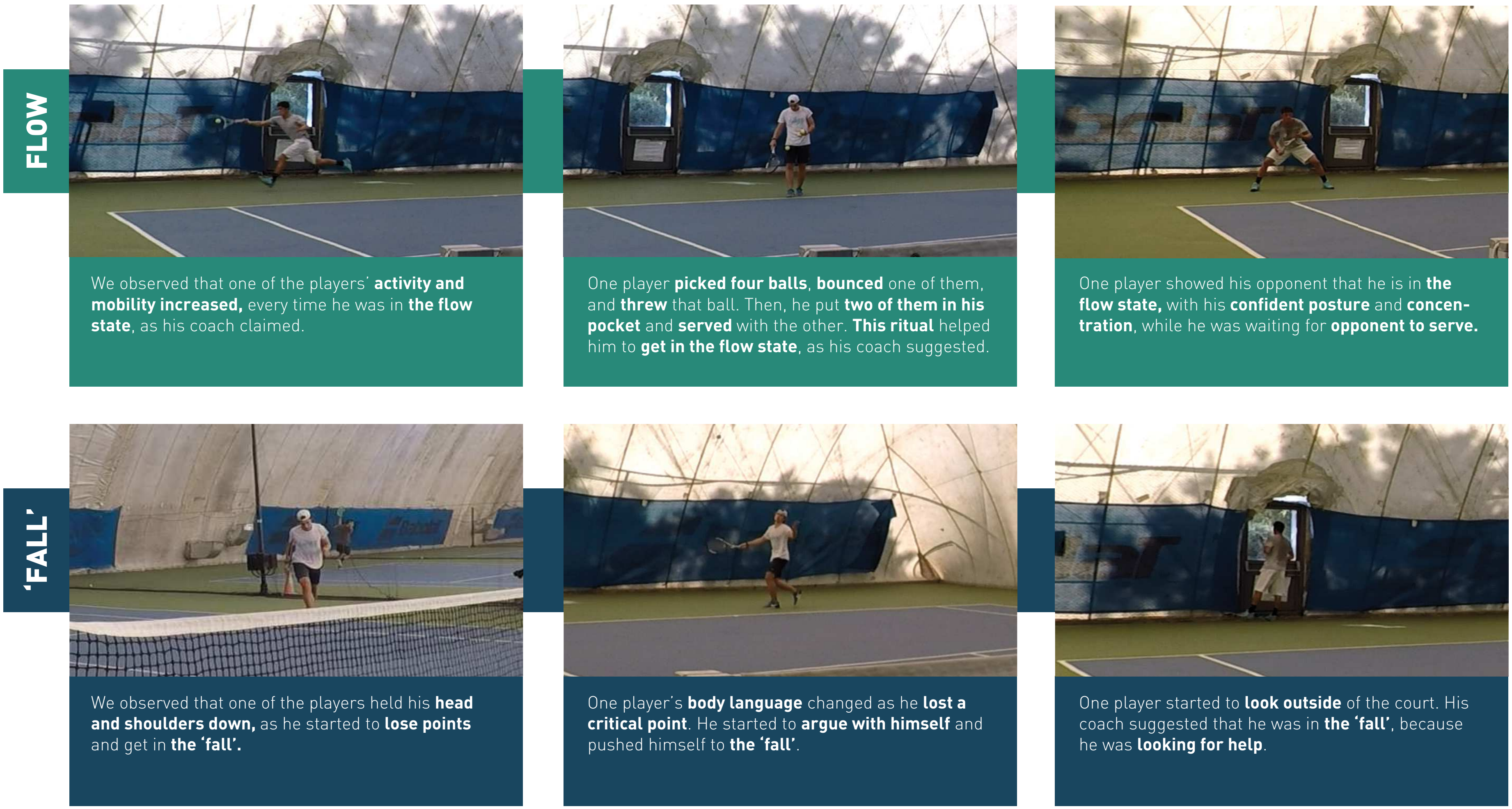


Figure 4. Field insights from the tennis game.

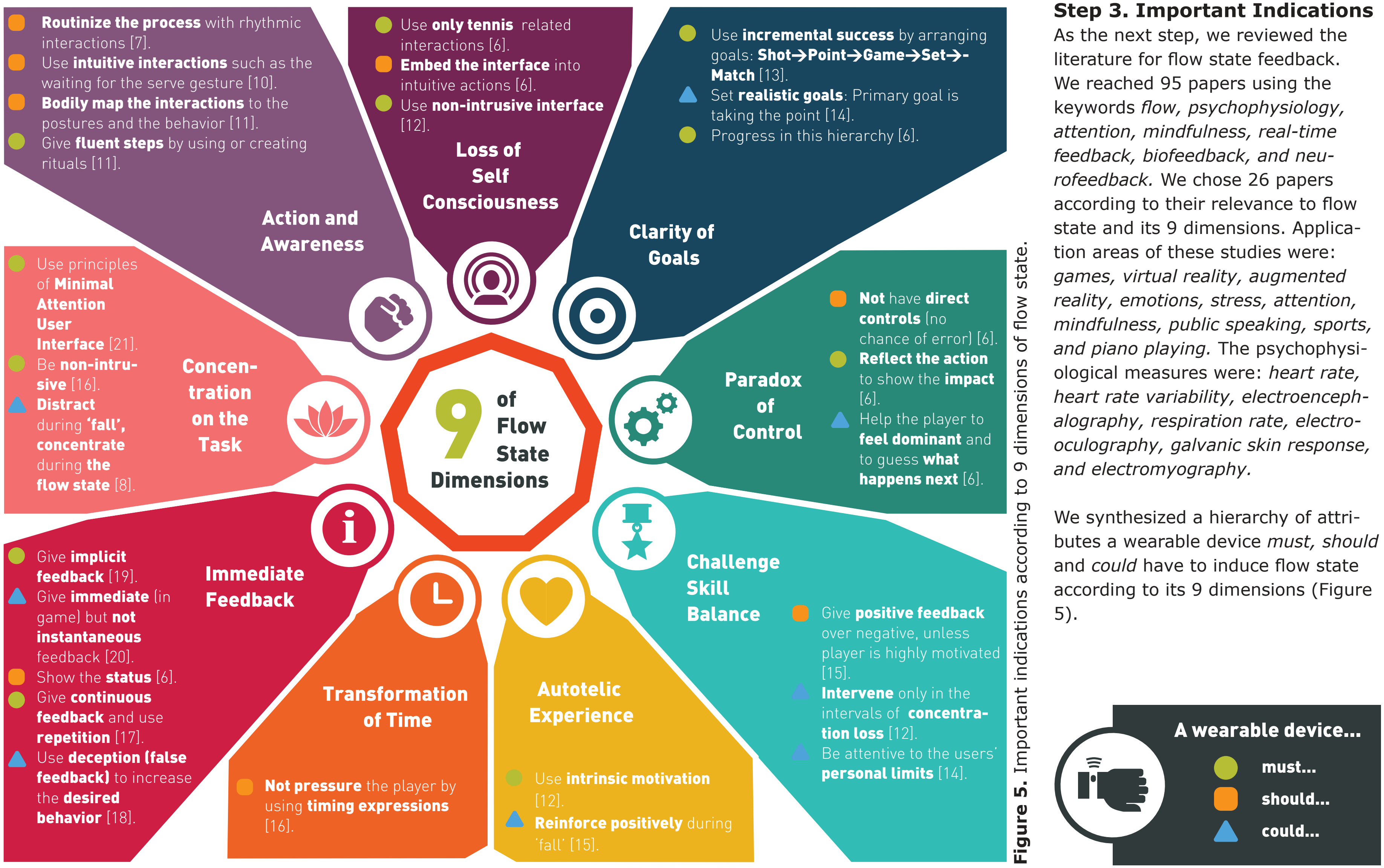


Figure 5. Important indications according to 9 dimensions of flow state.

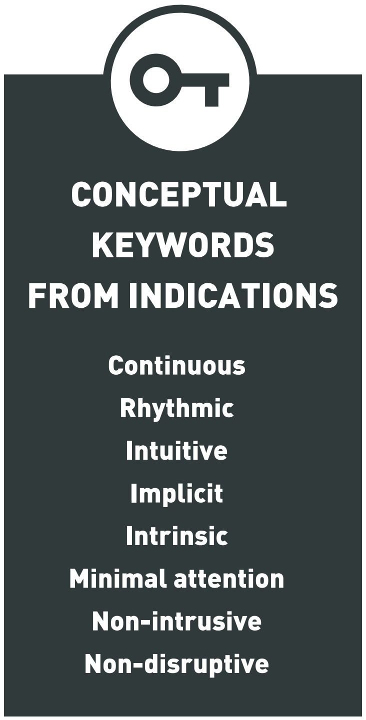
Step 3. Important Indications

As the next step, we reviewed the literature for flow state feedback. We reached 95 papers using the keywords *flow, psychophysiology, attention, mindfulness, real-time feedback, biofeedback, and neurofeedback.* We chose 26 papers according to their relevance to flow state and its 9 dimensions. Application areas of these studies were: *games, virtual reality, augmented reality, emotions, stress, attention, mindfulness, public speaking, sports, and piano playing.* The psychophysiological measures were: *heart rate, heart rate variability, electroencephalography, respiration rate, electrooculography, galvanic skin response, and electromyography.*

We synthesized a hierarchy of attributes a wearable device *must, should* and *could* have to induce flow state according to its 9 dimensions (Figure 5).

Step 4. Feedback Modalities

We grouped strengths and shortcomings of feedback modalities that are presented in the reviewed studies, to identify the most appropriate modality (Figure 6). Additionally, we mapped 'the musts' of the previous analysis to the modalities. We then generated 8 conceptual keywords to inspire wearable device concepts. We believe that the most suitable modality should be *continuous, rhythmic, intuitive, implicit, intrinsic haptic feedback*, and *minimal attention visual feedback*.



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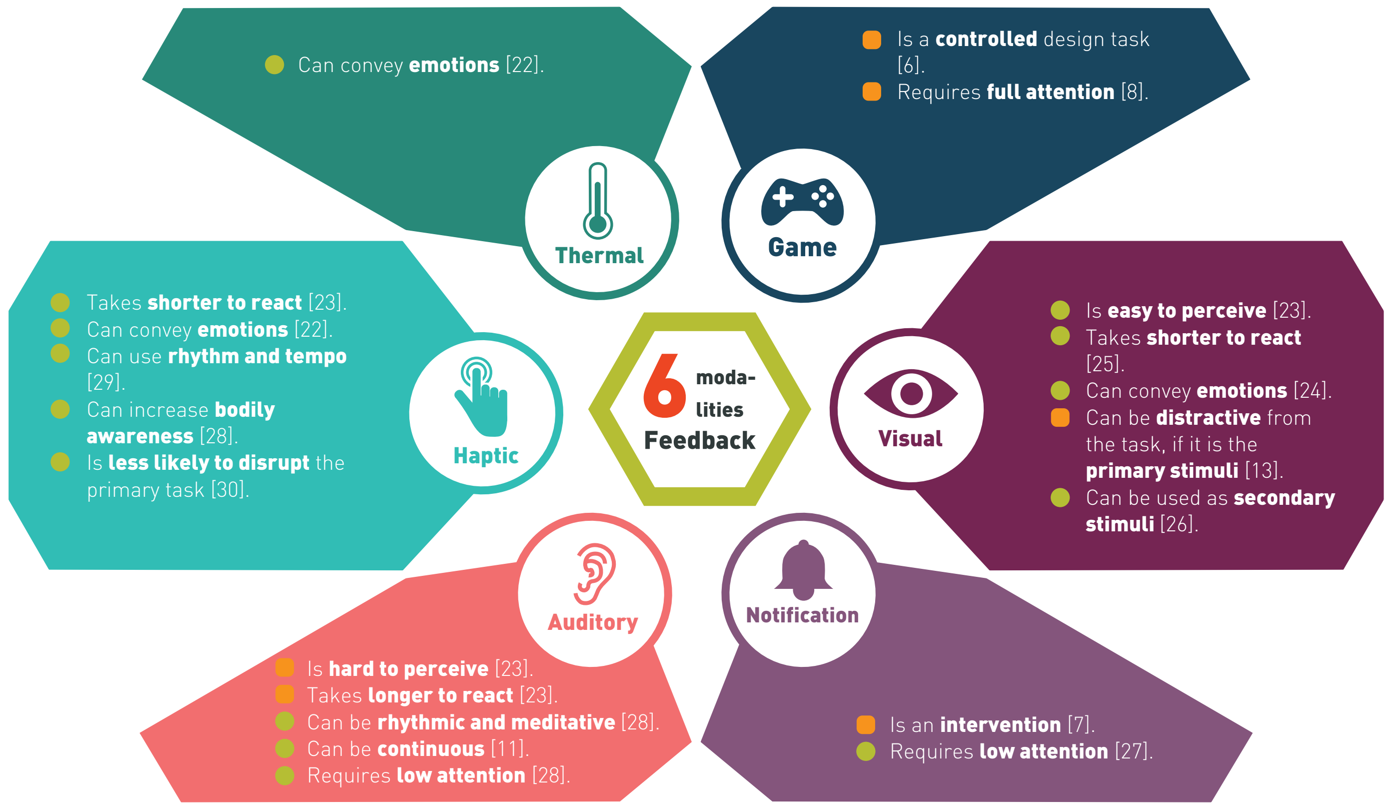

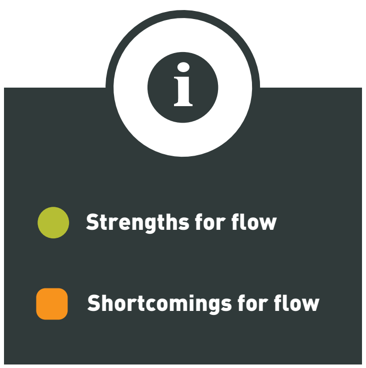

Figure 6. Feedback modalities.

Step 5. Concepts

So far, we have gathered 4 tennis specific flow state cues from coaches, and derived conceptual keywords from the literature, to design a diverse range of wearable device concepts. Accordingly, we designed 6 wearable device concepts. Note that we did not consider technological limitations in this process. In this section, we elaborate on these concepts according to 3 tennis related design themes: *tennis tools, tennis garments and tennis rituals* (Figure 7). We present 2 concepts for each theme. In the *'Discussion and Reflection'* section we show how we combined the conceptual keywords via wearable devices.

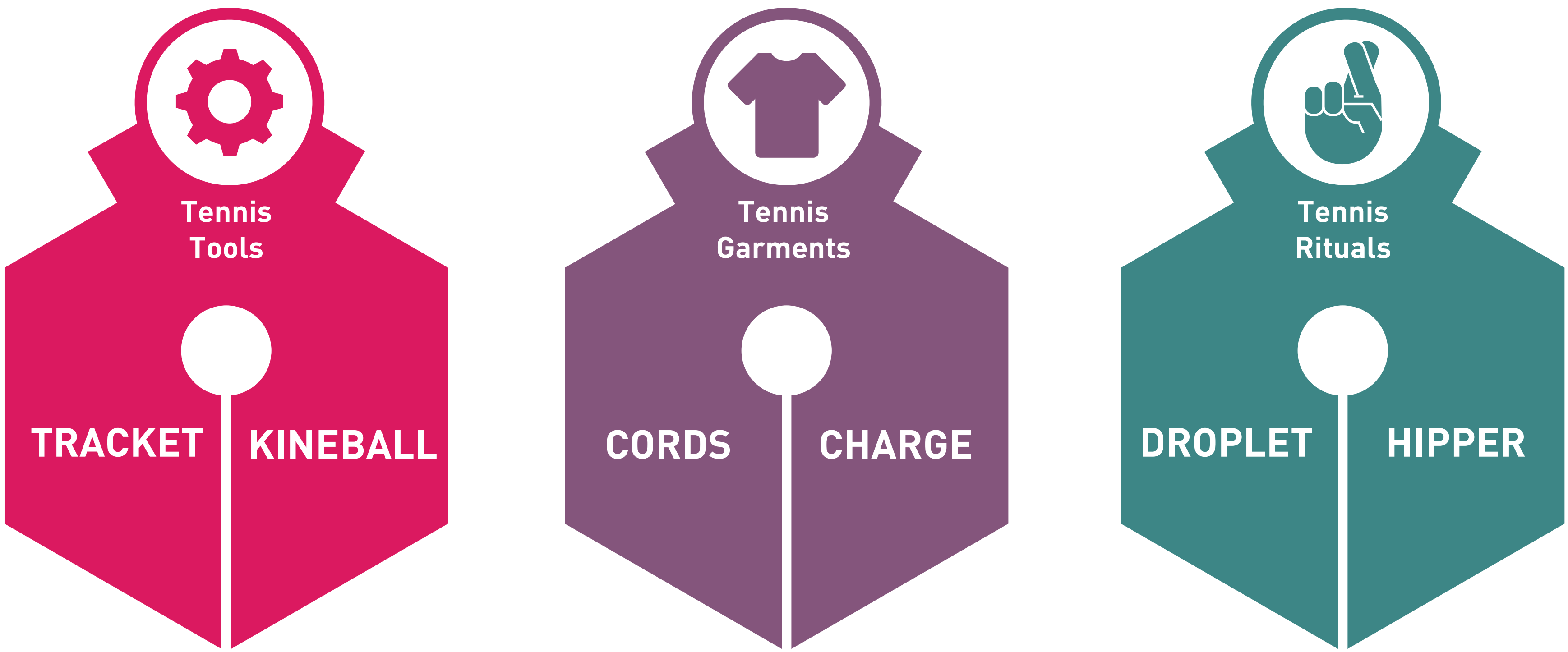

Figure 7. 6 wearable device concepts under 3 design themes.

TRACKET

Tracket is an **augmented tennis racket** that has **haptic cords** on the handle and **LEDs** on the sides. It has **motion sensors** to detect the player's flow state. When it detects the flow state, the haptic actuators embedded in **the haptic cords start to vibrate**, generating a **circular, continuous, rhythmic motion** perceived by the hand. Also, it detects **in-game breaks** through the motion sensors, **to show the status** of the player. As an example, while the player is **waiting for the opponent to serve, the LEDs light up rhythmically** to reveal the flow state status of the player.

Tennis Tools

Tennis Tools

Conventional tennis has 2 main tools: the racket and the ball. These tools can serve as feedback modalities. Correspondingly, we designed *Tracket*, an augmented tennis racket (Figure 8), and *Kineball*, an augmented tennis ball with a complementary smart glove (Figure 9).

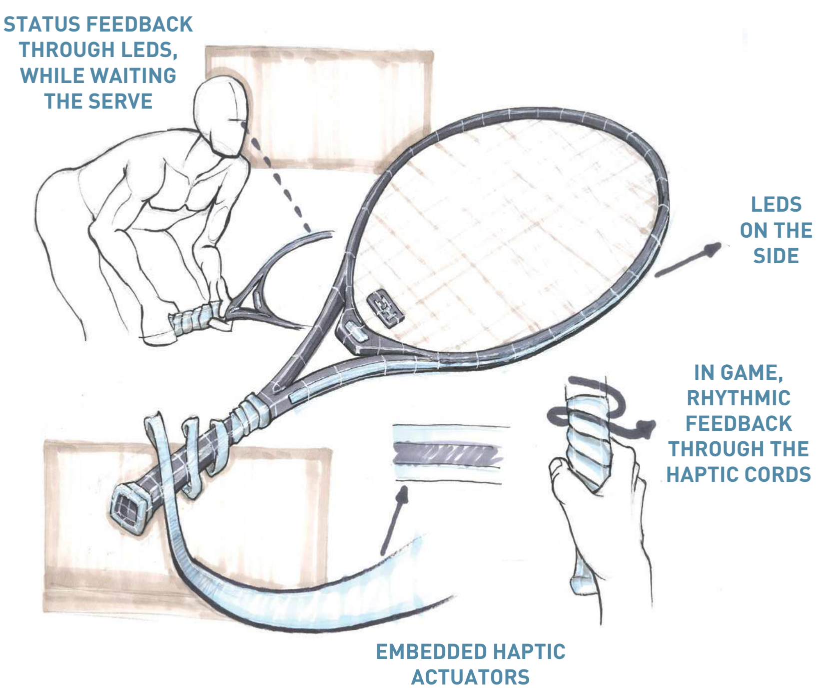

Figure 8. Tracket's design concept.

KINEBALL

Kineball is an **augmented tennis ball with motion sensors** and a **complementary smart glove with haptic actuators**. When flow state is detected, the haptic actuators embedded in the glove **simulates the kinesthetic sense**, such as the grip of the ball. The motion sensors in the ball **detects the contact points of the ball**, such as the contact with the opponent's racket, and creates a similar **reaction on the glove**.

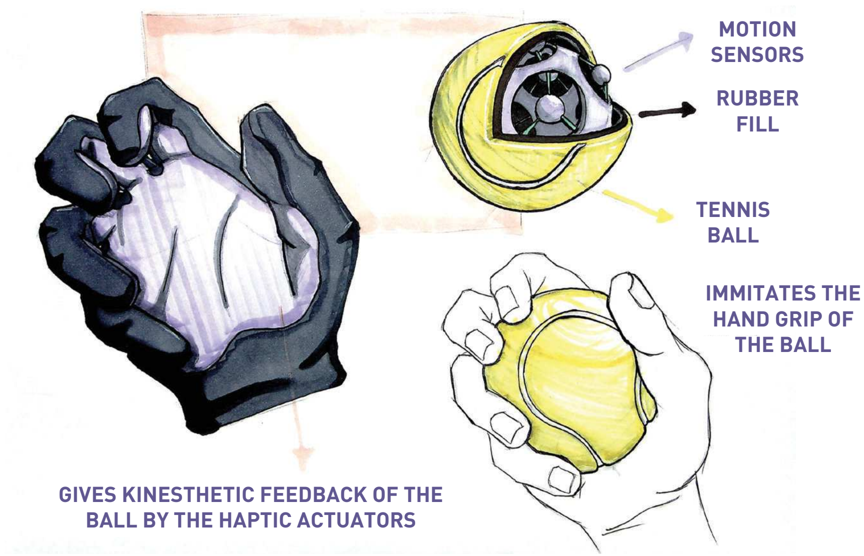

Figure 9. Kineball's design concept.

CHARGE

Charge is a **haptic shoe**. It detects the flow state by 2 methods: **the body language and posture** cues by **the pressure pads**, and **the activity and ritual** cues by **the motion sensors** embedded in the shoe. When flow state is detected by either method, the shoe **encloses its outer layer with a haptic feedback**. It results in tightenining the laces Also, the **LEDs under the shoe** starts to light up in a **rhythmic motion**. These LEDs can also project the status of the player on court, with a stomp gesture.

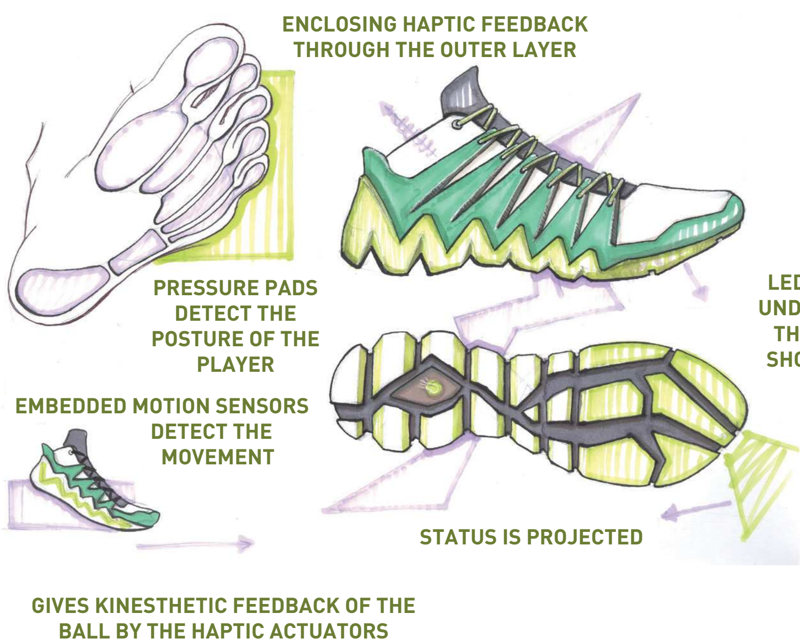

Figure 10. Charge's design concept.

Tennis Garments

Aside from the tennis tools, there are also tennis garments, which players wear in conventional tennis settings. The most common garments are tennis shirts, shorts and shoes. Thus, we designed *Charge,* a haptic shoe (Figure 10), and *Cords*, a haptic body suit (Figure 11).

CORDS

Cords is a **haptic body suit**. It detects flow state, through the **heart rate and motion sensors embedded in the collar** of the suit. When flow state is detected, the **haptic feedback circulates through the body** via haptic cords. These cords are located between **the muscles**. Also, it has **LEDs on the sleeves** of the suit. When the player lifts his/her hand, the LEDs show **the status** of the player.

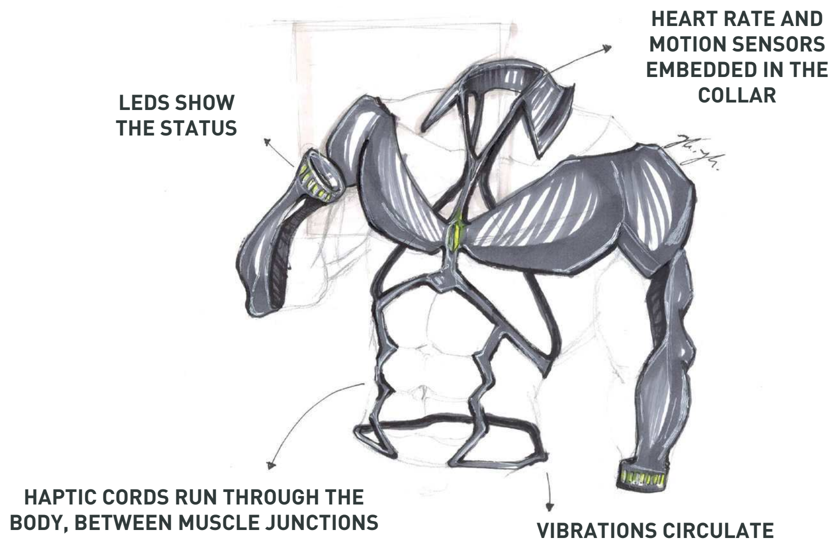

Figure 11. Cords' design concept.

DROPLET

Droplet is a **smart water bottle** with a **complementary wristband**. The **wrist band collects data** of the flow state and if necessary gives **instantaneous feedback**. Meanwhile, **the water bottle changes the pH** level of the water, thus its **taste,** according to the data sent by the wristband. When there is a break, the water bottle first gives a **haptic feedback** to the players grip. Then the player drinks the water and evaluates him/herself according to the **change in taste**. The water bottle also has **LEDs to show the status** of the player.

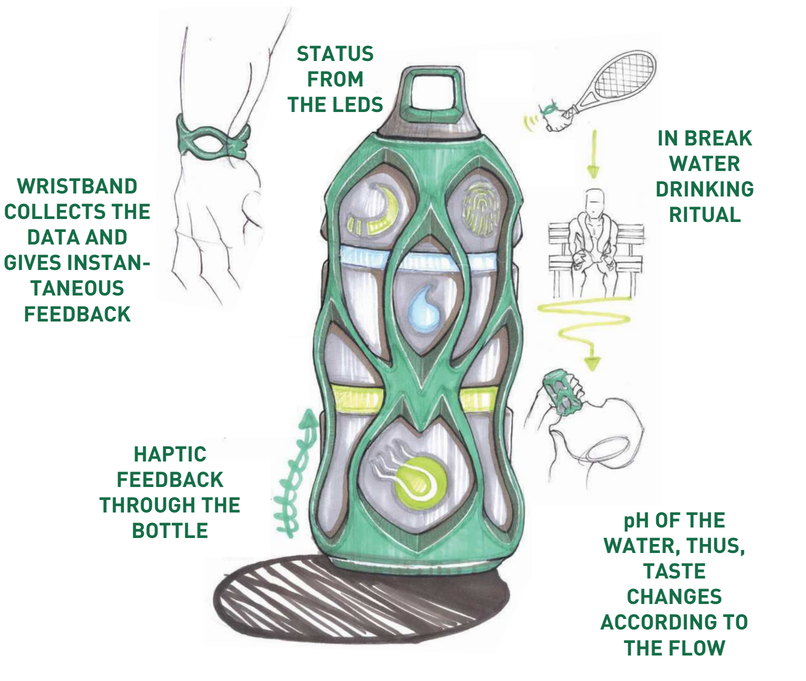

Figure 12. Droplet's design concept.

Tennis Rituals

Rituals are repetitive and superstitious personal behavior such as bouncing the ball 3 times before serving or arranging the water bottles in a specific order before every 2nd set. Our coaches and field insights highlight that rituals are a part of flow state in tennis. Inspired by this unique attribute, we designed *Droplet*, a smart water bottle for water break rituals (Figure 12), and *Hipper*, smart shorts for ball collecting rituals (Figure 13).

HIPPER

Hipper is **smart tennis shorts**. It has a **V-shaped pocket** from a **shape changing fabric,** on the back side. Throughout the game, **the player collects balls** in this pocket. When flow state is detected, **the pocket tightens** and **squeezes the tennis balls** to the hip reflexory **massage trigger points**. Thus, the carried balls **massage the player giving haptic feedback.**

Figure 13. Hipper's design concept.

Discussion and Reflection

Our 5 step research through design process yielded in a diverse range of wearable device concepts to discuss. We designed 6 wearable device concepts under 3 themes: *tennis tools, tennis garments and tennis rituals.* In this section, we discuss design opportunities and challenges by comparing the 3 design themes with our findings.

Tennis tools. These tools are mandatory in tennis, such as the racket or the ball, to which every player is accustomed. We explored ways in which they provide rhythmic and continuous feedback by relentless touch, as well as intuitive, implicit, intrinsic, and minimal attention attributes by habitual contact. Furthermore, they mainly afford tactile interactions that allow us to incorporate haptic features. However, these tools are also the main actors in the dynamics of a conventional tennis setting. Since they are a part of the unchangeable in tennis, re-designing these tools according to appropriate feedback modalities poses a challenge. This challenge reflected on our concepts as both *Tracket* and *Kineball* cannot offer more than augmenting haptic features to conventional tennis rackets and balls. They also cannot offer more than motion tracking to detect the flow state cues, because they are limited to their generic use. Due to the same limitation, we argue that both concepts have the risk to becoming intrusive and disruptive, which is not ideal as indicated by our findings.

Tennis garments. Tennis garments such as the shirt or the shoe provides similar opportunities as the tennis tools. However, these garments are not considered mandatory. They come in many varieties and they are not integral to the game, which creates a higher flexibility to design appropriate feedback modalities. Although *Cords* does not offer more than our tennis tool concepts, *Charge* has a higher potential. It can detect all cues of the flow state, suggested by the coaches. It detects the body language and posture from the pressure pads, and the activity and rituals from the motion sensors. This is achieved by moving the area of stimulation from the hands to the feet. Furthermore, it provides most of the feedback modality attributes we found in the review. Charge gives rhythmic and continuous feedback by relentless touch to the feet, and implicit and intrinsic haptic feedback by habitual contact of the shoe. It projects the status as a minimal attention visual feedback, from the LEDs incorporated underneath the shoe. Charge only shows the status when flow state is interrupted. Thus, we claim that it is non-disruptive. Additionally, we can discuss that Charge is intuitive and non-intrusive, however our knowledge on how tennis players use their feet, and foot interactions in HCI is limited [31]. How users will perceive the stimulation of the feet is an open research question. Similarly, Cords stimulates muscle junctions, which is another unexplored area. We argue that both concepts face this psychological challenge. Still, it would be interesting to explore new interactions in HCI through these concepts.

Tennis rituals. We claim that the most innovative and exhilarating concepts can be incorporated with tennis rituals. Both *Hipper* and *Droplet* benefit from the rituals every tennis player performs such as collecting the balls in pockets and drinking water during breaks. As a result, they are the most intuitive, least disruptive and least intrusive concepts. Also, these concepts are more tennis behavior oriented rather than being tennis object oriented unlike tennis tools and garments. Thus, they are more relevant to the tennis specific cues of the flow state. In addition, they both provide more innovative feedback modalities than we found in the literature. Hipper uses tennis ball massaging techniques rather than common vibration based haptic feedback. Droplet adds the taste value by changing the pH level of the water. We claim that both modalities create more intrinsic and implicit attributes, because they provide subtle changes only valued by the user. Finding intrinsic value is necessary to induce flow state [5]. We expect that conventional feedback modalities such as the vibration for haptic feedback, will be limited to the value we assign to them through past experience. However, we also expect that through innovative feedback modalities such as massaging effect for haptic feedback, we can create new intrinsic values as do these tennis ritual concepts. Therefore, they would become more suitable for giving feedback on flow and other psychological states, to which we have yet to assign our value. Considering the opportunities, tennis rituals provide the most flexibility to design appropriate feedback modalities, and present less challenges compared to other concepts. Nonetheless, these concepts can only give feedback when the ritual is performed. Although it supports the rhythmic attributes, the continuous attributes are limited to the time spent during the ritual. Hipper is limited to when balls are present in the pocket. However, our field insights showed that the balls are present for the majority of the game. On the other hand, Droplet is limited to the relatively short water breaks. We argue that we need to combine different rituals and different modalities to overcome this challenge.

Conclusion

In this pictorial, we aimed to explore external feedback modalities to induce flow state in opponent based sports. We tackled the issue by a 5 step research through design approach with tennis as our design case.

We designed 6 wearable device concepts under 3 tennis related design themes: *tennis tools, tennis garments and tennis rituals.* We discussed that tennis tool concepts present opportunities due to their habitual use in tennis. However, they also present limitations to incorporate appropriate feedback attributes because they are mandatory in tennis, and it is a huge challenge to re-design these tools accordingly. On the other hand, tennis garment concepts provide more flexibility, and better incorporate attributes. Still, they do not offer more than changing the area of the stimulation compared to tennis tool concepts. In addition, they present psychological challenges regarding the perception of the feedback. However, tennis ritual concepts provide the most innovative and relevant feedback modalities. Although, they present challenges on the continuity attribute, they are also the most promising for the remaining of the attributes.

Future Work

We believe that tennis ritual concepts are more relevant to appropriate feedback modalities for the flow state of tennis, and they offer more innovative designs for future wearable technology. However, we did not consider any technological limitations, in order to create a diverse range of concepts to discuss. Nevertheless, instead of speculating, we plan to prototype and conduct user tests to find which modality is more appropriate. As the next step, we want to consult with technologists, psychologists and tennis players to see the challenges on implementing our ideas. Once we clearly understand those challenges, we will revise our concepts to a producible state. Finally, we plan to test them in an actual tennis game, to understand the effects on user's flow state. We speculate that our wearable design concepts can inform design researchers and practitioners for future directions of the wearable technology.

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