Tim Winkler
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Enhancing Performance through Group Fitness Tracking

Exploring the Role and Dynamics of Metaphors and Group-Based Feedback in Fitness Apps

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Author: **Tim Winkler**
Student Number: 800338

Project Supervisor/First Examiner: Eelco Herder
Daily Supervisor: Eelco Herder
Second Examiner: Michael Behrisch

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Abstract

. The "Quantified-Self" (QS) movement has transformed personal fitness applications through the use of wearable technology and real-time feedback. However, while fitness apps predominantly focus on individual metrics, they overlook the potential of group dynamics to improve performance. Offline group feedback has proven to be very useful, fostering a sense of community and accountability that can significantly increase motivation and performance in team settings. This highlights a gap in the literature on group fitness feedback in technology, which this thesis addresses.

Using wearable devices, custom-designed visualisations and group feedback, this study investigates how different feedback and visualisation strategies affect motivation and performance in rowing *teams*. Using a between-subjects design, the research compares metaphorical visualisations with simple graphs and explores the effects of public versus private feedback. Participants shared their training data with the developed application, which then provided feedback according to one of four experimental conditions. Qualitative interviews were conducted to gain insight into the effectiveness of these feedback modalities.

The results reveal that metaphorical visualisations, when well designed, outperformed simple diagrams by fostering greater engagement. Public feedback was found to be more motivating and to increase accountability and cohesion within the group. These findings offer initial and significant implications for the design of team fitness applications. Advocating the integration of tailored, visually appealing and context-sensitive feedback systems. By bridging the gap between individual metrics and collective performance goals, this research provides actionable insights for improving motivation, performance and efficiency in team-based sports and other group settings.

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Chapter 1

Introduction

The overarching goal of this research is to systematically investigate and analyse how diverse feedback and visualization strategies influence performance outcomes and motivation within rowing teams.

Background

The emergence of the Quantified-Self movement, rooted in the practice of self-tracking and self-quantification, has revolutionized the way individuals approach their health and fitness routines [87]. This movement, popularized by Gary Wolf and Kevin Kelly in 2007, encompasses the use of technology to collect, analyse, and reflect on personal data, aiming to enhance health and wellness through informed, data-driven decisions. This paradigm shift has been significantly propelled by advancements in wearable technology and mobile applications, which facilitate the continuous monitoring of various physiological and behavioural parameters.

The Quantified-Self in Fitness Apps

Fitness applications leveraging the Quantified-Self concept have become increasingly sophisticated, incorporating persuasive technologies designed to influence user behaviour. These technologies employ various strategies, including gamification, social comparison, and feedback mechanisms, to motivate users towards achieving their fitness goals [35, 46, 64]. Positive and negative feedback, integral components of these apps, play a crucial role in reinforcing desired behaviours and improving adherence to fitness regimens [45]. Typically, these apps are targeted at individuals, focusing on personal metrics and progress to enhance user engagement. However, offline group feedback has proven to be very useful, fostering a sense of community and accountability, which can significantly boost motivation and performance in team settings.

Feedback in Groups

Feedback within group settings, particularly in team sports, has been shown to impact performance and cooperation immensely. The type of feedback — whether positive or negative, individual or group-oriented — can either enhance or undermine team dynamics and overall effectiveness [12]. Positive feedback tends to foster motivation and cohesion, while negative feedback, if not managed appropriately, can lead to demotivation and conflict [57]. To optimize these dynamics, innovative methods of delivering feedback are continually being explored. One such method involves the use of visualization techniques, which can further enhance the effectiveness of feedback in group settings.

Visualizing Group Performance

Visualization techniques have emerged as powerful tools for enhancing group performance [25]. By providing detailed or real-time feedback on collective efforts, visualizations can help synchronize team members and align their actions towards common goals. Metaphoric visualizations, which offer more engaging and relatable representations compared to simple diagrams, have been found to be particularly effective in motivating individuals and improving group coordination [85]. Studies have demonstrated that visualizations combining cooperative and competitive elements can yield better performance outcomes than those focusing solely on one aspect [88]. Despite their potential, these techniques are not commonly used in fitness apps, which tend to focus on individual metrics and feedback. This work therefore aims to fill that gap in research.

Research Goals

This study is grounded in the research goals that certain types of feedback and visualizations can significantly enhance group synchronization and effort alignment, ultimately leading to improved performance outcomes. The specific research questions to be tested include:

- Metaphoric visualizations vs. simple diagrams: Investigating whether engaging, relatable visual representations can better motivate rowers and improve their performance compared to straightforward, diagrammatic feedback.
- Public vs. private feedback: Evaluating whether feedback given in front of the group has a greater motivational impact than feedback given individually, regardless of its nature.

Methods

This study systematically addressed the research questions by employing a between-subjects experimental design, where participants from rowing teams shared their training data recorded using wearable devices. These devices provided a range of performance metrics, such as heart rate and speed. These metrics were prepared through the implementation of diverse feedback and visualisation strategies, facilitated by a custom-developed iPad application. Qualitative insights were then gathered through interviews to understand user preferences and perceptions. By comparing metaphoric visualizations with simple diagrams, as well as public versus private feedback delivery, the study provided a comprehensive evaluation of how different feedback strategies influence individual and group dynamics. This approach ensured a thorough investigation of the hypotheses, offering actionable insights into optimizing group performance through tailored visualization tools.

Contribution

This thesis makes several key contributions to the field of Human-Computer Interaction (HCI) and group dynamics in sports technology. First, it expands the application of the Quantified-Self (QS) movement to a group context, exploring the "quantified-us" paradigm, which has been underexplored in previous research. By investigating how team-level visualizations affect group motivation and performance, this work provides valuable insights into designing feedback systems that balance individual and collective goals. Additionally, the study introduces and evaluates innovative metaphoric visualizations, demonstrating their potential to enhance motivation and engagement in team settings. These findings contribute to the growing literature on persuasive technologies, particularly in their capacity to leverage visual feedback for behavioural change in group scenarios. Ultimately, this work lays a foundation for future research on integrating visualization strategies in team-based applications, bridging gaps between individual-focused fitness tools and collective performance optimization.

Chapter 2

Literature Research

2.1 The Quantified-Self In Fitness Apps

Consider the potential of integrating technology into your fitness regimen, where each movement, heart rate, and energy expenditure is meticulously tracked and analysed. This chapter examines the integration and impact of self-quantification in fitness applications. It charts the development of the Quantified Self (QS) movement, emphasising the transition from conventional self-monitoring techniques to sophisticated digital resources such as wearable devices and mobile applications. This chapter examines the manner in which these technologies collect and provide real-time health and fitness data, thereby fostering user motivation and behaviour change through the provision of personalised feedback.

Furthermore, the chapter examines the impact of persuasive technology in encouraging healthier behaviours and the implications of the fitness data revolution. It also evaluates the behavioural effects of self-quantification, noting both benefits, such as increased physical activity, and potential drawbacks, such as a reduction in intrinsic motivation. This analysis provides a basis for enhancing the effectiveness and user engagement of fitness apps.

2.1.1 The Quantified-Self

The Quantified Self is a movement and methodology that involves individuals utilising technology to collect, analyse and reflect on data related to their daily lives, particularly health and wellness metrics [64]. The term was first used by Gary Wolf and Kevin Kelly in 2007 [87]. However, the earliest known record of self-tracking dates back to the 16th century, when Sanctorius of Padua meticulously recorded and measured various aspects of his bodily functions. He is renowned for weighing his food intake, excrement, and other bodily outputs both before and after eating. This initial form of self-quantification sought to comprehend the impact of diet and digestion on his health, thereby establishing the foundation for contemporary personal data tracking and the QS movement [70]. This practice encompasses the monitoring of physical activities, sleep patterns, dietary habits, and a range of physiological parameters through the use of devices such as wearable fitness trackers, mobile applications, and other digital tools. The objective is to gain insights into personal behaviours and to make data-driven decisions with a view to improving one's quality of life. In addition to "Quantified-Self", there are several other terms used to describe the practices by which people may seek to monitor their everyday lives. These include, for example, "lifelogging" [39] and "self-tracking" [64, 87]. For example, lifelogging can be defined as the practice of maintaining a personal record of one's daily life in varying degrees of detail for diverse purposes. Such records may comprise a comprehensive dataset of human activities, encompassing physical movements, health metrics, social interactions and environmental conditions. The data thus collected can then be subjected to analysis with a view to enhancing our understanding of how people live. This analysis offers valuable insights into behavioural patterns, health outcomes and lifestyle choices [39].

Another term that is frequently employed is that of personal informatics (PI) systems, which are designed with the objective of enabling users to gather and examine information that is personally relevant to them with regard to their lives. The principal objective of PI systems is to furnish users with actionable, data-driven insights into their behaviours and routines. By providing a comprehensive and detailed representation of an individual's habits, these systems facilitate informed decision-making and the implementation of changes aimed at enhancing health and well-being. To illustrate, a PI system may identify patterns in sleep disturbances or dietary inconsistencies, prompting users to modify their habits accordingly. The ultimate objective is to facilitate positive behavioural changes that enhance the overall quality of life through the continuous feedback and personalised recommendations provided by these advanced self-monitoring technologies [54].

In conclusion, the QS represents a data-driven methodology for self-improvement, utilising technology, such as PI-systems, to monitor and analyse personal metrics with the objective of promoting enhanced health and well-being through informed decision-making. The data can then be employed to provide feedback, which can be highly beneficial in persuasive technology.

2.1.2 Persuasive Technology

Persuasive technology (PT) is defined as interactive systems designed to alter users' attitudes or behaviours through the use of persuasion and social influence, rather than through coercion. The term was first used by B.J. Fogg [35, 36]. This field, situated at the intersection of technology and psychology, draws upon principles derived from behavioural science to develop tools and applications that encourage particular actions or lifestyle modifications [66].

The key techniques include goal setting, which involves the establishment of specific, measurable, attainable, relevant, and time-bound (SMART) objectives to guide behaviour and motivate users towards desired outcomes. Furthermore, feedback and emotional support are of paramount importance. They provide users with information regarding their performance and progress, as well as encouragement and positive reinforcement, which serve to enhance motivation and emotional well-being. Incentives and rewards provide users with tangible or intangible benefits as a means of motivating them to perform desired behaviours, thereby reinforcing their efforts and achievements.

Furthermore, self-monitoring and social comparison facilitate users' ability to track their own behaviours and progress while enabling them to compare their performance with others, thus fostering motivation through social benchmarks. Persuasive messages are crafted with the intention of influencing users' attitudes or behaviours, leveraging psychological principles and tailoring content to resonate with the intended audience.

In examining the various methods of providing feedback, three prominent conceptual and technological categories emerge as key elements in persuasive technology. These **include** the Quantified-Self, as outlined in reference [41]:

1. *Quantified-Self* - benefiting from advances in big data and wearables, QS designs collect, store and visualize data related to users' performance, attempting to provide users personal and precise **informational** feedback [64, 87]
2. *Gamification* - drawing design from games with the aim of making activities, services and systems more intrinsically motivating and enjoyable by providing users **affective** feedback [46, 58]
3. *Social networking* - drawing from the designs of social networking services and social computing to attempt to invoke socio-psychological responses, such as a sense of community through **social** feedback [17, 19]

2.1.3 The Fitness Data Revolution

In light of the QS's function in offering users tailored and detailed feedback on the data collected from persuasive technologies, it is worthwhile to examine human physical activity.

It is evident that as our world becomes increasingly data-driven, the scope of measurement has expanded beyond merely tracking our physical activities. This resulted in a revolution in the field of fitness data. The introduction of the first wireless heart rate monitor by Polar in 1982 marked the beginning of efforts to quantify user health and fitness [55]. Other brands subsequently introduced products incorporating additional sensors. Garmin, for instance, can track users' speed, steps, and other data with the help of GPS, pedometers, accelerometers, gyroscopes, and other sensors [38].

The advent of Fitbit [34] marked a pivotal moment in the history of wearable technology, as it democratized the tracking of physical activity and data collection. The subsequent popularity of Strava [84] and RunKeeper [79] has led to them becoming some of the most widely used apps. They allow users to share their progress and work, and even to create social networks for QSs. The latest developments in the field of wearable technology include subscription apps, such as Whoop [91], which have the capacity to track not only exercise but also sleep, heart rate variability, and other factors related to recovery. This enables the provision of personalised feedback to users, allowing them to optimise their performance. Moreover, niche applications such as Ludum [63] have gained significant traction, offering enhanced personalisation for specific activities, such as rowing. Nevertheless, this is not a novel concept. For an extended period, sports scientists have employed laboratory-based assessments to quantify the performance, level of fitness, and progress of athletes undergoing specific training regimens [31]. It should be noted that these resources are not accessible to the general public or to those without the requisite expertise. In conjunction with machine learning tools and the data amassed from readily available wearables, simple supervised learning tasks can now supplant laboratory-based assessments, equipping daily athletes with comparable scores and metrics, including VO2Max and lactate threshold [6, 20, 28].

Consequently, the advent of the QS has enabled fitness apps to not only gauge our physical capabilities and performance, but also to facilitate comparisons between athletes' fitness levels and progress, thereby enabling the monitoring of their training. The subsequent logical progression was the development of personalised training plans, which optimise the training regimen for specific goals. To illustrate, the user is instructed to train at specified intensity levels over a defined optimal duration in order to achieve their fitness objective [6]. Furthermore, the progress did not cease at this point. It has been demonstrated that apps in conjunction with activity trackers can assist users in acquiring tangible physical abilities and instilling behavioural modifications [44].

2.1.4 The Quantified-Self Changing Our Behaviour

The possibility of behavioural change through the use of quantified self in conjunction with physical therapy (PT) has been employed in a multitude of applications, particularly within the health context. The evidence from multiple studies has demonstrated that monitoring activity levels leads to an increase in the volume of activity engaged in by the subjects [27, 52]. Health interventions are frequently accompanied by the use of wearable devices for measurement purposes. Nevertheless, although it has been demonstrated to enhance the quantified activity and users report considerable anticipated and initial motivation from their quantified self, there appears to be a hidden cost [27]. While measurement may increase the amount of activity performed, it can also reduce the level of enjoyment derived from that activity. This is due to the fact that measurements can have the effect of undermining intrinsic motivation. The act of measurement can serve to diminish the enjoyment derived from enjoyable activities, as it draws attention to the output. Consequently, the act of measurement may result in a reduction in both continued engagement in activities and subjective well-being. Furthermore, the act of monitoring one's activities was found to result in a decline in overall feelings of happiness and satisfaction. In addition to merely drawing attention away from an enjoyable activity, measurement also draws attention to the output, which has the effect of undermining intrinsic motivation. This resulted in a notable decline in activity levels following the removal of the measurement. It is noteworthy that the majority of individuals tend to select measurement and anticipate that it will enhance the enjoyment derived from the activities in question [27].

Nevertheless, when the activity was initially conceptualised as work, the impact of measurement on its perceived value was less pronounced. It is also possible that the effect of reduced enjoyment may be reversed when activities are performed in the service of a goal [27].

Conclusion

In conclusion, the QS movement has resulted in the development of fitness apps that measure performance, compare fitness levels, and provide personalised training plans. Such applications and monitoring devices assist users in acquiring physical abilities and modifying their conduct, frequently resulting in elevated levels of activity. Nevertheless, the act of measuring activities has been demonstrated to diminish enjoyment and intrinsic motivation, thereby transforming these activities into a form of work and reducing long-term engagement. It is noteworthy that when the activity is perceived as work or goal-oriented, the reduction in enjoyment is less pronounced.

2.1.5 More Persuasive Technologies In Fitness Apps

The impact of positive and negative feedback in fitness apps has been the subject of research, which has yielded a range of findings with regard to user motivation and physical activity levels. Fitness apps frequently employ gamification techniques [46], which encompass the use of rewards (such as points, badges, and financial incentives) and punishments (such as the loss of points or the receipt of negative feedback) to influence user behaviour. The objective of these strategies is to enhance user engagement and improve physical activity outcomes.

As with other behaviours, studies have demonstrated that both intrinsic and extrinsic motivations are essential for the sustained use of fitness apps. Intrinsic motivations encompass self-improvement and enjoyment, whereas extrinsic motivations include positive feedback such as rewards and social recognition ([45, 89]. The provision of financial rewards and social recognition has been demonstrated to exert a beneficial influence on user engagement and the sustained utilisation of fitness apps. Such positive reinforcement offers users tangible benefits, thereby encouraging increased physical activity levels [45].

The incorporation of feedback mechanisms, such as the provision of rewards for the achievement of designated goals or the expression of social recognition from peers, has the potential to markedly enhance users' motivation and adherence to fitness routines. Conversely, the implementation of negative feedback or the loss of points can, on occasion, act as a deterrent to users, particularly if not implemented with sufficient care and attention to detail [59, 60]. A study examined the use of a rewards-for-exercise app and found that providing positive feedback for meeting exercise goals significantly increased physical activity and subjective well-being among participants. The study demonstrated that timely and appropriate feedback, particularly rewards, can enhance motivation and adherence to fitness routines [60].

The integration of diverse elements, including challenges, team activities and social interactions, within gamified fitness applications has been observed to result in enhanced user retention rates. These elements foster a sense of community and accountability, which can facilitate long-term engagement [45]. Nevertheless, the efficacy of these gamified elements hinges on the meticulous calibration of positive and negative feedback to circumvent demotivation among users. For example, excessive negative feedback has been demonstrated to result in reduced motivation and, ultimately, in the abandonment of the app in question [59]. A recent study investigated the influence of gain- versus loss-framed feedback on the uptake and utilisation of fitness apps. The study revealed that gain-framed feedback (positive) was more effective than loss-framed feedback (negative) in motivating users to engage with the app and maintain their exercise routines [5].

In sum, the literature on feedback in fitness apps reveals that the incorporation of positive reinforcement, such as rewards and social recognition, has been demonstrated to enhance user motivation and physical activity. Both intrinsic (self-improvement) and extrinsic motivations (rewards, social recognition) are essential for sustained app use, with financial rewards and social recognition positively influencing user engagement. Conversely, the implementation of negative feedback in a poorly designed manner has the potential to act as a deterrent for users. The use of gain-framed (positive) feedback is more effective than loss-framed (negative) feedback in motivating users. The incorporation of challenges and social interactions in gamified apps has been demonstrated to enhance user retention. However, it is essential to strike a delicate balance between the types of feedback provided to maintain user motivation and prevent the abandonment of the app.

2.1.6 Implications

This chapter examines the influence of feedback on user engagement and motivation in fitness apps, drawing upon the principles of persuasive technology and the QS perspective. The QS movement involves the utilisation of technology for the collection and analysis of personal health data, which has precipitated a revolution in the field of fitness tracking through the advent of wearable devices and apps. While persuasive technologies utilise goal setting, feedback, incentives and social comparison to influence user behaviour, with fitness apps employing these techniques to enhance user engagement.

The section goes on to indicate that although the use of fitness apps to measure activities can result in increased physical activity and motivation, it can also lead to a reduction in intrinsic enjoyment and long-term engagement, due to the perception that the activities are akin to work. The provision of positive feedback, such as rewards and social recognition, has been demonstrated to enhance motivation and engagement. Conversely, the implementation of negative feedback has the potential to deter users unless handled with care. The research highlights the necessity for a balanced approach to feedback types in order to maintain motivation and prevent user attrition.

In conclusion, the QS movement and PTs have significantly advanced the field of fitness tracking and user engagement in fitness apps for individuals. Such technologies offer valuable insights into personal health and facilitate behaviour change through the provision of data-driven feedback and the use of gamification techniques. However, the challenge remains in maintaining intrinsic motivation and enjoyment while leveraging these technologies. Effective fitness apps must provide a balanced approach to positive and negative feedback in order to maintain long-term user engagement and motivation. The research highlights the necessity of designing fitness apps that not only track and measure activities but also enhance user experience and promote sustained physical activity. This study aims to address the research gap that exists in the context of teams, as the majority of research focuses on individual experiences rather than examining group or team feedback.

2.2 Feedback In Groups

To understand how to effectively use feedback for the "quantified-**us**" instead of the Quantified-Self, one should first examine how feedback impacts groups in general, particularly group dynamics and performance. Through such an examination, one will find that feedback has a profound effects on groups and their performances. Feedback significantly shapes group behaviour and outcomes, profoundly impacting group cohesion and effectiveness.

Thus this chapter examines the dynamics and impact of various feedback types, such as positive and negative feedback, on group performance and individual motivation. It emphasizes the importance of feedback in fostering communication, cohesion, and overall team performance. The chapter also discusses how feedback can be tailored to meet both individual and collective needs, promoting a supportive and productive environment. Additionally, it addresses the challenges of delivering feedback in group settings and offers insights into best practices for effective feedback delivery.

2.2.1 Definition

Group feedback refers to the feedback provided to a team or group as a collective unit rather than to individual members. It encompasses assessments, comments, and evaluations aimed at improving the group's overall performance, cohesion, cooperation, and goal achievement.

According to research [59] in behavioural science, group feedback is a method of delivering performance information that reflects the group's achievements and shortcomings. It is essential in settings where collaborative efforts are crucial, as it helps align individual actions with group goals, enhances communication, and builds a cohesive team environment. Effective group feedback often includes specific, actionable suggestions that the group can implement to improve its performance and achieve its objectives [59].

In organizational psychology, group feedback is seen as a vital tool for improving team performance and effectiveness. It involves providing information about the group's performance, behaviours, and outcomes to all members of the group. This feedback can come from various sources, including peers, supervisors, or external evaluators. The primary goal is to foster a shared understanding of the group's strengths and areas for improvement, promoting collective responsibility and teamwork [60].

In the contexts of group feedback, positive feedback involves providing rewards such as praise, affirmations, points, badges, or virtual trophies to reinforce desired behaviours and enhance motivation and engagement. Conversely, negative feedback entails delivering punishments or constructive criticism, such as pointing out mistakes, deducting points, or sending reminders about unmet goals, to highlight areas for improvement. Effective use of both positive and negative feedback is crucial. Positive feedback boosts morale and motivation [23], while negative feedback helps users identify and correct errors, ensuring a balanced approach that promotes continuous growth and sustained engagement [57].

2.2.2 Increased Performance

Firstly, feedback significantly increases performance. Emmert [26] tested the effects of group feedback versus individual feedback on the performance of work crews in an industrial setting and found a performance increase during both interventions. Similarly, Pritchard et al. [74] suggested that a group's performance is enhanced by a combination of feedback, goal setting, and incentives. And Becker demonstrated already in 1978, that goal setting paired with feedback leads to substantial changes in performance. Specifically, feedback combined with difficult goals results in significant positive changes, while low goals with feedback do not lead to notable improvements [11]. This highlights the importance of challenging yet attainable goals in conjunction with feedback to drive performance.

Furthermore, a study by Matsui, Kakuyama, and Onglatco [67] showed that pairs setting both group and individual goals outperformed individuals who set only individual goals, despite similar levels of individual goals. This suggests that a collective focus enhances overall performance. Additionally, feedback (both group and individual) given midway through the task improved performance for participants who were below their target goals, emphasizing the critical role of timely feedback in achieving performance targets.

These studies collectively underscore that feedback, especially when integrated with goal setting and provided at strategic points, can substantially boost group performance. The combination of these elements creates a framework where team members are motivated, focused, and equipped to achieve higher levels of productivity and success.

2.2.3 Presentation Of Feedback

While feedback may improve performance, the details of the presentation play a crucial role in its effectiveness. One study involved 126 subjects engaged in two group tasks, receiving both individual and group-level feedback from peers and a superior. The results showed that individual-level feedback and feedback from peers were the most impactful, particularly when **negative**. This suggests that both the level and the source of feedback are essential for understanding its effectiveness [23, 24]. In their meta-analysis on feedback interventions Kluger and DeNisi [57] highlighted that **positive** feedback tends to enhance motivation and task performance more effectively than **negative** feedback alone. A study by Baron [10] found that combining positive and negative feedback can improve the acceptance of negative feedback and maintain the individual's motivation and performance. Positive feedback can create a supportive environment that makes the recipient more receptive to negative feedback. This approach aims to reduce defensiveness and encourage a constructive dialogue.

Moreover, the order in which feedback is given can significantly affect group behaviour. The "sandwich" approach, which involves presenting feedback in a positive-negative-positive sequence, has been found to be particularly effective. This method helps cushion the impact of negative feedback, making it more palatable and increasing the likelihood of constructive reception and action [22]. However, the positive-negative-positive sequence might dilute the impact of the negative feedback, making it less likely that the recipient will recognize and act upon the areas that need improvement. Further, the sandwich approach could be perceived as insincere or manipulative, reducing the overall effectiveness of the feedback [86]. Additionally, recipients might focus more on the positive feedback and miss the critical points that need attention. This can lead to ambiguity and a lack of clarity regarding what actions need to be taken.

Additionally, research by Mesch, Farh, and Podsakoff [68] showed that groups which received negative feedback were initially less satisfied, but subsequently set higher goals, developed more strategies, and performed at higher levels than groups that received positive feedback. This indicates that while negative feedback may cause temporary dissatisfaction, it can ultimately drive higher performance by motivating team members to improve and innovate.

Overall the presentation of feedback significantly impacts its effectiveness, as highlighted by various studies. Individual-level feedback, especially from peers, has been found to be highly impactful, particularly when negative. Positive feedback, on the other hand, tends to enhance motivation and performance, while a combination of both can improve acceptance and maintain motivation. The "sandwich approach", which delivers feedback in a positive-negative-positive sequence, can cushion the impact of negative feedback, making it more palatable. However, it may also dilute the critical points, leading to potential confusion and perceived insincerity. Negative feedback, although initially less satisfying, can drive higher performance by motivating groups to set higher goals and develop better strategies. These findings underscore the importance of carefully considering the content, delivery method, order, and source of feedback to optimize group performance and outcomes.

2.2.4 Circumstances Of Feedback

Given the diverse nature of groups in terms of their composition and the dynamic contexts in which they operate, applying a one-size-fits-all feedback strategy for team performance is inherently ineffective. Research, for example by Beersma [12], underscores the importance of tailoring feedback approaches to accommodate the unique characteristics of team members. For instance, teams characterized by extroverted and agreeable individuals tend to thrive under cooperative reward structures, which promote teamwork, mutual support, and shared goals. In contrast, teams composed of disagreeable introverts may respond more positively to competitive reward systems, where individual achievements and recognition are emphasized.

Moreover, environmental stability plays a crucial role in determining the effectiveness of feedback strategies. In stable environments, characterized by consistent conditions and predictable outcomes, cooperation often proves advantageous. This cooperative approach fosters long-term relationships, trust, and a collective focus on achieving common objectives. On the other hand, in dynamic and rapidly changing environments where agility and adaptability are paramount, competitive strategies may be more suitable. These strategies incentivize innovation, risk-taking, and individual initiative, which are essential for navigating uncertainty and seizing opportunities.

Task complexity also guides the choice between cooperation and competition. Complex, interdependent tasks that require extensive coordination and collaboration among team members typically benefit from cooperative feedback mechanisms. Such tasks encourage information sharing, problem-solving, and synergistic efforts that contribute to achieving comprehensive solutions. Conversely, simpler, independent tasks that involve straightforward objectives and clear-cut performance metrics may be better suited for competitive feedback approaches. Here, individual performance can be directly measured and rewarded, motivating team members to excel and achieve measurable outcomes.

Therefore, effective leadership and management involve a nuanced understanding of the team's composition, environmental dynamics, and task complexity. By carefully assessing these factors, managers can determine whether a cooperative or competitive feedback approach will optimize team performance, foster a supportive work culture, and ultimately contribute to achieving organizational goals. This tailored approach not only enhances motivation and engagement among team members but also ensures that feedback mechanisms align with the specific challenges and opportunities inherent in their operational context [12].

2.2.5 Positive And Negative Feedback And Their Effect On Cooperation

In 2000, a study by Fehr et al. [32] demonstrated that negative feedback can significantly increase cooperative behaviour in public goods games by creating accountability and peer pressure. This finding aligns with the idea that public notifications of failures would enhance adherence, making individuals more likely to cooperate to avoid public reprimand as it is described with the theoretical model and experimental evidence from reciprocity research [30]. Falk and Fischbacher [30] suggest that the threat of punishment can enforce cooperative norms through reciprocity, supporting the idea that public notifications of failures could enhance adherence through increased peer pressure.

Moreover, the potential of negative feedback to boost cooperation can be extended beyond the initial study. Research by Fehr and Gächter [32] found that when individuals know their failures will be publicly disclosed, they are more likely to align their behaviours with group norms to avoid negative social consequences. This principle can be harnessed in fitness apps by incorporating features that publicly display progress or lack thereof, thereby motivating users to adhere to their fitness goals due to the fear of social scrutiny.

Later research suggested that negative feedback could also be detrimental to cooperation. Herrmann et al. [43] and Sigmund [82] found that in some contexts, the incurred costs of punishment outweighed the benefits of increased cooperation, leading to negative outcomes. However, some of the same authors showed in a paper published in Science that these claims are short-sighted. They argued that the negative effects were observed in short-term experiments, where the costs of punishment were immediate, but the benefits of increased cooperation had not yet materialized. By extending the duration of the games or experiments, they demonstrated that negative feedback can lead to **sustained** cooperation over time in repeated public goods games. This suggests that punitive measures in fitness apps could maintain high adherence to fitness goals if users understand that the system will be in place for the long term [37].

A comparative-statics analysis of negative feedback in public-goods experiments found that contributions increase monotonically with punishment effectiveness. Nikiforakis [72] provided data showing that as the effectiveness of negative feedback increases, so do the contributions to the public good. This further underscores the importance of punishment in fostering cooperation. The analysis supports the notion that effective negative feedback mechanisms can enforce adherence to cooperative norms, suggesting that fitness apps can leverage this strategy to ensure users remain committed to their fitness regimens.

Balliet, Mulder, and Van Lange, looked into the effectiveness of positive and negative feedback mechanisms in promoting cooperation within various social dilemmas [9]. Their meta-analysis synthesizes findings from numerous studies to assess how different types of incentives influence cooperative behaviours. Positive and negative feedback are two powerful tools used to shape behaviour. Positive feedback typically includes positive reinforcement, such as monetary incentives, social recognition, or other benefits, which encourage individuals to continue or increase their cooperative actions. Conversely, negative feedback involves negative consequences, such as fines, social disapproval, or other penalties, aimed at discouraging non-cooperative behaviour.

Their paper reveals several critical insights. First, it confirms that both positive and negative feedback can effectively enhance cooperation, with negative feedback showing a slightly higher impact on promoting cooperative behaviour compared to rewards. However, the relative effectiveness of these strategies can vary depending on the context and implementation. Another significant finding is the conditional use of negative feedback. Individuals are more likely to employ punitive measures when there is a high risk of free-riding or non-cooperation. This strategic use of punishment underscores its role not just as a deterrent but also as a means of maintaining social norms and expectations. Furthermore, the interaction between positive and negative feedback can significantly influence cooperation. A combined approach, using both positive feedback to reinforce positive behaviour and negative feedback to deter negative behaviour, tends to create a more robust incentive structure that maximizes cooperative efforts.

These insights provide a nuanced understanding of how positive and negative feedback can be strategically used to foster cooperation, offering valuable guidance for designing interventions in various settings, from organizational management to public policy and beyond. However, further investigation is needed to understand how these mechanisms play out in online group settings, such as fitness apps.

Conclusion

In conclusion, while there are concerns about the potential negative effects of punishment on cooperation, extensive research indicates that when implemented effectively and over a sustained period, punishment can significantly enhance cooperative behaviour. By applying these principles to fitness apps, developers can create environments that encourage users to adhere to their fitness goals through the strategic use of public notifications and punitive measures, ultimately leading to improved group performance and individual success. Additionally, integrating positive feedback to reinforce positive behaviours can further enhance the effectiveness of these interventions, creating a balanced approach that maximizes cooperative efforts and adherence.

2.3 Visualizing Group Performance

The objective of this chapter is to examine the impact of group feedback visualisations on collective performance. It is therefore essential to evaluate the current visualisations employed in cooperative settings or sports, in order to understand their efficacy and suitability. The investigation focuses on sports that rely heavily on synchronised effort and teamwork, with a particular emphasis on rowing and cycling. By analysing these existing methods, the aim is to develop optimised visual feedback mechanisms that can enhance performance and motivation in team sports.

2.3.1 Visualization Of Cooperation

The process of visualising cooperation is not a simple one, and a number of researchers have developed a variety of strategies to facilitate this. For example, one team used natural language processing and machine learning to analyze online chat discourse, identifying elements like coordination, conflict, agreement, and idea generation to assess and enhance the quality of group collaboration in educational and professional settings [1]. This is an example of a Mirroring Tool as defined by Jermann [50]. The authors provide an overview of the current technologies designed to enhance collaborative work. The technologies are classified into two main categories: mirroring tools and guiding tools:

- **Mirroring Tools:** These tools reflect the learners' actions and contributions, providing feedback and allowing self-assessment, to provide users with a clear view of their activities and interactions, helping them to reflect. These include features for visualizing participation, tracking progress, and facilitating communication and collaboration among group members. Examples include shared workspaces and interactive whiteboards or the aforementioned study [1].

- **Guiding Tools:** These tools offer more proactive support by providing prompts, suggestions, and scaffolding to guide learners through the learning process. To offer structured support and direction, helping users achieve specific learning goals and improve their collaborative skills. These tools often use artificial intelligence and machine learning to adapt to the needs of the learners, providing real-time feedback, personalized suggestions, and targeted interventions. Examples include intelligent tutoring systems and adaptive learning environments.

Cooperative vs. Competitive Visualizations.

One of the challenges associated with these tools is the evaluation of their impact on learning outcomes and the identification of optimal practices for their utilisation. To illustrate, the paper by Tausch et al. examines the influence of diverse group mirror visualisations on collaborative activities during brainstorming sessions [88]. They compared Cooperative Visualizations (positive) – designed to encourage teamwork by displaying shared goals and group progress, fostering a sense of unity and collaboration among participants - with Competitive Visualizations (negative) – designed to stimulate competition by highlighting individual performances and achievements – potentially motivating participants through rivalry.

Metaphoric Visualizations and Engagement

Additionally, a mixed visualization was tested, combining both approaches with a baseline group. Moreover, as evidenced by the findings presented in [85], which demonstrated that metaphoric visualisations outperformed simple diagrams, the researchers selected a balloon metaphor to visualise the number of ideas contributed by each user during the brainstorming session. The results demonstrated that participants who received feedback via a competitive visualisation exhibited the greatest motivation and productivity. However, the mixed version of the visualisation resulted in the generation of a greater number of ideas and a more balanced level of participation, while the participants reported the greatest sense of comfort. This demonstrates the necessity of achieving an appropriate equilibrium when offering feedback through visualisation on the subject of cooperation, in order to achieve the optimal level of performance.

Challenges in Personalizing Group Feedback

In conclusion, visualizing cooperation in collaborative tasks is a complex endeavour. Studies have demonstrated the potential of mirroring tools to enhance group collaboration [1, 8, 13]. These tools reflect learners' actions and provide valuable feedback for self-assessment, enabling users to visualize participation and track progress. On the other hand, guiding tools offer proactive support through real-time feedback and personalized interventions, helping users achieve specific learning goals. Evaluating the impact of these technologies and identifying best practices remains a challenge. Tausch et al.'s[88] comparison of cooperative and competitive visualizations highlights the importance of the type of visualization used. Cooperative visualizations foster teamwork and collaboration, while competitive visualizations can motivate through rivalry. Their study found that mixed visualizations, combining both approaches, led to more balanced participation and a higher number of ideas, suggesting that finding the right balance in feedback is crucial for optimal performance. Ultimately, leveraging the strengths of both mirroring and guiding tools, and carefully considering the type of visualization, can significantly enhance the effectiveness of feedback in groups.

Existing studies have largely focused on visualizations in educational or professional settings, leaving sports-specific applications underexplored. Additionally, while competitive feedback is shown to enhance individual motivation, its interaction with public group settings remains unclear. This study addresses these gaps by focusing on team fitness tracking in rowing and comparing feedback types across settings.

2.3.2 Accounting For Group And Individual Preferences

Finding out what can be visualized and how are important questions, but preferences and learning styles in a team or group may also differ, so understanding what to visualize is one of the challenges when trying to give feedback to a group. Digital interfaces enable a whole new way of personalizing what users get to experience when using or interacting with any kind of content. How to personalize content to individual users has been widely investigated. However, how to visualize and personalize feedback for a group is less understood.

One study by Akhuseyinoglu et al. [4] tried to adapt different mirroring tools that were deviating from the commonly used (fixed) average [14, 51], arguing that comparison to class average (fixed comparison) might be ineffective for some users and may only motivate a *subset* of users. As research indicates, users tend to perceive comparisons with their peers as discouraging when their performance is below the class average or when they are outperformed by another individual. [2, 61, 69, 78]. Instead, Akhuseyinoglue et al.[4] tested different adapted social references. Although the results were not significant, due to the small sample size, interview answers and performance trends indicated that personalized and adapted visualization motivated the group more.

Research therefore has explored different strategies for combining preferences, including average preference, least misery (minimizing dissatisfaction), and most pleasure (maximizing satisfaction) [65]:

- **Average Preference:** Aggregates preferences by averaging the scores of items across all group members.
- **Least Misery:** Prioritizes the preferences of the least satisfied member, ensuring that no one in the group is extremely dissatisfied.
- **Most Pleasure:** Focuses on maximizing the satisfaction of the most pleased member, which may not always lead to a balanced solution.

The paper by Masthoff et al. [65] indicated that different scenarios might require different aggregation strategies to achieve the optimal level of group satisfaction. Given the inherent difficulty in balancing diverse preferences, especially in larger groups, A comprehensive understanding of the dynamics and interactions within a group is essential for the effective recommendation of appropriate courses of action.

2.3.3 Visualizing Teams In Sport

Research on visualizing team performance in sports has been extensive, covering a wide range of methodologies and sports. In this section, we discuss key insights and publications related to visualizing team performance, with a specific focus on rowing, cycling, and canoeing.

2.3.4 General And Popular Sport Visualization

Most research focuses on popular team ball sports. We refer to [25] for a more in-depth discussion, as they provide a comprehensive overview of the state-of-the-art techniques in sports data visualization and visual analysis in team ball sports. Those visualizations should be most familiar as they are often used in TV broadcasts. This survey categorizes sports data visualization into two main types: spatiotemporal information and statistical information. Spatiotemporal data involves tracking the positions and movements of players or equipment over time, while statistical data includes metrics and performance indicators derived from sports events. An overview of that categorization can be found in figure 2.1.

Often, these visualizations in team sports are simple diagrams designed to align closely with the branding of the league, event, tournament, or video game. These visualizations typically use team colours, logos, and other brand elements to create a cohesive and familiar look for the audience. The primary focus of research in this area tends to be on the data and informational content, aiming to present key statistics and metrics in a clear and accessible manner.

However, more advanced and unusual graphical representations are increasingly being utilized to provide deeper insights. These include heat maps, trajectory plots, and interactive graphics [15, 62, 90]. Heat maps are particularly useful for showing the intensity of player movements and activities across different areas of the field, helping to identify patterns and hotspots of action [62, 90]. Trajectory plots track the paths of players or the ball, allowing for a detailed analysis of movement and strategy over time. Interactive graphics take this a step further by enabling users to engage with the data directly, allowing them to filter and drill down into specific metrics and time periods [15].

These advanced visualization techniques not only enhance the understanding of complex game dynamics but also support more effective decision-making for coaches, analysts, and players. They provide a richer, more nuanced view of the game, enabling a deeper analysis of strategies, player performance, and overall team dynamics. This shift towards more interactive and detailed visualizations represents a significant advancement in sports analytics, offering new tools for improving team performance and fan engagement.

Nevertheless, most recently the fitness data revolution, mentioned in chapter 2.1.3, and the companies that brought tracking to the everyday user, highlight the need for new solutions in less popular team sports. Those companies and their Software Platforms are developed to visualize GPS data, heart rate, power output, and other metrics. Research here has focused on the usability and effectiveness of these platforms in providing actionable insights to athletes, mainly on an individual level [40, 81].

2.3.4.1 Cycling

Research on performance visualization in cycling focuses on strategy, pacing, and environmental conditions [7]. Studies often utilize data analytics and simulation models to predict outcomes and optimize training routines [75]. These methods help cyclists under-

- Competitive Sports Data
  - Spatio-temporal Information
    - Absolute Spatio-temporal Information
      - Spatio-temporal Information for Ball
      - Spatio-temporal Information for Player
    - Relative Spatio-temporal Information
      - Possession Information
      - Shooting Information
      - Battle Array Information
      - Tactical Information
  - Statistics Information
    - Event Statistics Information
      - Moment Event
      - Period Event
    - Staff Statistics Information
      - Player's Personal Information
      - Comparative Information among Players
      - Team Information

Figure 2.1: Categories Of Sport Data Visualizations [25]

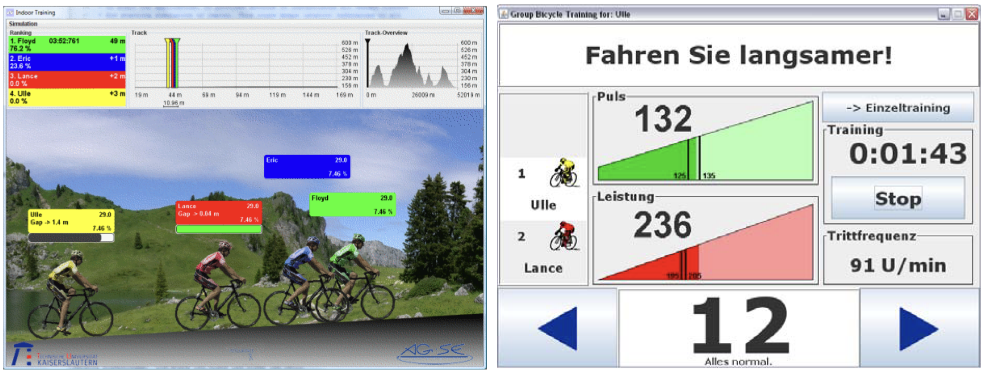

Figure 2.2: TCTS screenshots [49]

stand the impact of various strategies and conditions on their performance, leading to better decision-making during races [92].

Performance visualization incorporates telemetry data, GPS tracking, and physiological metrics. Tools like power meters and heart rate monitors provide data that are visualized through software platforms, enabling detailed analysis of cyclists' performance during training and races [53, 83, 92]. These studies highlight the use of these visual tools for optimizing strategies and monitoring athletes' health. This illustrates how visualization techniques and data analytics contribute to enhancing cycling performance and decision-making on an individual level.

However, research has been conducted into the ways in which individuals can cooperate and subsequently visualise the act of cycling in a training context. The paper [49] introduces an innovative system designed to enhance team training in cycling through ambient intelligence technologies. The system integrates real-time data collection, analysis, and feedback mechanisms to optimize team coordination, performance evaluation, and strategic decision-making during training sessions. It aims to improve overall team cohesion and effectiveness through enhanced data-driven insights and interactive training environments. And in that context also developed a visualization tool to give that feedback, it can be seen in figure 2.2.

Cycling, like running, is in itself an individual activity and sport. This makes it quite popular, as it can be done individually, which means the body of research is extensive. However, it also means training and research are usually aimed at improving one's own performance. Therefore training is usually individualized, in its intensity, distance or other intensity metrics. Nevertheless, group training remains a valuable tool, and the ability to cooperate effectively within teams is frequently a decisive factor in competitive racing, due to the benefits of slipstream effects.

Also worth mentioning is that Visualized Feedback can have its pitfalls. The authors of [18] argue that traditional visualizations are insufficient for the nuanced needs of cyclists, the state-of-the-art displays may be misleading many cyclists to sub-optimal outcomes. Leaderboards or Stress Scores could lead to users pushing themselves too hard, leading to over-training. While a recovery score might lead to the opposite and therefore no training effect. They propose new, user-centered designs that better convey complex data such as power output, cadence, and heart rate.

In conclusion, cycling is a prevalent individual sport with a substantial body of research exploring the potential of tailored visualisations to enhance personal performance. The metrics and training philosophies employed are similar to those used in rowing. Despite this focus, group training and team cooperation are essential for competitive success. And while visualization tools highlight strategy, pacing, and environmental conditions and leverage telemetry data, GPS tracking, and physiological metrics, helping cyclists make better decisions during races. [49] introduces a system that enhances team training through real-time data collection, analysis, and feedback, improving team coordination and decision-making.

2.3.4.2 Rowing And Canoeing

Research on rowing and canoeing is quite similar, often concentrating on performance visualization through biomechanical analysis. These studies typically employ motion capture and video analysis to evaluate athletes' techniques and synchronization, which are crucial for optimizing performance in these sports. For example, motion capture systems track the precise movements of rowers and canoeists, allowing for detailed biomechanical analysis. Video analysis complements this by providing visual feedback that can be used to identify and correct technical flaws [16, 48, 56]. Bowen et al. [16] explored the use of biomechanical analysis to design feedback systems that improve athletes' performance by focusing on movement efficiency and synchronization and [56] discussed various biomechanical principles in rowing, including the importance of stroke rate, force application, and body mechanics.

The three visualization areas are:

- *Motion Capture*: Captures detailed data on athletes' movements, which can be analyzed to detect inefficiencies and potential areas for improvement.

- *Video Analysis*: Provides a visual representation of performance, allowing coaches to give more precise feedback on technique and synchronization.
- *Visual Feedback Systems*: Combine motion capture and video analysis data to create comprehensive training aids that help athletes visualize their movements and understand how to adjust them for better performance.

To conclude, research on visualizing team performance in canoeing and rowing almost solely focused on motion caption, video analysis and by combining both creating a visual feedback system. Leaving a big gap in research for team visualization of training efforts through the methods of the Quantified-Self.

Chapter 3

Research goals

3.1 Status Quo

The QS movement has significantly impacted the way individuals and groups approach fitness and sports. By utilizing wearable technology and mobile applications, athletes can track a wide range of metrics, from physical activity to sleep patterns and dietary habits. This data-driven approach enables athletes to make informed decisions aimed at optimizing their performance and health. (Chapter 2.1)

Further persuasive technology aims to influence user behaviour through non-coercive means, leveraging principles from behavioural science. Key techniques include goal setting, feedback, incentives, and social comparison. These techniques are integral to fitness apps, which use them to enhance user engagement and motivation. Positive feedback, such as rewards and social recognition, generally boosts motivation, while negative feedback must be carefully implemented to avoid discouragement. (Section 2.1.2)

Group feedback, distinct from individual feedback, focuses on the collective performance of a team. Effective group feedback can significantly enhance group dynamics, promoting better communication, cohesion, and performance. Positive feedback can boost morale and motivation, while negative feedback helps in identifying and correcting errors. The combination of both types of feedback, when balanced correctly, can lead to continuous improvement and sustained engagement. (Chapter 2.2) Visualized group feedback therefore refers to the use of graphical and interactive elements to present performance data to a group. This approach is increasingly employed in various domains, including sports, to enhance group cohesion, motivation, and overall performance. By leveraging technology to visualize data, teams can gain insights into their collective performance, identify areas for improvement, and foster a competitive yet collaborative environment. (Chapter 2.3)

It thus follows that visualization tools are of critical importance when it comes to presenting group performance data and, consequently, the effectiveness of subsequent training programmes and the resulting performance outcomes. The aforementioned tools may encompass a variety of formats, from basic charts and graphs to more sophisticated interactive platforms that facilitate real-time feedback. In the context of sports, visualisation tools facilitate the monitoring of team performance, the formulation of strategic plans, and the implementation of data-driven decision-making processes. To illustrate, in the sport of rowing, motion capture and video analysis are frequently employed to evaluate techniques and enhance team synchronisation.

3.2 Research Gap

Despite the advancements in visualized group feedback, several gaps remain, particularly in the context of sport:

The current state of integration of advanced visualisation techniques is limited. Although basic individual tools are widely used, there is a need for more advanced visualisation techniques, such as metaphors, which can facilitate deeper insights and more intuitive feedback. Additionally, the potential benefits of advanced techniques in group settings have yet to be fully explored in the context of quantified sports. Moreover, the majority of existing tools concentrate on providing individual feedback, which frequently results in the exclusion of the group. It is evident that there is a necessity for the development of systems that are capable of providing personalised feedback within a group context, with the objective of catering to the distinctive requirements and dynamics of each team.

3.3 Research Goals

Based on existing literature, this study proposes two research goals to explore the impact of various feedback mechanisms on the performance and motivation of teams. The hypotheses are designed to investigate the efficacy of different types of visualizations and feedback on both individual and group levels within a training context.

3.3.1 Hypothesis 1: Metaphoric Visualizations vs. Simple Diagrams

Hypothesis: Metaphoric visualizations will be more effective in motivating athletes and improving performance than simple diagrammatic feedback.

Rationale: Tausch et al. [88] found that metaphoric visualizations, such as balloon metaphors, outperform simple diagrams in collaborative brainstorming. Similarly, Akhuseyinoglu et al. [4] noted improved team motivation with adaptive visualizations. This supports Hypothesis 1 by suggesting metaphoric visualizations will enhance engagement and performance over simple graphs.

3.3.2 Hypothesis 2: Public vs. Private Feedback

Hypothesis: Feedback given in front of the group will result in higher motivation and better performance outcomes than feedback given individually, regardless of whether it is individual or group feedback.

Rationale: Receiving feedback in a group setting can increase accountability and motivation among team members. Public feedback can also promote a sense of shared responsibility and collective goals. This visibility encourages individuals to align their efforts with the group, thereby enhancing overall performance and synchronization.

The aforementioned hypotheses and their underlying rationales provide a framework for investigating the potential of different feedback strategies to optimise team dynamics and performance in a team sport context. The objective of this study is to contribute valuable insights to team performance optimisation through empirical testing.

3.4 Why Visualize Rowing

In Rowing you often literally are sitting in the same boat when it comes to training. Training at varying intensity levels, as recommended by an individualized cycling or running program, is not a viable option. Consequently, each individual is required to complete the same intensity of workout. To illustrate, a long, steady-state training session may be conducted at the endurance heart rate zone. It is not uncommon for the subjective experience of a training session, often referred to as the ”eye-test” or ”feeling”, to be used as a rationale for the outcomes of that particular team training session. Although at the end of the training, each individual often is provided with their own heart rate data and other feedback by the wearable device. It is therefore crucial to acknowledge that these "eye-test" observations, may be influenced by a number of factors, including the level of effort and other identifiable variables. Such factors could be identified through the analysis of the data. Making Rowing the perfect sport to investigate the potential of group feedback and the two research questions posed in this work.

Therefore, this work sets out to examine the knowledge gap, about the use of the "quantified-us" in rowing. The objective is to investigate how data-driven feedback affects behavioural change in groups. By gaining a deeper understanding of how group feedback is best visualised, within the context of comparing the impact of group feedback with that of individual feedback. The goal is to create a visualization with a similar approach as the tcts program [49] that gives the group or individuals feedback on their effort to make sure everyone in the boat trains at the right intensity. Based on insights from related work discussed in previous chapters, this study investigates the missing link between fitness-tracking, visualization and public versus private group scenarios. And by evaluating the feedback delivering empirical proof of the effectiveness.

To address the research gap and objectives, this study will take several steps to evaluate different feedback conditions. A team of rowers, training and monitoring their performance using wearable devices, will share their data. Then, the information derived from the individual data will be used to create feedback that can be provided to the group or individual about the team's performance. For example, an individual's average heart rate can be compared to the team's average heart rate. To facilitate this comparison, various visualisations of group performance are developed. These visualisations range from simple graphs to more metaphorical representations. Testing and a concise evaluation of these will then provide first insights into the research questions posed.

Utilizing a between-subjects design, this work tests how feedback affects users differently under various conditions:

- When feedback is presented as a simple diagram versus a metaphoric visualization.
- When feedback is provided public vs private.

Investigating The Research Goals

In order to investigate the impact of different visualisation techniques, it is necessary to adopt a multi-faceted research approach. A crucial phase of the process entails the creation of both simple and metaphorical visualisations that are capable of conveying data in a user-friendly format. Once the visualisations have been created, a qualitative research methodology can be employed to assess their impact on user understanding, motivation and performance. The following chapters will examine the development process of the visualisation application and the initial research conducted to explore its potential impact. A comprehensive account will be provided of the design choices, implementation techniques, and technical considerations that informed the development process. The objective of the research phase is to investigate the effectiveness of the visualisation techniques in terms of user understanding, motivation, and performance. The objective of this work is to provide valuable insights into the design and evaluation of visualization tools for groups and teams by combining technical implementation with rigorous research.

Chapter 4

Design, Development and Implementation of the Visualizations

4.1 Exploration of Available Data and Visualization

The initial phase of the visualisation development process entailed a comprehensive examination of the data types that can be monitored through the use of wearable devices during rowing training. This was followed by an investigation into the aggregation of individual-level data to generate group-level insights. Furthermore, this phase examined the most efficacious methods for visualising both individual and aggregated data. The objective was to develop an application or dashboard that would provide the group of rowers with a range of feedback, which would then be used to assess the hypothesis in the second phase of the project.

4.1.1 Data Sources Identification

The utilisation of wearable technologies in the context of rowing training practices provides a diverse range of data sources that can markedly enhance the monitoring of performance and the optimisation of training regimens. Global Positioning System (GPS) technology, in conjunction with motion sensors, including accelerometers and gyroscopes, provides detailed insights into a number of key performance indicators, including speed, rowers' stroke mechanics, rhythm, and boat movement dynamics. This data is of great importance to both coaches and athletes, as it allows for the refinement of technique and the achievement of optimal performance outcomes.

Simultaneously, biometric sensors, such as those measuring heart rate (HR), provide immediate insights into the physiological state of the subject. The monitoring of heart rate enables the assessment of the cardiovascular fitness levels, recovery rates and overall exertion levels of rowers during training sessions. This information is of great value in adjusting training intensity, preventing overtraining and maximising performance gains over time.

In view of the considerable diversity of wearable devices and the associated data formats, this study focused on a single brand in order to ensure consistent data collection and analysis. Garmin was selected as the primary device for three key reasons: an existing data agreement between Utrecht University and Garmin, the availability of a robust API for data extraction, and the widespread use of Garmin devices among local rowers. By standardising on a single brand, the study aimed to minimise data variability and facilitate the development of visualisations.

4.1.2 Garmin Data

To facilitate the collection of data, participants were invited to share their training data via Garmin's application programming interface (API). The API provided access to comprehensive JavaScript Object Notation (JSON) files, which offered a detailed overview of the activity in question, which included an array of data samples. Each data sample was comprised of a series of key variables, including a timestamp, elapsed time, speed, heart rate, and GPS coordinates.

In order to align with the focus of this study on rowing, the raw speed data, measured in metres per second, was converted to a more commonly used metric in rowing: time per 500 metres. This conversion facilitated a more meaningful analysis of pacing and performance. The study was able to investigate the nuances of rowing performance and the influence of diverse feedback modalities by leveraging the comprehensive data set provided by the Garmin API.

4.1.3 Aggregation Techniques

In order to derive comprehensive insights from individual data, the aggregation of data sets is a crucial technique. The process entails an investigation of diverse methodologies that are intended to integrate individual performance metrics into meaningful group-level analyses. Statistical techniques such as averaging and clustering are particularly valuable for aggregating heterogeneous data types, which include variables such as heart rates, locations and speed.

Averaging allows for a straightforward calculation of central tendencies across multiple rowers, thereby providing an overall perspective on training intensities and trends. Meanwhile, clustering techniques can categorise rowers based on similarities in their training data, thereby revealing distinct groups with shared performance characteristics or training patterns. In the context of this research and its associated visualisation, the focus was placed on averages, due to the objective of increasing group motivation rather than identifying individuals through clusters.

However, the integration of data from multiple wearables presented a number of challenges, including the necessity to ensure synchronisation across different devices in order to maintain data consistency and accuracy. The presence of missing or erroneous data points introduces further complications to the process of aggregation, necessitating the implementation of rigorous data management procedures to prevent the generation of skewed interpretations of group-level insights.

In the interest of mitigating the impact of potential data gaps and ensuring accurate calculations, a smoothing technique was applied to the raw data. In particular, a five-second simple rolling average was calculated for each rower [47]. This approach entailed the averaging of data points within a five-second window, thereby effectively smoothing out noise and missing data and reducing the impact of individual data points. To illustrate, if Rower 1 had a data point at second 10 and Rower 2 had a data point at second 13, the average heart rate and speed for both rowers would be calculated based on the data points within the 5-second window from seconds 10 to 15. Subsequently, the averages were employed to calculate the overall mean. This smoothing technique provided a more robust and reliable estimate of the mean heart rate and speed for all rowers at a given time point.

4.1.4 Visualization

In the pursuit of facilitating group feedback, the examination of visualisation methods is of importance in transforming aggregated data into actionable insights. Effective visualisation techniques represent a powerful tool for the presentation of aggregated group data in a clear and comprehensible manner. Such techniques permit the identification of trends, patterns and anomalies, which can then be used to inform training strategies and enhance overall performance. The following categories will be the focus of this work: common diagrams versus metaphorical and competitive versus cooperative visualisations.

Competitive vs Cooperative Visualizations

In addition to the visualization methods, exploring cooperative, competitive, mixed visualizations enhances the depth and impact of data presentation in rowers' training contexts. Cooperative visualizations could emphasize collaborative efforts and mutual goals within the team, highlighting positive correlations and shared achievements among rowers. For example, synchronized line charts showing collective improvement in stroke efficiency over time foster a sense of teamwork and collective progress. On the other hand, competitive visualizations introduce elements of comparison and achievement against benchmarks, competitors, or even team mates. Bar graphs displaying individual performance metrics relative to average or best-in-class standards can motivate rowers through healthy competition and drive personal improvement. And lastly, mixed visualizations can combine cooperative and competitive elements to balance collaboration with individual performance assessment [88]. For instance, radar charts showcasing both team-wide strengths and areas needing improvement could enable users to identify both collective strengths and individual weaknesses.

To maintain a balanced approach and avoid overemphasising either competitive or cooperative aspects, a mixed visualization strategy was adopted. This approach incorporated both competitive and cooperative elements to provide a comprehensive and informative feedback experience.

On one hand, a competitive visualization was included to motivate individual performance. By comparing each rower's heart rate to the team average and the performance of other crew members, individuals could identify areas for improvement and strive to outperform their peers.

On the other hand, a cooperative visualization was integrated to foster teamwork and collective effort. This visualization highlighted the team's overall speed and efficiency, comparing it to the collective effort expended, as indicated by the average heart rate. By emphasizing the importance of synchronized effort and collective performance, this visualization encouraged teamwork and collaboration among the rowers.

This balanced approach aimed to strike a harmonious blend of competitive and cooperative feedback, ultimately enhancing both individual and collective performance.

Common Visualizations

Various common visual formats, such as charts, graphs, and maps, were considered for their suitability. Charts and graphs are usually particularly effective in illustrating temporal changes in performance metrics such as stroke rates, heart rates, and distances covered during training sessions. These visual representations provide a dynamic snapshot of individual progress and allow for direct comparisons across rowers within the group. Maps can spatially depict training routes and environmental conditions, offering insights into geographical aspects that may impact training outcomes. This visualization approach helps contextualize performance data with external factors like weather conditions or course variations, enabling a more holistic understanding of training effectiveness.

To enhance user understanding of environmental factors influencing rowing performance and to provide a spatial context for the visualized data, a map was incorporated into both visualization conditions. This map allowed users to visualize the rowing route and identify potential environmental factors that may have impacted performance.

Further, to align with common practices in fitness and tracking apps, line graphs were employed in the simple visualization condition to depict time-dependent variables such as heart rate and speed. This familiar representation provides a clear and intuitive way to track changes in these metrics over time.

Metaphorical Visualizations

Metaphorical visualizations, on the other hand, employ creative representations to convey training insights beyond numerical data. Using imagery like a boat navigating rough seas (representing training challenges) or a steady upward trajectory (indicating consistent improvement) provides intuitive, metaphorical insights into training dynamics. Such visualizations facilitate deeper engagement and understanding among team mates, transcending raw data to evoke emotional and strategic responses.

The selection of appropriate metaphors for the visualization design was a complex process that warranted careful consideration. A dedicated chapter (4.2) delves into the detailed exploration and evaluation of various metaphoric representations, ultimately leading to the selection of the most effective and engaging metaphors for the specific context of rowing performance feedback.

Summary

This section has outlined the foundational steps in developing effective visualizations for rowing performance feedback. By leveraging wearable technology data and employing appropriate data processing and visualization techniques, we aim to create a comprehensive feedback system that enhances performance and motivation. This application then can be tested in the next phase of the project, aiming to validate its effects and usefulness in real scenarios.

4.2 Developing the Visualizations

In an effort to effectively visualise rowing performance data and provide actionable insights, it is essential to undertake a meticulous examination of the relevant metrics and available visualisation techniques. In Chapter 4.1, the key performance indicators are identified as heart rate, location, and speed. These indicators were deemed to be valuable sources of information regarding both individual and team performance. In order to cater to the diverse learning styles and preferences of the participants, two distinct visualisation approaches are developed: a competitive approach, which emphasises individual performance relative to team averages, and a cooperative approach, which focuses on team dynamics and collective effort.

In the absence of metaphorical representation, the data is depicted in the form of standard line graphs, which are employed to illustrate variables that are dependent on time, such as heart rate and speed. This representation, which is readily comprehensible, offers an effective means of monitoring fluctuations in these metrics over time. However, for the metaphoric visualisation condition, a more creative approach is necessary to engage users and convey complex information in a visually appealing manner.

To identify suitable metaphors, a detailed analysis was conducted of the common rowing training types (Table 4.2) and the associated challenges for groups and individuals (Table 4.1). The analysis revealed the significance of data-driven feedback in addressing challenges such as unequal training zones and overtraining. The existence of unequal training zones has the potential to result in imbalances in performance and coordination, while the phenomenon of overtraining has the capacity to exert a detrimental effect on the process of recovery and the overall performance of the individual. The implementation of data-driven feedback in the form of visualisations can assist in the identification and resolution of these issues by facilitating insights into both individual and team performance.

Figure 4.1: Rower Metaphor

To develop effective metaphors, a creative design process was employed. A variety of metaphorical representations were devised for each training type, and these metaphors were evaluated in terms of their simplicity, realism, and capacity to convey the desired information. By carefully considering the specific requirements of the rowers and the nature of the data, a set of suitable metaphors was selected for implementation in the second phase of the project, namely the metaphoric visualisation condition. The objective of these metaphors is to facilitate a more engaging and intuitive comprehension of performance data, thereby enhancing the overall efficacy of the feedback system.

4.2.1 Metaphor Rower

For the first visualisation, which in the simple condition is a line graph showing the heart rate of the rowers including the average, the goal is to provide each rower feedback on their effort or training intensity. Therefore the visualization incorporated a visualization of heart rate zones. By analysing heart rate data, the users could determine whether rowers were training at the appropriate intensity level. To visually represent this information, a simple yet effective metaphor is employed: a rower icon with a colour-coded head (Seen in Figure 4.1). The colour of the head corresponded to the specific heart rate zone, providing a clear and intuitive indication of the rower's effort level.

The visualization system included both individual and group-level information to provide a comprehensive overview of team performance. Not only are individual rowers represented, but the team's average heart rate is displayed as a rower metaphor. This enables rowers to evaluate their performance in comparison to the team average and other rowers, in a manner similar to that of the line graph from the preceding condition.

To address the challenge of visualizing time-dependent data in a metaphoric context, a timeline is integrated into the visualization. The timeline served as a reference point, highlighting key moments and significant variations in performance. By using a horizon graph to represent the difference between each rower's heart rate and the team average, a compact and informative visualization is created. This approach avoids redundancy and provides a clear visual representation of individual performance relative to the group.

4.2.2 Speed And Efficiency Metaphor

For the simple visualization condition, a line graph is chosen to represent speed over time. To provide additional context, the team's average heart rate is overlaid on the graph, allowing users to identify periods of efficient effort. By breaking down the information into speed and heart rate, the visualization aims to provide a clear and intuitive understanding of performance.

To create an engaging and informative metaphoric visualization, common visual metaphors are employed. A speedometer (Figure 4.2) is used to represent speed, with the needle indicating the current pace. A heart icon (Figure 4.3) is used to represent heart rate intensity, with the fullness of the heart indicating the level of effort. To account for the time dimension, a colour-coded timeline is introduced. Green segments represented periods of high speed, while red segments indicated periods of low speed. A second colour-coded bar for the heart rate is created. And here again, the high heart rate was green and the low heart rate was colour-coded red. This colour-coded timeline provides a quick and intuitive overview of the training session, highlighting key moments and trends.

Training Type	**Goal**	**Individual Issues**	**Team Issues**	**How Visual Feedback Can Help Individual**	**How Recorded Data Can Help Team**

Low Heart Rate Endurance	Build aerobic capacity, enhance stamina, and improve recovery.	Not maintaining the target low heart rate; underestimating effort.	Some crew members may push too hard, causing others to struggle or slowing down the group.	Helps monitor and ensure heart rate remains within the target zone.	Identifies discrepancies in effort levels and ensures uniformity in training zones.
Steady-State	Maintain a steady, moderate intensity for sustained periods.	Drifting into too high or too low an intensity zone.	Crew may lose synchronicity if not all members are in the same intensity zone.	Provides immediate feedback to adjust intensity if drifting out of the zone.	Helps identify which rowers are not in sync, enabling corrective action.
Threshold Training	Increase lactate threshold to sustain higher intensity longer.	Exceeding threshold heart rate, leading to premature fatigue.	Inconsistent effort across the crew, with some hitting their threshold while others are below it.	Alerts when the heart rate exceeds the threshold, allowing timely adjustments.	Compares how each crew member responds to intensity, fostering better alignment.
High-Intensity Interval Training (HIIT)	Improve anaerobic capacity, speed, and power.	Inadequate recovery between intervals; pushing too hard or not hard enough during sprints.	Uneven recovery times among crew members, causing loss of timing and coordination in subsequent intervals.	Tracks recovery and exertion, ensuring effective interval execution.	Analyses variance in performance and recovery to improve synchronized effort.

Race Pace Training	Simulate race conditions to improve speed and mental toughness.	Inconsistent speed or heart rate, failing to maintain race intensity.	Crew members may struggle to maintain a uniform race pace, leading to disjointed boat movement.	Helps maintain consistent race pace and heart rate through real-time monitoring.	Identifies inconsistencies in pace and heart rate, helping to fine-tune team coordination.
Sprint Training	Maximize short-burst power and speed.	Overexertion leading to poor form or early burnout.	Mismatch in power output, causing uneven boat speed and balance.	Monitors heart rate spikes to avoid overexertion and maintain peak form.	Provides data to align sprint intensity and power output across all team members.
Recovery Row	Facilitate recovery by keeping intensity low.	Rowing too hard, preventing adequate recovery.	Some rowers might push too hard, hindering overall recovery and synchronization.	Ensures heart rate stays low, confirming recovery is effective.	Helps ensure all crew members are adhering to recovery intensity, maintaining team cohesion.
Technical Drills	Improve rowing technique and efficiency.	Focusing too much on heart rate instead of technique; underperforming drills.	Disparities in focus on technique can lead to inconsistent rowing form across the crew.	Visual feedback is less crucial but can confirm the appropriate intensity for drills.	Combines technique assessments with heart rate data to ensure drills are effective without overexertion.

Table 4.1: Analysis of Training Types: goals, issues and potential for feedback

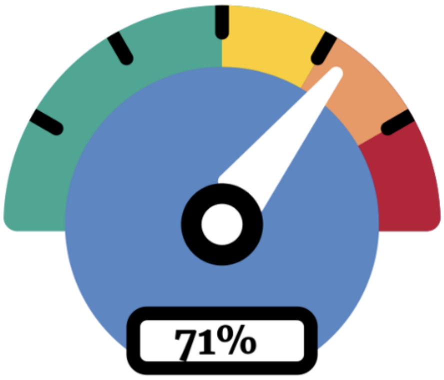

Figure 4.2: Speedometer Metaphor

Figure 4.3: Heart Rate Metaphor

Training Type	**Heart Rate Zone**	**% of Maximum Heart Rate**	**Description**
Low Heart Rate Endurance	Zone 2	60-70%	Light aerobic zone; ideal for building aerobic capacity and endurance with minimal fatigue.
Steady-State	Zone 3	70-80%	Moderate aerobic zone; sustainable effort that improves cardiovascular fitness and endurance.
Threshold Training	Zone 4	80-90%	High aerobic/low anaerobic zone; increases lactate threshold allowing sustained high-intensity effort.
High-Intensity Interval Training (HIIT)	Zone 5 (during intervals) Zone 2-3 (recovery)	90-100% (intervals) 60-70% (recovery)	Anaerobic zone during intervals to boost speed and power with recovery periods in lower zones.
Race Pace Training	Zone 4-5	85-95%	Anaerobic threshold to near maximum effort; simulates race conditions to improve speed and mental toughness.
Sprint Training	Zone 5	90-100%	Maximum effort anaerobic zone; focuses on short bursts of power and speed.
Recovery Row	Zone 1-2	50-60%	Very light effort focused on promoting recovery and reducing muscle stiffness.
Technical Drills	Zone 2-3	60-75%	Light to moderate intensity ensuring that focus remains on technique rather than cardiovascular strain.

Table 4.2: Training Types and the according Heart Rate Zones

4.3 Realization And Implementation Of Visualizations

This chapter will delve into the technical aspects of developing an iPad app for the research project, leveraging the power of React Native and Expo. The app, designed to collect and visualize rowing data, will integrate with the Garmin API to streamline user authentication and data acquisition. The app will adhere to strict data security policies, ensuring that sensitive information is only accessible to authorized users while they are actively logged in.

4.3.1 React Native And Expo Implementation

The App

React Native [76], a popular framework for building cross-platform mobile apps, will be employed to develop the user interface and core functionality of the app. Expo [29], a set of tools and services for building React Native apps, will streamline the development process by providing a fast and efficient way to build, test, and deploy the app.

D3 For The Simple Visualisations

For the Graphs and Timelines D3.js [21] is used. It is a powerful JavaScript library for creating dynamic, interactive data visualizations. It empowers the developers to bring data to life through custom visualizations built with SVG, Canvas, and HTML. D3 offers a low-level, flexible approach, allowing you to craft highly tailored and visually stunning data displays.

SVGs For The Metaphors

The visual metaphors were meticulously crafted using Figma [33], a robust design tool. Once finalized, they were exported in the SVG format. These SVG assets were then seamlessly integrated into the React Native app, where they were brought to life through dynamic animations. This integration ensured that the metaphors remained visually appealing and interactive across various screen sizes and devices.

4.3.2 App Architecture And Functionality

The app will be structured around four primary tabs:

- **Home:** This tab serves as the entry point, allowing users to log in using their Garmin credentials. Upon successful authentication, the app will fetch the user's recent training activities from the Garmin API.
- **Activities:** This tab displays a list of the rower's recent rowing activities. Users can select a specific activity to visualize its data in greater detail.

- **Simple Visualization:** This tab presents data in a straightforward, line-graph-based format.
- **Metaphoric Visualization:** This tab employs visual metaphors to convey data in a more intuitive and engaging manner.

4.3.3 Data Security And Privacy

To safeguard the sensitive nature of user data, the app has been meticulously designed with robust security measures. The integration with the Garmin API has been carried out in a secure manner, employing advanced authentication protocols and robust encryption techniques. This ensures that unauthorized access to user data is prevented at all times.

Furthermore, the app adheres to a strict principle of data minimization. User data is stored locally on the iPad device only while the user is actively logged in. This temporary storage approach significantly reduces the potential risk of data breaches and unauthorized access. Once the user logs out, the local data is securely erased.

To further bolster data security, all data transmitted between the app and the Garmin API is encrypted using the HTTPS protocol. This encryption ensures that the data remains confidential and protected from interception during transit.

It is important to acknowledge that the successful implementation of these security measures was made possible through a collaborative effort between Utrecht University and Garmin. Garmin's commitment to data privacy and security aligned with the university's stringent requirements, enabling the development of a secure app.

4.3.4 Visualization Components

Both the simple and metaphoric visualization tabs share a common structure, comprising four core modules:

- **Summary:** This module provides a concise overview of the training session
- **Map:** This component displays a map of the rowing route, with pins indicating the location of each rower at specific timestamps
- **Heart Rate:** depicting the heart rate of each rower over time, along with the calculated average heart rate

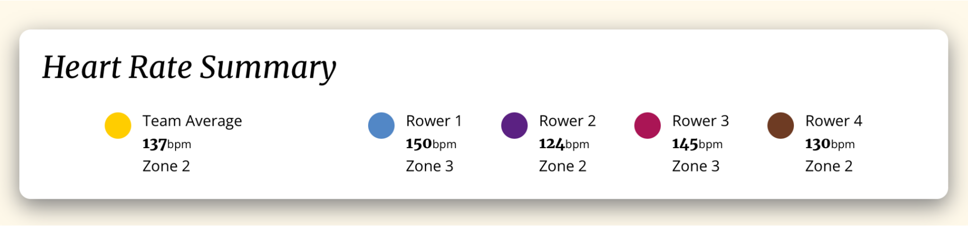

Figure 4.4: Simple Heart Rate Summary

- **500 meter/split:** *Simple Visualization:* A line graph showing the speed for each rower, with an optional overlay of the average heart rate.
  Metaphoric Visualization: A speedometer to represent the speed, with an optional heart icon to indicate heart rate intensity. A colour-coded bar on the timeline represents the overall intensity of the rowing session.

Heart Rate Summary

This component, aptly named "Heart Rate Summary," provides a concise overview of the training session. It presents key insights into the team's overall effort and the individual contributions of each rower.

Both components display the team's average heart rate alongside the corresponding heart rate zone, offering a quick reference for the overall intensity of the session. Furthermore, it highlights the average heart rate of each rower, accompanied by their respective heart rate zone. The Rowers are next to the label also identifiable by an assigned colour. This allows for a detailed analysis of individual performance and potential areas for improvement. The simple version therefore relies on text as shown in figure 4.4.

To enhance the visual appeal and understanding, the metaphoric version of this component (figure 4.5)employs a metaphoric representation. Each rower is represented by a coloured icon, with the colour of the icon's head indicating the heart rate zone they were predominantly in during the session. This colour-coded system provides a quick and intuitive way to compare the intensity levels of different rowers and identify any significant variations.

Overall, the "Heart Rate Summary" component was designed as a valuable tool for coaches and athletes to gain a comprehensive understanding of training performance, identify areas for improvement, and optimize future training sessions.

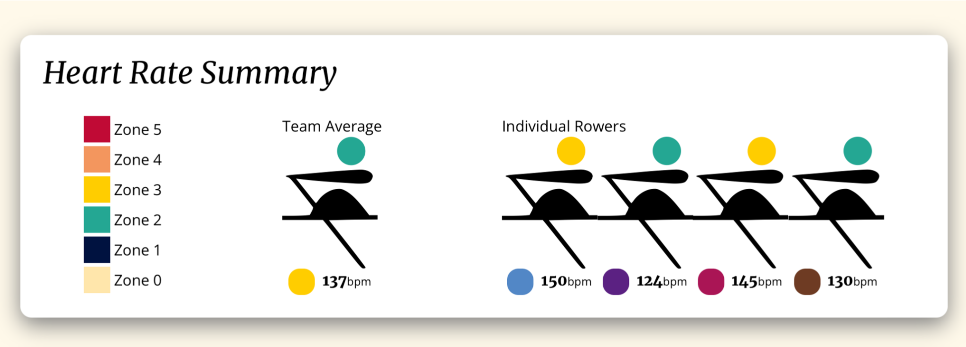

Figure 4.5: Metaphoric Heart Rate Summary

Map

This map module (figure. 4.6) offers a dynamic and interactive visualization of the rowing route, providing valuable insights into the spatial aspects of the training session. The map displays the path traversed by the rowers, with coloured pins marking their positions at specific timestamps. This allows users to track the progress of each rower along the route, identify any deviations or changes in course, and analyze the overall team dynamics.

The map can be zoomed in and out to explore the route in greater detail, revealing finer nuances of the rowing path. Users can also pan the map to focus on specific areas of interest, such as challenging sections or areas where rowers may have encountered obstacles.

By combining the spatial information with the temporal data from the heart rate and speed visualizations, users can gain a comprehensive understanding of the rowing session. They can correlate changes in rowing speed with specific locations on the map, identify areas where the team may have experienced difficulties, and analyze the impact of environmental factors on performance.

Heart Rate

The ”Heart Rate” module provides a detailed visualization of the heart rate data collected during the rowing session.

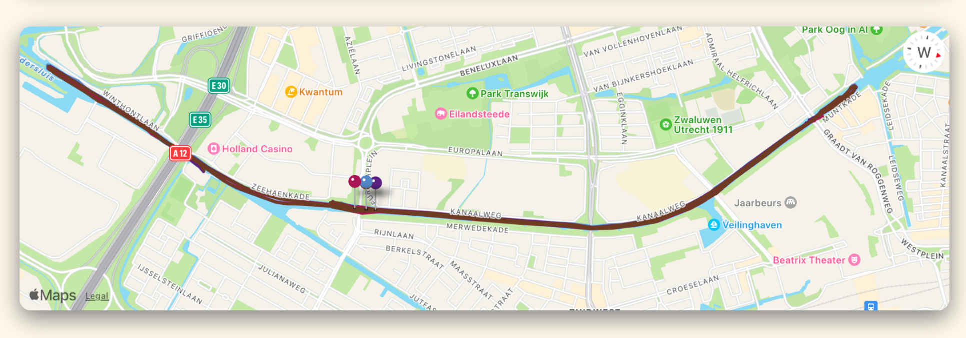

Figure 4.6: Map of example training session

4.3.4.1 Simple Visualization:

The line graph presents a clear and concise representation of the heart rate data for each rower over time and can be seen in figure 4.7. Each rower's heart rate is depicted as a separate line, allowing for easy comparison and analysis. The average heart rate for the entire team is also plotted as a reference line, providing a benchmark for individual and collective performance.

4.3.4.2 Metaphoric Visualization:

The metaphoric visualization, shown in figure 4.8, offers a more intuitive and engaging way to interpret the heart rate data. Just like in the heart rate summary, each rower is represented by a coloured rower icon, with the colour of the icon's head indicating the heart rate zone they were in during the session. This colour-coded system provides a quick and intuitive way to compare the intensity levels of different rowers and identify any significant variations at a given moment.

A timeline is included in the metaphoric visualization, allowing users to select and view specific time periods of interest. By tapping or dragging on specific points, users can see the corresponding heart rate data for each rower, providing a detailed analysis of their performance at different stages of the session. To avoid showing redundant data, such as the heart rates of each rower and to emphasize significant deviations, a horizon graph visualization of the difference to the average, was proposed as a timeline. This technique, inspired by Reijner [77], effectively visualizes time-dependent variables within a compact space. Building upon Saito et al.'s [80] two-tone pseudo-colouring approach, horizon graphs excel at comparing multiple time series, such as our different rower's deviation from the heart rate average, as highlighted by Aigner [3].

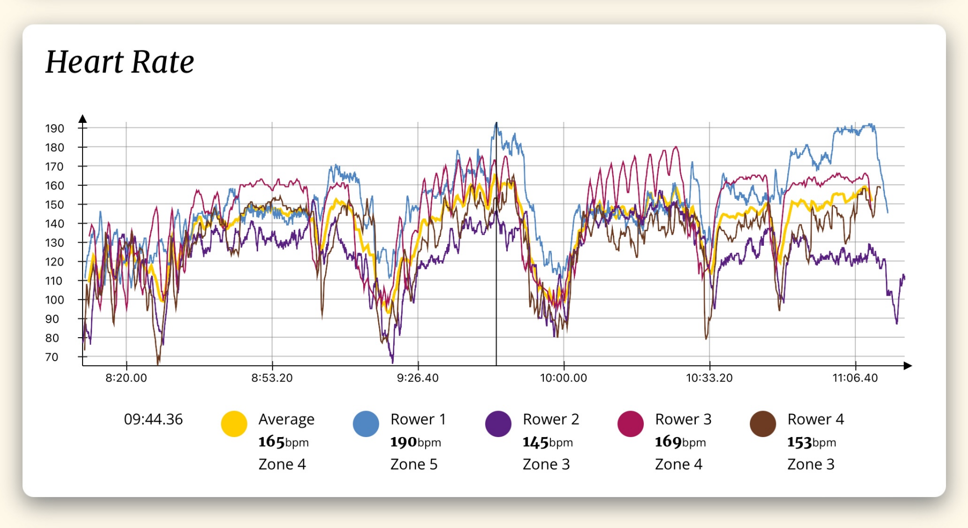

Figure 4.7: Simple Heart Rate

The figure 4.9 illustrates the process of creating a horizon graph. Starting with a time series line graph (top), the data is first normalized to a zero-mean distribution (second row). Next, positive values are coloured blue, and negative values are coloured red (third row). Finally, the coloured areas are stacked to form the horizon graph (bottom row).

Both visualizations offer valuable insights into the intensity and dynamics of the rowing session. By analysing the heart rate data, coaches and athletes can identify periods of high and low intensity, assess the impact of different training strategies, and optimize future training plans.

500 Meter/Split

The "Speed" module provides a detailed visualization of the 500-meter split times for the boat during the training session. This module offers a clear and concise representation of the rowers' pacing and performance over the course of the session.

Simple Visualization:

The line graph displays the split times for each rower as a separate line, allowing for easy comparison and analysis. The x-axis represents the time elapsed during the session, while the y-axis represents the 500-meter split time. By observing the slope of each line, users

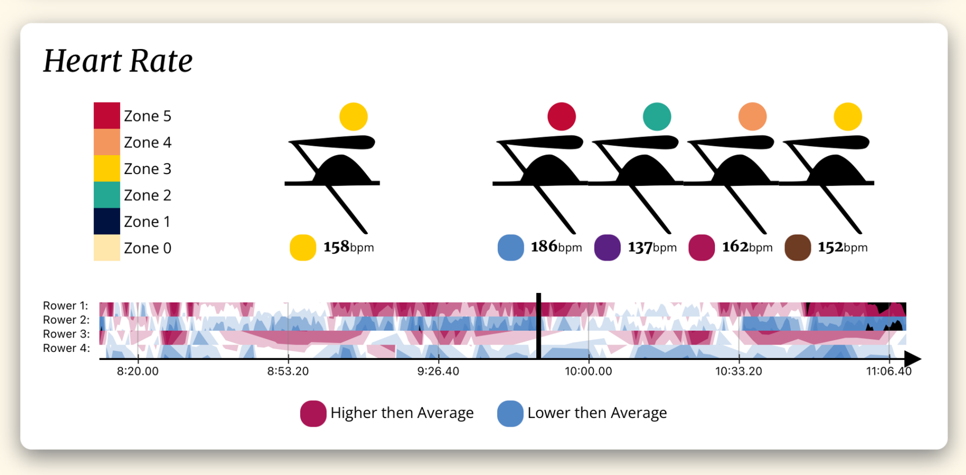

Figure 4.8: Metaphoric Heart Rate

can identify periods of acceleration, deceleration, and steady-state pacing.

Additionally, as can be seen in figure 4.10, the module includes an optional overlay for the average heart rate data. This overlay allows users to correlate changes in split times with variations in heart rate, providing valuable insights into the relationship between physiological effort and performance. By analysing the combined visualization of split times and heart rate, coaches and athletes can identify optimal pacing strategies, assess the impact of different training intensities, and optimize future training plans.

Metaphoric Visualization:

The "Speed" module in the metaphoric visualization is designed to provide an engaging way to represent the 500-meter split times and their relationship to heart rate intensity as shown in figure 4.11.

A prominent speedometer-like gauge displays the current 500-meter split time, visually representing the rower's speed. The needle of the speedometer points to the specific split time, providing a clear and intuitive indication of the current pace.

Alongside the speedometer, an optional heart icon is displayed, visually representing the heart rate intensity during the selected split. The colour of the heart icon changes dynamically based on the heart rate zone, providing a quick visual cue for the level of effort exerted by the rower.

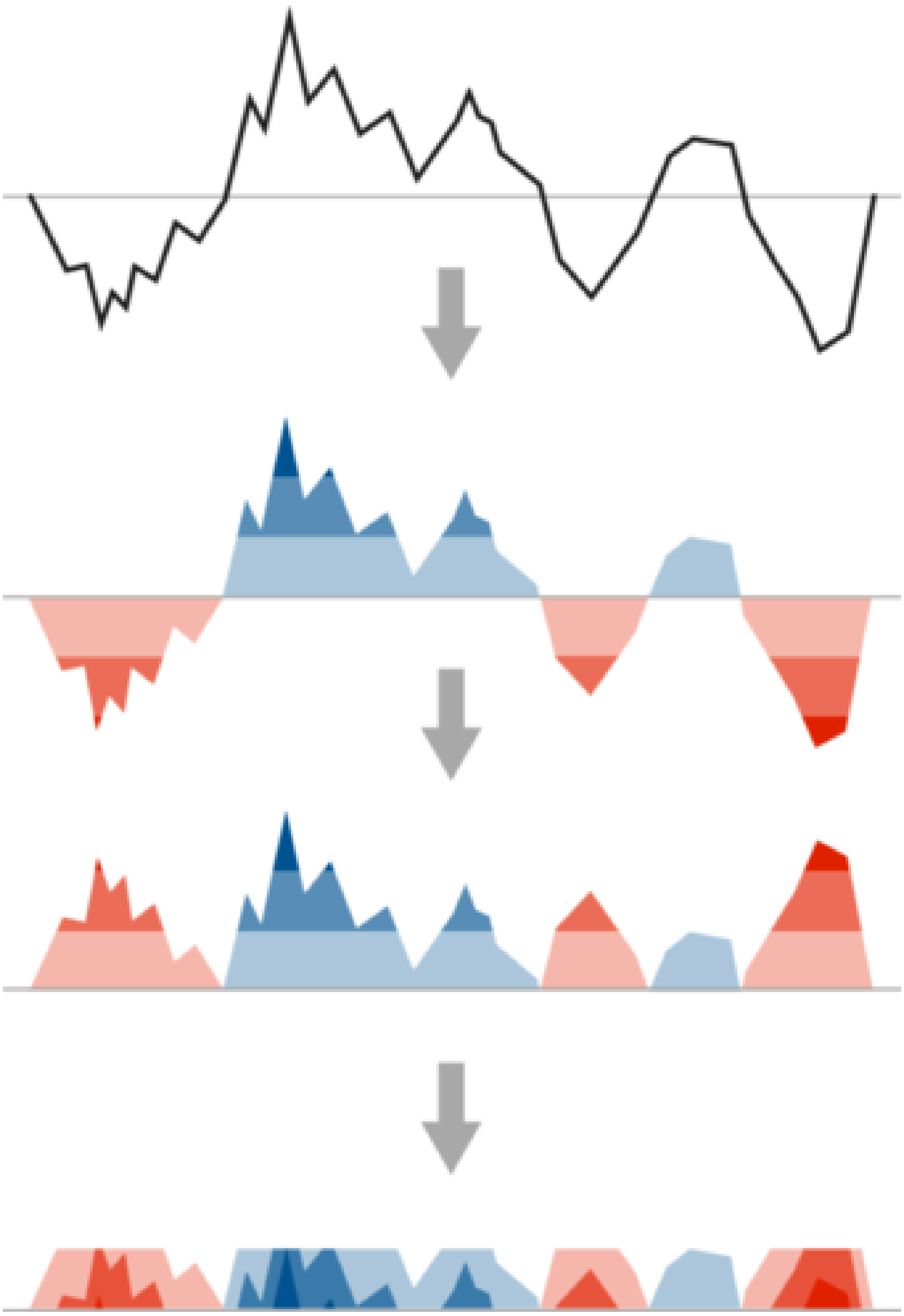

Figure 4.9: Creation of a horizon graph [3]

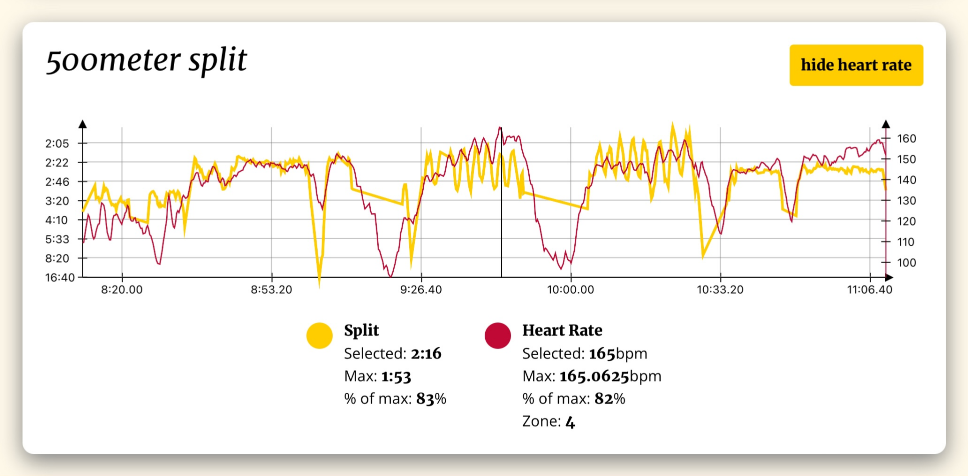

Figure 4.10: Simple 500 Meter Split

A colour-coded timeline complements the speedometer and heart icon, offering a holistic view of the rowing session's intensity. The timeline is divided into segments, each representing a specific time period. The colour of each segment corresponds to the predominant heart rate zone during that time period, creating a visual representation of the overall intensity profile of the session.

By combining these visual elements, the "Speed" module offers a dynamic and informative way to analyse rowing performance. Coaches and athletes can easily identify periods of high and low intensity, assess the impact of different pacing strategies, and optimize future training plans.

4.3.5 Conclusion

By combining the power of React Native and Expo with the capabilities of the Garmin API, this research project developed a robust and user-friendly iPad app for visualizing rowing data. The app prioritized data security and privacy, ensuring that sensitive information is protected at all times. Through innovative visualization techniques, the app provided interactive Components that could be evaluated.

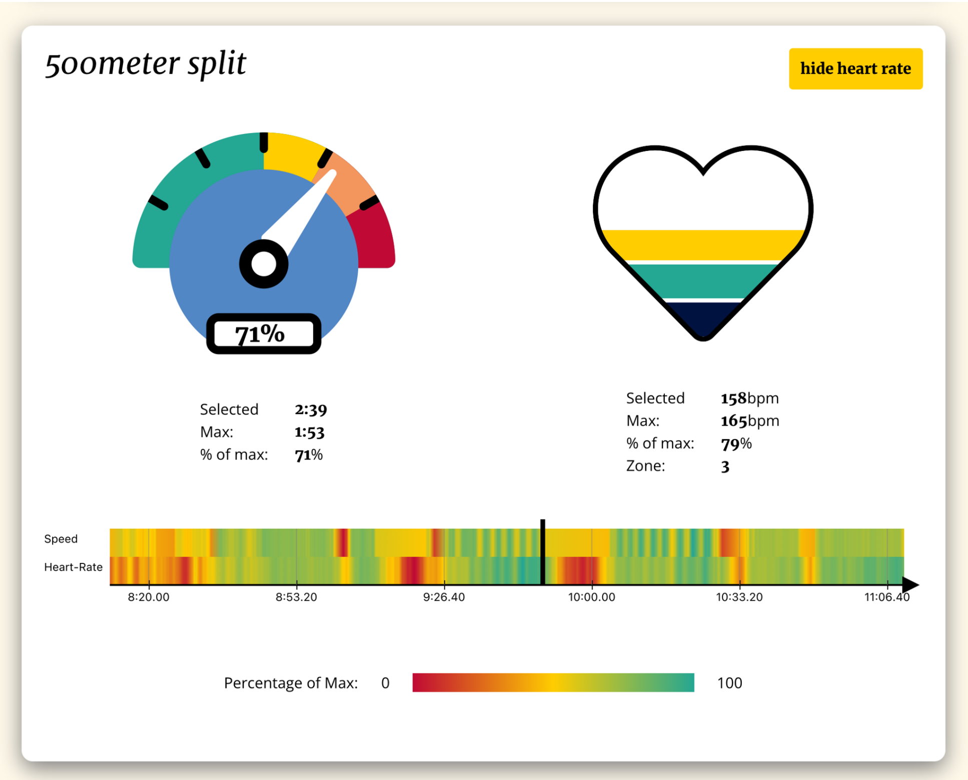

Figure 4.11: Metaphoric 500 Meter Split

Chapter 5

Study Design

To answer the research questions with the different versions of visualizations and feedback mechanisms, an in-between-subjects experimental design was employed. The research was of an investigative nature and relied on self-reported information. The study manipulated two independent variables, Feedback Delivery Method (individual/private feedback vs Group/public feedback) and Feedback Presentation Style (Standard Graphs vs. Metaphoric Visualizations). The four resolving conditions were as follows:

1. Public Feedback with Simple Visualizations: Feedback was shared with the entire team, and visualizations were presented in a simple, straightforward format.
2. Private Feedback with Simple Visualizations: Feedback on the group was provided individually to each rower, using simple visualizations.
3. Public Feedback with Metaphoric Visualizations: Feedback was shared with the entire team, using more abstract and visually engaging metaphors.
4. Private Feedback with Metaphoric Visualizations: Feedback on the group was provided individually to each rower, using metaphoric visualizations.

By investigating these factors, the study aimed to get the first insights into the most effective combination of feedback delivery method and presentation style for enhancing rowing performance and motivation in a group setting.

The following methodological approaches were employed to conduct the study. These methods were then applied to the specific procedures outlined in the subsequent section.

5.1 Questionnaire

To gain a deeper understanding of participants' experiences with data tracking and wearable technology in the context of rowing, a questionnaire was administered. This questionnaire explored various aspects of their data usage, including:

- **Frequency of Use:** Participants were asked to specify how often they utilized their Garmin smartwatch to track their rowing workouts.
- **Valued Metrics:** The questionnaire inquired about the specific rowing metrics that participants found most valuable to track on their Garmin smartwatch. This information helped identify the key performance indicators that were most relevant to rowers.
- **Data Visualization Clarity:** Participants were asked to assess the overall clarity and readability of the rowing data visualizations presented on their Garmin smartwatch. This feedback provided insights into the effectiveness of the device's visualization capabilities.
- **Helpful Visualizations:** Participants were asked to identify any specific visualizations or data points that they found particularly helpful or insightful for tracking their rowing progress. This information highlighted the visualizations that were most effective in supporting performance analysis and goal setting.
- **Difficult Visualizations:** Participants were asked to identify any data visualizations that they found difficult to understand or interpret. This feedback helped identify areas where the visualization design could be improved to enhance user experience.
- **Preferred Visualization Methods:** Participants were asked about their preferred methods for viewing rowing data, whether it was through the smartwatch itself, a mobile app, or a web-based platform. This information provided insights into the most convenient and effective ways to access and analyze data.
- **Desired Features and Customization:** Participants were asked to suggest any specific features or customization options related to data visualization that they would like to see added to the Garmin smartwatch app. This feedback provided valuable input for future app development and improvement.
- **Impact on Motivation:** Participants were asked how the ability to easily visualize their rowing data on their Garmin smartwatch affected their overall motivation to train. This information helped assess the motivational impact of data visualization and its role in fostering a positive training mindset.

- **Goal Setting and Achievement:** Participants were asked whether having access to detailed and personalized data visualizations helped them set and achieve specific rowing goals. This question explored the relationship between data visualization and goal setting, and how it influenced performance outcomes.
- **Motivational Visualizations:** Participants were asked to identify any visualizations or data points that they found particularly motivating or inspiring, and to explain why. This information provided insights into the psychological impact of data visualization and its ability to enhance motivation and performance.

By gathering detailed information on participants' experiences and preferences, the questionnaire provided valuable insights into the role of data visualization in rowing training, before the intervention. This included understanding participants' expectations for the app and its visualizations, identifying the most interesting and relevant metrics to track, and assessing the effectiveness of the implemented visualizations. These insights can be used to inform the development of more effective and engaging data visualization tools, ultimately enhancing the training experience and performance of rowers. The exact questions and answers can be found in the Appendix B.

5.2 Interview Guide

Given the practical constraints of rowing, where participants were required to train as a group and complete full workouts of approximately one and a half hours, time was a crucial factor. This necessitated a flexible interview guide that could be adapted to varying time constraints. Interviews were conducted either individually or in small groups, depending on the experimental condition, further limiting the available time.

To maximize the efficiency of data collection, a concise yet comprehensive interview guide was developed. The guide focused on key themes such as motivation, satisfaction, perceived effectiveness, and feedback delivery method. By prioritizing essential questions and tailoring the interview duration to the specific circumstances, researchers were able to gather valuable qualitative data while minimizing the time burden on participants.

The questions were categorized into several key themes, allowing for a flexible approach to the interview process. Depending on the available time and the specific insights gained, the interviewer could delve deeper into particular topics or focus on the most relevant areas. This approach ensured that the interviews were both efficient and informative.

Motivation:

- How motivated did you feel during the training?
- Did the feedback make you more or less motivated to continue training?
- What factors influenced your motivation level?

Satisfaction:

- How satisfied were you with the feedback?
- Were there any specific aspects of the feedback that you found particularly helpful or unhelpful?
- What could have been improved about the feedback?

Perceived Effectiveness:

- Did the feedback help you understand your performance better?
- Did the feedback help you identify areas for improvement?
- Did the feedback help you set goals for future learning?

Feedback Delivery Method and Presentation Style:

- Did you prefer individual or group feedback? Why?
- Did you find the standard graphs or metaphors easier to understand? Why?
- Which feedback format do you think was more effective for learning?

Additional Questions:

- Were there any challenges or difficulties you encountered during the training or
- feedback process?

- Do you have any other comments or suggestions about the experiment?

To ensure that the participants' perspectives were captured accurately, the interviews were audio-recorded and transcribed verbatim. The transcripts were then coded to identify key themes and patterns in the data. By analysing the qualitative data, the researchers aimed to gain an initial understanding of the participant's experiences and the effectiveness of the different feedback modalities.

5.3 Procedure

To investigate the impact of different feedback modalities on rowing performance and motivation, an in-between-subjects mixed-methods research design was employed. Prior to the main study, while obtaining consent from all participants a baseline questionnaire was administered to assess their familiarity with data tracking and wearable technology.

While following their normal training plan and schedule, participants then completed multiple interview sessions after an on-water rowing training. For each of those sessions, they were randomly assigned to one of four experimental conditions, each combining a specific feedback delivery method (public or individual) with a particular visualization style (simple or metaphoric), as laid out in list 5. Thus, following each training session, participants synchronized their data with their Garmin devices and completed an interview session with the researcher. In this session, the researchers together with the participants analysed the data and the generated feedback, tailored to the specific condition of each participant. Which then was evaluated by the participants during the interview.

5.3.1 Consent and Questionnaire

Before the study commenced, informed consent was collected from all participants to ensure they understood the nature of the research and agreed to participate voluntarily. Participants then were given a thorough explanation of the aim of the training, detailing how the feedback and visualization strategies being tested are intended to enhance their performance and motivation. Although most participants were already familiar with their Garmin Watches, as they were using them on a regular basis already, the instructions included a demonstration of how to use the devices and what specific data points needed to be captured. Once the instructions were clear, participants proceeded to record and execute their rowing training sessions as usual and according to their training plan.

Further, while obtaining informed consent, participants were also administered the brief questionnaire described in the earlier section 5.1.

5.3.2 Session Procedure

Following an on-water training session, participants would synchronise their data with their smartphones and Garmin Platform as usual. This data was then shared with the researchers during the session to create the visualization feedback. To investigate the impact of different feedback modalities, participants were randomly assigned to one of four conditions per session (see list 5).

A session or interview then consisted of two parts. In the first part, the researcher helped the rowers to understand their data and helped to analyse the visual feedback in collaboration with the participants. In the second part, participants were interviewed about the visualizations and the generated insights or feedback, as outlined in section 5.2. As mentioned, both steps were either done individually or as a group, depending on their assigned condition. During the interview, participants were presented with one of the two visualization types (simple or metaphoric) and then asked to provide feedback on its clarity, usefulness, and motivational impact. The interviews were recorded and subsequently coded using NVivo software, outlined in chapter 5.6.

By collecting qualitative data through interviews, the study aimed to gain a deeper understanding of participants' perceptions of the different feedback modalities. This included exploring their preferences for visualization styles, their ability to understand and interpret the data, and the impact of the feedback on their motivation and performance. This comprehensive feedback process aimed to capture an investigative and holistic view of the participant's experiences and the effectiveness of the feedback mechanisms employed in the study.

5.4 Participants

For this study, a convenience sampling method was employed to recruit participants. This approach involved selecting individuals from a local rowing club, comprising experienced rowers who regularly engaged in team training sessions and who were readily accessible and willing to participate. Their familiarity with both individual and group training dynamics made them ideal candidates for examining the impact of different feedback and visualization strategies on performance and motivation. In this case, the participants consisted of four rowing boats, each comprising four rowers. Thus there were 16 participants and to ensure diversity, the teams were balanced in terms of gender, with 50% male and 50% female participants. In other words two female boats and two male boats. The age range of the participants was between 18 and 24 years old, participation was voluntary, and informed consent was obtained from all. It is important to note that all participants were actively training together during the evaluation period, providing a consistent and controlled study environment. The rowers were already actively engaged in data collection practices with smartwatches, sharing their training data with their coaches for analysis and feedback. Therefore, most participants used their own Garmin devices. Participants using different brands were provided a wearable Garmin Watch to record the training session, to ensure consistency of the data format and compatibility with the implemented App.

5.5 Ethics And Data Security

To ensure the ethical conduct of the research, several measures were implemented to protect participant privacy and data security. All participant data was anonymized using unique identifiers and encrypted during storage. Access to the data was restricted to the primary researcher, who adhered to strict confidentiality protocols.

Training data shared by participants was stored temporarily on the iPad used during the interview sessions. This limited storage duration minimized the risk of data breaches. Participants were granted the right to opt out of the study and request the deletion of their data at any time. Informed consent forms were obtained from all participants prior to data collection and were securely stored in compliance with GDPR regulations. These measures collectively contributed to a robust ethical framework, safeguarding participant privacy and ensuring the integrity of the research.

5.6 Analysis

The qualitative data collected through interviews were systematically analysed to extract meaningful insights. Initially, all interviews were transcribed verbatim to ensure an accurate representation of the participants' responses. Subsequently, a thematic analysis approach was employed to identify and categorize key themes within the data. Using

NVivo software, the transcripts were coded, assigning specific codes to passages that related to particular themes. These codes were then organized into a coding framework, which served as a structured system for categorizing and analysing the data. To further deepen the analysis, the coded data was sorted by case and condition, allowing for comparisons between different participant groups and experimental conditions. This systematic approach ensured a rigorous and comprehensive analysis of the qualitative data, enabling the identification of patterns, trends, and emerging themes.

5.6.1 Code Categories

As mentioned the qualitative data collected from participant interviews were analysed using NVivo software. A thematic analysis approach was employed to identify and categorize key themes within the data. The following themes emerged from the analysis and are Visualised in Figure 5.1:

Visualization Feedback

The feedback provided to participants was a critical component of the study. It encompassed a range of responses, from positive affirmations to constructive criticism. Participants also received neutral feedback on their performance, highlighting areas of strength and areas for improvement. Additionally, they were provided with specific goals and actionable recommendations to enhance their training. This personalized feedback aimed to motivate and guide participants towards achieving their individual goals. (Codes: Positive feedback, negative feedback, neutral feedback, goal feedback)

General Feedback

Beyond specific feedback on performance, participants were encouraged to provide general feedback on the overall app experience. This included comments on the user interface, data visualization, and feature suggestions. By gathering general feedback, the researchers were able to identify areas where the app could be improved to enhance user satisfaction and engagement. (Codes: General positive, general negative, general neutral, feature suggestions)

Feedback Delivery Method

To investigate the impact of different feedback delivery methods, participants were asked about their preferences for public versus private feedback. Their responses were categorized based on their support for, reservations about, or opposition to group feedback. (Codes: negative group, positive group, depends on use)

Goal Setting and Achievement

A key aspect of the study was to evaluate the app's effectiveness in supporting goal setting and achievement. Participants were asked to reflect on how the app helped them set specific, measurable, achievable, relevant, and time-bound (SMART) goals. Additionally, they were asked to assess whether the app provided the necessary tools and insights to track progress towards these goals. By understanding how the app influenced goal-setting and achievement, the researchers could identify areas for improvement and optimize the app's features to better support user aspirations. (Codes: positive answer goals, negative answer goals)

Motivation

A central goal of the study was to investigate the impact of visualizations on motivation. Participants were asked to assess whether the visualizations motivated them to strive for improvement. Responses were categorized as either positive or negative to determine the overall impact of visualizations on motivation. By analysing these responses, the study aimed to identify which visualization techniques and group settings were most effective in stimulating motivation. (Codes: positive motivation, negative motivation)

Understanding

The effectiveness of the visualizations in enhancing understanding was another key focus of the study. Participants were asked to assess whether the visualizations helped them interpret their performance data, identify areas for improvement, and make informed decisions about their training. By analysing the effectiveness of the different visualization techniques. (Codes: Positive, Neutral and Negative Answers)

```
Feedback
├── Negative
├── Neutral
└── Positive
Topic
├── General
│   ├── Negative
│   ├── Neutral
│   ├── Positive
│   └── Feature suggestion-optimization
├── Group-Individual
│   ├── Negative Group
│   ├── Depends-on-use
│   └── Positive Group
├── Goal
│   ├── Negative Answer
│   └── Positive Answer
├── Usefulness
│   ├── Negative Answer
│   ├── Neutral Answer
│   └── Positive Answer
├── Understanding
│   ├── Negative Answer
│   └── Positive Answer
└── Motivation
    ├── Negative Answer
    └── Positive Answer
```

Figure 5.1: Code Tree

Usefulness

Ultimately, the perceived usefulness of the app and the feedback provided a critical factor in evaluating its overall impact. Participants were asked to assess the app's utility in enhancing their understanding of rowing sessions. Responses were categorized as positive (useful), neutral (neither useful nor unhelpful), or negative (not useful) to determine the overall perceived value of the app and its feedback mechanisms. (Codes: Positive, Neutral and Negative Answers)

Chapter 6

Results

This chapter presents the comprehensive findings of a mixed-methods study investigating the impact of data visualisation and feedback mechanisms on rowing team performance. Using a multifaceted approach combining quantitative questionnaire data and qualitative interview findings, this thesis explored how athletes perceive and interact with performance-tracking technologies.

The research methodology incorporated two primary data collection strategies:

1. An online questionnaire was administered to 16 rowing volunteers, which provided structured insights into current wearable technology usage, preferred tracking metrics, and motivational factors.
2. In-depth interview sessions conducted across multiple training groups, capturing nuanced perspectives on visualization techniques, feedback delivery, and their potential to enhance team performance.

Our investigation focused on critical areas including:

- Usage patterns and preferred performance metrics of wearable technology
- Effectiveness of different visualization approaches
- Impact on motivation and goal setting
- Group dynamics and feedback preferences

By systematically analysing participants' responses, this study aimed to uncover the intricate relationships between data visualisation, individual motivation and collective team performance. The following sections detail the findings and provide insights that could significantly inform the design of future performance-tracking tools for rowing, and potentially other team sports.

6.1 Questionnaire

To collect baseline data on participants' experiences with wearable technology and data visualization, an online questionnaire was administered to 16 volunteers who had signed informed consent forms. Three participants were unable to fully complete the questionnaire due to various reasons, such as using a non-Garmin smartwatch or primarily tracking off-water training activities. This resulted in a final sample size of 13 participants for the questionnaire analysis.

The questionnaire was designed to ascertain the current individual feedback and to determine whether the visualised metrics identified by the researchers as being important were also considered important by the participants. Additionally, the questionnaire aimed to investigate whether the selection of inappropriate metrics could potentially lead to a lack of motivation.

The Survey Questions can be categorized into two Groups: Categorical Questions and Free-Text Responses.

6.1.1 Categorical Questions

Categorical Questions were designed to collect structured, quantitative data such as usage patterns and preferences:

Frequency of use (Q1)

A significant portion (64%) of participants reported using the smartwatch daily. This indicates a high level of reliance on the device for regular monitoring of rowing activities. In contrast, a considerable number of participants (29%), reported using the smartwatch rarely. This suggests that a portion of the user base may not be actively engaging with the device for consistent tracking of their rowing workouts. Interestingly, no participants reported using the smartwatch weekly or occasionally, indicating that these usage patterns were not prevalent in the surveyed population.

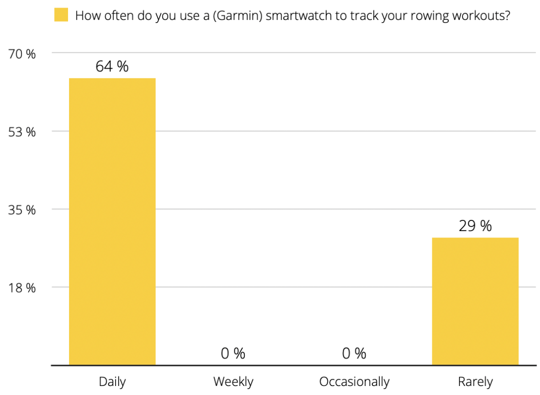

Figure 6.1: Q1: How often do you use a (Garmin) smartwatch to track your rowing workouts?

Interesting metrics for tracking (Q2)

The bar graph seen in figure 6.2 presents the distribution of rowing metrics that participants find most valuable to track on their Garmin smartwatches.

Heart rate emerged as the most frequently cited metric, with 12 participants highlighting its importance. This suggests that heart rate monitoring is valuable if not the most valuable metric when tracking a rowing session. Stroke rate and split time were also considered important metrics, with 8 and 6 participants, respectively, selecting them. These metrics provide insights into rowing technique and pacing. Distance was a commonly tracked metric, with 4 participants indicating its value. A smaller number of participants, 1 and 0 respectively, indicated the importance of power output and other metrics. This suggests that these metrics may be less commonly tracked or less relevant to the specific needs of the participants.

Overall, the results highlight the importance of heart rate, stroke rate, split time, and distance as key metrics for rowing performance monitoring. These findings can inform the development of data visualization tools and wearable device features that prioritize the display and analysis of these metrics.

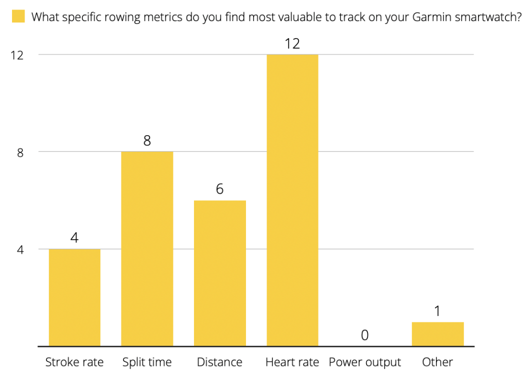

Figure 6.2: Q2: What specific rowing metrics do you find most valuable to track on your Garmin smartwatch?

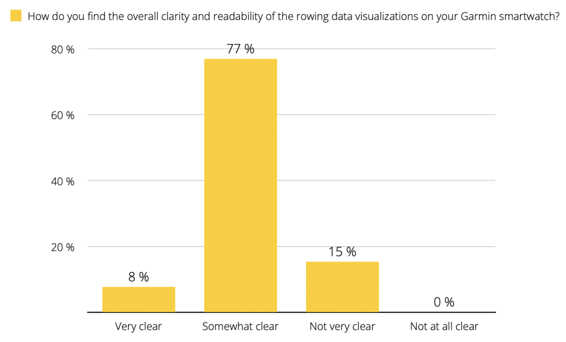

Figure 6.3: Q3: What specific rowing metrics do you find most valuable to track on your Garmin smartwatch? (You can select more then one) - Selected Choice

Interesting metrics for tracking (Q3)

A significant majority of participants (10), indicated that the visualizations were "somewhat clear". This suggests that while the visualizations are generally understandable, there may be room for improvement in terms of clarity and ease of interpretation. A smaller number of participants (2), found the visualizations to be "not very clear". This indicates that for some users, the visualizations may be difficult to interpret or may lack essential information. Only a single participant found the visualizations to be "very clear"

Overall, the results suggest that while the majority of participants find the visualizations to be somewhat clear, there is a need to further enhance the clarity and readability of the visualizations to improve user experience and understanding.

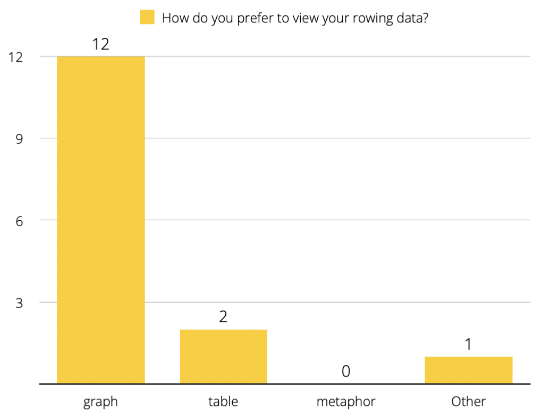

Figure 6.4: Q6: How do you prefer to view your rowing data?

Preferred Visualization Method (Q6)

Most respondents prefer viewing their rowing data in graph format (10 respondents). A smaller group prefers both graphs and tables (2 respondents).

The majority of respondents expressed a preference for viewing rowing data in graph format. This suggests that traditional graph-based visualizations, such as line charts and bar charts, are widely understood and appreciated by rowers. However, a small number of respondents indicated a preference for a combination of graphs and tables, suggesting that a more diverse approach to data presentation could be beneficial.

Impact on Motivation (Q8)

The results suggest that visualizing rowing data has a positive impact on motivation, although the magnitude of the effect varies among individuals. While a significant proportion of respondents reported a slight increase in motivation (9 respondents), a smaller group experienced a more substantial boost (2 respondents). A few respondents indicated that data visualization had no noticeable impact on their motivation (2 respondents).

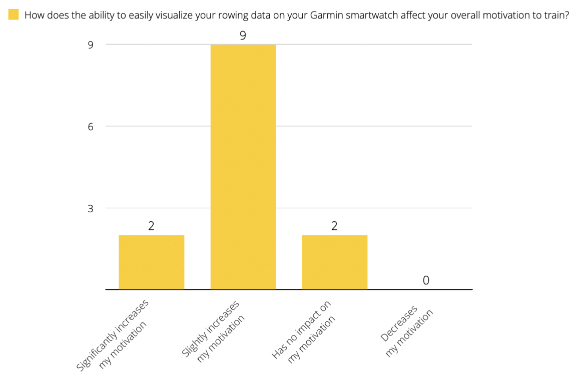

Figure 6.5: Q8: How does the ability to easily visualize your rowing data on your Garmin smartwatch affect your overall motivation to train?

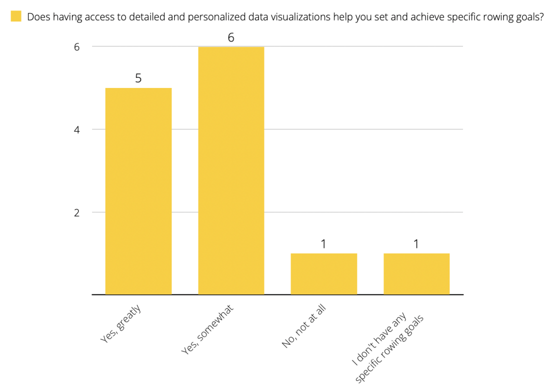

Figure 6.6: Q9: Does having access to detailed and personalized data visualizations help you set and achieve specific rowing goals?

Goal-Setting and Achievement (Q9)

The findings suggest that detailed and personalized data visualizations can play a role in goal setting and achievement. A majority of respondents indicated that visualizations helped them, either to some extent(6 responses) or significantly(5 responses), in achieving their rowing goals. However, a small minority reported that visualizations were not helpful(1 respondent) or that they did not have specific goals(1 respondent).

6.1.2 Free-Text Responses

Free Text Responses are designed to gather detailed qualitative feedback on user experiences and needs.

Data Visualizations of Interest (Q4)

Participants expressed a strong interest in tracking heart rate (8 mentions) as a key metric. This aligns with the established importance of these metrics in the analysis of rowing performance. Furthermore, some respondents indicated a desire for more granular data, such as split times (3 mentions), to facilitate in-depth analysis of specific training segments. Other metrics mentioned were stroke rate and GPS (each 1 mention).

Frustrations with Current Visualizations (Q5)

Several participants identified issues with the current visualizations, such as poorly scaled graphs and unnecessary or redundant information. These findings suggest that there is room for improvement in the design and presentation of data visualizations to improve the user experience and understanding.

Desired Customizations (Q7)

Participants expressed a desire for features that track progress over time, allowing them to monitor their improvement and set meaningful goals. In addition, some respondents suggested tailoring metrics to individual needs, highlighting the importance of personalized data analysis. However, a significant proportion of respondents indicated satisfaction with the current level of customization.

Motivational Visualizations (Q10)

The most common motivator identified by participants was the observation of improvements in key performance metrics, such as reduced split times or heart rates. This finding underscores the importance of providing clear and actionable insights that can drive positive behavior change.

Additional Feedback (Q11)

The non-existent additional feedback suggests that participants' primary concerns were addressed by the specific questions in the questionnaire, leaving the field blank.

Observations

The majority find value in graphical data representation and emphasize metrics that allow for monitoring performance improvements. Motivational impact and utility for goal setting vary widely, suggesting that personalized data visualization could enhance usefulness. Addressing frustrations with scaling and tailoring metrics to individual needs could improve user satisfaction.

Conclusion

The results demonstrated that heart rate and speed are the two most crucial metrics, thereby eliminating the possibility that the subsequent reported lack of motivation could be attributed to the utilisation of irrelevant metrics. Furthermore, the findings indicated that the utilisation of metaphors is lacking, and the current graphs are not fully satisfactory.

6.2 Interview Sessions

Introduction

Qualitative data was collected via interviews conducted over the course of multiple sessions following on-water training sessions. Three boats participated in three of the scheduled sessions, while one boat was unable to complete the requisite number of sessions due to illness. In total, 15 interviews were recorded. Eight of the interviews were conducted in a group setting, while seven were one-on-one private interviews. Six interviews were conducted with the metaphoric visualisations, and nine with the simple diagrams. The precise number of interviews conducted for each condition can be found in Table 6.1.

The feedback provided by participants covered a wide range of aspects, including positive and negative experiences, suggestions for improvement, and the impact on goal setting

	Group Interview	Individual Interview
Simple Visualisation	5	4
Metaphor Visualisation	3	3

Table 6.1: Interviews per Condition

and motivation. General feedback on the overall user experience was also collected, providing insights into the app's usability and design

The following sections present a detailed analysis of the qualitative data, which was systematically coded and categorized according to the coding framework outlined in Chapter 5.6. This rigorous coding process enabled the identification of key themes and patterns within the data, facilitating a deeper understanding of participant experiences and perceptions.

6.2.1 Feedback Given Through The Visualisations

The majority of feedback provided *to* participants was of a neutral tone, as evidenced by the following quotation:

> The team average is zone 2. And both individuals Rowers and you are were in zone 2, as well, the whole time.

When negative feedback was necessary, it was often framed with positive feedback, as discussed in section 2.2.5. One example of it is:

> So the **good** news is you're all working hard together. The **bad** news is, you know, you could row more efficiently. You know this is based on your max heart rate.

This contributes to the higher ratio of positive to negative feedback, as can be seen in Table 6.2. There was no significant difference in provided feedback for any of the conditions.

	Goal	Negative	Neutral	Positive
Total	46	40	158	98

Table 6.2: The number of **Feedback Given** codes distributed between the two conditions is as follows

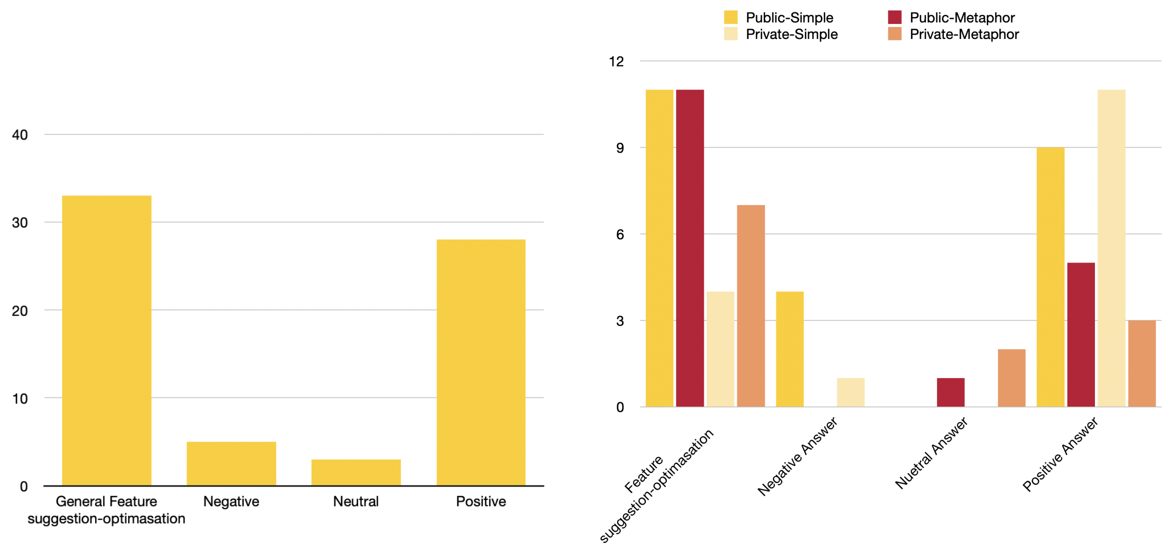

Figure 6.7: Number of General Remarks(left) and General Remarks by Condition (right)

	Feature suggestion-optimization	Negative Answer	Neutral Answer	Positive Answer
Total	33	5	3	28

Table 6.3: The number of **General Feedback** codes

6.2.2 General Responses

The comprehensive qualitative analysis of the interview data revealed a consistent positive sentiment towards the feedback mechanisms and the app's overall utility.

> I really like this idea. The idea behind the app. Being able to see a little bit more detail into the Rowing

> This is a nice way of visualizing it.

> I find it very nice.

> Nice layout as well.

These four quotes are just a small sample of the in total 28 positive remarks, which are shown in table 6.3 and visualised in graph 6.7. The graph on the right, which illustrates the number of codes per answer and condition, may suggest that both simple conditions are receiving more positive feedback. However, given that the simple condition was investigated more often (9 versus 6 times), it is more accurate to conclude that: The average number of positive responses per interview for each conditions are between 4 and 5 and thus not significantly different. Regardless of the experimental condition, participants frequently expressed positive sentiments about the feedback they received and the apps and visualisations design. The prevalence of positive feedback across various themes suggests that the app and its associated feedback mechanisms were well-received by participants and contributed positively to their training experiences. (Detailed breakdown for the codes General feedback in the appendix section A.2)

The negative comments on the general feedback, were only done in the simple diagram conditions, and all formed around the unclear line graph due too much cluster:

> So it's too cluttered?
> – Maybe a little.
> – If could you also do this with like 8 rowers, because then you wouldn't see anything, yeah.

> Maybe this [Line Graph] is too bad, too much crowded. Or like the average is.. you don't see the... Like purple is

The aforementioned negative quotes directly informed feature suggestions for optimising the system by the participants. It is also noteworthy that these suggestion were only a small proportion of the big number of suggestions (33 that is 47.8% of all general remarks) for optimising the system. They collectively highlight areas for potential improvement in the user interface and user experience.

> ***They comments reached from colour remarks...***
>
> The yellow like fades away between the blue and purple, I think.
>
> Maybe if it's red, like the red and yellow, the red is very really visible.
>
> I have one thing about this. For me it's not really confusing when we are in the red this arrow is in the green.
>
> The colours are like opposites of the thing
>
> ***... over comments about filtering, selecting or comparing data, ...***
>
> Or like an option that when you click on like the one, that the other ones, not like go away, but maybe like fade. And then the other ones get thicker, so that you see which one you are.
>
> That's why I asked, is this the average or can you like click on a different person. It's maybe interesting to see, yeah.
>
> Or it would be nice if you can touch them, like in this screen and then you can like select or deselect them.
>
> Yes, yes. So if there was an option to just get the little part, just cut it out, see what you were doing.

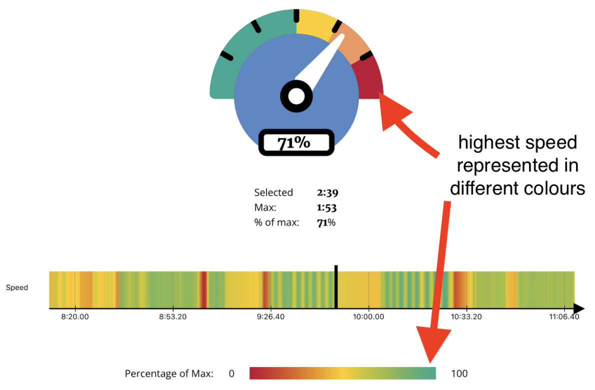

Figure 6.8: Conflicting Colour Assignment

> ***...to one request on extra metrics:***
>
> Maybe it's cool to see your power outlets. Like the Watts you are producing, but then you would need like a system.

A total of 33 optimizations and new feature suggestions were proposed by the users. These quotes underscore the need for further research and development to optimize visualization techniques. The most common suggestions can be categorized into two primary themes, small remarks about colour choices and feature suggestions. Both categories are outlined in the following sections.

6.2.2.1 Colour Remarks

The remarks about the Colour can be broken down into two usability issues found in the app:

1. Visibility/Similarity: Colours of lines graph were overlayed by other more prominent lines, or too similar (e.g. Rower 3 hat a burgundy red while the heart rate average was also in a different shade of red)
2. Conflicting assignment: For the Speed Metaphor the red and green of the speedometer did not match the Colour of the colour-coded timeline. Red and Green were actually opposite. Displayed in Figure 6.8

6.2.2.2 Feature Suggestions

While many of these suggestions were minor design tweaks, several innovative ideas were also put forward. These suggestions have the potential to significantly enhance the functionality and user experience of the visualization system.

- **Zoom Functionality:** Implement a ”zoom” feature to allow users to select specific time intervals for detailed analysis. This technique, known as brushing in data visualization, can provide deeper insights into performance variations and trends.
- **Data Filtering and Selection:** Enable users to filter and select data by individual rower to facilitate focused analysis of specific athletes' performance.
- **Comparative Analysis:** Provide options to compare current training sessions with previous performances or external benchmarks. This feature can help users track progress, identify areas for improvement, and set realistic goals.

Zoom In – Brush

”brush” typically refers to a technique used in data visualization to interactively select and highlight subsets of data points. This allows for a more focused analysis of specific regions within a graph. And exactly that was also requested when participants spoke about potential optimisations and zooming in:

> So if there's any option to zoom, that would be fine.

> So if there was an option to just get the little part, just cut it out, see what you were doing.
> — Like zoom in?
> — Yes.

By implementing the concept of brushing, furutre visualisation could more effectively use interactive data visualization to gain deeper insights from the performance data.

Filter/Select rowers

To address the potential visual clutter associated with multiple data streams, participants frequently suggested the implementation of filtering and selection capabilities. This would allow users to focus on specific rowers or time periods, enhancing data clarity and interoperability:

> Or it would be nice, if you can touch them like in this screen and then you can like select or deselect them.

> Or like an option that when you click on like the one, that the other ones, not like go away, but maybe like fade. And then the other ones get thicker, so that you see which one you are.

> That's why I asked, is this the average or can you like click on a different person. It's maybe interesting to see, yeah.

While these features in itself is not necessarily novel, building upon those concepts as described in the following conversation by participants, could help solve privacy concerns. Further improving acceptability and therefore usefulness:

> But maybe there should be like an option. Like if you if you want to see somebody else's then OK and if the other one like...
> – And then you can give consent as well, like I, I can show my data.
> – OK, but I like, I only look at mine, so I only have interest in mine. So I yeah.

This approach would allow for a more personalized user experience, where individual users could access their own data and compare it to team averages, without the need to share a single device, like the current implementation requires. By enabling selective data sharing, users could maintain privacy while still benefiting from collaborative insights. This could be useful, as it allows individuals to focus on their own performance and progress while still seeing their contribution to the overall team effort. And the majority of rowers reported that they anyways are most interested in how their performance compares to the average.

> I would prefer to see the team average and me alone.

> Maybe to clear that up a bit more. So you can really Like, not only the team average, but also look at your own individual.

This feature has the potential to provide participants with the option of obtaining group feedback through the team average, thus avoiding the necessity of placing other team members in a compromising position, as the data pertaining to each individual will only be compared to the average. The advantage of observing the collective performance of the boat remains. On the other hand group dynamics and effects might be diminished through this feature, for example, you would lose the chance for everyone to get the same insights:

> And then you know for sure that everybody gets the same information.

Nevertheless, this represents an intriguing approach to providing team feedback while maintaining the confidentiality of individual contributions.

Compare Data and sessions

Lastly, participants indicated a keen interest in comparing their performance not only to the team or team average but also to their own previous results. This indicates that the capacity to monitor individual advancement over time is an advantageous attribute that can facilitate motivation and goal-setting.

> Yeah. Or at least, yeah. When you're in the season, you have Data from the entire season, so your own max and so. So **compared** to your to yourself or maybe the other four.

> Does it also show or is there an option to show how many kilometers you did? [...] Yeah, but more because then I can **compare** like ohh if I do a longer training like in more kilometers. What my heart rate would do.

> I think maybe, like more during the season, it's like a month's long process. In the long term you can like overlap certain kinds of training. You can like maybe map certain training like training where you have strong winds coming from one side. You can group them together and then **compare**. But like week-to-week or even day-to-day.

	Negative Answer	Positive Answer
Total	3	23

Table 6.4: The number of **Goal Feedback** codes

> Yeah, and it would be nice to like **compare**, if you have the data of multiple weeks. Then you can compare them, maybe see if you're making progress.

Or simply comparing the team's performance to a standardized benchmark, such as historical averages or external standards of excellence. This allows the team to assess their progress relative to established norms and identify areas for improvement:

> Maybe with the speed, the gold standard by type of boat. It will be interesting to see.

> Or not even like a golden standard, more just like an individual time or goad that you customize.

6.2.3 Goal Setting

The Positive sentiment, found in the answers coded as general remarks, was also evident in the category of goal setting and achievement, where participants reported that the app helped them set clear objectives and track their progress effectively. This is evident in Graph 6.4 and in the following quote:

> Yeah, like it's useful for setting **goals** for me. For example, right now you said like its inconsistent. So you can say for the coming trainings, like that's slightly more consistent with that. But it's also, of course, like then you want to look at this from a longer-term instead of training to training, because sometimes the difference is too small.

(Detailed breakdown for the codes Goal Feedback in the appendix section A.3)

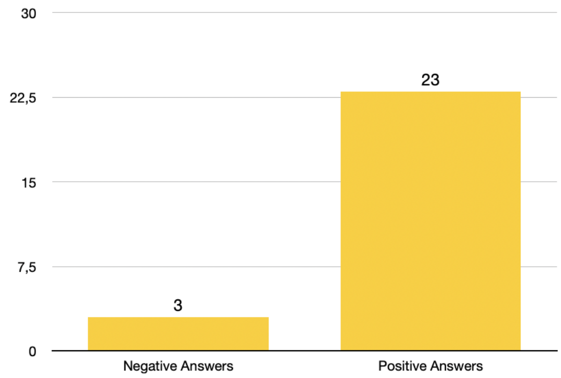

Figure 6.9: Number of General Remarks(left) and Goal-setting Remarks (right)

6.2.4 Usefulness

The positive sentiment reported by participating rowersm described in the earlier categories of Goal setting and general feedback continuous in the reported usefulness. The results consistently highlight the perceived usefulness of the app across all conditions. Participants in all conditions expressed positive sentiments regarding the app's utility in understanding their performance, tracking progress, and setting goals. This widespread appreciation for the app's functionality underscores its potential to be a valuable tool for rowers of all levels. (Detailed breakdown of the data in the appendix section A.7) However, one interesting pattern emerged and can especially be seen in Figure 6.10 on the right. The simple feedback when provided in a public setting is significantly reported as the most useful. Even when correcting for the amount the conditions were administered, this condition produces almost twice as much positive answers.

This phenomenon can be attributed to the fact that it is the visual representation most similar to other applications, which has led to a considerable number of comparisons, intensified by the group dynamics.

> Is this more useful than looking on your phone, on your own, or is this less Useful?
> – More useful
> — Especially as these 500-meter splits. You don't get that on the Polar. For example, that's also kilometres, so...
> – Yes, definitely. Yeah, its in kilometers not 500 m splits.
> – I think it's easier to track, to see than on the Apple, Garmin or Polar
> – Yeah. You also can compare like everybody's heart rates. So you know, like

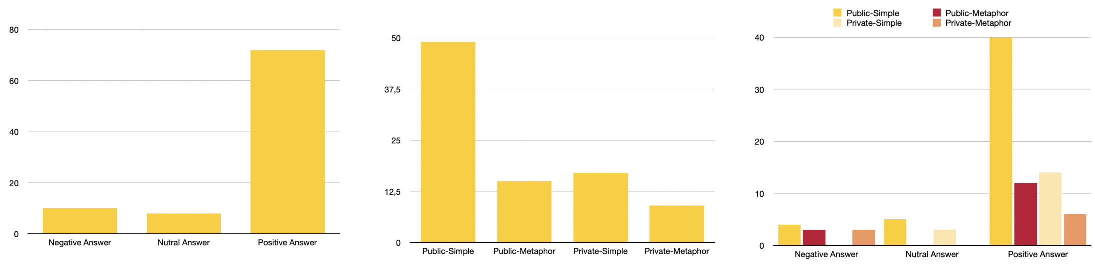

Figure 6.10: Number Usefulness Remarks from participants: Left by Answer sentiment, Center by Condition and right by Condition and Answer sentiment)

> did I push just as hard or harder than the others? So you get a lot more feedback on how the boat is actually going together. So like, oh what kind of heart rate do you have for this training?

> And I think it gives more insight. [then standard apps]
> – Yeah.
> – So I think we said the same last time, but you only get the number [from the other application] and I don't really look into it. And now I can see, OK, we did this and it felt like the, it's the comparison. It's easier to compare.

6.2.5 Group Preferences

As described in the study plan section 5.6.1, all answers in which participants indicated that, feedback should be given in a group setting were coded as ”positive Group” answers and remarks against public feedback as ”Negative Group” answers. If the participants restrict their answer, this is coded as ”Depends-on-use”. The amount of codes can be seen in Table 6.5. (Detailed breakdown of the data in the appendix section A.6) Analysis of participant feedback showed a strong preference for public feedback (38 mentions for public feedback vs. 8 mentions against). Figure 6.11 shows, that while the desire for public feedback was expressed across all conditions, it was particularly pronounced in the group interview setting. Participants in group interviews often (27 of the 38 mentions) emphasized the importance of public feedback, highlighting its potential to foster a sense of community, shared learning, and collective motivation. However, this preference was often tempered by the caveat ”it depends” (16 times). Examples for restrictions were:

> I don't think that's really a problem. I think it's more about how people will deal with it.

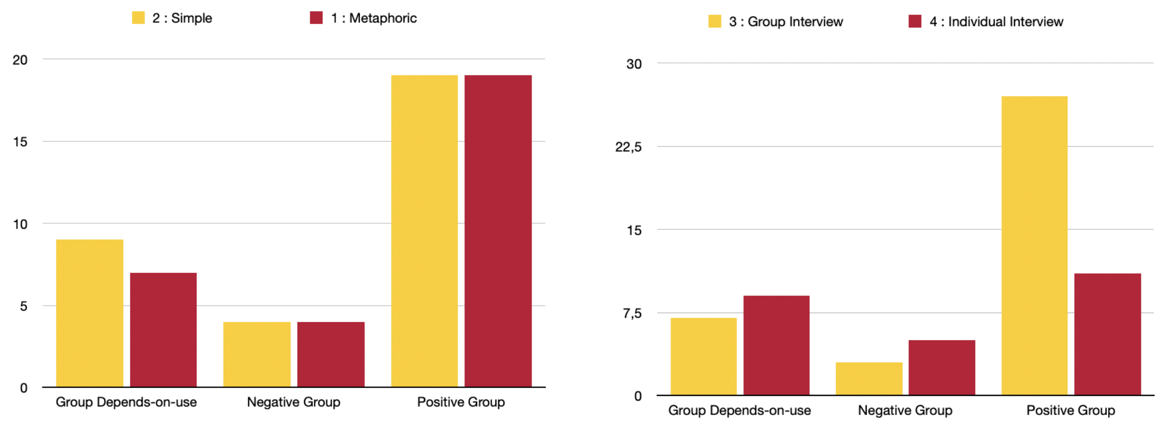

Figure 6.11: Number of Group Preference Remarks: left by visual condition and right by interview condition

	Depends-on-use	Negative Group	Positive Group
total	16	8	38

Table 6.5: The number of **Group Preference** codes

> I don't really mind, but it depends what you are going to use it for. Because if it's really like if you're going to be sort of blaming someone like ohh your your heart rate is not high enough. You didn't do well enough, like of course, the lower heart rate could mean something. It shouldn't become sort of an easy way to blame someone for it not doing well or something like that.

These examples illustrate that although participants typically indicated a preference for public feedback, they also recognized that the usefulness of this approach could be contingent upon a number of factors. This indicates that a detailed understanding of individual preferences and group dynamics is essential for optimising the delivery of feedback.

6.2.6 Motivation

A review of the total responses regarding motivation, as illustrated in Figure 6.12 on the left, reveals a discernible positive impact on motivation:

> No, it motivates because, you know where you can maybe work a little bit on, what you can change to achieve better results.

> Yeah. I would like I would be kind of obsessed with it.

> It was motivating for sure.[...] Because I can see if the entire team gets the data and coaches as well. It's more transparent, the effort everyone put in. You would on the one hand, feel guilty. Maybe if you just don't push.

When considering the impact of the investigated conditions on motivation, an interesting pattern emerged. While the simple visualization condition appeared to elicit slightly higher levels of reported motivation (24 positive in the simple condition vs 20 in the metaphor condition), this could be attributed to the higher number of interviews conducted for this condition (5 simple vs 3 metaphor Interviews). A more intriguing finding relates to the influence of group dynamics on motivation. Participants in group feedback sessions reported significantly higher levels of motivation (38 mentions versus only 6 in the individual condition), this is visualised in the center bar chart in Figure 6.12. It might suggested that the collective experience of reviewing performance data and receiving feedback can be a powerful motivator. This effect may be attributed to social comparison, peer support, and the shared sense of accomplishment that arises from team-based training. The number of simple confirmations of the statement's motivational impact lends support to this assumption. A total of 21 responses were recorded, comprising brief affirmative statements such as "Yes" or "Yeah," as well as other a little bit more elaborate responses such as the following examples:

> That's true, yeah.

> I really like this. Yeah. This motivates me. Yeah, when it's nice and sync

> Yes, I would say yes

This represents over 55% of the total positive comments regarding motivation. Notably, such brief affirmations were less common in individual interviews, suggesting that the group setting may play a significant role in fostering a motivational environment. This finding highlights the potential of group dynamics to amplify positive feedback and enhance motivation among athletes.

(Detailed breakdown of the data in the appendix section A.5)

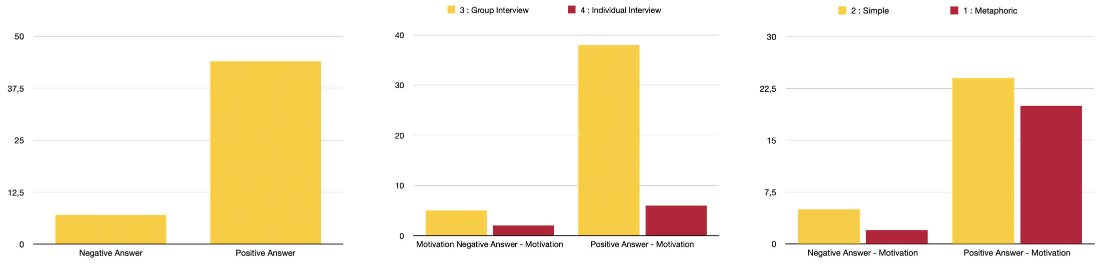

Figure 6.12: Number of Motivation Remarks: left total number of answers and right by interview condition

6.2.6.1 Interesting Pattern In The Details

While the metaphoric visualizations did not appear to have a significant impact on overall motivation, as visualised on the right in Figure 6.12. A more nuanced analysis reveals an interesting pattern. When examining the data more closely, it becomes evident that certain types of metaphors may have a more pronounced effect on motivation than others. For instance, metaphors that evoke positive emotions or that are particularly relevant to the rowing context may be more likely to stimulate motivation:

> Well, I think it's I think for me I also rather like the Feedback about compared with the speed and such and the heart rate itself is not the most important factor that motivates me.

> Oh, I like this one [speed component] the most

> Is my favourite, especially the splits and the heart rate like the together they. Yeah, like this.

> Ohh, I'm motivated by this [speed component]. I don't know. I don't know about this.[heart rate component]

> I think it does. I want to see higher splits.

> Speed of course always motivates me, so

Most comments regarding motivation were focused on the speed component of the visualization. This suggests that visualizing speed data, such as split times and pacing, may be particularly effective in motivating rowers. Conversely, the heart rate component, while important for physiological monitoring, had non or even negative impact on motivation. This finding highlights the importance of carefully selecting and designing visualizations to maximize their motivational impact. This should be kept in mind for the analysis of the understanding of the feedback in the next section.

6.2.7 Understanding

The evaluation of visualization clarity and understanding was also a focus of the interview process. From the analysis of the code quantity, as shown in Figure 6.13, two interesting patterns emerge: First Understanding is mentioned both negatively and positively. Second, interestingly, the metaphoric visualization condition, specifically the public metaphor, elicited the most number of mentions related to understanding. Both positive and negative. This suggests that the use of metaphors may have enhanced the comprehension of complex data concepts for some participants while creating the opposite effect for others. The distribution of positive and negative responses within the public-metaphor conditions was relatively even, with 9 participants expressing positive sentiments and 12 expressing negative sentiments. This indicates that while metaphors can be effective, their impact may vary depending on individual preferences and the specific design of the visualization.

When taking a look at what participants explicitly said, the diversity of responses, particularly within the metaphoric condition, can be attributed to the use of different metaphors and their associated timelines. Some participants found the heart rate metaphor and especially its timeline, to be less effective:

> I'm having trouble with this[timeline heart rate metaphor]. Your thing, but maybe if there's just an explanation like that comes with the anything that it will be clearer.

> But I think it's easier, the [simple heart rate] graphs. I think they're easier to understand for me there.

> And apart from that, I just find it[heart rate metaphor timeline] a Difficult graph to read. I'm not that good with graphs, so especially this.

> Heart rate [metaphor] isn't quite there yet, no.

> At least the small graph [heart rate timeline].

Whereas other participants found certain metaphors, in this case, the Speed metaphor described in section 4.3.4.2 to be particularly helpful in understanding the data:

> I don't know. I Like to read this[speed metaphor] as well. Because this is like the other version of the speed, going like this and heart rate going like this but...

> Especially for the 500 meter splits, this is better. Yeah, it's it shows us all more context of like, the entire training.

> Yeah, [the speed metaphor is] more simplified, yeah. Then just regular graphs.

This finding aligns with the earlier observation that participants were particularly motivated by the speed component of the visualization. The high level of understanding associated with the most effective metaphor suggests that well-designed visualizations can not only enhance comprehension but also positively impact motivation. Conversely, a poor design might hinder understanding of the metaphor due to flawed design or context, which then can impede motivation.

To confirm a correlation between negative reported understanding and positive motivation, a Spearman's rank correlation coefficient analysis was conducted. The calculation yielded a p-value of 0.2621, indicating a weak negative correlation between motivation and understanding across the four conditions. Which means that motivation increases when bad understanding decreases, in other words understanding increases.

This highlights the importance of careful metaphor selection and design to ensure optimal comprehension and engagement. Choosing a different timeline or metaphor might have reduced the negative responses on understanding. (Detailed breakdown of the data in the appendix section A.6)

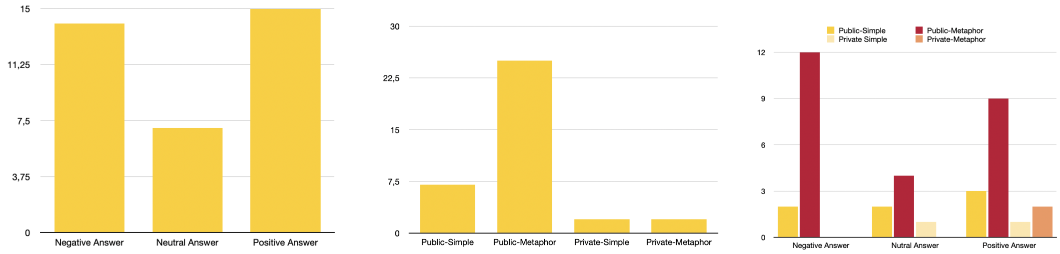

Figure 6.13: Bar chart of Understanding Code mentions
left by answer, center by condition, right by condition and answer

6.3 Conclusion

This research demonstrates the potential of data visualisation and feedback mechanisms in enhancing the performance of rowing teams. While technology offers promising tools for performance tracking, the key lies not just in data collection, but in its intelligent and engaging presentation.

The study highlights three critical insights:

1. **Personalization Matters:** Athletes value metrics that directly relate to their performance, with heart rate, stroke rate, and split times emerging as most significant.
2. **Group Dynamics Drive Motivation:** Public, collective feedback consistently demonstrated higher motivational impact compared to individual tracking, suggesting that team context significantly influences athlete engagement.
3. **Visualization is an Art:** The effectiveness of data representation varies widely. Metaphoric visualizations show potential but require careful, thoughtful design to truly enhance understanding and motivation.

These findings highlight the intricate interrelationship between technology, visualisation and athletic performance. By integrating technological capabilities with human psychological insights, it is possible to develop more effective and motivating performance-tracking systems that genuinely support the pursuit of athletic excellence.

Chapter 7

Discussion

In the context of the rapid evolution of sports technology, the investigation of the manner in which athletes interact with performance data represents a crucial frontier of research. This chapter presents the detailed findings of the study investigating rowing performance tracking, examining the complex relationships between data visualisation, individual motivation and team dynamics. By conducting a systematic investigation into the impact of different visualisation techniques and feedback mechanisms, this study aimed to identify the subtle yet significant ways in which data representation can influence athlete engagement and team cohesion.

The discussion that follows is structured around three key dimensions:

1. **Relevance for Innovation:** An exploration of how current data visualization tools meet—or fail to meet—the diverse needs of athletes.
2. **Implication Insights:** An analysis of how our findings intersect with existing literature on persuasive technology, group dynamics, and performance psychology. Including its strengths and limitations.
3. **Future Possibilities:** A critical examination of our research approach and potential future directions.

Through this comprehensive lens, this work aims to not only present the research findings but to provoke deeper reflection on the role of technology in athletic performance tracking.

7.1 Relevance For Innovations

The baseline questionnaire provided valuable insights into rowers' preferences and needs for data visualisation. The high frequency with which heart rate and speed were identified as important metrics is consistent with existing literature and confirms their relevance for performance analysis. This finding highlights the appropriateness of focusing on these metrics in the development of the visualisation system in this project.

Furthermore, the questionnaire revealed a mixed level of satisfaction with existing data visualisation tools. While some participants expressed satisfaction with the current state of visualisation technology, others expressed frustration with certain aspects, such as poorly scaled graphs and unnecessary information. This highlights the need, and therefore relevance, of this research for innovative and user-centred approaches to visualisation that address the specific needs and preferences of groups of athletes such as rowers.

The questionnaire also revealed a diverse range of user experiences, with participants ranging from novice to experienced users of wearable technology. This diversity underscores the importance of designing visualizations that are accessible to users of all levels, from those who are new to data-driven training to experienced athletes who seek advanced insights.

Additionally, the questionnaire highlighted the underutilization of metaphoric visualizations in the field of rowing. No participants suggested the use of metaphors as a preferred visualization method, likely due to the limited availability of such tools in current rowing apps. This presents an opportunity for innovative visualization approaches that can engage users and enhance learning through creative and intuitive representations.

By effectively leveraging the insights, applications can be designed to create more engaging and user-friendly experiences. By incorporating well-designed visualizations and personalized feedback, developers can motivate users and teams to track their performance data consistently. This is particularly important for casual and first-time users who may not fully appreciate the benefits of data-driven training. By providing clear and actionable insights, these applications can help users set and achieve their goals, leading to increased satisfaction and long-term engagement.

7.2 Implications Of The Research

7.2.1 Qualitative Data

While the self-reported nature of the data limits the extent to which causal relationships can be definitively established, it does provide valuable qualitative insights into user experiences and preferences. As Nielsen showed, a group of 5 is sufficient to find most usability problems [71], so the relatively small sample size of 16 participants was more than sufficient to identify key issues and opportunities for improvement. The focus of this study was exploratory, to explore the potential of different visualisation techniques and feedback modalities in the context of groups and rowing. The large number of suggestions for feature optimisation highlights the need for further research and development in this area.

7.2.2 Possible Limitations

Before looking at the implications, it is essential to recognise the potential for a sample selection bias [42] inherent in the study's participant pool. The sample comprised competitive rowers from the Netherlands, who had been subjected to rigorous selection processes and were therefore accustomed to public scrutiny, including weekly performance reviews. It is possible that their pre-existing familiarity with data-driven feedback and competitive environment may have influenced their responses and preferences. The strong preference for individual performance comparisons is evidenced by the following statement: "And I would like to see myself compared to the average." Furthermore, the participants' experience of data tracking and sharing with coaches may have influenced their expectations and perceptions of the visualisation tools.

Despite these potential biases, the study's findings offer valuable insights into the design of effective visualisation tools for rowers. This suggests that even among members of a team-oriented sport, the provision of personalised feedback can be an effective motivational tool. Nevertheless, it is essential to strike a balance between individual feedback and a focus on team dynamics and collaboration. The incorporation of both individual and team-level visualisations enables the creation of a feedback system that fosters both individual improvement and collective success.

Thus, one of the limitations of the study is the relatively small sample size and the specific characteristics of the participant pool. Further research with a more diverse range of participants, including recreational rowers and rowers from different levels of competition, is required to validate the findings and identify additional factors that may influence the effectiveness of visualisation tools.

7.2.3 Implication 1: Are Metaphor The Solution?

The first research question this work helped to understand was if, Metaphoric visualizations would be more effective in motivating rowers and improving performance than simple diagrammatic feedback.

Improved Understanding

The findings support Hypothesis 1, which posited that metaphoric visualizations would be more effective in improving their performance than simple diagrams. The results reveal that participants exposed to metaphoric visualizations reported a better understanding of the data compared to those who interacted with simple diagrams. Most evidenced by the speed component, which is discussed in section 4.3.4.2. These findings align with the literature in Chapter 2.3, which highlights the potential of metaphoric visualizations to make abstract performance metrics more relatable and engaging. For example, Tausch et al.[88] demonstrated that metaphoric representations, such as balloon visualizations, enhance motivation and balance participation by fostering emotional engagement.

Improvement Depending On Design

However, while metaphoric visualizations improved engagement, participants also noted that the complexity of certain designs required additional time for interpretation. This was made obvious by the heart rate component described in section 4.3.4.2), which was described as to complex in the results (section 6.2.7). As the design had the potential to hinder comprehension and distract from the underlying data. This aligns with Akhuseyinoglu et al.[4], who observed that user-centered design principles are critical to ensuring metaphors do not become overwhelming. In this study, the timeline component, which was used to contextualize the metaphoric visualization of the heart rates, proved to be particularly challenging for users (see quotes in section section 6.2.7). This suggests that a more familiar and intuitive approach, such as combining metaphoric elements with traditional visualizations, may be more effective. Such an approach could mitigate the risks associated with novel visualizations while still harnessing their potential to enhance understanding and motivation.

No Effect On Motivation

Finally, the relationship between understanding and motivation is complex and bidirectional. Improved understanding should result in increased motivation, as the found correlation (in Results Section 6.2.7) suggests, as users develop a more profound appreciation for the data and their own performance. However as evidenced by the absence of notable discrepancies in reported motivation between the two versions, with and without the metaphors, it can be concluded that the metaphors in this case had a minimal influence on motivation. In contrast to the other independent variable, namely the group setting. This is despite the clear impact of metaphors on understanding. The discrepancy in understanding between the two metaphors is likely to have been insufficient to produce a notable change in overall understanding, which in turn explains why the findings indicate that the metaphors had a minimal influence on motivation.

Conclusion

This study explored the impact of metaphoric visualizations on rowers' understanding and motivation. While metaphoric visualizations were found to enhance understanding of performance data, their impact on motivation was less pronounced. The complexity of certain designs can hinder comprehension, highlighting the importance of user-centred design principles. It is important investigate the optimal design principles for metaphoric visualizations and the interplay between understanding, motivation, and behaviour change to maximize their effectiveness.

7.2.4 Implication 2: Private Or Public Feedback?

The second research question investigated in this project hypothesised, that feedback given in front of the group should result in higher motivation and better performance outcomes than feedback given individually.

Greater Motivation Through Group Feedback

The results partially validate Hypothesis 2, which suggests that public feedback fosters greater motivation than private feedback. As one of the most noteworthy findings to emerge from the analysis of participant motivation was as follows: A notable increase in self-reported motivation was observed among participants who received feedback in a group setting. This indicates that the social aspect of group feedback, including peer comparison and collective goal setting, has the potential to serve as a significant motivational factor. And shows that public feedback increased participants' sense of accountability and fostered group cohesion, consistent with findings in Chapter 2.2 that public accountability amplifies cooperative behaviour through social pressure and shared responsibility. With a significant proportion of participants expressing a preference for sharing insights within a group setting.

Unclear Underlying Reason

Nevertheless, further research is required in order to gain a full understanding of the underlying mechanisms that are responsible for this effect. It seems reasonable to hypothesise that the social dynamics inherent to group feedback may foster a sense of pressure to falsely report one's motivation. As it was also observed that the efficacy of public feedback could be contingent upon individual preferences and group dynamics. The results indicate that some participants felt discomfort with public feedback, particularly when it highlighted individual underperformance. This nuance echoes the findings of Herrmann et al. [43], who noted that public scrutiny can sometimes lead to disengagement if not paired with positive reinforcement. A mixed-feedback approach that combines public group metrics with private individual feedback could mitigate these challenges, enhancing the perceived fairness and motivational impact of the feedback.

Context And Privacy Matter

While all participants indicated a willingness to share their data, several instances were noted where this may have depended on the circumstances, with some negative situations also being mentioned. It is crucial to understand these concepts when handling private data, in order to guarantee the efficacy of the group feedback. Nissenbaum's [73] contextual integrity theory could provide a helpful framework for understanding this issue. The theory proposes that privacy is maintained when information flows align with specific contextual norms. In the context of a sports team, the aforementioned norms might include:

- **Shared Purpose:** Team members share data to collectively improve performance.
- **Mutual Benefit:** The shared data benefits all team members.
- **Limited Access:** The data is primarily accessible to the team and its coaches.

This is consistent with the views expressed by the majority of participants, as illustrated by the following statement: "I think in the group is fine, but it depends. It depends how the group picks it up. I think if you're like motivated to work together and get it better as a Group." Describing a shared purpose with mutual benefit from gaining inside.

Conclusion

In conclusion, the findings of this study provide valuable insights into the impact of public and private feedback on motivation within a team setting. While public feedback demonstrated the potential to significantly enhance motivation through social comparison and accountability, it is essential to consider the nuances of individual preferences and group dynamics. A mixed-feedback approach, combining public and private elements, could optimize the motivational impact while mitigating potential negative consequences. By understanding the contextual norms around privacy that govern information flow, users can ensure that data is used effectively to maximize the benefits of feedback and minimize potential drawbacks.

7.3 Iteration And Future Work

The version of the visualisation system illustrated its efficacy in examining diverse visualisation techniques and feedback modalities. However, feedback from participants has identified several areas for improvement that could be addressed in future iterations of the application. The incorporation of quantitative research into future studies would serve to complement the current qualitative findings, providing robust metrics with which to evaluate the impact of optimised visualisations on user engagement, task performance and motivation. Such an approach would also facilitate a more comprehensive understanding of the system's generalisability across diverse user groups.

Furthermore, an expansion of the user base to include rowers of varying skill levels and experience would serve to enhance the comprehensiveness of the evaluation. A more diverse demographic would facilitate the identification of any usability issues or limitations that may not have emerged during the initial trials. This would also address potential sampling biases and increase the reliability of the findings.

Further research could also examine the potential of mixed visualisations to accommodate diverse user preferences and cognitive styles. Some participants explicitly requested this approach, for instance:

“If you still have like the graph with the entire heart right[simple version] and then edit this beneath that [metaphor Version] so that you can have both graphs, but you also have the context of how high was the object actually in the entire visualization over there.”

The presentation of both simple and metaphorical visualisations simultaneously would enable users to select the format best suited to their needs, which may lead to an improvement in satisfaction and comprehension.

Additionally, a longitudinal study would offer invaluable insights into the long-term impact of the visualisation system on rowing performance and motivation, illuminating sustained behavioural changes and goal achievement. The integration of mobile and wearable devices represents another promising avenue for future research. Such integration has the potential to transform the delivery of feedback, enhancing accessibility and utility for rowers during both training and competition. In particular, real-time feedback systems have the potential to facilitate dynamic adjustments in effort and technique, thereby optimising individual and group performance by providing immediate and actionable insights.

Finally, further research into the visualisation of group performance and the refinement of team-level feedback mechanisms could lead to improvements in collective outcomes. The challenge remains to understand how to balance individual and group-level insights in a way that fosters collaboration. By addressing these areas, future studies could facilitate the development of more personalised, impactful and user-friendly visualisation systems that enhance both individual and group rowing experiences.

Chapter 8

Conclusion

This thesis explored the impact of diverse feedback and visualization strategies on rowing team performance and motivation, addressing gaps in the literature surrounding group-focused fitness tracking. By integrating insights from the Quantified-Self movement and the principles of persuasive technology, this study extends current understanding of how feedback mechanisms can influence team dynamics and individual effort alignment in sports contexts.

Key Findings

The study demonstrated that metaphoric visualizations, compared to simple diagrams, foster greater engagement and improved motivation. These visualizations provided a more intuitive understanding of team performance, resonating with participants and enhancing their motivation. However, the complexity of some metaphoric designs highlighted the need for user-centered approaches to ensure accessibility.

Public feedback offers a promising approach to increase accountability and motivation. However, its effectiveness can vary based on individual preferences and group dynamics. Understanding the underlying mechanisms is crucial to ensure that public feedback is delivered in a way that maximizes its positive impact.

Contributions to Research

This work contributes significantly to the fields of Human-Computer Interaction (HCI), sports psychology, and group dynamics. By shifting the focus from individual metrics to team-based visualizations, it expands the application of the Quantified-Self paradigm to the "Quantified-Us" context. Furthermore, the study's findings offer empirical validation for the effectiveness of metaphoric visualizations and mixed-feedback strategies, providing actionable insights for designing more engaging and impactful fitness tools.

Implications And Future Directions

The findings have direct implications for developers of sports tracking applications and wearable devices. To enhance user experience and effectiveness, future systems should incorporate customizable metaphoric visualizations and flexible feedback mechanisms tailored to individual *and* group needs. Longitudinal studies investigating the long-term impact of these designs on performance and motivation could further validate their efficacy. Additionally, exploring applications beyond rowing, such as in other team sports or organizational settings, would extend the relevance of this research.

Implications For Developers

In light of the findings presented in this study, it is recommended that developers of fitness apps consider the following strategies to enhance user engagement and motivation:

- **Metaphoric Visualizations:** Employing metaphoric visualizations, can make data more relatable and engaging and improve motivation.
- **Group Feedback:** Facilitating group feedback in public settings can foster a sense of community and shared goals, while also offering the option for individual privacy through toggle settings.
- **Customization:** Providing users with the ability to customize their feedback visualizations can cater to individual preferences and enhance user satisfaction.

Although this study is specifically concerned with rowing teams, its findings have implications that extend beyond this context, to other domains that require group synchronisation and motivation. By way of illustration, educational tools and workplace collaboration platforms could derive benefit from the deployment of analogous feedback mechanisms, with a view to enhancing engagement and team performance.

In conclusion, this work underscores the transformative potential of feedback and visualization strategies in fostering collaboration and improving performance within teams. By bridging the gap between individual and group-focused approaches, it provides a robust foundation for future innovations in fitness tracking and beyond. This research lays the groundwork for leveraging tailored visualizations and strategic feedback mechanisms to enhance group dynamics, providing a roadmap for innovation in team sports and beyond.

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Appendix A

Interview Results

	Public	Private	
Simple	5	4	9
Metaphor	3	3	6
	8	7	15

Table A.1: Number of Interviews per Condition

A.1 Feedback Given

	Public-Simple	Public-Metaphor	Private-Simple	Private-Metaphor	
Goal	10	7	20	9	46
Negative Answer	15	5	21	9	50
Neutral Answer	36	48	41	33	158
Positive Answer	32	18	25	23	98
	93	78	107	74	352

Table A.2: feedback codes given to the participants per conditions

	Goal	Negative	Neutral	Positive
Metaphoric	16	14	81	41
Simple	30	36	77	57
Group Interview	17	20	84	50
Individual Interview	29	30	74	48

Table A.3: The number of **Feedback Given** codes distributed between the two conditions

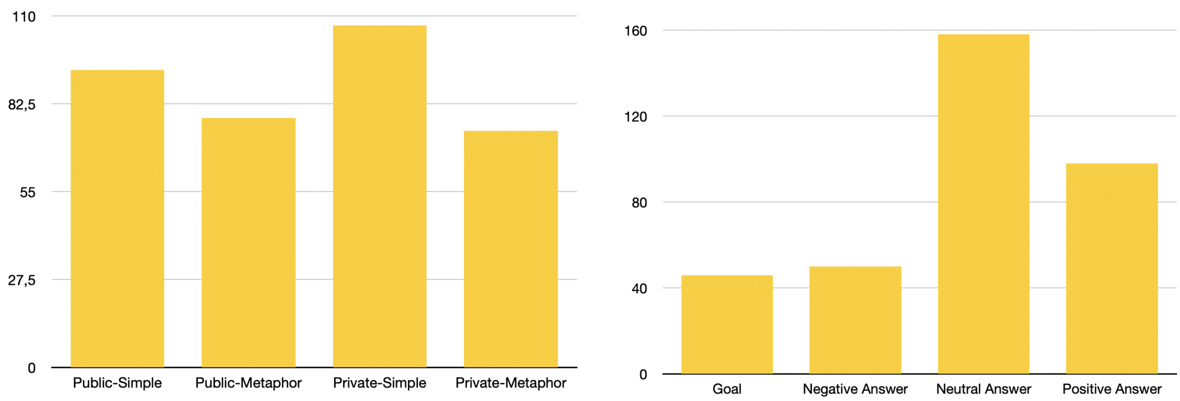

Figure A.1: Number of codes by condition (left) and by answer (right).

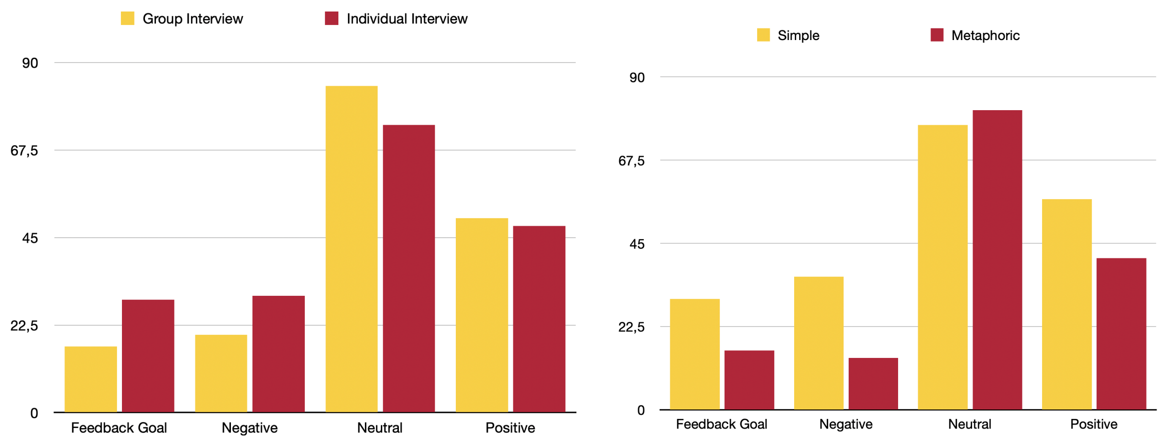

Figure A.2: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

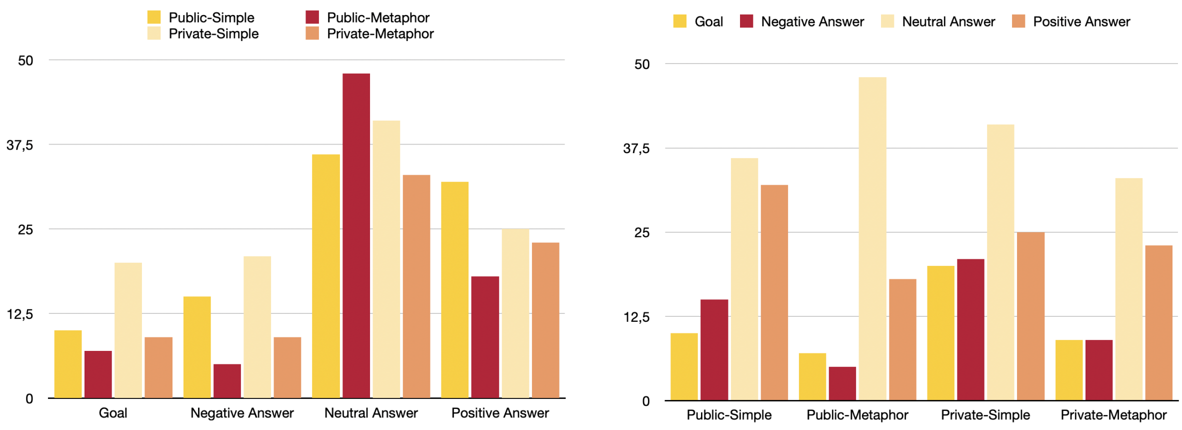

Figure A.3: Number of codes per answer and condition

A.2 General Feedback

	Public-Simple	Public-Metaphor	Private-Simple	Private-Metaphor	
Feature suggestion-optimasation	11	11	4	7	33
Negative Answer	4	0	1	0	5
Nuetral Answer	0	1	0	2	3
Positive Answer	9	5	11	3	28
	24	17	16	12	69

Table A.4: General Feedback Codes by conditions

	Feature suggestion-optimization	Negative Answer	Neutral Answer	Positive Answer
Metaphoric	18	0	3	8
Simple	15	5	0	20
Group Interview	22	4	1	14
Individual Interview	11	1	2	14

Table A.5: The number of **General Feedback** codes distributed between the two conditions is as follows

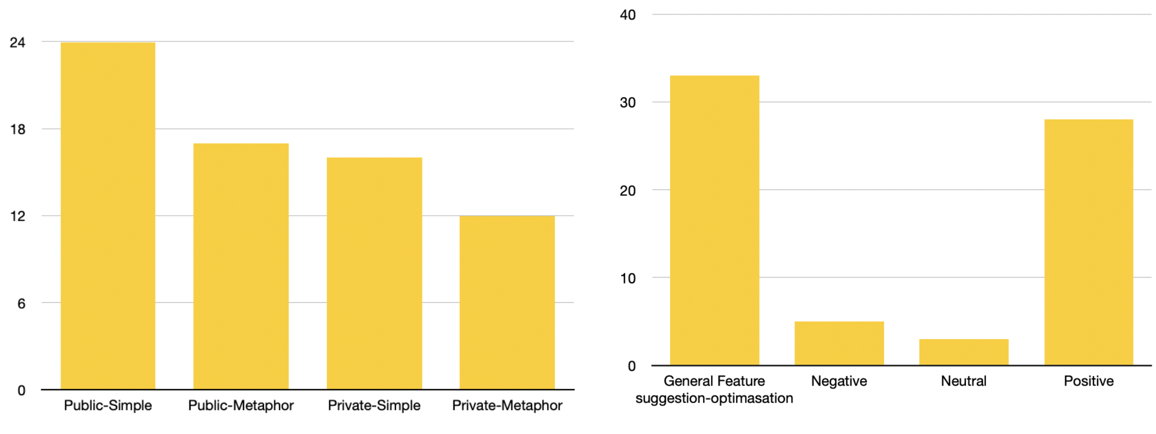

Figure A.4: Number of codes by condition (left) and by answer (right).

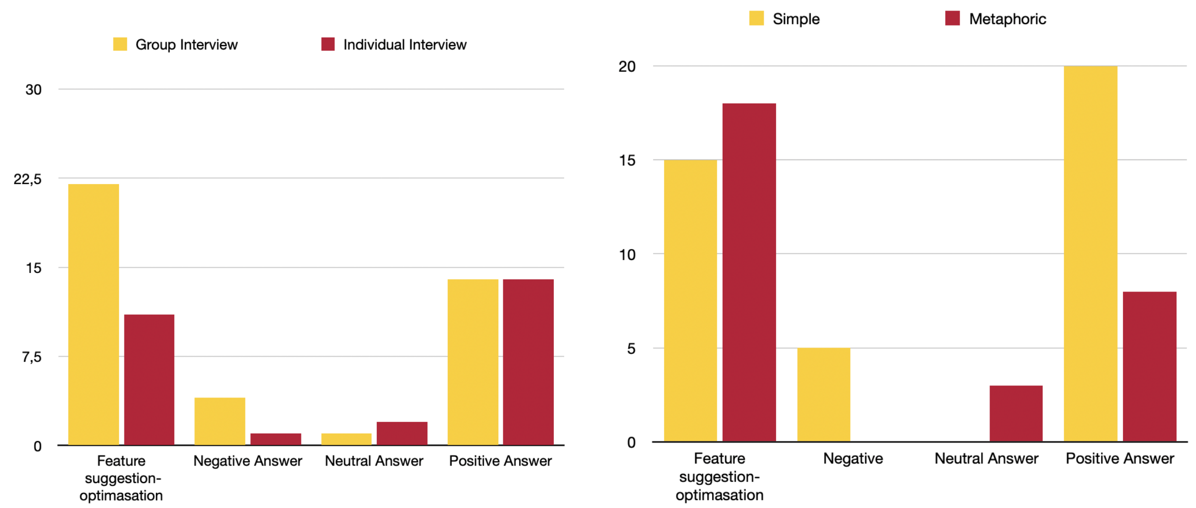

Figure A.5: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

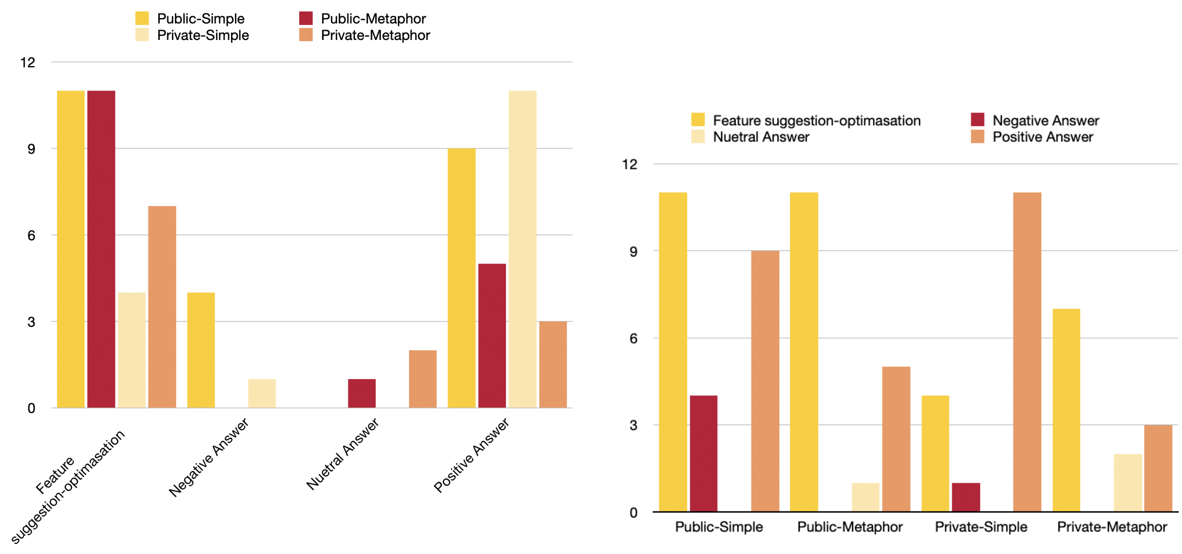

Figure A.6: Number of codes per answer and condition

A.3 Goal

	Public-Simple	**Public-Metaphor**	**Private-Simple**	**Private-Metaphor**	
Negative Answer	2	0	0	1	3
Positive Answer	10	5	7	1	23
	12	5	7	2	26

Table A.6: goal codes per conditions

	Negative Answer	Positive Answer
Metaphoric	1	6
Simple	2	17
Group Interview	2	15
Individual Interview	1	8

Table A.7: The number of **Goal Feedback** codes distributed between the two conditions

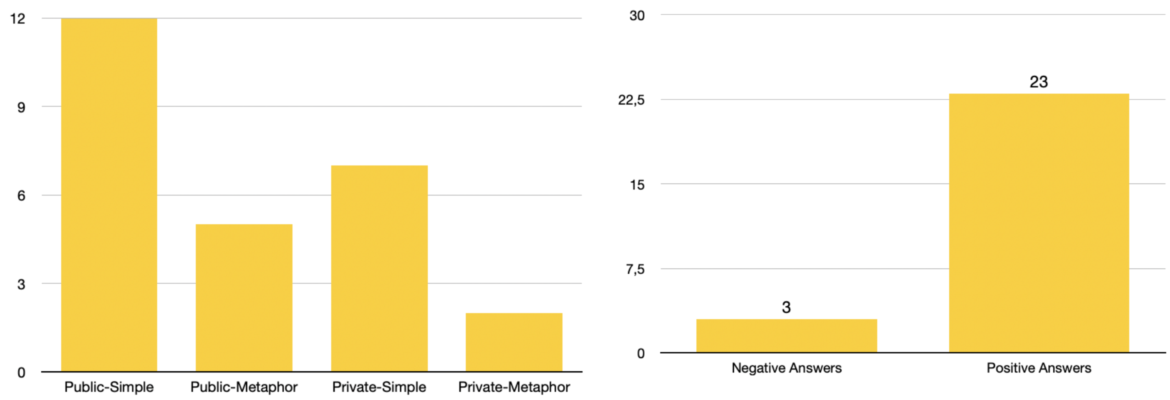

Figure A.7: Number of codes by condition (left) and by answer (right).

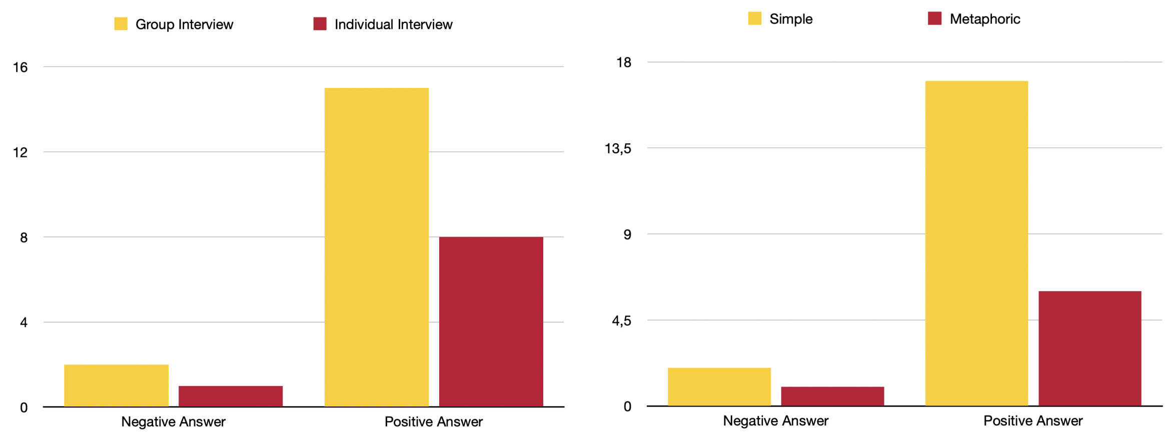

Figure A.8: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

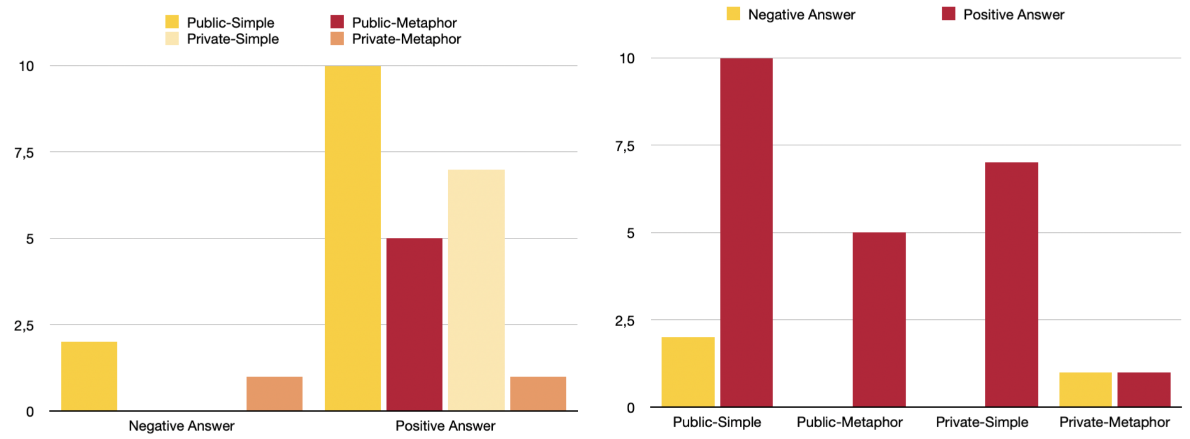

Figure A.9: Number of codes per answer and condition

A.4 Group

	Public-Simple	Public-Metaphor	Private-Simple	Private-Metaphor	
Depends-on-use	5	2	4	5	16
Negative Group	1	2	3	2	8
Positive Group	16	11	3	8	38
	22	15	10	15	62

Table A.8: Group codes per conditions

	Depends-on-use	Negative Group	Positive Group
Metaphoric	7	4	19
Simple	9	4	19
Group Interview	7	3	27
Individual Interview	9	5	11

Table A.9: The number of **Group Preference** codes distributed between the two conditions

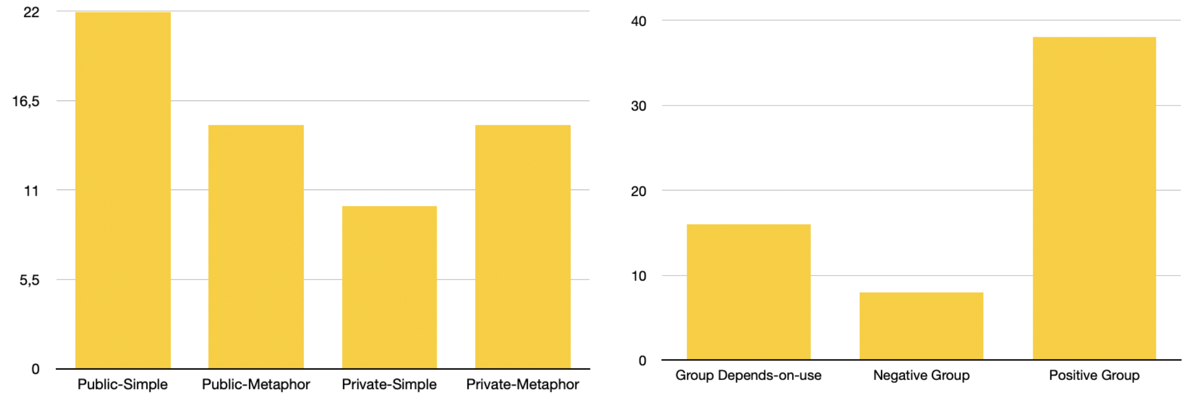

Figure A.10: Number of codes by condition (left) and by answer (right).

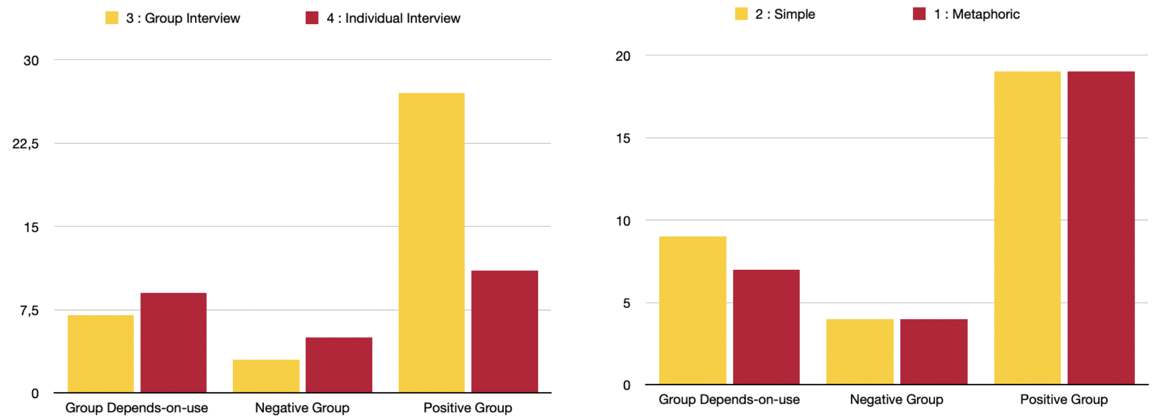

Figure A.11: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

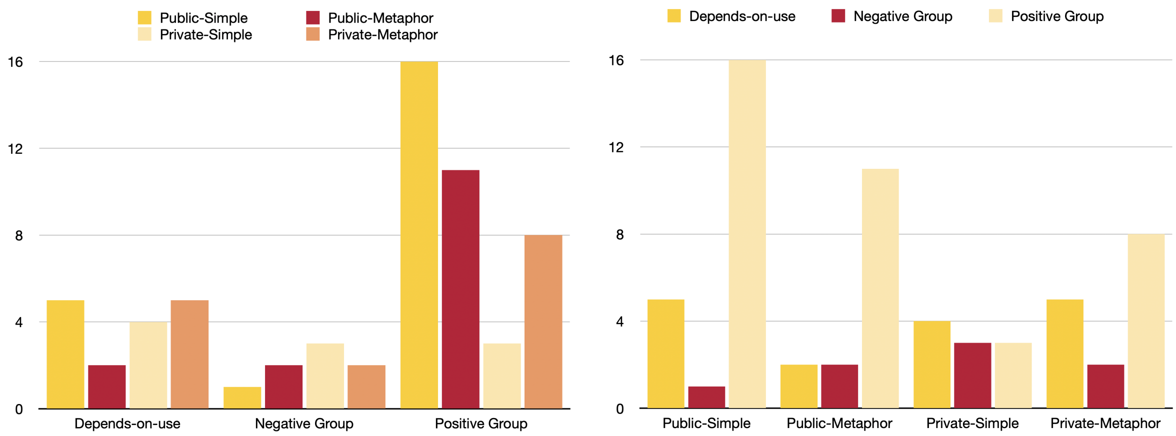

Figure A.12: Number of codes per answer and condition

A.5 Motivation

	Public-Simple	**Public-Metaphor**	**Private-Simple**	**Private-Metaphor**	
Negative Answer	5	0	0	2	7
Positive Answer	22	16	2	4	44
	27	16	2	6	51

Table A.10: Motivation codes per conditions

	Negative Answer	Positive Answer
Metaphoric	2	20
Simple	5	24
Group Interview	5	38
Individual Interview	2	6

Table A.11: The number of **Motivation Answer** codes distributed between the two conditions

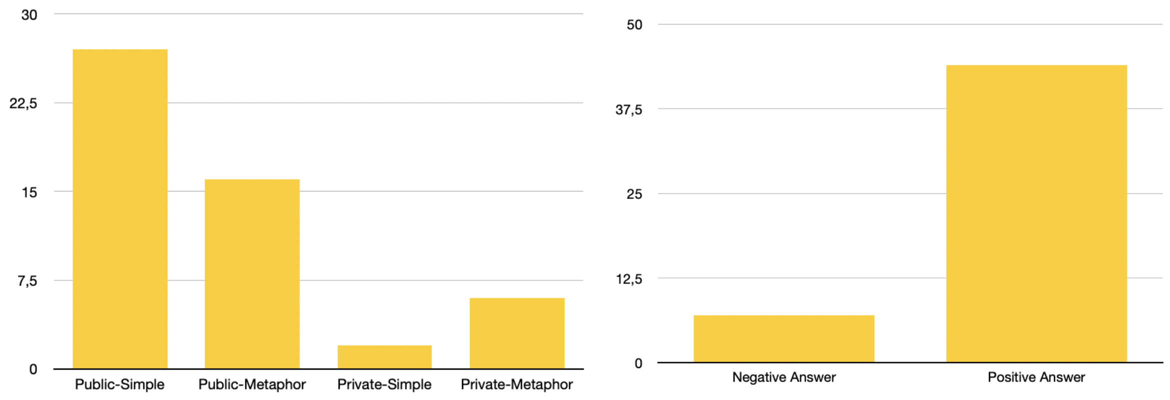

Figure A.13: Number of codes by condition (left) and by answer (right).

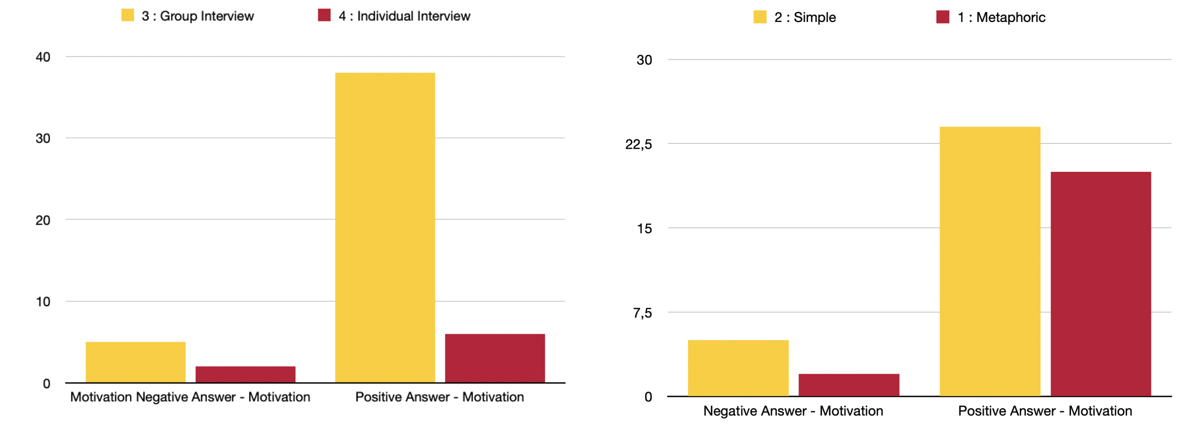

Figure A.14: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

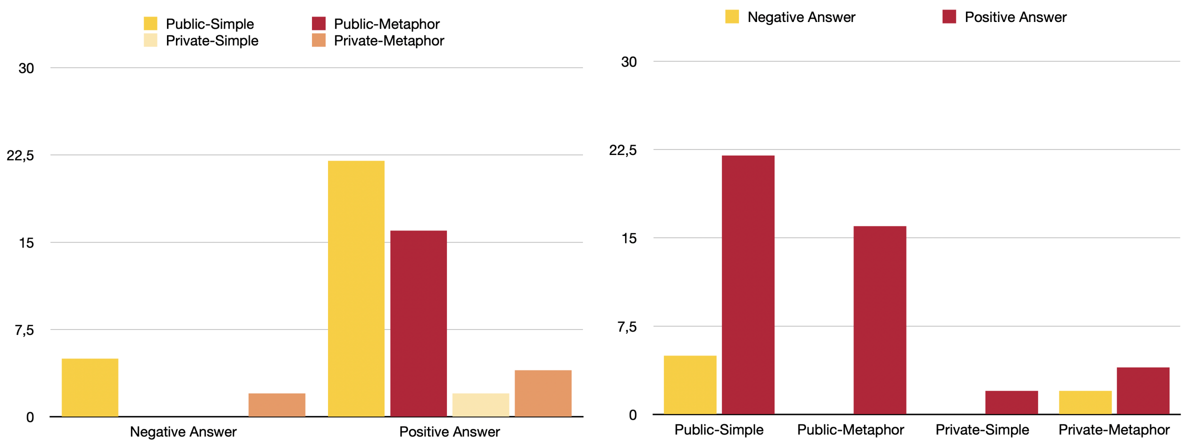

Figure A.15: Number of codes per answer and condition

A.6 Understanding

	Public-Simple	Public-Metaphor	Private-Simple	Private-Metaphor	
Negative Answer	2	12	0	0	14
Nutral Answer	2	4	1	0	7
Positive Answer	3	9	1	2	15
	7	25	2	2	36

Table A.12: Understanding codes per conditions

	Negative Answer	Neutral Answer	Positive Answer
Metaphoric	12	4	11
Simple	2	3	4
Group Interview	14	6	12
Individual Interview	0	1	3

Table A.13: The number of **Understanding Answer** codes distributed between the two conditions

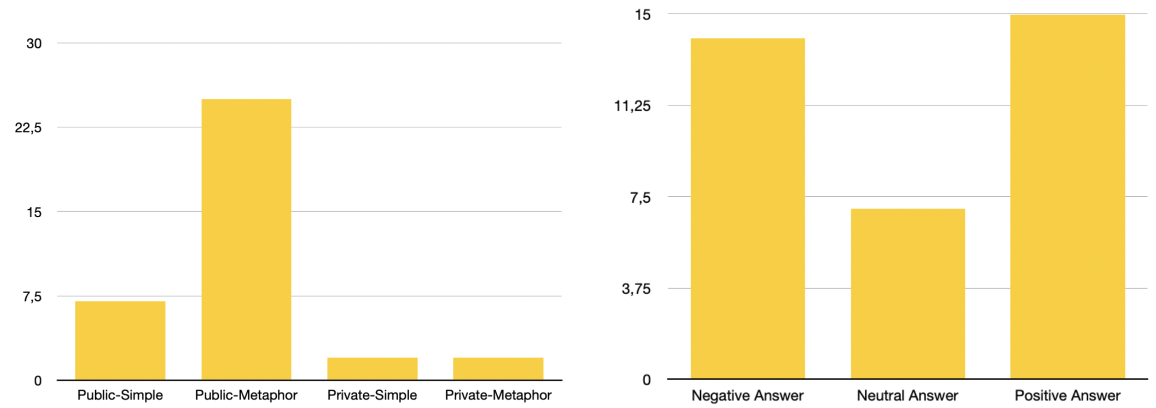

Figure A.16: Number of codes by condition (left) and by answer (right).

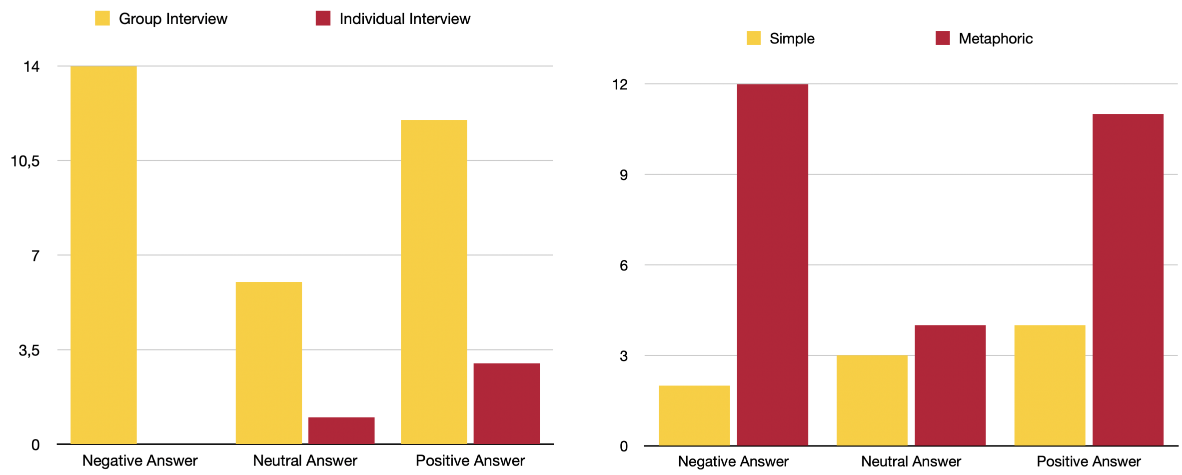

Figure A.17: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

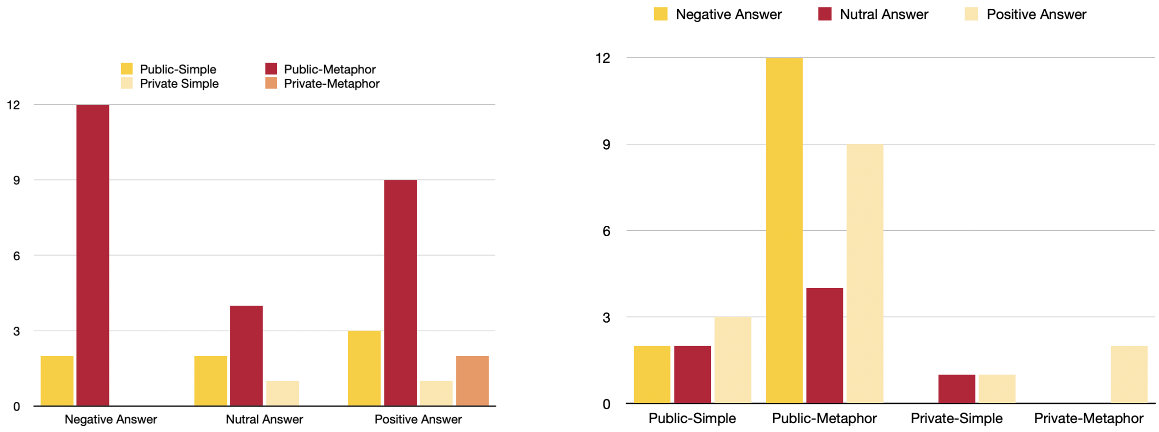

Figure A.18: Number of codes per answer and condition

A.7 Usefulness

Table A.14: Usefulness

	Public-Simple	Public-Metaphor	Private-Simple	Private-Metaphor	
Negative Answer	4	3	0	3	10
Nutral Answer	5	0	3	0	8
Positive Answer	40	12	14	6	72
	49	15	17	9	90

Table A.15: Usefulness codes per conditions

	Negative Answer	Neutral Answer	Positive Answer
Metaphoric	6	0	18
Simple	4	8	54
Group Interview	7	5	52
Individual Interview	3	3	20

Table A.16: The number of **Usefulness Answer** codes distributed between the two conditionsp

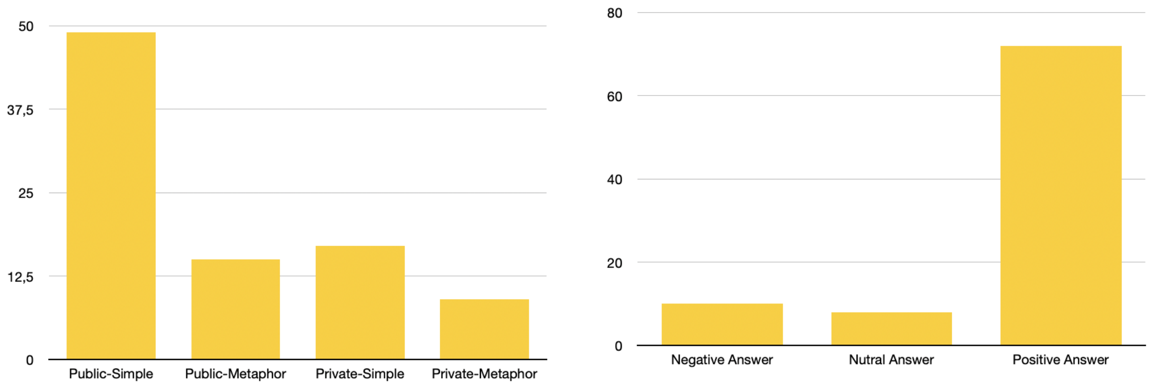

Figure A.19: Number of codes by condition (left) and by answer (right).

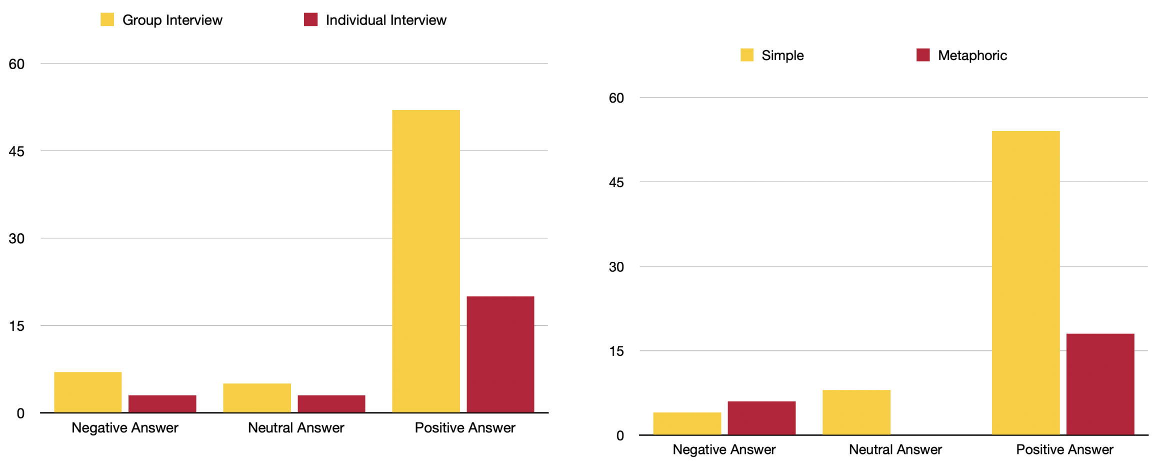

Figure A.20: Number of codes per answer by public vs private condition (left) and by visualisation condition (right)

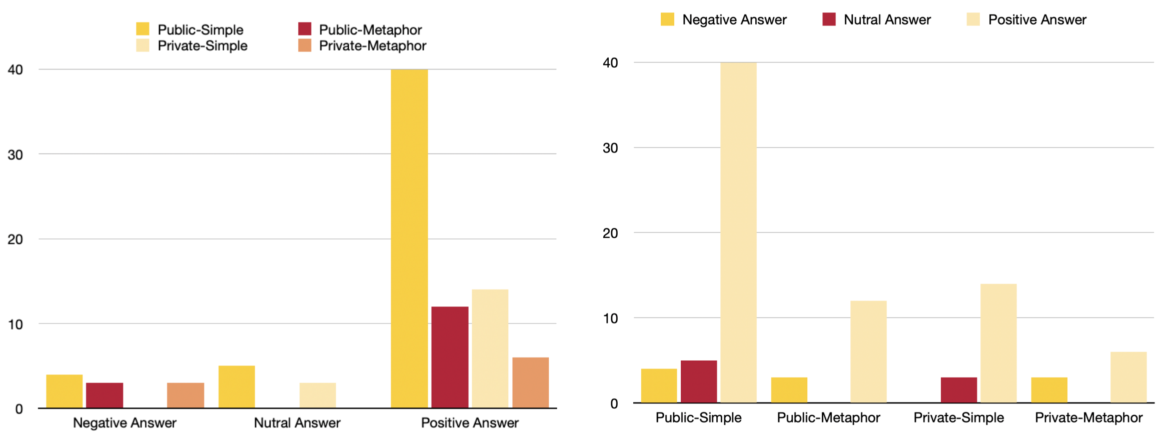

Figure A.21: Number of codes per answer and condition

Appendix B

Questionnaire Results

ID	Q1
	How often do you use a (Garmin) smartwatch to track your rowing workouts?
R_8vW1QickvwpgAdb	Rarely
R_8kTw9NGKkS1EvsZ	Rarely
R_8H16Dm3JIDwWI4D	Daily
R_2fkGTwH6TLDZZAn	Daily
R_8jp2ll6cl2H624h	Daily
R_2gC7pKQDpASkopo	Rarely
R_8QnkeRAEy5RVOsP	Daily
R_8gXbaV9p5w9CXWr	Daily
R_29t4XtdPpr9Pxzn	Daily
R_2zzeG1hSr54ew8N	Daily
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Daily
R_84nS93nxcNmp9Hb	Rarely
R_27glu9ZJ3G6at2r	Rarely
R_8CHj5G2wEGBTh8I	Daily
R_8dG4gzb6qu0bUVl	

ID	Q2
	What specific rowing metrics do you find most valuable to track on your Garmin smartwatch? (You can select more then one)
R_8vW1QickvwpgAdb	Distance,Heart rate
R_8kTw9NGKkS1EvsZ	Stroke rate,Split time,Heart rate
R_8H16Dm3JIDwWI4D	Split time,Distance,Heart rate
R_2fkGTwH6TLDZZAn	Heart rate,Other (please specify) = Kcal burned
R_8jp2ll6cl2H624h	Distance,Heart rate
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	Split time,Distance,Heart rate
R_8gXbaV9p5w9CXWr	Split time,Distance,Heart rate
R_29t4XtdPpr9Pxzn	Distance,Heart rate
R_2zzeG1hSr54ew8N	Heart rate
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Split time,Heart rate
R_84nS93nxcNmp9Hb	Stroke rate,Split time,Heart rate
R_27glu9ZJ3G6at2r	Stroke rate,Split time,Heart rate
R_8CHj5G2wEGBTh8I	Stroke rate,Split time
R_8dG4gzb6qu0bUVl	

ID	Q3
	How often do you use a (Garmin) smartwatch to track your rowing workouts?
R_8vW1QickvwpgAdb	Somewhat clear
R_8kTw9NGKkS1EvsZ	Not very clear
R_8H16Dm3JIDwWI4D	Somewhat clear
R_2fkGTwH6TLDZZAn	Somewhat clear
R_8jp2ll6cl2H624h	Somewhat clear
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	Somewhat clear
R_8gXbaV9p5w9CXWr	Somewhat clear
R_29t4XtdPpr9Pxzn	Somewhat clear
R_2zzeG1hSr54ew8N	Not very clear
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Somewhat clear
R_84nS93nxcNmp9Hb	Somewhat clear
R_27glu9ZJ3G6at2r	Somewhat clear
R_8CHj5G2wEGBTh8I	Very clear
R_8dG4gzb6qu0bUVl	

ID	Q4
	Are there any specific visualizations or data points that you find particularly helpful or insightful for tracking your rowing progress?
R_8vW1QickvwpgAdb	
R_8kTw9NGKkS1EvsZ	Stroke rate and split time
R_8H16Dm3JIDwWI4D	Heart rate on hard pieces
R_2fkGTwH6TLDZZAn	My heart rate is generally low (my rest heart rate is around 45-50), so I like to see my maximum for a training
R_8jp2ll6cl2H624h	Heart rate
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	
R_8gXbaV9p5w9CXWr	I mostly look at my heart rate during the training. And for the boat the split time is also very convenient in case we do an AT training.
R_29t4XtdPpr9Pxzn	Heartrate- zone during ED of AT
R_2zzeG1hSr54ew8N	Comparing my heart rate to my rate of perceived exhaustion
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Gps with heartrate
R_84nS93nxcNmp9Hb	heart rate changes during training
R_27glu9ZJ3G6at2r	
R_8CHj5G2wEGBTh8I	The splitrate graph.
R_8dG4gzb6qu0bUVl	

ID	Q5
	Are there any data visualizations that you find difficult to understand or interpret?
R_8vW1QickvwpgAdb	
R_8kTw9NGKkS1EvsZ	Graphs that are not properly scaled, making it difficult to extract details from the graph.
R_8H16Dm3JIDwWI4D	Splits
R_2fkGTwH6TLDZZAn	I don't spend much time looking at my stats (apart from what
R_8jp2ll6cl2H624h	no
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	
R_8gXbaV9p5w9CXWr	Sometimes the stroke rate is not correct
R_29t4XtdPpr9Pxzn	Stroke rate or split, not always accurate
R_2zzeG1hSr54ew8N	-
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Fat and calories
R_84nS93nxcNmp9Hb	-
R_27glu9ZJ3G6at2r	
R_8CHj5G2wEGBTh8I	No
R_8dG4gzb6qu0bUVl	

ID	Q6
	How do you prefer to view your rowing data? - Selected Choice
R_8vW1QickvwpgAdb	graph
R_8kTw9NGKkS1EvsZ	graph
R_8H16Dm3JIDwWI4D	graph
R_2fkGTwH6TLDZZAn	Other: Stats option in the app / on Strava
R_8jp2ll6cl2H624h	graph
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	graph
R_8gXbaV9p5w9CXWr	graph, table
R_29t4XtdPpr9Pxzn	graph
R_2zzeG1hSr54ew8N	graph
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	graph, table
R_84nS93nxcNmp9Hb	graph
R_27glu9ZJ3G6at2r	graph
R_8CHj5G2wEGBTh8I	graph
R_8dG4gzb6qu0bUVl	

ID	Q7
	Are there any specific features or customization options related to data visualization that you would like to see added to the Garmin smartwatch app?
R_8vW1QickvwpgAdb	
R_8kTw9NGKkS1EvsZ	I have not used my Garmin for rowing, so I cannot really answer this question
R_8H16Dm3JIDwWI4D	Specific split times for pieces. Like a summary on the end of an AT training
R_2fkGTwH6TLDZZAn	Not that I know of
R_8jp2ll6cl2H624h	not yet
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	
R_8gXbaV9p5w9CXWr	
R_29t4XtdPpr9Pxzn	Its sort of neuw for me still so i dont really know yet
R_2zzeG1hSr54ew8N	I don't have the app so I can not say.
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	
R_84nS93nxcNmp9Hb	-
R_27glu9ZJ3G6at2r	
R_8CHj5G2wEGBTh8I	Route overview together with split & HR
R_8dG4gzb6qu0bUVl	

ID	Q8
	How does the ability to easily visualize your rowing data on your Garmin smartwatch affect your overall motivation to train?
R_8vW1QickvwpgAdb	Slightly increases my motivation
R_8kTw9NGKkS1EvsZ	Significantly increases my motivation
R_8H16Dm3JIDwWI4D	Slightly increases my motivation
R_2fkGTwH6TLDZZAn	Slightly increases my motivation
R_8jp2ll6cl2H624h	Slightly increases my motivation
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	Slightly increases my motivation
R_8gXbaV9p5w9CXWr	Slightly increases my motivation
R_29t4XtdPpr9Pxzn	Slightly increases my motivation
R_2zzeG1hSr54ew8N	Has no impact on my motivation
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Slightly increases my motivation
R_84nS93nxcNmp9Hb	Significantly increases my motivation
R_27glu9ZJ3G6at2r	Slightly increases my motivation
R_8CHj5G2wEGBTh8I	Has no impact on my motivation
R_8dG4gzb6qu0bUVl	

ID	Q9
	Does having access to detailed and personalized data visualizations help you set and achieve specific rowing goals?
R_8vW1QickvwpgAdb	I don't have any specific rowing goals
R_8kTw9NGKkS1EvsZ	Yes, somewhat
R_8H16Dm3JIDwWI4D	Yes, somewhat
R_2fkGTwH6TLDZZAn	Yes, greatly
R_8jp2ll6cl2H624h	Yes, somewhat
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	Yes, greatly
R_8gXbaV9p5w9CXWr	Yes, somewhat
R_29t4XtdPpr9Pxzn	Yes, somewhat
R_2zzeG1hSr54ew8N	Yes, greatly
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	Yes, greatly
R_84nS93nxcNmp9Hb	Yes, greatly
R_27glu9ZJ3G6at2r	Yes, somewhat
R_8CHj5G2wEGBTh8I	Yes, somewhat
R_8dG4gzb6qu0bUVl	

ID	Q10	
	Are there any visualizations or data points that you find particularly motivating or inspiring, and why? - Selected Choice	
R_8vW1QickvwpgAdb	I don't find any visualizations particularly motivating	
R_8kTw9NGKkS1EvsZ	No, I find all visualizations equally motivating	
R_8H16Dm3JIDwWI4D	Yes, please specify:	If I can see that I am improving. For example my ED rowing split improving while heart rate stays the same
R_2fkGTwH6TLDZZAn	Yes, please specify:	I like to see the average split decrease (but know that sometimes it can be higher because of a specific practice or break on the water)
R_8jp2ll6cl2H624h	Yes, please specify:	split per stroke, max. split and heart rate
R_2gC7pKQDpASkopo		
R_8QnkeRAEy5RVOsP	I don't find any visualizations particularly motivating	
R_8gXbaV9p5w9CXWr	Yes, please specify:	Heart rate, split time
R_29t4XtdPpr9Pxzn	No, I find all visualizations equally motivating	
R_2zzeG1hSr54ew8N	No, I find all visualizations equally motivating	
R_8ehuhjden8GRvD1		
R_2Yz4p7NF1hL1vY5	Yes, please specify:	Heartrate and zone
R_84nS93nxcNmp9Hb	Yes, please specify:	heart rate zones, to make sure your training intensities stay efficient
R_27glu9ZJ3G6at2r	No, I find all visualizations equally motivating	
R_8CHj5G2wEGBTh8I	Yes, please specify:	Low heartrate combined with low split.
R_8dG4gzb6qu0bUVl		

ID	Q11
	Is there anything else you would like to add?
R_8vW1QickvwpgAdb	
R_8kTw9NGKkS1EvsZ	
R_8H16Dm3JIDwWI4D	
R_2fkGTwH6TLDZZAn	-
R_8jp2ll6cl2H624h	no
R_2gC7pKQDpASkopo	
R_8QnkeRAEy5RVOsP	
R_8gXbaV9p5w9CXWr	
R_29t4XtdPpr9Pxzn	
R_2zzeG1hSr54ew8N	
R_8ehuhjden8GRvD1	
R_2Yz4p7NF1hL1vY5	
R_84nS93nxcNmp9Hb	
R_27glu9ZJ3G6at2r	
R_8CHj5G2wEGBTh8I	
R_8dG4gzb6qu0bUVl	

Appendix C

Quick Scan

C.1 Section 1. Research projects involving human participants

P1. Does your project involve human participants? This includes for example use of observation, (online) surveys, interviews, tests, focus groups, and workshops where human participants provide information or data to inform the research. If you are only using existing data sets or publicly available data (e.g. from X, Reddit) without directly recruiting participants, please answer no.
Yes

Recruitment

P2. Does your project involve participants younger than 16 years of age?
No

P3. Does your project involve participants with learning or communication difficulties of a severity that may impact their ability to provide informed consent?
No

P4. Is your project likely to involve participants engaging in illegal activities?
No

P5. Does your project involve patients?
No

P6. Does your project involve participants belonging to a vulnerable group, other than those listed above?

No

P8. Does your project involve participants with whom you have, or are likely to have, a working or professional relationship: for instance, staff or students of the university, professional colleagues, or clients?
No

Informed consent

PC1. Do you have set procedures that you will use for obtaining informed consent prior to collecting data from all participants, including (where appropriate) parental consent for children or consent from legally authorized representatives? (See suggestions for information sheets and consent forms on the website.)
Yes

PC2. Will you tell participants that their participation is voluntary?
Yes

PC3. Will you obtain explicit consent for participation?
Yes

PC4. Will you obtain explicit consent for any sensor readings, eye tracking, photos, audio, and/or video recordings?
Yes

PC5. Will you tell participants that they may withdraw from the research at any time and for any reason?
Yes

PC6. Will you give potential participants time to consider participation?
Yes

PC7. Will you provide participants with an opportunity to ask questions about the research before consenting to take part (e.g. by providing your contact details)?
Yes

PC8. Does your project involve concealment or deliberate misleading of participants?
No

C.2 Section 2. Data protection, handling, and storage

The General Data Protection Regulation imposes several obligations for the use of personal data (defined as any information relating to an identified or identifiable living person) or including the use of personal data in research.

D1. Are you gathering or using personal data (defined as any information relating to an identified or identifiable living person)?
Yes

High-risk data

DR1. Will you process personal data that could jeopardize the physical health, (physical, social, etc) safety, or legal rights of individuals in the event of a personal data breach?
No

DR2. Will you combine, compare, or match personal data obtained from multiple sources, in a way that exceeds the reasonable expectations of the people whose data it is?
No

DR3. Will you use any personal data of children or vulnerable individuals for marketing, profiling, automated decision-making, or to offer online services to them?
No

DR4. Will you profile individuals on a large scale?
No

DR5. Will you systematically monitor individuals in a publicly accessible area on a large scale (or use the data of such monitoring)?
No

DR6. Will you use special category personal data, criminal offense personal data, or other sensitive personal data on a large scale?
No

DR7. Will you determine an individual's access to a product, service, opportunity, or

benefit based on an automated decision or special category personal data?
No

DR8. Will you systematically and extensively monitor or profile individuals, with significant effects on them?
No

DR9. Will you use innovative technology to process sensitive personal data?
No

Data minimization

DM1. Will you collect only personal data that is strictly necessary for the research?
Yes

DM4. Will you anonymize the data wherever possible?
Yes

DM5. Will you pseudonymize the data if you are not able to anonymize it, replacing personal details with an identifier, and keeping the key separate from the data set?
Yes

Using collaborators or contractors that process personal data securely

DC1. Will any organization external to Utrecht University be involved in processing personal data (e.g. for transcription, data analysis, data storage)?
No

International personal data transfers

DI1. Will any personal data be transferred to another country (including to research collaborators in a joint project)?
No

Fair use of personal data to recruit participants

DF1. Is personal data used to recruit participants?
No

Participants' data rights and privacy information

DP1. Will participants be provided with privacy information? (Recommended is to use as part of the information sheet: For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.)
Yes

DP2. Will participants be aware of what their data is used for?
Yes

DP3. Can participants request that their personal data be deleted?
Yes

DP4. Can participants request that their personal data be rectified (in case it is incorrect)?
Yes

DP5. Can participants request access to their personal data?
Yes

DP6. Can participants request that personal data processing is restricted?
Yes

DP7. Will participants be subjected to automated decision-making based on their personal data with an impact on them beyond the research study to which they consented?
No

DP8. Will participants be aware of how long their data is being kept for, who it is being shared with, and any safeguards that apply in case of international sharing?
Yes

DP9. If data is provided by a third party, are people whose data is in the data set provided with (1) the privacy information and (2) what categories of data you will use?
Yes

Using data that you have not gathered directly from participants

DE1. Will you use any personal data that you have not gathered directly from participants (such as data from an existing data set, data gathered for you by a third party, data scraped from the internet)?
No

Secure data storage

DS1. Will any data be stored (temporarily or permanently) anywhere other than on password-protected University authorized computers or servers?
Yes

DS2. Does this only involve data stored temporarily during a session with participants (e.g. data stored on a video/audio recorder/sensing device), which is immediately transferred (directly or with the use of an encrypted and password-protected data-carrier (such as a USB stick)) to a password-protected University authorized computer or server, and deleted from the data capture and data-carrier device immediately after transfer?
Yes

DS4. Excluding (1) any international data transfers mentioned above and (2) any sharing of data with collaborators and contractors, will any personal data be stored, collected, or accessed from outside the EU?
No

C.3 Section 3. Research that may cause harm

Research may cause harm to participants, researchers, the university, or society. This includes when technology has dual-use, and you investigate an innocent use, but your results could be used by others in a harmful way. If you are unsure regarding possible harm to the university or society, please discuss your concerns with the Research Support Office.

H1. Does your project give rise to a realistic risk to the national security of any country?
No

H2. Does your project give rise to a realistic risk of aiding human rights abuses in any country?
No

H3. Does your project (and its data) give rise to a realistic risk of damaging the University's reputation? (E.g., bad press coverage, public protest.)
No

H4. Does your project (and in particular its data) give rise to an increased risk of attack (cyber- or otherwise) against the University? (E.g., from pressure groups.)
No

H5. Is the data likely to contain material that is indecent, offensive, defamatory, threatening, discriminatory, or extremist?
No

H6. Does your project give rise to a realistic risk of harm to the researchers?
No

H7. Is there a realistic risk of any participant experiencing physical or psychological harm or discomfort?
No

H8. Is there a realistic risk of any participant experiencing a detriment to their interests as a result of participation?
No

H9. Is there a realistic risk of other types of negative externalities?
No

C.4 Section 4. Conflicts of interest

C1. Is there any potential conflict of interest (e.g. between research funder and researchers or participants and researchers) that may potentially affect the research outcome or the dissemination of research findings?
No

C2. Is there a direct hierarchical relationship between researchers and participants?
No

C.5 Section 5. Your information.

This last section collects data about you and your project so that we can register that you completed the Ethics and Privacy Quick Scan, sent you (and your supervisor/course coordinator) a summary of what you filled out, and follow up where a fuller ethics review and/or privacy assessment is needed. For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information. Please see the guidance on the ICS Ethics and Privacy website on what happens on submission.

Z0. Which is your main department?
Information and Computing Science

Z1. Your full name:
Tim Winkler

Z2. Your email address:
T.m.winkler@students.uu.nl

Z3. In what context will you conduct this research?
As a student for my master thesis, supervised by:
Eelco Herder

Z5. Master programme for which you are doing the thesis
Human-Computer Interaction

Z6. Email of the course coordinator or supervisor (so that we can inform them that you filled this out and provide them with a summary):
e.herder@uu.nl

Z7. Email of the moderator (as provided by the coordinator of your thesis project):
e.herder@uu.nl

Z8. Title of the research project/study for which you filled out this Quick Scan:

Enhancing Cooperation in Group Fitness Tracking: The Role of Rewards and Punishments

Z9. Summary of what you intend to investigate and how you will investigate this (200 words max):
The research to investigate the impact of various feedback and visualization strategies on the performance and motivation of rowing teams. The study is grounded in the hypothesis that certain types of feedback and visualizations can significantly enhance group synchronization and effort alignment, ultimately leading to improved performance outcomes. The study will recruit participants from a local rowing club, ensuring a diverse sample of experienced rowers. Participants will be informed about the study's aims and instructed on how to record their training sessions using wearable devices. Data collected will be analyzed, and feedback will be provided during post-training discussions. Participants will complete questionnaires to evaluate the feedback's clarity, usefulness, and motivational impact. The study design includes testing different visualization techniques and feedback strategies, focusing on both cooperative and competitive elements to maximize overall team performance.

Z10. In case you encountered warnings in the survey, does supervisor already have ethical approval for a research line that fully covers your project?
Not applicable

Scoring Privacy: 0 Ethics: 0

Appendix D

Other

Garmin Activity Data:

```
{
    activityId: ID of Activity;
    samples: Array with Sample Data;
    summary: Object with Summary of Activity;
}
```

Sample Data from Garmin API

```
{
    clockDurationInSeconds: number;
    heartRate: number;
    latitudeInDegree?: number;
    longitudeInDegree?: number;
    speedMetersPerSecond: number;
    startTimeInSeconds: number;
    totalDistanceInMeters: number;
}
```

Summary of a Garmin Activity:

```
{
    summaryId: string;
    activityId: number;
    activityName: string;
    durationInSeconds: number;
    startTimeInSeconds: number;
```

```
    startTimeOffsetInSeconds: number;
    activityType: string;
    averageHeartRateInBeatsPerMinute: number;
    averageSpeedInMetersPerSecond: number;
    averagePaceInMinutesPerKilometer: number;
    activeKilocalories: number;
    deviceName: string;
    distanceInMeters: number;
    maxHeartRateInBeatsPerMinute: number;
    maxPaceInMinutesPerKilometer: number;
    maxSpeedInMetersPerSecond: number;
    startingLatitudeInDegree: number;
    startingLongitudeInDegree: number;
    totalElevationGainInMeters: number;
    totalElevationLossInMeters: number;
    isWebUpload: false;
}
```