Universität Regensburg

Iterative development of visualisations for a floor-projected verbal participation feedback system in the context of group therapy

Master's Thesis in Media Informatics
at Institute for Information and Media, Language and Culture (I:IMSK)

Handed in by:	Thilo Hohl
E-Mail (University):	thilo.hohl@stud.uni-regensburg.de
E-Mail (private):	thilo.hohl@gmail.de
Student Number:	2093510
Primary Corrector:	PD Dr. Raphael Wimmer
Secondary Corrector:	Prof. Dr. Youssef Shiban
Supervisor:	Vitus Maierhöfer
Current Semester:	6th semester M.Sc. Medieninformatik
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Zusammenfassung

Group Mirrors erlauben das Darstellen von Aspekten einer zwischenmenschlichen Interaktion mithilfe von Informationssystemen (Jermann et al., 2001). In Gruppentherapiesitzungen müssen Therapeut:innen einerseits auf Inhalte der Aussagen ihrer Patient:innen achten, haben aber auch die Aufgabe, Redeanteile gleichmäßig zu halten, wodurch Sie vom eigentlichen Zweck der Sitzung abgelenkt werden können. Durch die Darstellung von Redeanteilen mit einem visuellen Group Mirror könnte die moderierende Person entlastet und die Gesprächsbalance verbessert werden. Dazu muss eine Visualisierung nicht nur die speziellen Anforderungen der klinischen Anwendung erfüllen, sondern auch eine hohe Menge Teilnehmender darstellen können. Therapiesitzungen dieser Art haben bis zu 12 Patient:innen, während die Forschung zu Group Mirrors bisher Gespräche zwischen maximal vier Personen behandelt hat. In dieser Abschlussarbeit werden iterativ drei Visualisierungskonzepte mit Expert:innen zusammen erarbeitet. Diese werden dann in ein System integriert, das mithilfe eines Richtmikrofons die Redeanteile von Teilnehmenden misst. Die drei Visualisierungen werden in zwei Studien verglichen. Eine erste Studie in zwei Gruppen (n=7 und n=8) wurde von einer Psychologin als Simulation einer Gruppentherapie abgehalten, während in der zweiten Studie acht Personen eine nicht moderierte Gruppendiskussion abhielten und danach in einer Fokusgruppe die Wirkung des Systems beschrieben. Das technisch simple System aus nur einem Mikrofon, einem Projektor und einem Rechner konnte in einer Gruppe von bis zu neun Leuten für alle drei Visualisierungen verständlich Redeanteile darstellen. In den qualitativen Ergebnissen beider Studien wird die Visualisierung Partikel präferiert. Diese stellt die Redezeit als kleine Teilchen dar, die sich zwischen Teilnehmenden hin- und herbewegen. Vor allem Teilnehmende mit geringer Beteiligung wurden durch die Partikel motiviert, mehr beizutragen. Eine andere Visualisierung, die aus wachsenden Kreisen mit Referenzlinien besteht, wurde als intuitiv bewertet und half Personen mit höherer Teilnahme dabei, sich selbst auszubremsen. Der leitenden Psychologin zufolge ist der Einsatz eines solchen Systems hilfreich und in echten Therapiesitzungen denkbar.

Abstract

Group Mirrors are ways to represent specific elements of an interaction between people with information systems (Jermann et al., 2001). In group therapy sessions, a therapist has to keep track of participation rate, which may distract from the underlying objective of educating about or treating psychological stresses. Reflecting participation using a visual group mirror could be a solution to take cognitive load off a moderator and improve balance in group therapy scenarios. This requires the design of group mirror visualisations that take both the special requirements of the setting as well as a number of participants higher than previously researched into consideration. In this thesis, three different visualisation concepts are developed based on iterations of expert interviews and requirement lists. These visualisations are then implemented in a functional system using a far-field directional microphone to measure participation based on the direction and length of statements. Two studies are conducted, one two-group (n=7 and n=8) mock group therapy session led by a psychologist with experience in group therapy as an analogue to the target application, and an unmoderated group discussion (n=8) followed by a focus group where the three visualisations and their impacts are discussed. The relatively lightweight implementation using one microphone, a short-throw projector and a computer was successful in displaying an understandable group mirror for up to nine participants at a time and has potential to be scaled to even larger groups. In qualitative feedback for both studies, PARTICLES, a visualisation where speaking time is abstracted as moving particles being exchanged between users, was rated as the most interesting concept with potential to be used in real therapy sessions. It had a greater reported effect on users with too little participation, while the metacognitive concept of scaling CIRCLES was rated as more intuitive and had a greater effect in braking overparticipators.

1. Introduction

This thesis is part of a joint project between the chair for Media Informatics at the University of Regensburg and the psychology department of the PFH Göttingen.

One of the goals of this collaboration is to find novel approaches to integrate technologies into psychological processes.

A possible application for group therapy sessions are group mirrors. In group therapy, psychotherapists have several tasks. Firstly, they have to reach the main goal of each session, which usually includes a psychoeducative component, informing people about symptoms of psychological conditions and ways to deal with them. Then, experiences with and solutions for these symptoms are shared and discussed between members of the group while the therapist moderates the session, paying attention to multiple aspects: Keeping the discussion close to the topic at hand and preventing people from straying in different directions, as well as avoiding delving too deeply into certain topics or traumatic experiences.

On top of that, a balance of participation has to be kept. Every participant should have the opportunity to speak and to share their own experience. Here, some people tend to contribute naturally while others don't have the energy or social confidence to create room for themselves. The moderator needs to slow down or even interrupt people who overcontribute, while underparticipators need to be called upon and motivated. Confronting people about their participation is often a stressful situation for both parties and takes up energy and time.

This mental load could instead be handled by reflecting participation using a visual group mirror. Group mirrors that display participation can help balance conversations, as participants have hard evidence of their contribution in comparison with the entire group. Seeing a only a small representation might motivate and pressure underparticipators to speak up, while a representation of their dominance might get overparticipators to pause, leaving more space for others.

Therapy sessions held in this manner also include up to twelve participants, a number higher than in previous research regarding such systems. So far, most group mirrors have supported two, three, or at most, four participants. Therefore, a mirror needs to be designed specifically to fit such a large group.

The task at hand can be described in three research questions:

RQ1. *Which special requirements to group mirrors exist in the context of group therapy?*

RQ2. *Can group mirrors be applied to balance participation in group therapy sessions?*

RQ3. *Which requirements does a group mirror have to fulfil for large groups?*

To answer them, literature pertaining to the design of group mirrors (chapter 2) and discussion with experts is used to generate a set of requirements for the application (subsection 3.1). Then, ten concepts for suitable mirrors are developed and reviewed with HCI researchers and psychologists (section 3.2). Three of those concepts—a particle system, a modified pie chart with centrally scaled slices representing participation, and a metacognitive circle approach—are then implemented using D3.js to visualise participation, which is measured using a far-field directional microphone fed into a python3 back end. This system is displayed on the floor of a circle of chairs using a short-throw projector. Description, implementation and validation of the system are documented in sections 4–4.2.2. Two studies are described in chapter 5 and conducted. Results of questionnaires, log data, a focus group and an in-depth expert interview are listed in chapter 6. In chapter 7, these results as well as tools and methodology used are interpreted and reflected upon and steps to be taken are laid out.

2. Related Work

The following list of related work was collected using the search engine Google Scholar along with filtering online conference libraries, especially CHI and ACM proceedings. Backward snowballing through revelant papers' citations was also employed. Since the thesis at hand ties into a larger research project, I was also able to utilise the assorted library of the chair of Media Informatics.

2.1. Group Mirrors

"Group Mirror" is a term for an information system that reflects or contextualises dimensions of an interaction (Jermann et al., 2001). These systems have been applied in a number of fields, including Computer-Supported Collaborative Learning (CSCL), business meetings (Roman et al., 2012) and discussions or brainstorming sessions (Schiavo et al., 2014; Streng et al., 2009; DiMicco et al., 2004).

2.2. Visualising group dynamics

Since we intend to focus on different visualisations, it is important to be able to define and contextualise the different designs of group mirrors. In chapter four of her 2016 dissertation, Tausch listed different factors to describe the design space for group mirrors. Her categorisation has been a vital foundation for this work. The factors described range from simple dimensions like *Feedback Modality* or *Type of Visualisation* to cardinality categorisations and *Amount of Guidance*, which she cited from Jermann et al.'s 2001 review. Guidance is differentiated between *mirroring tools*, which simply represent values, *metacognitive tools*, which include reference points in their modelling, and *coaching systems*, which interpret and advise on the interactions they support.

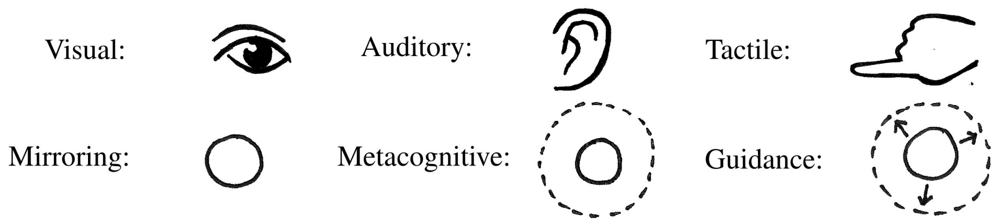

Figure 1: Sketches illustrating different *Modalities* and *Levels of Guidance* of group mirrors by Tausch (2016)

While other possibilities exist, the modality to consider for the application at hand is the visual domain, as this does not disrupt communication over the auditory channel.

To investigate guidance levels, Jermann & Dillenbourg compared firstly a collaborative and a cumulative mirroring tool (*n=98*) and then no support with a metacognitive visualisation (*n=72*), each in pairs of two participants working together to solve problems. Their results indicated that the choice of mirroring tool did not really have an effect on their subjects while in terms of guidance, the metacognitive gauge increased dialogue, which led to "more frequent and precise planning".

In her dissertation, Tausch counted more mirrored studies than metacognitive ones, but argued that the differences between the two categories are fluent and some mirrors, even when lacking clearly defined reference states, still have inherent optimal conditions derived from context. The aim for this thesis is to provide a reference value or at least an inherent balanced state in the developed visualisations.

2.3. Diagram or Metaphor?

Group mirror visualisations can be divided into *overt* versus *subtle* (Tausch, 2016) or *diagrammatic* versus *metaphoric* (Streng et al., 2009) variations. Tausch describes overt visualisations as diagrammatic, but then includes Schiavo et al.'s text mode as the only overt visualisation in her review. In this paper, any visualisation that is more abstracted than metaphoric or in some way comparable to a diagram is classified as overt.

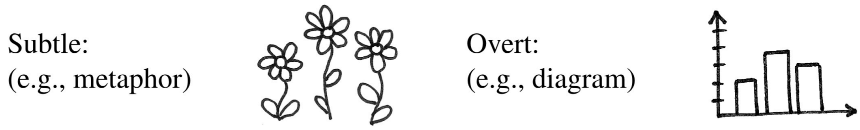

Figure 2: Sketch illustrating *visualisations* of group mirrors by Tausch (2016)

Streng et al. compared a metaphorical display—using a landscape with trees representing reviewers, weather representing analysers and day/night cycles indicating turns—with a simple bar plot and colour dot indicator as the overt option. Their nine groups of three (*n=27*) held a discussion with each of the conditions in addition to a baseline without computer-mediated feedback. The subtle visualisation scored significantly better, as it significantly shortened the time for self-regulation of participants, balancing the discussion more effectively. However, the visualisations used in this study were implemented using the now defunct Adobe Flash[1], and, as the authors themselves state, preferences regarding type might depend more on the quality of visualisation and specific context and can therefore not be generalised.

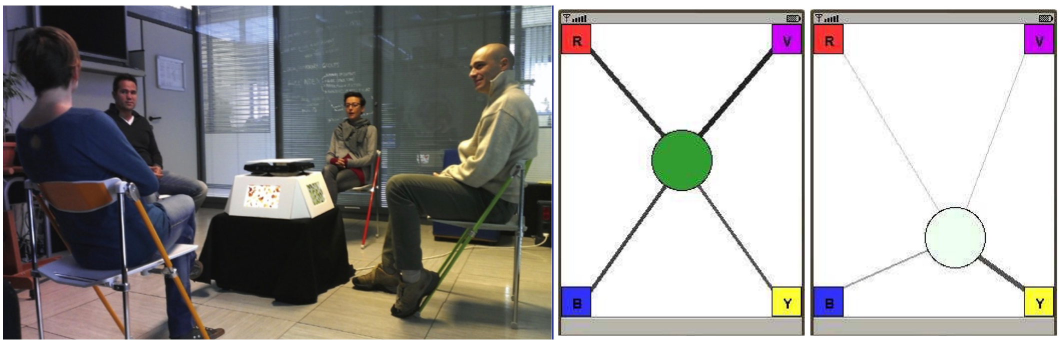

Figure 3: The prototype built by Schiavo et al. (*left*), screenshots of different discussion balances in Kim et al.'s Meeting Mediator (*right*).

Similarly, Schiavo et al. compared an uninformed subtle visualisation with an informed subtle visualisation and overt directives (*n=60, 15 groups of four*), each on private displays in a non-controlled setting (a science fair). Their application approximated gaze through head position tracking using XBox Kinect cameras and tried to achieve a balanced group interaction by indicating when participants were not looking at others enough, which the authors used as a measurement of atten-

[1]https://www.adobe.com/products/flashplayer/end-of-life-alternative.html, retrieved on 20.05.2025

tion paid to that person. In the OVERT condition, their feedback was communicated using text directives like "What does the person on the green chair think?". In both SUBTLE conditions, green-coloured particles moved towards the person least interacted with. For this target, their particles diminished in size and colour. To assess the intuitiveness of their visualisation, Schiavo et al. tested SUBTLE once with prior explanation and once without. Both the OVERT and UNINFORMED SUBTLE conditions scored moderately well in terms of balancing, where the EXPLAINED SUBTLE condition performed best. This was also reflected in the qualitative feedback of participants, who found the OVERT condition "distracting and intrusive, not really helpful for their activity". UNINFORMED SUBTLE was often ignored or interpreted as "meaningless" or a "sort of screensaver". At least one person in each of the 15 groups of four used the SUBTLE display as intended, monitoring the conversation and adjusting their behaviour. However, some participants were uncomfortable when the system indicated they were the under-participant, stating that the visualisation only furthered their sense of exclusion.

A strong metaphor can be found in Group Garden (Tausch et al., 2014), where brainstorming sessions between groups of three were supported by a mirror that represented each person's ideas as flower petals on an individual flower and represented group performance with a growing tree. In a first study (*n=30*), they compared a non-mirrored session with the group mirror displayed on a wall. Then, a second study (*n=24*) compared a wall- and an adapted top-down table projection. In both studies, the qualitative feedback the mirror gave was generated using a Wizard-of-Oz setup. The first study indicated that people had slightly more ideas and more balanced contribution in the mirrored condition. Comparing table and wall did not show significant differences for balance or amount of ideas, but "indicate[d] that peripheral feedback such as a visualization on a wall is less disturbing and puts less pressure on the group members. [...] A centralized group mirror may ease collaboration and communication."

A study using an overt visualisation in an interesting hardware approach is found in Bachour et al. (2010), where a "semi-ambient" table featuring LEDs below a

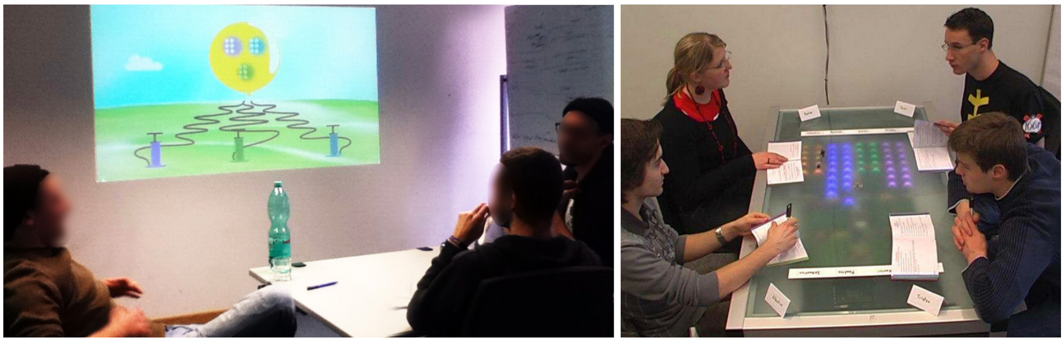

Figure 4: A study group in Tausch et al.'s *mixed* metaphor (*left*) and a study group in Bachour et al.'s Reflect (*right*).

transparent tabletop was used as an unobtrusive, but visible display. They explored (and initially favoured) a circular "territory" approach with bubbles emerging from the speakers' position, but ultimately displayed the measures in coloured bars, comparable to a bar chart. In two studies (*n=72, 18 groups of four*), Bachour et al. found that the table mirror balanced participation, more significantly for over-participators, and distracted a quarter of subjects (which authors found acceptable). 15% of subjects reported feeling "uncomfortable with seeing their participation levels displayed for all to see". Qualitative Feedback pointed to the LEDs being a strong brake. A 2012 long-term follow-up study using the table in managers' meetings did not provide much generalisable results, but observed a balancing trend from the fourth meeting onwards and was able to describe specific patterns of participation for the groups tested.

Another interesting overt idea can be found in Kim et al.'s 2008 Meeting Mediator, which connected a central circle to a user in each corner of a small, private phone screen. A line drawn between each user and the moving circle denoted speaking time, while the circle's position indicated balance and its colour the interactivity level. This tool was tested with 144 people between 36 groups of four and significantly reduced the average length of speech segment, which the authors interpreted as improving interaction. The interface was also reportedly not distracting to its users.

In 2016, Tausch et al. compared cooperative and competitive visualisations that displayed the group's contributions either in a completely aggregated (cooperative), a semi-distinctive (mixed) and an entirely distinctive (competitive) balloon visualisation projected on to a wall. In a study with 12 groups of three, in which the groups held brainstorming sessions, the COMPETITIVE visualisation was rated as the most motivating one, but also produced the most pressure in subjects. The CO-OPERATIVE and MIXED conditions were preferred by 34 participants, but balance of participation did not differ from the baseline.

2.4. Group Sizes

The studies mentioned so far only catered to smaller group sizes, ranging from two (Jermann & Dillenbourg, 2008) to four (Bachour et al., 2010; Kim et al., 2008; Schiavo et al., 2014) people. It is difficult to find records of group mirrors that cater to medium-sized or even large groups. In 2018, Praharaj et al. used a Wizard-of-Oz approach to visualise participation during PhD student meetings of up to seven people. Their visualisation was initially a pie chart, but was changed to a line graph after participant feedback to better display development over time. In a 2019 follow-up paper, the authors stated plans to test a functional prototype with metaphorical feedback in the form of a three-dimensional tree for each user called 'Group Coach'. They aimed to test in meetings of two to six people, but have not published an update since, focusing instead on post-hoc analysis of collaboration (Praharaj et al., 2022).

2.5. Pilot Study

In an unreleased 2024 study (n=4) at the University of Regensburg, Maierhöfer and Kilger explored the impact of table-projected participation display using a growing half-circle for each user. They varied three conditions (NO VISUALISATION, VISUALISATION and UNRELATED VISUALISATION, which drew circles, but changed their size randomly), and observed that a growing circular visualisation is not optimal for longer durations of speech, as the non-linear difference in surface area is not intuitively readable. They also recommend updating the visualisation *after* input has finished in order to prevent distraction. Their findings and approach are a central starting point to this thesis.

2.6. Summary

A number studies have researched Computer Mediated Feedback tools over the past 30 years. They mostly focus on collaborative learning, problem-solving or discussion applications. When deciding on the type of visualisation, some studies indicate metaphoric mirrors perform better than overt mirrors (Jermann & Dillenbourg, 2008; Schiavo et al., 2014), while other groups have proposed strong examples of intuitive overt visualisations (Kim et al., 2008; Bachour et al., 2010).

Comfort of users is an important aspect for a supporting system and especially relevant in the context at hand. Comfort has been measured directly or indirectly in several of the aforementioned papers, with Schiavo et al. (2014) and Bachour et al. (2010) both reporting on situations where comfort was suboptimal. A mixed visualisation similar to Tausch (2015), emphasising the collaborative nature of interaction, while still keeping participants identifiable, could be a suitable approach. These and other dimensions in the design space of group mirrors have been summarised and described in her PhD dissertation by Tausch (2016). Little research has yet been published regarding mirrors for groups larger than four, indicating a research gap.

3. Ideation and Concept

Group therapy sessions, especially transdiagnostic group therapy, require multiple tasks from the psychotherapist conducting the session. Their primary role is a psychoeducative one, in which they give background information and strategies to combat symptoms of psychological stresses. In the interactive portions of the session, they have to moderate the content of discussions and use of language in order to keep the intervention in a productive spirit and prevent self-deprecation or aggressive behaviour. In addition to those tasks, they have to keep conversational balance to keep all participants included and control people who take too much space in the discussion. This relatively simple aspect of the session provides an opportunity to relieve the therapist and free up cognitive space to their primary goals by employing a participation feedback system.

From this idea, we can derive our first two research questions.

RQ1. *Which special requirements to group mirrors exist in the context of group therapy?*

RQ2. *Can group mirrors be applied to balance participation in group therapy sessions?*

The therapy sessions described by members of the psychology department in Göttingen are held in a circle of chairs counting up to twelve people plus the therapist. The number of participants in related work, however, seldom exceeded four. This leads to a third, inherent question we can investigate in the thesis:

RQ3 *Which requirements does a group mirror have to fulfil for large groups?*

The space between chairs is kept free from obstructions like tables, as there is no need for note-taking amongst the participants and opening the space serves to reduce opportunities to retract oneself from the discussion. Educational materials and notes are displayed or written on a whiteboard next to the therapist. A group mirror display should not disturb this constellation and be integrated with as little friction as possible, eliminating, for this number of participants, private devices and, given the interpersonal attention necessary, multiple display screens. A system projecting the mirror onto the shared floor could fit these limitations, requiring only a ceiling-mounted or mobile projector facing downwards and sensors to measure participation. This way, the entirety of the empty space between participants, approximately 4 by 2 metres, can be projected upon, leaving ample area to accommodate a high number of users in the display.

3.1. Requirements

Given the motivation and related work, project requirements were discussed with the stakeholders and ranked in terms of priority by both developer and stakeholders. Listed in tables 1 and 2, the centre column indicates the combined priority, and rightmost indicates the primary source for each requirement.

Requirement	**Priority**	**Source**
Identify current speaker	Essential	Discussion
Visualise participation in relation to group	Essential	Discussion
Display information publicly	Essential	Stakeholders
Individual display (not aggregated)	Essential	Discussion
Metacognitive display (reference values)	Essential	Tausch (2016)
Discrete changes *after* each utterance	Practical	Maierhöfer & Kilger
Reflect both total session and exercise sections	Practical	Stakeholders
Flexible timekeeping (10 up to 90 minutes)	Practical	Discussion
Include corporate identity colours	Practical	Stakeholders

Table 1.: Functional Requirements

Identifying the current speaker was effectively implicit, as it is the core function of conversational group mirrors. *Visualising participation in relation to group* was chosen as the group mirror's target dimension for this thesis as it was technically simple to address, promises to free up cognitive space for the moderator and relieves them—and the patients—of potential stress from confrontation about participation levels.

To *display information publicly* was a requirement facilitated in part by the projection, as it works best on a flat and therefore easily visible surface. Whilst steps could have been taken to increase privacy for such a display—using angled surfaces or sizing the information to be readable only by the concerned person—the stakeholders considered that a public or semi-public display (in the sense of Tausch's design space factors) of contribution would increase pressure on users to adjust their output, which they preferred. This would only work if people had an *individual display* as per Tausch, so their participation would be reflected clearly ind identifiably. The stakeholders also feared that a cooperative display, like in Tausch et al. (2016), might encourage extroverted users to 'save' or 'help' the group (in their eyes) by carrying the conversation, which would still take time and opportunity from less active participants.

A *metacognitive display* was chosen over the other two variants as it promised a subtle, but informative reference value. The notion of *changing the display discretely*, after each finished statement, was carried over from Maierhöfer and Kilger's yet unpublished 2024 small-scale study, which served as the primer for this thesis. In comparison to a continually updating visualisation, they deemed the discrete approach to be less distracting.

The two requirements for *flexible timekeeping* and a dual measurement for *total and exercise sections* stem from the format of a group therapy session. The stakeholders added that the two values did not have to be displayed simultaneously, which would mostly distract and add to visual clutter.

The stakeholders' ideal vision for the system was to be a reliable, neutral third party that *did not judge users*, but *generated motivation* by displaying the conversation status accurately. Considering the diverse user group, it should be *easy and quick to understand*, even for non-'digital natives'. *Disruption* and *distraction* should be *minimised* to increase usability.

Technical requirements derived from the format of the group therapy are catering for large number of participants by providing a *clear visualisation for twelve users*. *Floor surfaces* both in Regensburg and Göttingen labs are not ideal for projection and have to be considered as well, possibly including photometric compensation and *text sizes* that might be readable even on carpet fibres.

Requirements specific to the sensitive application context include reducing the

Requirement	Priority	Source
Judgement-free, automatic motivation	Essential	Stakeholders
Easy and quick to understand	Essential	Discussion
Don't disrupt flow of conversation	Essential	Stakeholders
Don't distract	Essential	Stakeholders
(Semi-)public display to challenge users	Essential	Stakeholders
Clear layout for twelve participants	Essential	Discussion
Good readability on darker flooring and carpet	Essential	Testing
Text height $\geq$ 9 cm	Essential	Testing
Consistent performance over full duration	Essential	Implicit
Usable for older people	Essential	Stakeholders
No flickering elements	Essential	Stakeholders
No problematic iconography	Essential	Stakeholders
No sense of punishment	Essential	Stakeholders
No intense red or blood-like colour	Essential	Stakeholders
Fast reaction to change of speaker	Practical	Implicit
Subtle Animations	Practical	Stakeholders
50 cm margin to chair legs	Practical	Testing
Blue base colour, orange highlights	Nice-To-Have	Stakeholders

Table 2.: Non-Functional Requirements

risk of epileptic seizures by *eliminating flickering* where possible and *using subtle, slow animations*, if any. *Iconography* and *colours* associated with violence or traumatic experience are as important to avoid as a *sense of punishment* when the system shows a change in participation is needed.

Testing indicated the obstruction of approximately 50 cm of floor by a person's legs when seated, requiring a *margin* around the floor projection area, and adhering to established *identity colours* would be a nice addition.

3.2. Iterative Concept Design

After collecting and ranking the list of requirements, several concepts were developed based on the requirements and designs in related literature. These concepts were then discussed in multiple meetings with two groups—a group of PhD students in psychology and a group of HCI researchers—where they were narrowed down and iterated upon further to establish the final designs for the studies.

The concepts were presented using mock-ups drawn in Inkscape[2], a vector-based

[2]https://inkscape.org/

illustration program. They feature a top-down view of a seating circle and the projected visualisation on the left and each visualisation's states along with its theorised advantages and disadvantages on the top and bottom right, respectively. Participation rates of the twelve users in the illustrations are kept consistent between different concepts to ensure comparability. Please note the focus of these drawings was to communicate the essence of the design and its general proportions rather than ensuring mathematical accuracy.

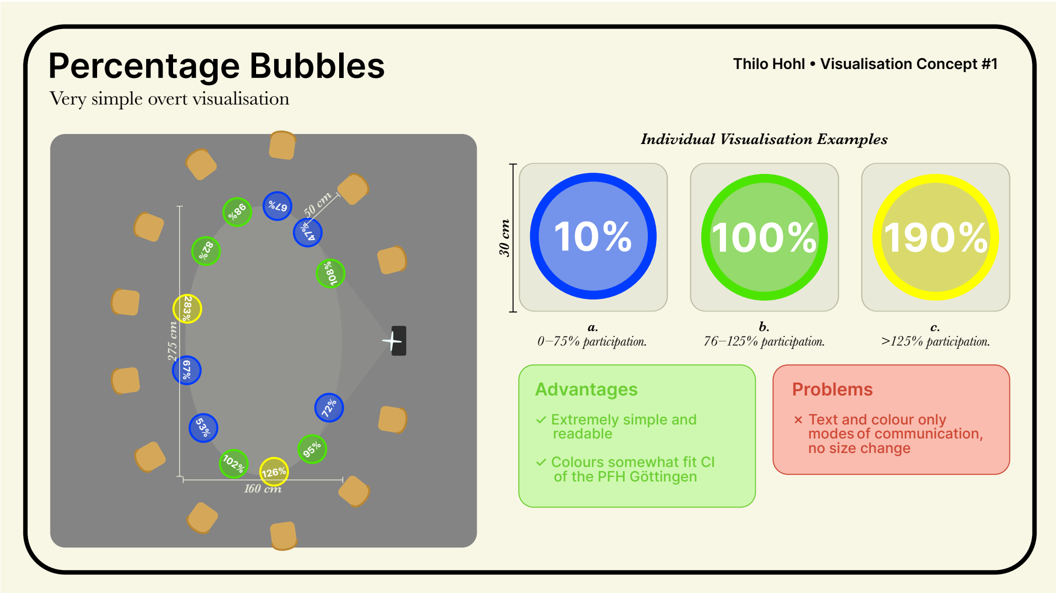

Figure 5: Percentage Bubble Concept

Figure 5 shows a bubble of static size (around 30 cm) to be displayed on the rim of the circle encompassing the usable projection area. The colour of each displayed mirror element changes according to its value, which is a percentage of participation. This is an example of a very overt visualisation, clearly presenting its value in a simple way.

Experts initially expressed concern about changing numbers being too distracting, but were content with full integers, which should not change too frequently. They found the colour scheme to not be very intuitive, but given the limitations of brightness in a projection and the total exclusion of red as an option, it was agreed to be functional.

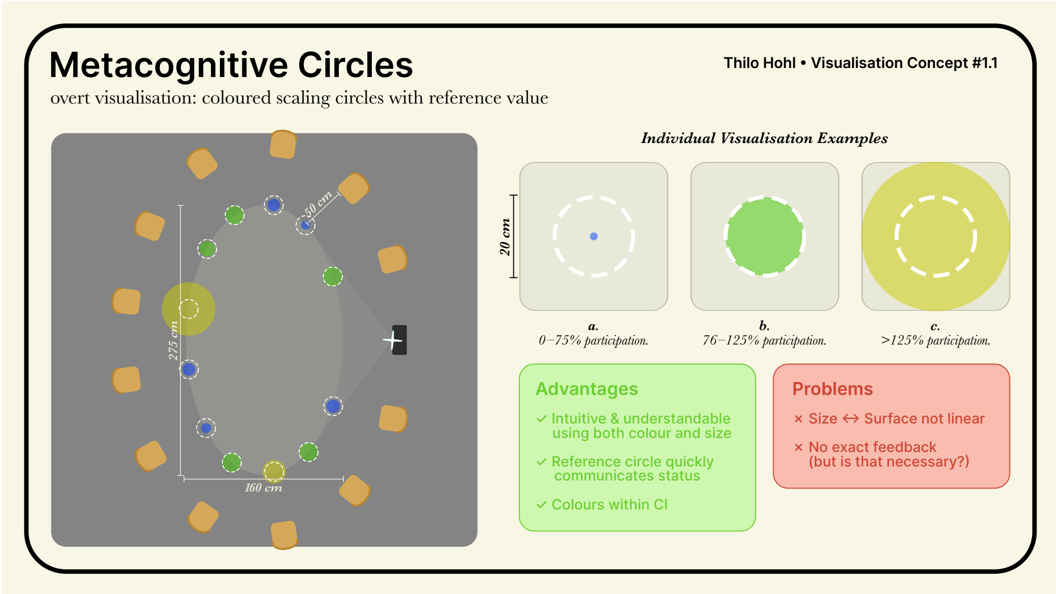

Figure 6: Metacognitive Circles Concept

Concept 1.1 (fig. 6) displays participation as a scaling circle against a reference value clearly marked by a dashed white line. The same colour symbolism as before is used, with blue indicating below-average participation and yellow warning of crossing the threshold. The reference value remains static at the radius of a circle for 100% participation.

This visualisation, though less exact, can be understood intuitively without having to read numbers.

Experts agreed that it had a lot of potential, especially in a situation like an introduction round. Informatics experts also preferred it to the percentage bubbles, making it the first concept accepted to progress onwards into development.

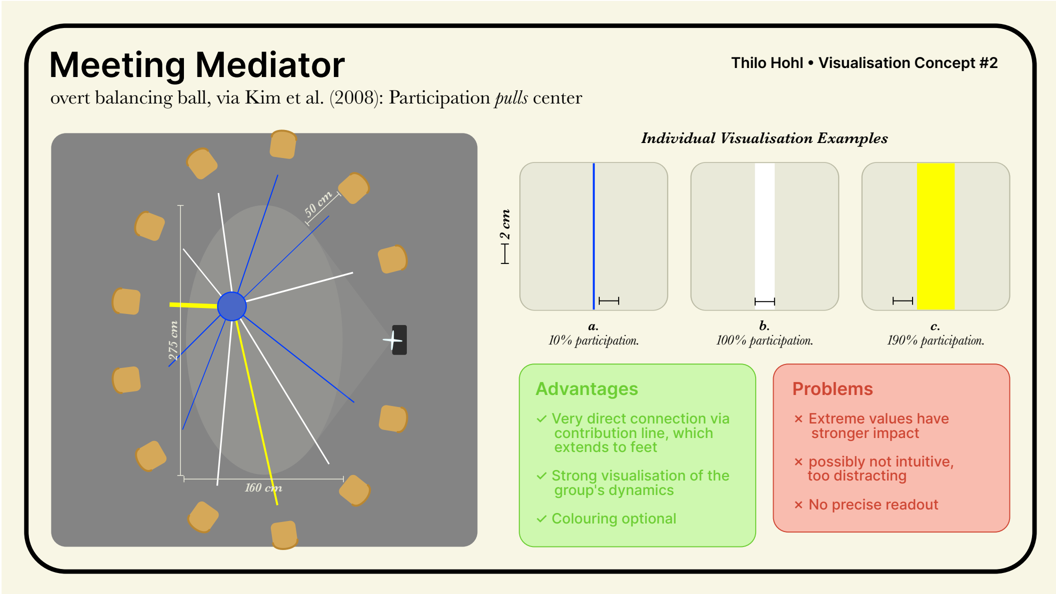

Figure 7: Meeting Mediator Concept

Figure 7 displays an iteration on Kim et al.'s Meeting Mediator, which connects all participant nodes to a central ball whose position is driven by their contribution. Speaking pulls the ball towards the speaker's position. Additionally, line strength and colour communicates amount of participation.

In expert discussions, the psychological character of this visualisation—suggesting people 'pull the conversation towards them'—was lauded. It also promised to indicate group dynamics, and could be altered to focus even more on relations between nodes, similar to a network graph. The concept could also be used as a mini-game, potentially as an ice breaker. However, both groups noted the visualisation was quite cluttered and that extreme values could have too much influence.

This problem is also reflected in the concept illustration, where the two seats anti-clockwise from the over-participator due west still have a very close proximity to the ball despite their lack of participation. The visualisation works more to reflect general group climate rather than exact individual participation and was therefore not developed further.

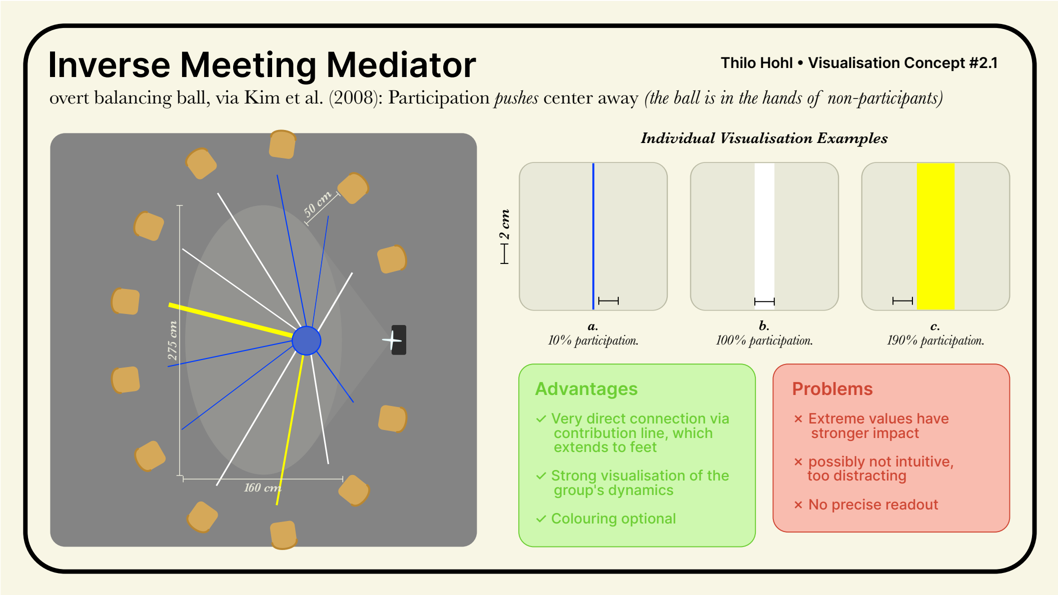

Figure 8: Inverse Meeting Mediator Concept

Figure 8 is simply an inverse of the meeting mediator, causing contribution to push the central ball away from each node. This was intended to suggest 'the ball being in the hands of underparticipators'.

The idea did was rejected considering both the downfalls of its predecessor and because of the implication of 'pushing the other people away' by talking too much, which could be too personal of an image to evoke for users in a therapy setting.

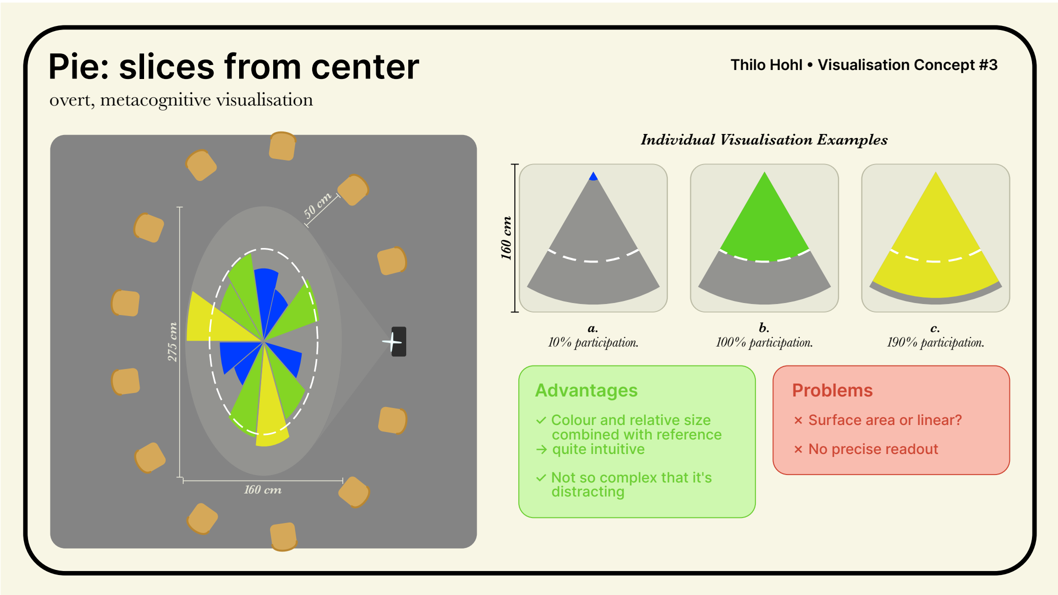

Figure 9: Pie Concept One: Slices from Center

Concept #3 (fig. 9) borrows its base structure from a pie chart, but chooses radius instead of arc length to display participation. The more one participates, the larger the radius of one's individual slice grows. The three-colour legend is used along with a reference circle for the entire group at the 100% radius.

This concept was rated best by both groups of experts, as the shared reference circle invokes a collaborative character while the slices are still easily understandable and assignable. It went on into development.

A psychology expert suggested a task description of "rounding the pizza as a group", which launched a discussion about ways to elaborate on this metaphor, including the addition or removal of condiments and toppings according to the size of the slice. The discussion was halted by the realisation that people facing eating disorders might not take this metaphor too well. It might also be too playful considering the potential topics of conversation in therapy sessions. However, this more colourful, metaphorical rendition of the concept still has potential applications, especially for learning or conversing amongst children.

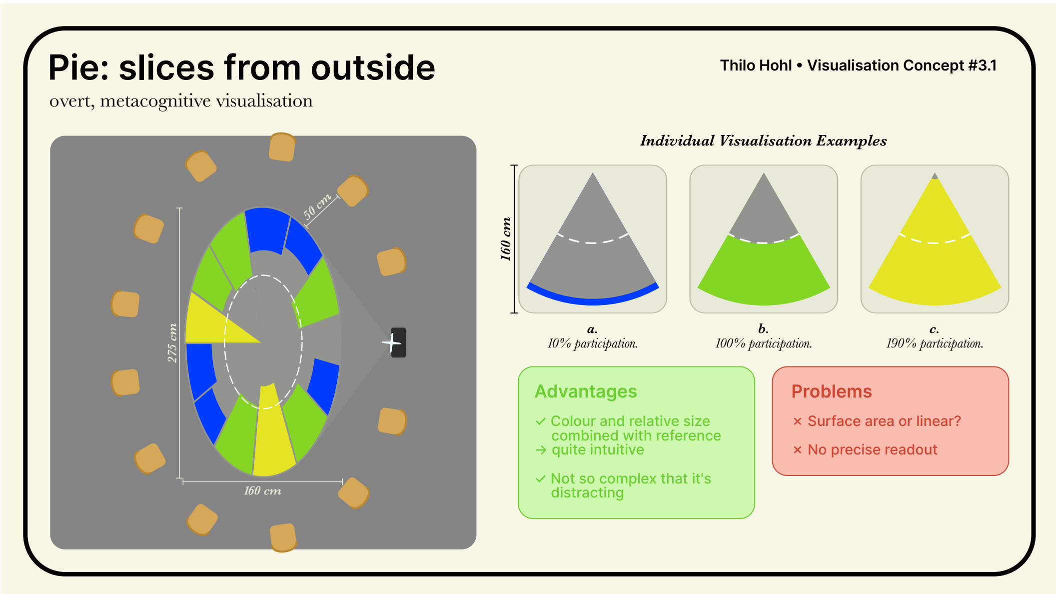

Figure 10: Pie Concept Two: Slices from Outside

The inverse of the center slices (fig. 10) was described as less intuitive. It starts filling the pie from the outside, mismatching lower participation with a wide base and coming to a diminishing point for maximum values. Since its ideal state is drawn outside the shared centre, populating the outer rim potentially obscured by knees or legs, it was deemed worse than its predecessor.

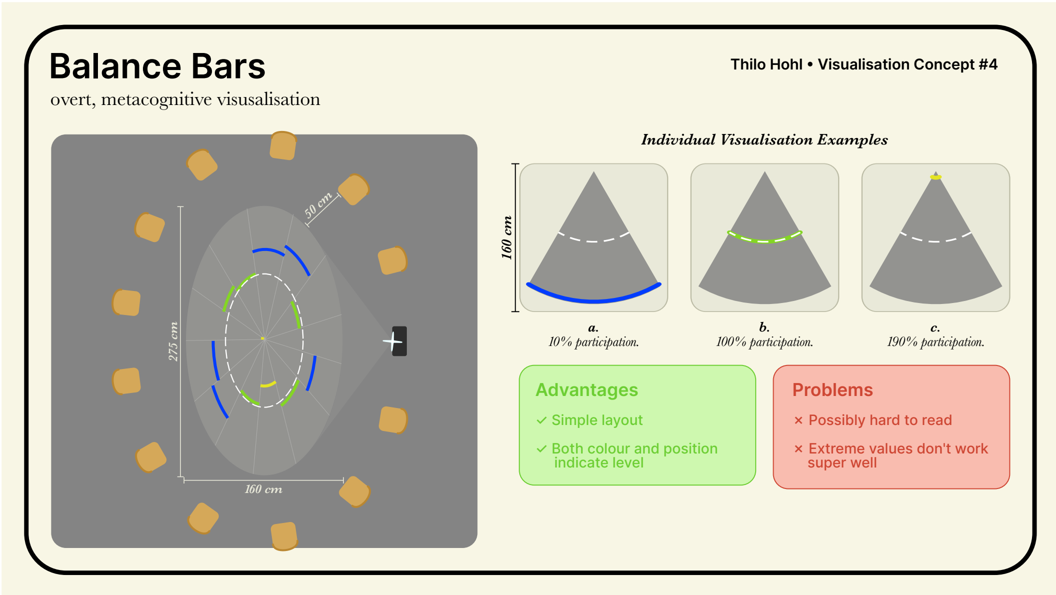

Figure 11: Balance Bars Concept

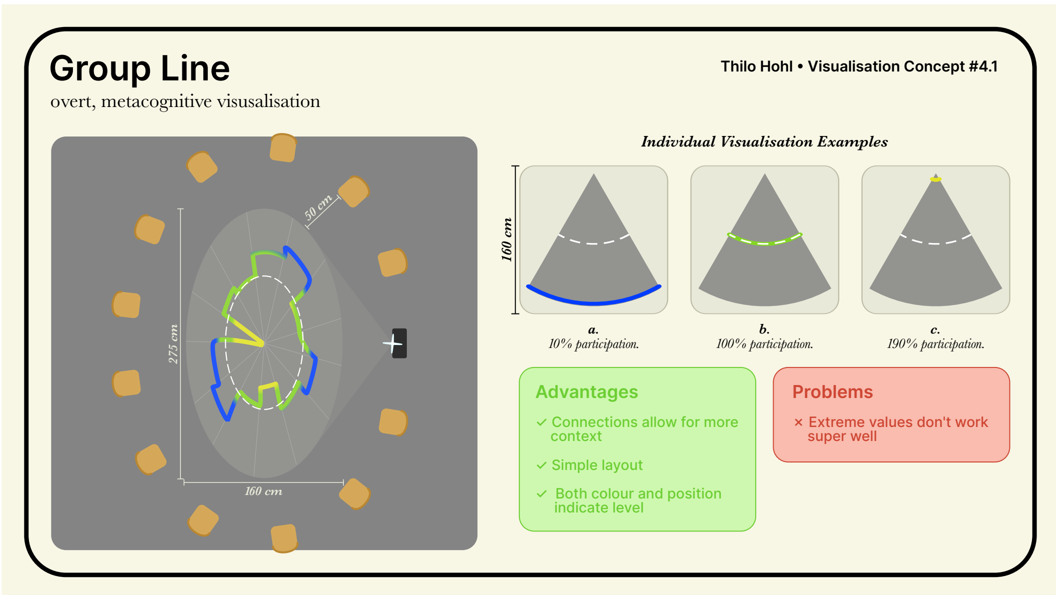

Figure 12: Group Line Concept

By taking just the inner arc of each pie slice, the Balance Bars concept in figure 11 was meant to provide a simpler visualisation. The 'Group Line' (fig. 12) iterated on this idea by connecting the bars and contextualising each users' participation level in relation with their direct neighbours.

In review, these two concepts were described as visually interesting, but not functional, as they were not clear or readable enough. The sense of community in figure 12 was mentioned as a possible advantage, but flipping the minima and maxima (i.e. drawing low levels *close to the center* and high levels towards the rim) was recommended for a more understandable illustration.

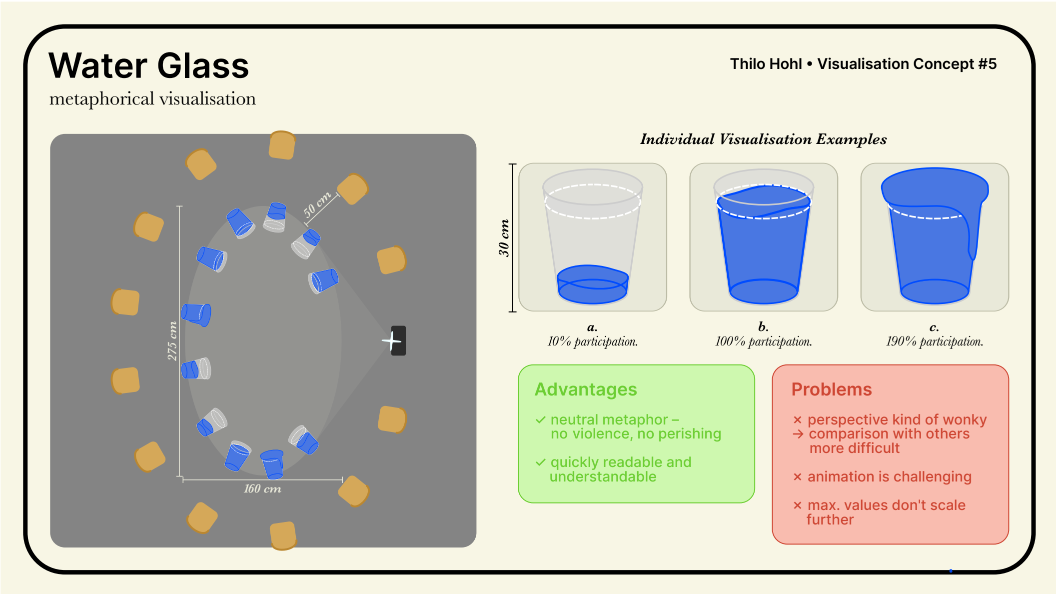

Figure 13: Water Glass Concept

An attempt at a purely metaphorical visualisation did not fare well due to limitations posed by the application context. Excluding topics like food, decay (ruling out growth and shrivelling of a plant, as used in Tausch et al. (2014)) and potential trauma triggers like flames resulted in the metaphor of a glass filling with water, which would be fine for individual, private displays, but was not feasible in a multi-perspective projection for a large number of participants and also lacked the quick readability of other approaches.

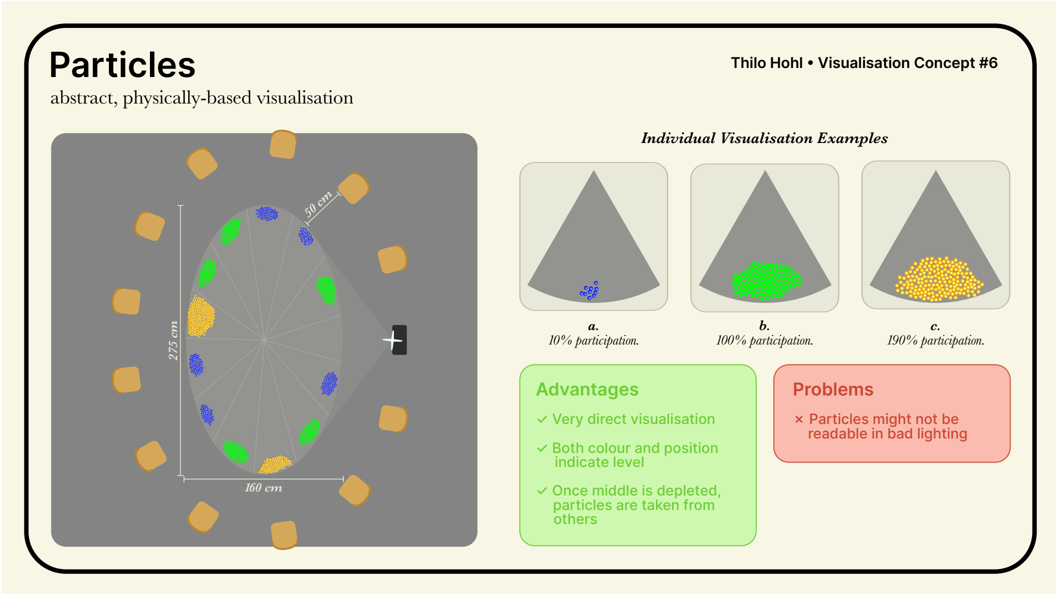

Figure 14: Particles Concept: Description

During the review with HCI researchers, they suggested a particle-based visualisation with limited, moving particles representing participation.

This idea was then conceptualised with two states (see fig. 15). Firstly, an initial mass of particles in the center of the circle, where utterances attract a number of particles towards a person's sector, grouped around a fixed point to their feet. In an advanced state, once the center mass has been fully distributed, statements would *take* particles from other users, therefore either balancing or increasing the disparity between speakers.

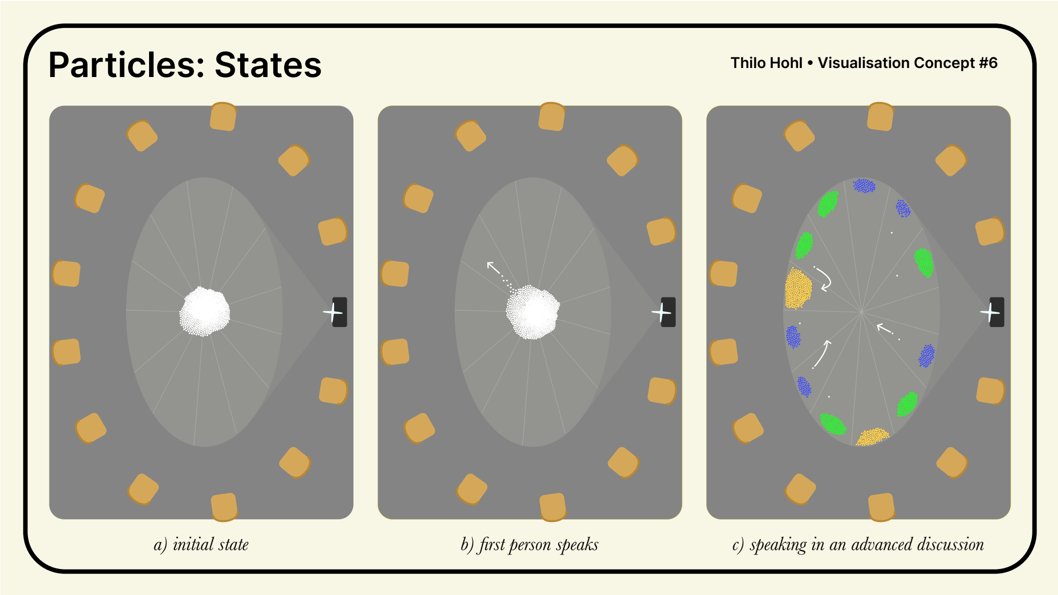

Figure 15: Particles Concept: Different states

The concept was then demonstrated to the psychology department, where an expert commented on its metaphorical value and comparing it in character to a psychological intervention by emphasising the act of "taking a resource—talking time—away from another person", which, according to them, "touched on the subject of depth psychology". It was therefore also accepted into the next phase of development.

After this round of discussion, with all the concepts narrowed down to three, implementation of the system could begin.

4. Implementation

To provide live feedback during a group therapy session, the application *mirror-level* was built using python with Flask to provide routing and a front end using JavaScript in a browser, utilising D3.js to draw on an HTML canvas.

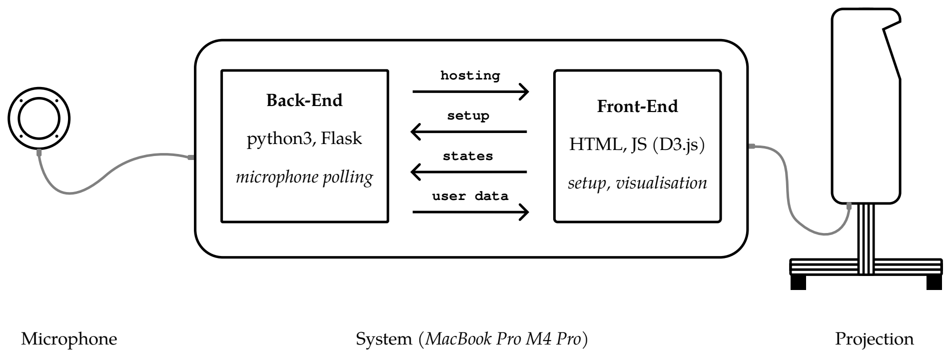

Figure 16: Input, Processing and Output Diagram of *levelmirror*

4.1. Back End

4.1.1. Speech Localisation

The localisation of audio signals to accurately identify the speaker is a core component of the feedback system. To correctly measure speech participation, Maierhöfer and Kilger utilised four separate USB Microphones, one for each participant. Although a similar setup would have been technically feasible by acquiring more microphones and using a multi-channel mixing console, it would have been rather expensive. Therefore, a more out-of-the-box solution was considered by using a far-field four-microphone-array[3] which promised to return the degree of arrival (DOA) for measured signals automatically. This setup would also be less intrusive and

[3] ReSpeaker USB Mic Array from seeedstudio.com

technically challenging by replacing large microphones on stands or arms or multiple wired clip-on microphones with merely the single puck-like microphone centred on the floor.

```
if __name__ == "__main__":
    flaskThread = threading.Thread(target=runFlask, ...)
    flaskThread.start()

    pixel_ring = PixelRing(dev)
    pixel_ring.off() # disable LED

    MicTuning.set_vad_threshold(3.5)
    MicTuning.write("AGCGAIN", 0.0)

    speechDetection() # enter main detection loop
```

Python3

Figure 17: Startup function of the speechdetection.py script

A python3 back end initialises the microphone connection via USB and uses the 'Tuning' module provided by the manufacturer[4] to immediately set the volume threshold values for voice activation, disable automatic gain control (ACG) and turn the LED status ring off[5]. The volume threshold is set at 3.5dB as opposed to the default value of 6.5. This was changed after preliminary tests showed difficulty in detecting lower voices. ACG is disabled to prevent fluctuations in measurement levels and reduce processing overhead. The microphone has a ring of twelve LEDs embedded in its top face and uses them to indicate the direction a signal is coming from in its factory configuration. This indication reacts immediately to a person speaking, which is counterproductive in our strategy to only refresh the visualisation once a sentence is finished. It also draws unnecessary attention to the microphone, which is not a source of information for the user.

A processing thread is dedicated to the Flask server exclusively while *speechDetection*() handles microphone input and transforms the raw data into a user list available in JSON format. Then, the script listens for calls on the API endpoints, which

[4]https://github.com/respeaker/usb_4_mic_array.git
[5]https://github.com/respeaker/pixel_ring.git

trigger different functions.

```
json_list = {
 0: {
  "uid": 0,
  "deg": 267,
  "speaking_time": 128.34
 },
 1: {
  "uid": 1,
  "deg": 298,
  "speaking_time": 93.22
 }, ...
```

Python3

Figure 18: Exemplary snippet demonstrating the structure of the user list

Next to some basic endpoints serving HTML and CSS as well as exposing the current participation distribution stored in `json_list[]` to `/data`, four routes are triggered via AJAX in the front end to:

getAngleForUser If not already present, create a new item in the json_list with the `uid` sent with the request, then listen for a set duration (`GET_ANGLE_DUR`, 10 s) and save the mode of the angle returned by the microphone to `json_list[uid]["deg"]`.

setRecording Set the global variable `detectSpeech` to a given boolean sent in the request and then either write a header for a new .csv file or increment the number of recordings, depending on the boolean value.

resetTime Set the `speaking_time` for all users to a value sent with the request. For debugging purposes.

resetList Empty the `json_list` of all users.

Setting up the angle for each user is a vital step which needs to be run for each person in a group that uses the system. It can be integrated organically, using i.e. an introduction round. During this time, it is imperative that the primary sound source is the person we're setting up at the moment. In the supplementary function `getAngle()`, the microphone direction is polled and added to a list. Then, after ten seconds have elapsed, the mode of the angles in the list is saved. This angle is used as a baseline all incoming sounds are compared against during speech detection. The mode is used since it is a more solid foundation than the average, which would be influenced by disturbances in the calibration process.

Just compare these measures in a hypothetical setup phase, where a person is sitting and talking from 280° for most of the time, but a sustained car horn sounds at some point from 4° relative to the microphone. This might result in a final measured mean angle of

$$\mu_\alpha = \frac{(280° \times 9s) + (4° \times 1s)}{10s} = 252.4°$$

for our user, which is too far a departure given that in the case of twelve participants, each of them only has an arc of 30° for themselves *at most*. The mode, however, simply returning the number most frequent in the sample, would give the correct result here. Additionally, averaging directional data would also be problematic close to the crossover point from 360° to 1°.

Once `detectSpeech` is set to `true`, we enter the main loop inside of the function `speechDetection()`. The tool, as it is, only measures one person's speech at a time, receiving a single DOA value from the microphone and comparing it to the saved angles. To count towards a persons `speaking_time`, a signal from their angular span has to be sustained for at least 0.3 s. Then, it is recorded and gets saved as an utterance as soon as a break longer than 0.7 s is detected or the initial speaker is interrupted by sounds from another source. This way, `speaking_time` values don't change continuously, but are only updated once an utterance is completed, in accordance with the recommendations proposed by Maierhöfer and Kilger.

After an utterance is completed, the `speaking_time` is updated in `json_list[]` and a row containing the current timestamp and each users' speech durations is appended to the .csv file created at the start of the recording. The file is saved under `recordings/rec_dd-mm-YYYY_HH-MM-SS_ID.csv` each time it is modified, with the ID being an integer incremented for every recording in a session.

4.1.2. Microphone Validation

To validate the accuracy of the system, an audio file was generated using the free AI Text-to-Speech-Engine ElevenLabs[6]. It contained two voices, one male and one female, exchanging lines of text. Using the free and open-source audio editing software Audacity[7], length of utterance, time between utterances and order of speaker were varied. Short and long statements were each played 0.5 s and 3.0 s apart (with 5 seconds between trials) and repeated with the speaker order flipped (see fig. 19).

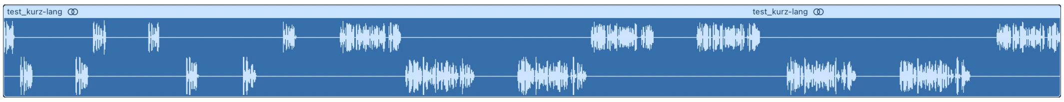

Figure 19: Waveform of Test Audio File.

The voices were panned to 100% left and right, respectively, to be played by one side of a stereo desktop speaker set. These speakers were then set up on opposite ends of the microphone (approx. 40 cm between speaker and microphone), their user position calibrated, and the audio file played.

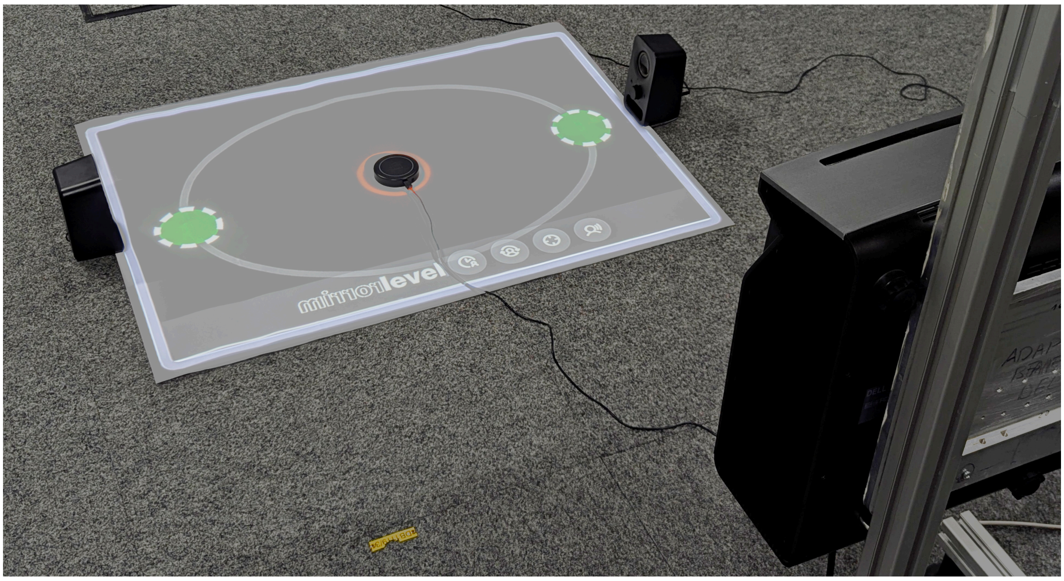

Figure 20: Test setup, with projection superimposed to help visibility.

In five trial runs, the back end measured participation for both users. The results of these measurements can be seen in figure 22. Ground Truth is displayed on the

[6]https://elevenlabs.io/
[7]https://www.audacityteam.org/

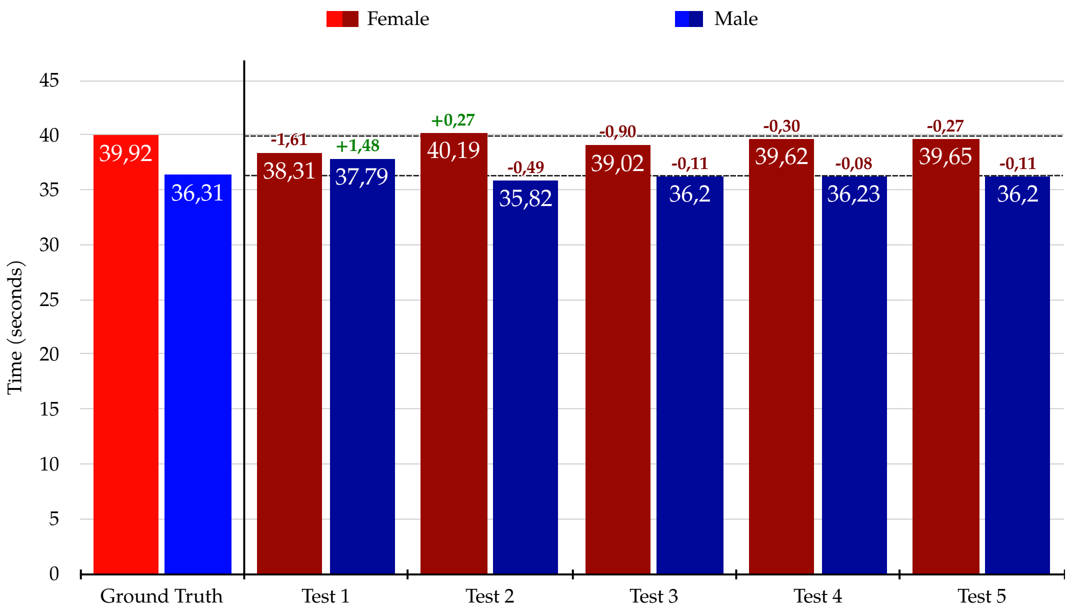

Figure 21: Ground Truth and measured participation in five trials.

left, while different trials are listed on the right. The two black dotted lines show the original value for each speaker. Compared to the original duration of 39.92 seconds (female voice) and 36.31 s (male voice), the worst of the test trials, test 1, had just 4.03% (1.61 s) deviation from Ground Truth. In each trial, the correct person had the higher measured participation, representing the balance truthfully.

4.2. Front End

4.2.1. Floor Projection

In accordance with the requirements, the display needed to be integrated in a seating circle of up to twelve chairs. Notably, there are no tables in the therapy sessions described by the stakeholders, as they are not required for activities and would serve as opportunities to hide behind. According to the stakeholders, a certain feeling of exposure can be beneficial in the context of group therapy.

A natural solution which makes use of the empty space between the participants would be floor projection. Compared to projecting on walls or screens, a floor-projected visualisation does not require multiple synchronised displays and lies within the natural periphery when sitting in a circle around it.

Figure 22: Projector on its mounting rig.

To display an adequately-sized area on the floor, a DELL S718QL short-throw projector was mounted to a machined aluminum plate suspended on a rig of 40×40 mm aluminum extrusion. To increase height and therefore projection area, four adjustable feet were added to the pre-existing construction, also allowing the unit to be levelled. The rig measured 113 cm in height, with the projector lens being 72 cm from the ground. Depth between the outer edges of the feet was measured at 32 cm and width for the rig at 35 cm, which is surpassed by the projector at 46 cm. The resulting projection area measured approximately 218×383 cm.

This approach requires a readable design which could tolerate different surface colours and textures, as there is large variety in floor finishes. Sub-optimally, both the laboratory of the media informatics chair and the group therapy room in Göttingen have dark-coloured carpeted floors, which diffuse light and pose difficulty in reading projected text. Even though contrast, size, and readability had been maximised during implementation, a roll of paper was used on the floor to ensure a smooth surface to project onto for both studies, as seen in figures 35 and 36.

Figure 23: Projection tests showing the need for a safe margin.

Initial tests also demonstrated that an area of approximately 50 cm in front of a seated person could be occluded by legs, establishing a margin around the safe area of projection.

4.2.2. Visualisations

After the concepts were developed and ranked by both teams of experts, implementation could begin. At first, using a game engine had been considered, which could handle different states of metaphoric animations, but since the concepts only consisted of different shapes which had to be transformed or scaled, simpler tools could be considered. It was decided to use a web-based application as support for JavaScript is nearly universal and required no installation.

D3.js, an open-source JavaScript library used primarily for interactive data visualisations[8], was a great candidate, supporting animations and force interactions, which would be especially useful for the particle concept.

Owing to the concurrent development work on visualisation and speech detec-

[8]d3js.org, used under ISC License

tion, the front end was initially implemented using generated dummy data. At first, the circles visualisation was realised. Then, the connection between back and front end was made. Logic for dynamically placing users and calibrating them was added and slices and particles followed, building on the functionality established for the circles. Finally, several smaller elements were polished and implemented prior to testing, including the ability to ignore the moderator, checks for state transitions and a blank mode to allow for rounds without visualisation to also use the speech detection seamlessly. Throughout the development process, the project was backed up to a GitHub repository intermittently. For some calculation logic, the LLM Claude by Anthropic[9] was used. Direct integration of generated code as well as modified usage are marked in the source code. The majority of these generated functions were taken as a starting point and then tested and adjusted further by hand.

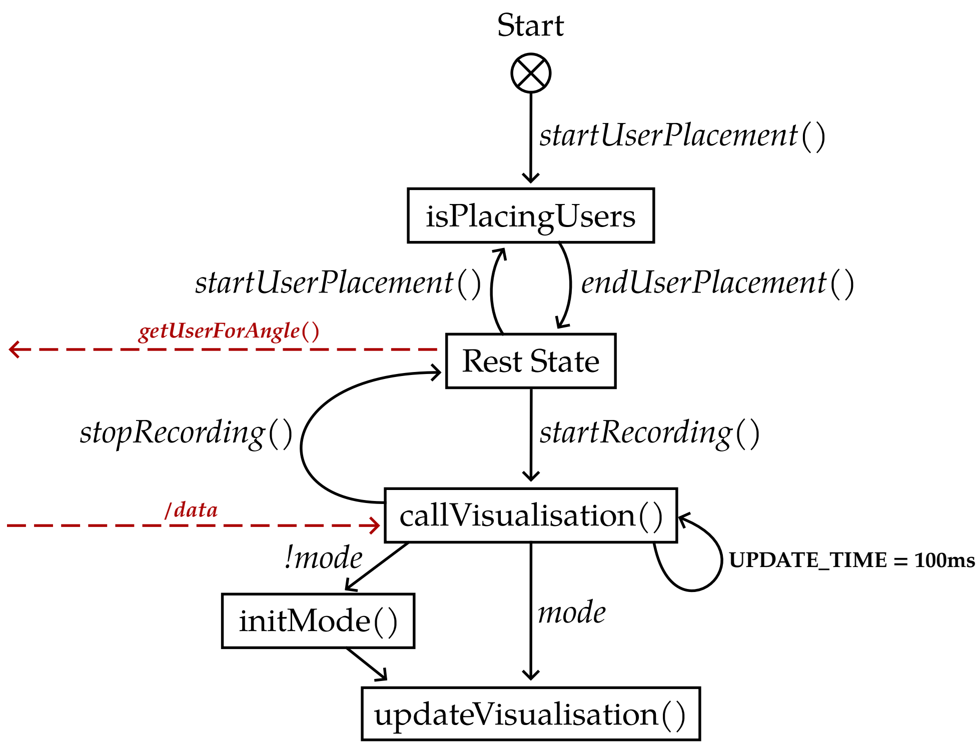

Figure 24: State diagram illustrating front-end workflow.

A simplified final core usage loop is illustrated in fig. 24. When starting the front end, a circle with the diameter of $\frac{8}{10}$ of the available width and height is drawn.

[9]https://claude.ai/

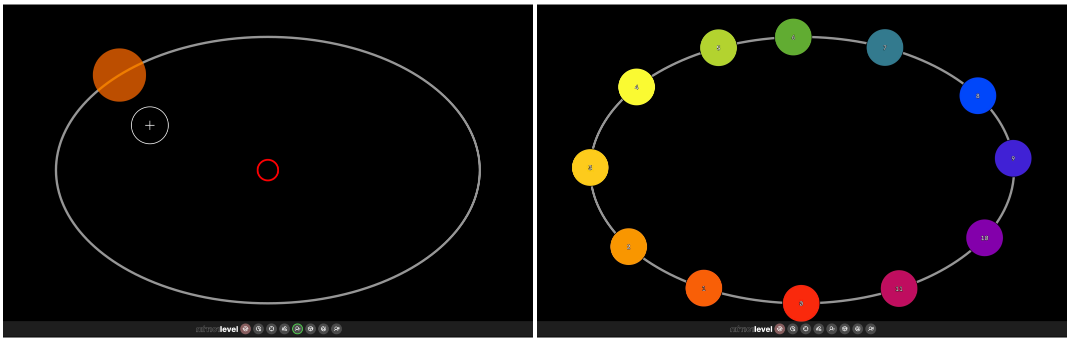

Figure 25: *Left:* user placement, *Right:* resting state modes.

Within this circle, the visualisations are later placed, so it is considered the "safe space" of the projection.

Initially, user placement is activated, indicated by replacing the cursor with a crosshair and drawing an orange circle closest to the mouse position along the radius of the safe space (see fig. 25). In this mode, the position of each user of the system is set and drawn as a small coloured circle with their uid. If a moderator is to be ignored, they need to be set as the first user (uid 0) and the according option toggled. Along with the safe space, mouse cursor and user positions, a small red circle is displayed in the centre to indicate the position where the microphone should be placed.

After finishing user placement, the mouse cursor changes back to default and both the microphone and placement hints disappear. In the resting state, user positions must be calibrated for the back end. Clicking one of the user position circles sends a request to get the angle for the given uid, using the process described in section 4.1.1. Proceeding to the recording state is only possible if all placed users are assigned an angle in this manner.

To record speech participation, a visualisation mode must be selected. Per default, mode blank is pre-selected, but this can be changed in the rest state. Once started, a visualisation is updated every 100 ms. At first, the geometry for visualisation modes is initialised with the according function. From then on, during a recording, `callVisualisation()` triggers the function `updateVisualisation()`, which fetches the current speech distribution from `/data` and transforms the visualisation accordingly.

```javascript
// Buffer so that first to speak is not punished with a
// NUM_P * 100% bubble; instead,
// linear growth towards MIN_SPEAKING/NUM_P
if (totalSpeakingTime < MIN_SPEAKING * 60) {
  totalSpeakingTime = MIN_SPEAKING * 60;
}

// Calculate number of participants for average
// (exclude uid 0 if countZero is true)
const participantCount = countZero ? NUM_P - 1 : NUM_P;
```
JavaScript

Figure 26: Speaking time handling in update function

The participation percentage of each person is calculated against the total speaking time, not the total time elapsed. At first, however, the total speaking time is set to a fixed value to prevent the first speaker's visualisation from ballooning to $n_{\text{users}} \times 100\%$. That way, instead of punishing the first out of a dozen to speak for two seconds by immediately drawing a 1200% speech bubble, the group first has to reach a speaking duration of 120 s total before the actual total speaking time is compared against. If the moderator is to be ignored, a flag in each mode's update function subtracts the speaking time of user 0 from the total speaking time. The position for user 0 is then drawn as an empty element of the current visualisation.

Circles Visualisation

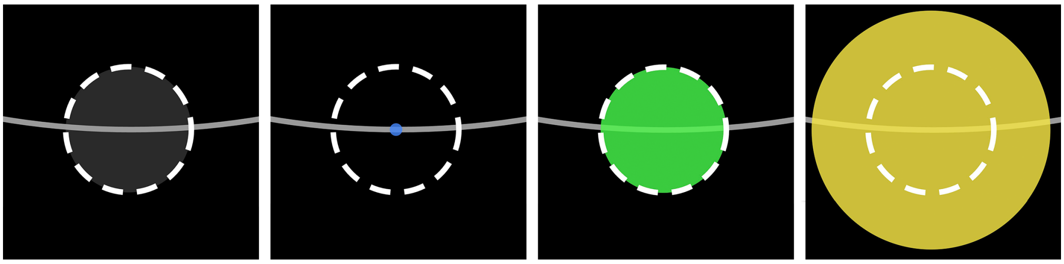

Figure 27: *Circles* for: ignored moderator, 10%, 100%, and 190% participation

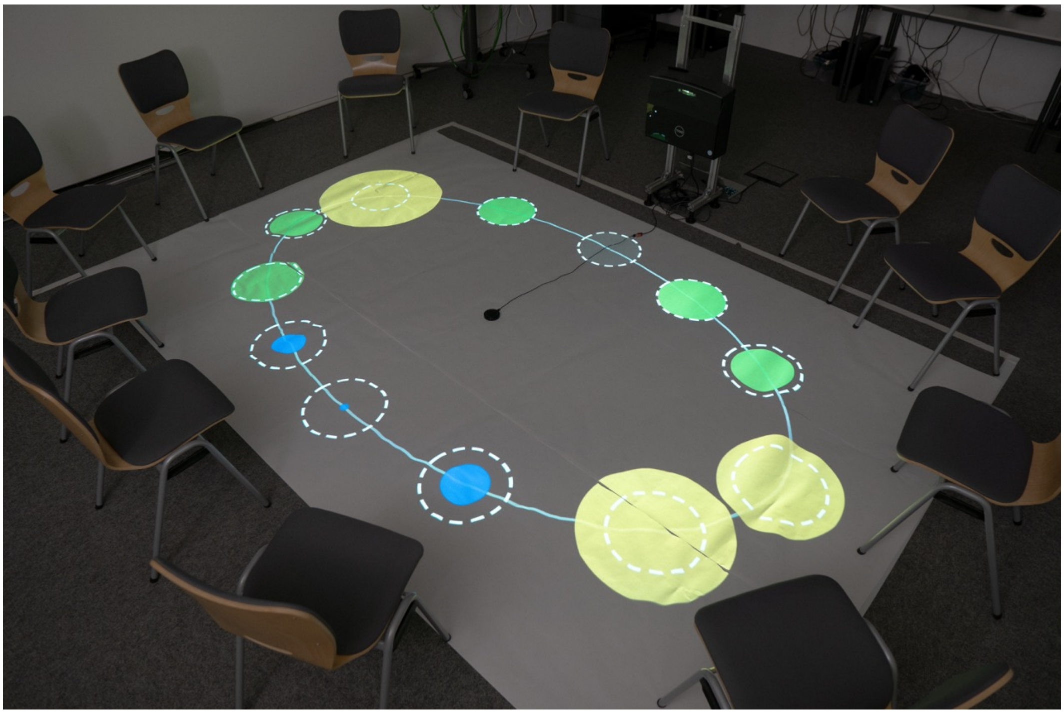

Figure 28: Example distribution visualised with *circles*, photograph

In the *circles* visualisation, each user is represented by a circle on the rim of the safe space. The radius of their circle scales according to the percentage of a person's `speaking_time` against the total speaking time. The base circle radius is set as 8% of the smaller of both size dimensions (width and height). This ensures consistent size across different resolutions. In the real projection with approximate dimensions of 218×383 cm, seen in fig. 28, the base circle measures in at a diameter of approx. 36 cm. To represent a person's participation, the base circle radius is multiplied with a scale factor, the ratio of the persons speaking time to ideal speaking time, which is the current total time divided by the number of people (possibly excluding user 0). The radius is capped at a minimum of 5% of the base circle radius (or, 0.4% of the total height, meaning the smallest possible circle in our projection would be 1.8 cm across) to ensure that a circle is still drawn even with little or no speaking time in order to signal to the user that they are recognised by the system.

$$scale\_factor = \frac{speaking\_time}{total\_speaking\_time \times \frac{1}{N}}$$

Placed concentrically with each users' circle is the dashed white outline of the reference circle, which marks 100% participation. This metacognitive hint is on a higher z-index than the changing circle and is therefore always visible. In accordance with the requirement, the colour red was avoided, and instead, blue and yellow warn users if they diverge more than 25% from the ideal percentage. Like all other visualisations, data for *circles* is fetched every 100 ms, but scale and colour changes are smoothly animated over a duration of 400 ms to ease transitions and not draw too much attention.

Slices Visualisation

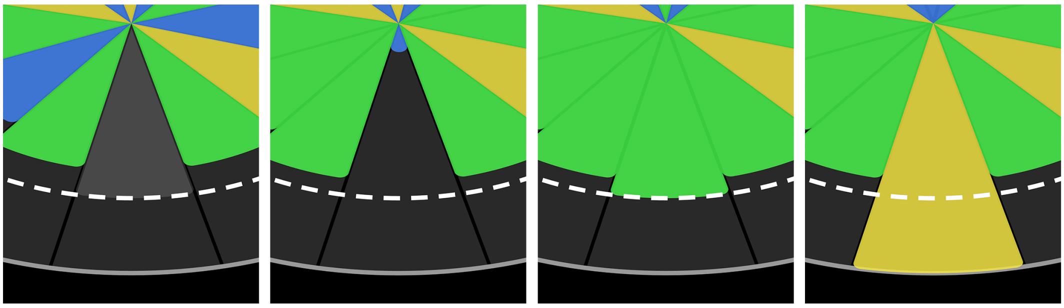

Figure 29: *Slices* for: ignored moderator, 10%, 100%, and 190% participation

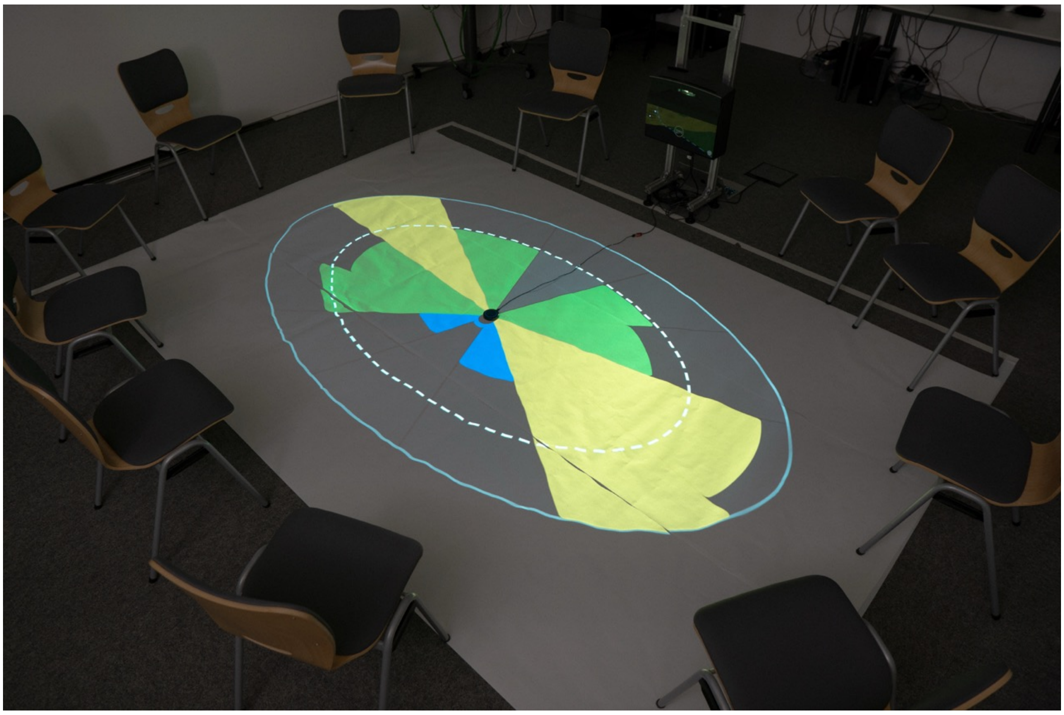

Figure 30: Example distribution visualised with *slices*, photograph

Like in *circles*, the basic idea of *slices* was to colour and scale different slices of a pie according to participation. Since all slices are then part of one circle, it was logical to have the reference line also be a circle at a set radius of that total circle. The `REFERENCE_LINE_RATIO` was set at 70% of the safe space, where the dashed line is drawn. The boundary of the safe space served as the upper limit for a slice's radius. So, compared to the scaled radius with lower boundary for the circles, the slices were drawn between a minimum and a maximum radius and had their ideal fixed at 70% between center and outer line.

This implementation effectively loses detail at the top range, which was accepted as a compromise—the difference between 190% and 220% participation appeared negligible, since both were clearly above the ideal value.

```javascript
// Calculate angle spans for each user based on
// adjacent users
sortedUsers.forEach((user, i) => {
  nextUser = sortedUsers[(i + 1) %  sortedUsers.length];
  prevIndex = (i - 1 + sortedUsers.length) % sortedUsers.length;
  previousUser = sortedUsers[prevIndex];

  angleForward = nextUser.angle - user.angle;
  if (angleForward < 0) angleForward += 2 * Math.PI;

  angleBackward = user.angle - previousUser.angle;
  if (angleBackward < 0) angleBackward += 2 * Math.PI;

  user.startAngle = user.angle - angleBackward / 2 + Math.PI / 2;
  user.endAngle = user.angle + angleForward / 2 + Math.PI / 2;
  user.angleSpan = angleForward / 2 + angleBackward / 2;
  user.speaking_time = 0;
});
```

JavaScript

Figure 31: Slice arcs calculated in *initSlices*()

The position of each slice is drawn so that the coordinates where users had been placed are at the center of the slice's arc. Since users might not be sitting at even gaps, the boundaries between slices are calculated using the midpoint of the user position angles. For each user, the halfway point between their and the previous user's angle and the halfway point between their and the next user's angle are calculated and an arc is drawn between those two points (see code example 31). This modified d3.js pie chart is then transformed to the ratio of the entire canvas. Since the projection area is not perfectly square, but at an aspect ratio of 16:9, this visualisation is the least precise of the three, with user arc lengths in the example (fig. 30) varying between 60 and 64 cm and the distance from the pie's center to the reference line ranging from 86 to 155 cm. To ensure differentiation between adjacent slices, the areas representing participation are slightly transparent and lie above a segmented background with clear lines separating each users' total area, as can be seen in figure 29.

Particles Visualisation

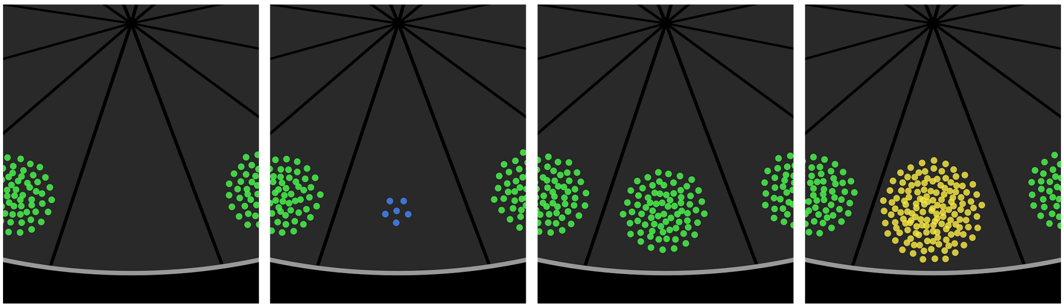

Figure 32: *Particles* for: ignored moderator, 10%, 100%, and 190% participation

The *particles* also inherit the colour symbolism, but instead of resizing, are limited in number, set at 75 per user. At the beginning of a recording, if no speaking_times are set, all particles are coloured grey and gather in the middle by means of d3.js forces. Particles are initialised with four forces acting upon them: a `forceX` and a `forceY` drawing them to the coordinates of their current `owner`—which is either one of the users placed down, or the center—as well as a "collide" force, which allows self-collision of particles, and a "boundary" force, which keeps the particles inside of the safe space. Both the boundary and the user placement positions are set in slightly when compared to the *circle* coordinates, and like in *slices*, an area is drawn in the background, creating a sense of one's own territory.

On an update, for all users, an integer of required particles is calculated. Then, the difference of a user's current and target particles is taken and particles are distributed, first from the center, or, if there are none left, from other users who have an excess of particles. The particles are taken in proportion in order to have an equal distribution. Then, updated X and Y forces are applied to particles, guiding them towards their new owners.

Since there is no reference values drawn, this visualisation is technically not *meta-cognitive* as per Tausch's design space definition. However, like in *Meeting Mediator*, there is still a strong sense of ideal equality indicated by a shared resource and the movement between all users.

Particles are all equal in size with a diameter of approximately 2 cm. A grouping of 75 particles, indicating adequate participation, spans 23 cm across.

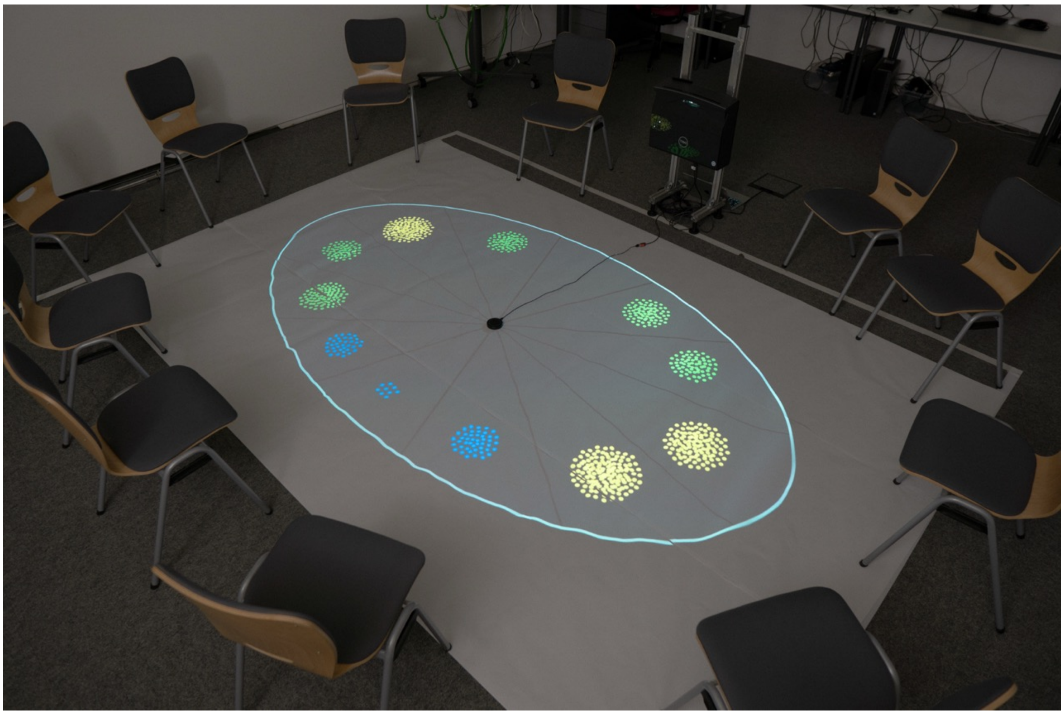

Figure 33: Example distribution visualised with *particles*, photograph

During development, the visualisations were tested for durations over 20 minutes each. Performance was measured at a consistent 120 frames per second for *circles* and *slices* and a minimum of 80 frames per second for *particles*, surpassing the refresh rate of the final projection at 60 Hz.

4.2.3. Control Interface

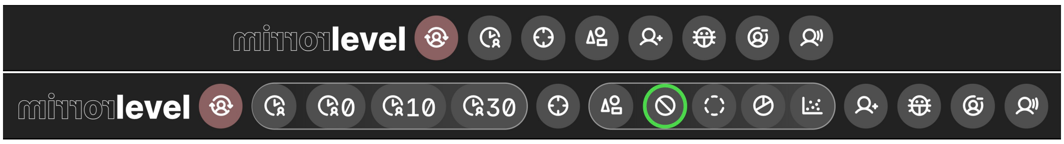

Figure 34: Collapsed and expanded toolbar of *mirrorlevel*

The control interface (see fig. 34) for the front end is drawn at the bottom of the screen and can be hidden using ‘H’ on the keyboard. It contains (left-to-right), indicated by icons from phosphor-icons[10]:

Reset toggle. Clicking this and confirming the alert it triggers stops the recording, sends a POST Request to the /resetList endpoint, where the list is cleared.

[10]https://github.com/phosphor-icons/homepage, used under MIT License.

Then, the webpage is reloaded, triggering a restart of the front end.

Time resets. This expanding group of buttons enables setting all users' speaking time to a fixed value (options 0, 10 and 30 seconds), which can be used for multiple rounds of discussion with the same people and to debug.

Microphone position. While the microphone's position is displayed in the user positioning screen, it can also be shown at any time using this button to account for accidental movement.

Visualisation modes. This expanding group of buttons enables selecting the different visualisation modes, blank, circles, slices, and particles. Clicking one of these buttons sets a global variable that is polled once a new recording starts.

User positioning. This initially active button starts and stops the user positioning mode. Also available on keyboard E.

Debug text. Shows or hides text for each visualisation displaying uuid and current speaking time in seconds. In the particles visualisation, the count of particles is also displayed.

Moderator exclusion. Toggles whether user 0's speaking time is included in the visualisation or not.

Start/Stop Recording. This toggles whether a selected visualisation is running or not and sends a message to the /setRecording Endpoint, handling the measurement loop and CSV/audio recording. Only functional if all placed users have been assigned a microphone section. Also available on keyboard L.

This interface was developed to help in debugging visualisations and conducting studies and is therefore not especially communicative or at all helpful for uninitiated users. Developing a more capable, intuitive and deeper user interface would be recommended in a final released application. It would also be useful to detach the UI from the visualisation window in order to supervise and control from a secondary display.

5. Method

To compare the three different visualisations and get an insight into the effectiveness of the system, two studies were conducted: firstly, a group therapy simulation moderated by an expert, and secondly, a group discussion and focus group to gain further qualitative feedback.

5.1. Apparatus

The application was run on an Apple Macbook Pro computer (M4 Pro 14-core processor with 20-core GPU, 24 GB RAM) receiving input from a Seeedstudio ReSpeaker Four-Microphone Array and outputting to a DELL S718QL projector at a spatial resolution of 2560×1440px and a temporal resolution of 60 Hz.

5.2. Measures

After a modified informed consent sheet generated using Schwind et al.'s online tool[11] including an statement warning against possible epileptic triggers was signed, participants filled out a demographic questionnaire with items regarding age, gender, occupation, and presence of uncorrected vision impairment.

Then, subsequent to each round, a likert questionnaire was provided with questions regarding group harmony and (in rounds featuring visualisations) visualisation understanding, feeling of accuracy, distraction and impact on participation.

A log of each round was automatically generated by the back end. Additionally, video and audio backups were recorded on an external camera, a Sony α6300.

[11] https://hci-studies.org/informed-consent-generator/

5.3. Study 1: Application-Related evaluation with psychology students

Figure 35: Setup for study 1.

At the psychology department of Private Fachhochschule Göttingen, the first study was conducted in the regular time slot for a lecture of first-semester psychology students. It was moderated by the course instructor, a psychology PhD student who has also held group therapy sessions before during her ongoing training to become a psychotherapist. The 15 students in attendance were divided into two groups of seven and eight and then took part in a mock group therapy session with selected neutral topics: values and goals. Participants were instructed, as real patients would also be, about the purpose of the system (to display their levels of participation) and the meaning of the three colours. Then, the moderator, who was excluded from the visualisation, started the introductory round, where each student reported their name, age, job experience and a favourite topic of theirs, while the developer calibrated the system. The sessions lasted between 10–15 minutes each.

The first two sessions (conditions BLANK and CIRCLES) were held in group one, consisting of 7 students, 6 of whom identified as female, 1 male. Their age ranged from 19 to 25 with a mean M_{Age} of 20.71 and a standard deviation SD_{Age} = 2.06. None of the students reported any uncorrected vision impairments or history of epileptic sensitivity.

The third and fourth sessions (SLICES and PARTICLES) were held with group two, consisting of 8 female students, aged 18 to 24, M_{Age} = 20.50, SD_{Age} = 2.00. Two students reported uncorrected vision impairment.

Between sessions, questionnaires were filled out, and after changing groups, the system was calibrated again. Students were compensated for their voluntary participation by receiving 2 out of 30 study credits which have to be collected throughout their degree.

5.4. Study 2: Group discussion evaluation with informatics students

Figure 36: Setup for study 2.

A second study was conducted at the University of Regensburg. Participants were recruited using the university's study participation platform and advertising in several informatics lectures. Students were rewarded with 2 of 15 participation credits, which they need to collect as one of the requirements to complete the Bachelor's degree.

A group of 8 students, 3 female, 5 male, participated in the study. Their age ranged from 21 to 28 (M_{Age} = 23.50, SD_{Age} = 2.56). All students were enrolled in Bachelor's or Master's degrees in either media informatics or data science.

The students were instructed to sit in a circle and discuss given topics freely without moderation. The topics chosen, similar to the study by Maierhöfer & Kilger (2024) and DiMicco et al. (2004), were related to areas users were likely to know, but were not experts in, or focused on personal experiences which they shared: The journey to and experience with informatics, transport and housing situation in their city, experiences on campus etc..

In regard to the system, no information was given except for that participants were not to engage in meta-discussion about the system. Participants were told the microphone needed to be calibrated, which was done in an introductory round where they stated their name, age, field of study and reason for enrolling in that program. The moderator started with their introduction and was therefore set as user 0, which was ignored for all visualisations.

Then, several discussion questions were given in four rounds of 15 minutes. Visualisations were inactive in round 1, followed by *particles*, *slices*, and *circles* in rounds 2 to 4. Between rounds, Participants filled out questionnaires and were given opportunity to rest.

After the last round, an open focus group was held where participants were informed what the system did and asked about their experience and preferences.

The discussion rounds and the focus group were recorded in video and audio for later comparison with *mirrorlevel* and transcription.

6. Results

In the following results, graphs and statements are sorted by studies 1 and 2 (Göttingen and Regensburg). Please note that in Göttingen, owing to time constraints, the conditions BLANK and CIRCLES were tested with the first group of students, while SLICES and PARTICLES were tested with the second group. Since both groups were relatively homogenous and, more importantly, led by the same moderator, they are grouped together. In Regensburg, all conditions were tested with the same group of participants.

6.1. Questionnaire Results

The paper questionnaires were transcribed manually with values from -2 to 2 and, like the following statistics, further analysed and plotted using R by Ihaka & Gentleman (1996). The following four likert distribution graphs are also attached in full size in the appendix (pages 72, 73, 74, and 75).

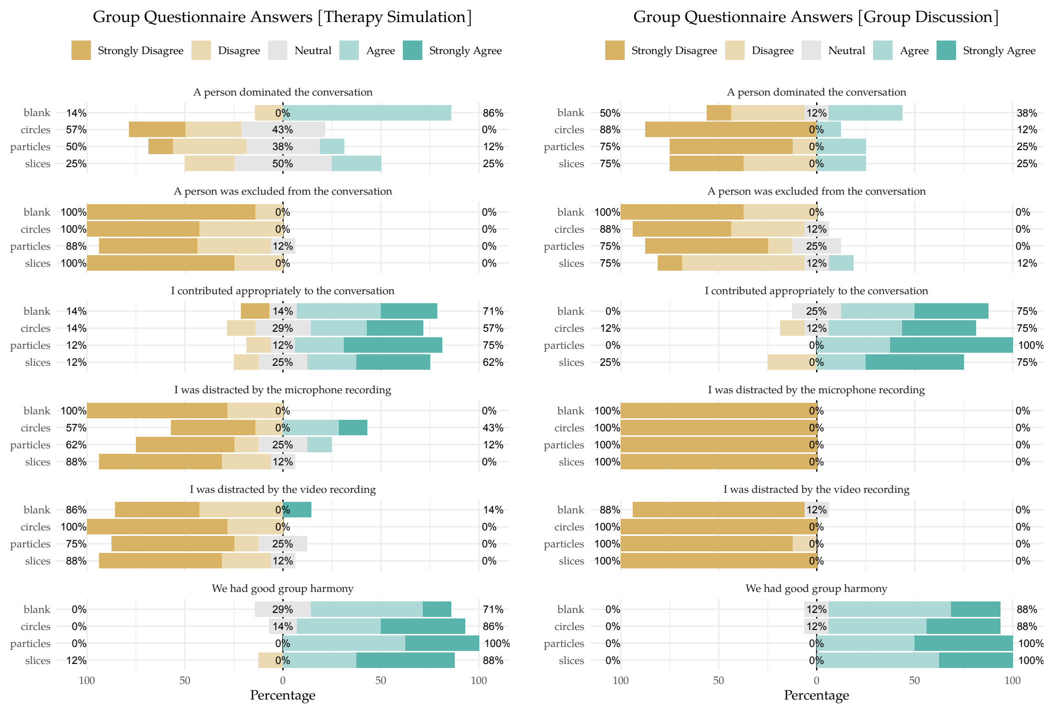

Figure 37: Group Questionnaire Results for Studies 1 and 2.

In figure 37, the results for the group questionnaire of both studies are compared. Notably, the dimension *Domination* was rated higher for the BLANK condition (G=86% and R=38% agree), while the other conditions showed neutral rating or disagreement. *Exclusion* was mostly not felt, as well as *distraction due to video recording*. *Distraction due to microphone recording* was also mainly low, but some participants of the therapy simulation reported it in CIRCLES (43%) and PARTICLES (12%). The sense of *adequate contribution* was generally quite high, but highest in PARTICLES (G=75% and R=100% agreement). Group harmony was rated positively throughout, with only one person disagreeing for SLICES$_G$ and reaching 100% agreement in both PARTICLE conditions.

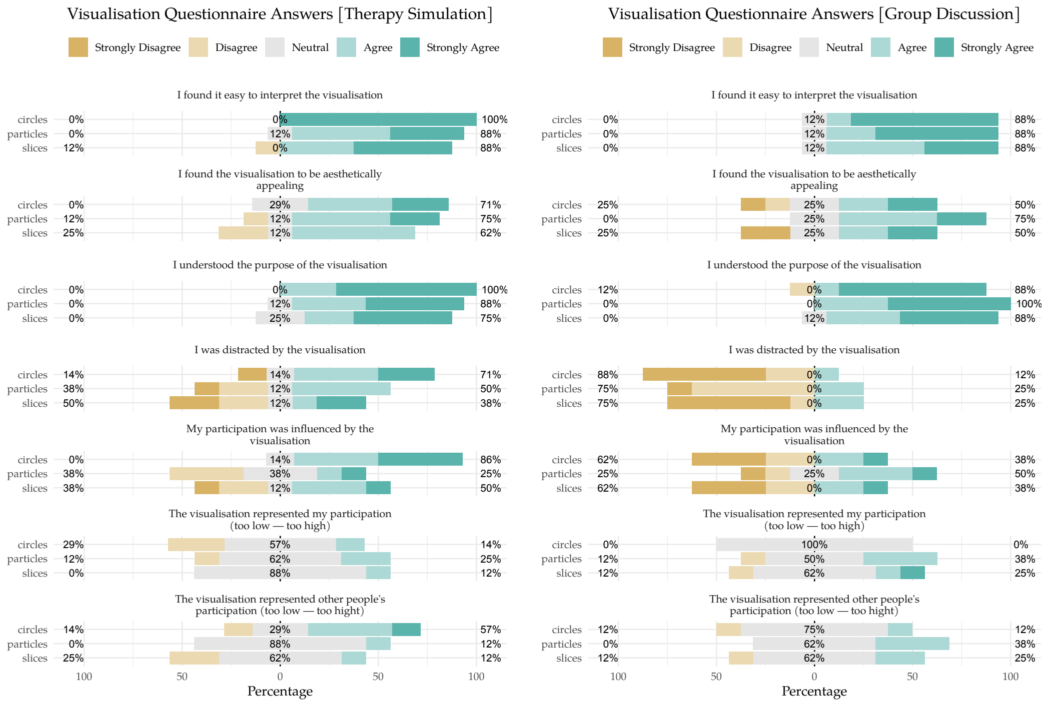

Figure 38: Visualisation Questionnaire Results for Studies 1 and 2.

When questioned about the visualisations, subjects rated *ease of interpretation* very highly, with CIRCLES scoring highest for both groups (G=100%, R=88%). *Aesthetic Appeal* was mostly positive, with SLICES scoring worst over all (G=25% disagree, R=25% strongly disagree), and the first visualisation displayed in each study scoring best ($\text{CIRCLES}_G = 71\%$ positive, $\text{PARTICLES}_R = 75\%$ positive). *Understanding* was also rated positively almost exclusively. Subjects in Regensburg rated the *distraction due to the visualisation* mostly low, while psychology students were more distracted, especially in the CIRCLES visualisation. Participants were also asked to rank both the *correctness of their participation* and of the *other people's participation* in the visualisation. Here, a neutral value indicates high subjective accuracy—the middle likert item was titled "just right"—a low value means too little displayed participation, and a high value too much. Participants rated the system to be mostly correct, but also recognised an error that occurred in Göttingen for the CIRCLES visualisation where one person's contributions were attributed to another user.

6.2. Participation and Group Balance

Figure 39: Participation over time for every round in both studies. Dashed line indicates ideal contribution percentage ($\frac{1}{N}$)

Plotting the raw recorded speaking times from the system log as running percentages results in the graphs visible in figure 39. Dominance of one person is visible throughout the top left graph, BLANK in Göttingen, where user 4 was quite active, and left in the third row, BLANK for Regensburg as well as bottom right, PARTICLES for Regensburg, where user 6 talked the most.

A measure for imbalance in groups is the Gini Coefficient, which was initially a model in political mathematics, describing people's difference from an ideal curve (Alker, 1965). It can, however, also be applied generally (Weisband et al., 1995; Tausch et al., 2016) and I use it here to measure inequality over time based on the logs from the system's back end. For every moment in a conversation, we can calculate the sum of the divergence of each users' participation rate x_i from ideal participation $\frac{1}{N}$, normalised by a coefficient scaling the results from 1 to 0.

$$G = \frac{N}{2(N-1)} \times \sum_{i=1}^{N} \left| x_i - \frac{1}{N} \right|$$

Therefore, a perfectly balanced group would have a low Gini coefficient G, while extreme imbalance approaches 1. When plotting the Gini coefficient over an entire session for both studies, we have very extreme values starting out, since only one person speaks at a time, which even out as time passes on. For comparison, we take the last recorded Gini index.

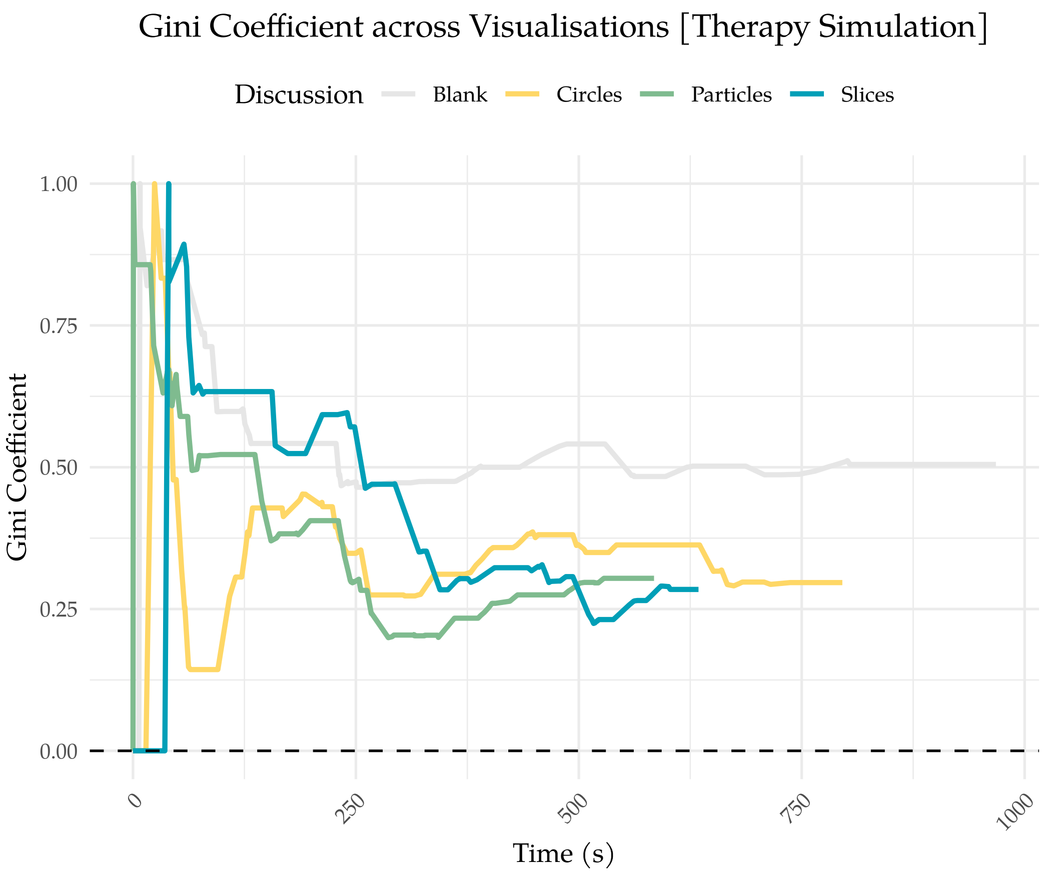

Figure 40: Gini coefficient over time for study 1.

In figure 40, the BLANK round performed noticeably worse than all three visualisations. BLANK ended with a coefficient of 0.505, while the visualisations were at $G_{\text{PARTICLES}} = 0.304$, $G_{\text{CIRCLES}} = 0.297$, and $G_{\text{SLICES}} = 0.285$. The areas of the graph where no change is recorded are sections where the moderator was talking. These statements are excluded from all statistics. Initially, a coefficient of 1 is reached very quickly for each round, as the first person makes their statement. The coefficient stabilises after around 5 minutes.

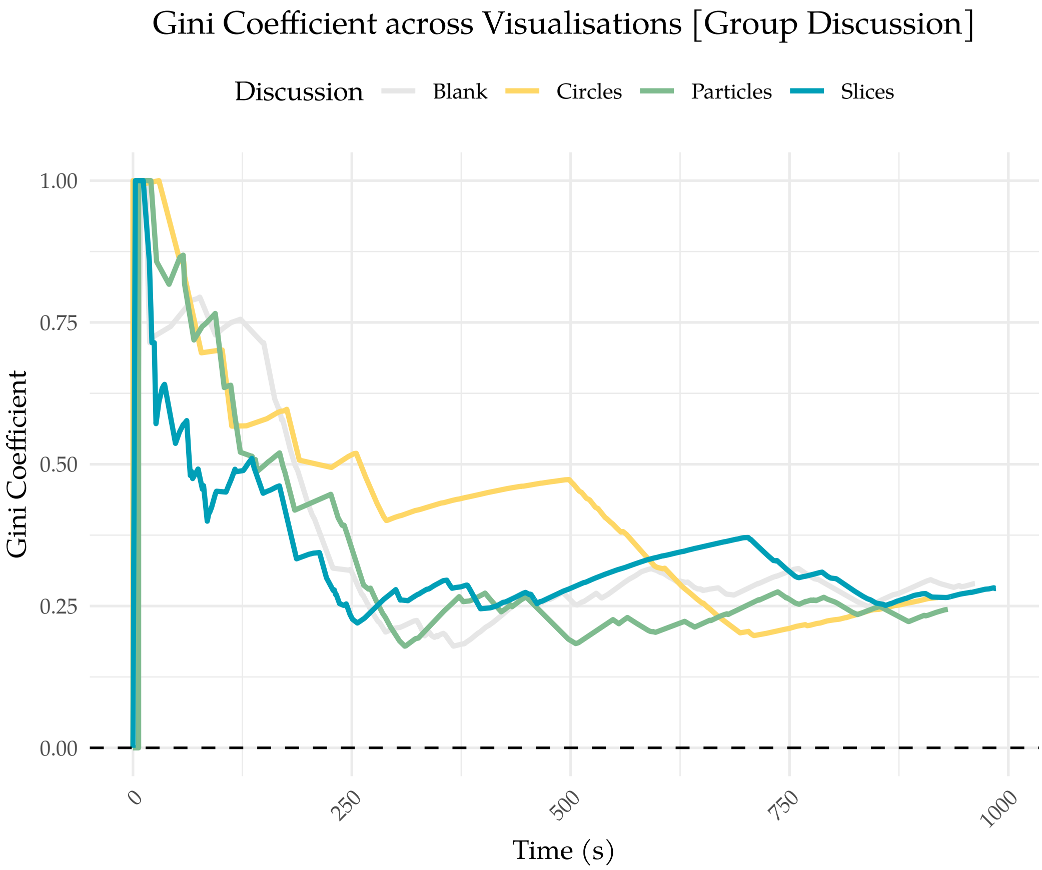

Figure 41: Gini coefficient over time for study 2.

In figure 41, the discussion rounds were grouped together more consistently, with final coefficients of $G_{\text{BLANK}} = 0.290$, $G_{\text{SLICES}} = 0.281$, $G_{\text{CIRCLES}} = 0.265$, and $G_{\text{PARTICLES}} = 0.244$. Since instructions are only given at the beginning of each round, the graph is always changing for the second study group.

6.3. Focus Group Findings

After all discussion rounds, the group in Regensburg were asked about different aspects of the system and how they interpreted them. When questioned whether they understood what the system did, all participants agreed. P6 stated that in the PARTICLES round, they were sure that participation was measured; however, in the SLICES visualisation, they shortly thought about whether it displayed when a person had spoken last. With further observation, they were able to reject this theory.

The accuracy of the system was also subjectively high, but P4 reported a sense of delay in the particles visualisation which they did not notice in subsequent rounds. P1 noted that "sometimes, you would notice that your neighbour also got something; but not too often". P7 stated that utterances seemed more impactful at the beginning, when not all people had talked yet, but was also not sure how to address this problem. They proposed starting without a visualisation and fading it into view once everyone had had a chance to speak.

When asked about any changes in their participation due to the system, several people had noticed something. P5 felt pressure due to the movement of the particles which resulted in the feeling that they needed to talk more. P4 and P6, who described themselves as talkative people, tried to talk less when faced with yellow mirror elements, especially so in slices and circles. They ascribed this braking effect to a stronger difference between extremes in those visualisations, with the "[circles] being the worst, because you have a huge circle around you" and the "slice almost driving into me" (P6), whilst the distribution felt more balanced in the particles. These were in turn more motivating for people inclined to talk less, leading to "seeing that your points go away, that gave me a feeling like I had to collect some more again... maybe a bit pointless, but it was a sort of motivation I developed [almost like a game]" (P8). P2 also stated stress due to a low number of particles, as they "suddenly had only three dots, that looked so sad". Both P8 and P4 wanted to call on people with lower participation to speak, which P4 acted upon successfully. P6 noticed that the system helped in the task of tracking who had and had not spoken and they also felt relieved of their usual need of having to fill a silence when they had already reached a yellow visualisation state. The system did not seem to have an impact on P1, who stated that if they didn't have to add anything, a small participation visualisation did not motivate them any further, but in turn, created a feeling of spite — "I'm not going to talk just to fill the circle". P1, who generally had a tendency to low participation, also felt in the last round, circles, that the discrepancy between their "small" circle and P6's "big" circle was too large to overcome.

In terms of distraction, P5 stated some momentary disturbances when particles moved between owners. P4 "paid too much attention to the projection" for the

SLICES, but also added that "it might be interesting to see whether after a few rounds of visualisations, you'd get used to it. In the first minute, it distracted me a bit, after that, I did not notice". P7 stated that they felt a constant, slight distraction, describing it as "tolerable": "it takes a little bit of cognitive performance away from the discussion, because I might look to my participation [visualisation] before a statement to see whether I want to say something or not".

When asked if they'd prefer a discrete update, like they just experienced, or a continuous one, P7 imagined a continuous visualisation to be more communicative, giving immediate feedback and showing that the system recognised your input. P6 feared that a continuous update might lead to people watching their elements grow and trying to talk faster. P4 suggested updating not after every sentence, but in a set interval, which might also improve the feeling of responsiveness.

For other improvements, P1 stated that their SLICE felt a little more narrow in comparison, which was in fact the case. P1, the projector (and, behind it, the ignored moderator) along with P8 were a total of three people to one flat of the ellipse, while on the other side, only two people were sat. For P1, this lead to a feeling of a 'smaller allowed area to speak in'. In response to this, P6 suggested pre-distributing the slices to be the same size and seating users accordingly, and P4 proposed drawing a smaller, perfect circle in the middle, and connecting each users' slice to their position with a small line, negating the effect of the projection aspect ratio.

Seven out of eight participants chose the PARTICLES as their favourite, with P5 preferring SLICES.

6.4. Expert Feedback

In a post-study interview, the moderator was asked for her perspective on using the system in a situation not unlike a real group therapy session.

She felt that the students understood the system and thought herself that the system had been mostly correct in its measurements. In cases where a person was not detected due to errors in the calibration, the moderator found it interesting to see a strong emotional reaction.

The system was very helpful in picking which of the students to choose next. Students raised their hands when they wanted to add something, and the expert chose whom to call on based on the information displayed in the visualisation. When PARTICLES were visualised, she felt a stronger sense of compassion for participants with little or no particles: "I know it's not a resource you can use to buy something, but I still felt I didn't want to be responsible for someone having nothing and others having a lot. That was quite intuitive. [...] I did not want the student [with less particles] to feel bad". She added that she had the same notion with the other two conditions, but it was especially intense with PARTICLES.

The therapist was also sure that the system changed the participation of her students: "Especially people that [usually] talk less were brought out of their shell". One student, who had been sick, "fought [their hoarse voice] to also reach a green circle". Students with generally more participation were not as easily slowed down, although the expert theorises that it might in some part due to some participants' will to explore how the system would react.

Distraction tended to be low for the expert, occurring only in the first few minutes and when an error was noticed. She ascribed this to the system only refreshing after statements.

When asked whether she could imagine using the system in a real group therapy session, the expert was confident. She felt it might be better suited to some topics and patients. For example, a visualisation—particularly the PARTICLES—could be a good introduction to Metaphor Therapy, a technique to illustrate patients' experiences with metaphors. In her opinion, taking the resource of talking time away from others could be a good metaphor to discuss further. Additionally, patients that tend to talk in order to mask or overcompensate their social fears or people with ADD might benefit from the feedback of a group mirror, as would people being brought out of their shell, which she observed in the study. She once again mentioned the support the moderator got in not overlooking participants. Another interesting application the moderator found would be "...agreeing to goals related to the system, like 'our therapy goal would be for you to participate enough to reach a green circle/green particles at least once in every group'". In this case, it would be important to her to be able to reflect on the impact the visualisation had on the patient, preferably in a one-on-one session.

Need for improvements was seen by the moderator in the calibration process to prevent errors. The requirement that red was to be avoided to evade associations with blood spreading from one's position could be somewhat extended to the colour yellow, which is why the moderator proposed changing the maximum state to an orange hue. Reasons opposing the use of the system in real sessions would be patients that have a sensibility to being offended or people with paranoid tendencies. To investigate and address other concerns, the expert suggests long-term studies. "One could criticise that the system might hinder a 'naturalistic' examination of the group and their dynamics. A moderator addressing someone who participates too much can also have a therapeutic use".

Another issue would be the measured dimension itself, which is merely the quantity of speech, not its content. The expert felt it might be irritating to respond to a constructive, but longer utterance by drawing a yellow visualisation.

The visualisation the moderator found most suitable was PARTICLES, but she remarked that CIRCLES with their "pre-drawn area" [metacognitive reference line] were the most intuitive.

7. Discussion

7.1. Interpreting the Gini coefficient

The results indicate that the group mirror had some effect on the participation rates in both studies. The stronger difference between Gini coefficients ($G_{\text{BLANK}} = 0.505$ compared to $\mu G_{\text{VIS}} = 0.295$) in the Group Therapy Simulation can likely be attributed to the moderation, which was not present in the Group Discussion. As the moderator stated herself, the system led her to favour people with little participation visualised when picking from all students with their hands raised, with the system therefore influencing both moderator and moderated, who were observed to talk more than usual. The unmoderated Group Discussion had a naturally more balanced participation in all rounds ($G_{\text{BLANK}} = 0.290$ compared to $\mu G_{\text{VIS}} = 0.263$). When comparing the results with Tausch et al.'s values from their 2016 comfort comparison, adjusted for difference in normalisation constants (Tausch et al. used $\frac{4}{5}$ for their study with three subjects, which, in the formula derived from Weisband et al. (1995), would be $\frac{3}{4}$), we find that our best balance for G_{SLICES}=0.285 surpasses their 0.525. Weisband et al., however, reported much lower coefficients, ranging from 0.19 to 0.09. It is to be noted that the creative brainstorming task set by Tausch et al. might be more cognitively demanding and less focused on balance than the interaction in our studies. Likewise, Weisband et al.'s ethical decision task might have needed more active discussion leading to better balance. Still, the Gini coefficient can be used to highlight differences in the two studies conducted in this thesis.

7.2. Questionnaires and Focus Group Feedback

Both Questionnaires showed altogether good *group harmony*, *interpretability*, and *understanding*, and little *exclusion*. The higher *dominance* in the BLANK rounds could be interpreted in two ways: Since both studies started with this condition, it is possible that the groups had not been fully "warmed up", which is, however, not fully reflected in the *harmony* dimension. Since the balance of participation also remained relatively stable at around 0.5 and 0.25, respectively, it could also be attributed to the lack of a group mirror. The positive response for *sense of contribution*, especially in the Group Discussion, in combination with the qualitative feedback, indicates that the PARTICLES led to one's participation being perceived better — both in terms of accuracy or in increasing satisfaction. Reports of *microphone distraction* by students in Göttingen for conditions CIRCLES and PARTICLES could be attributed to them confounding the puck-like input device with the system as a whole, owed also to the fact that questions referencing the visualisation were only on the second page of the questionnaire. Informatics students did not report any distraction from the microphone and very little by the *video recording*, which was—for both studies—mostly distracting in the first round, shortly after being informed about it. In both studies, *aesthetic appeal* and *influence on participation* were rated distinctly higher for the first visualisation on display. Here, it is difficult to consider Göttingen as a single entity, given that the students were replaced for two conditions. Therefore and in conjunction with the qualitative feedback, I would rank the PARTICLES as the best-performing condition in this comparison. It seemed to fare well especially for individuals with a tendency for less participation, motivating them to collect more particles. The distribution of particles appears to be a strong and motivating abstraction of participation. Its issues regarding a feeling of delay, as stated by P4 in the focus group, could be attributed to the sudden acceleration particles receive from the force system once owners change. Decreasing this to a smoother transition could also reduce the distraction mentioned by P5. To exhibit more pressure on participants with too much contribution, subtle scaling could be applied to particles in larger groups, either to the elements themselves or the distance between them.

Since the main focus of this work was to compare multiple visualisations, their more minute details were implemented to be similar, but not necessarily the optimum. The described intuitiveness and braking effect of the CIRCLES could justify further explorations with this visualisation, trying to keep and improve its features while also focusing on motivating users with less participation and balancing sizing to eliminate the feeling of being left behind reported by P1. Multiple aspects can be refined, including the aforementioned size of particles and balancing of sizes, in addition to the effect of update time or intervals, different state colours and also moving the threshold where hues are changed.

7.3. Large group mirroring

Although not explicitly tested in isolation, all visualisations were functional for groups of up to nine users, counting eight students and one moderator for both the second group in Göttingen and the study in Regensburg, with the only issue being P1 reporting feeling less heard due to smaller SLICE arc width. The high marks in subjective *understanding* and *interpretability* indicate that users knew which mirror element reflected their participation and how it related to the group. Therefore, the system answers RQ3: In all visualisations implemented, larger sizes work, and are not limited in size by the abstract mirror, but by available space and input/output fidelity; the luminosity (the manufacturer claims 5000 lumens) of the projector was low enough to necessitate rolling white paper over the dark and patterned carpet of both study locations and darkening of ambient light, via curtains or switching off laboratory ceiling lights and replacing with dimmer soft boxes. Increasing the size of the projection would be possible by increasing the height of the rig, but would also further reduce brightness. In terms of spatial resolution, there may be some headroom, but in its current implementation, the directional microphone is unlikely to accurately track more than a dozen participants. In such cases, other devices such as multiple directional microphones or on-person lavalier microphones could be considered.

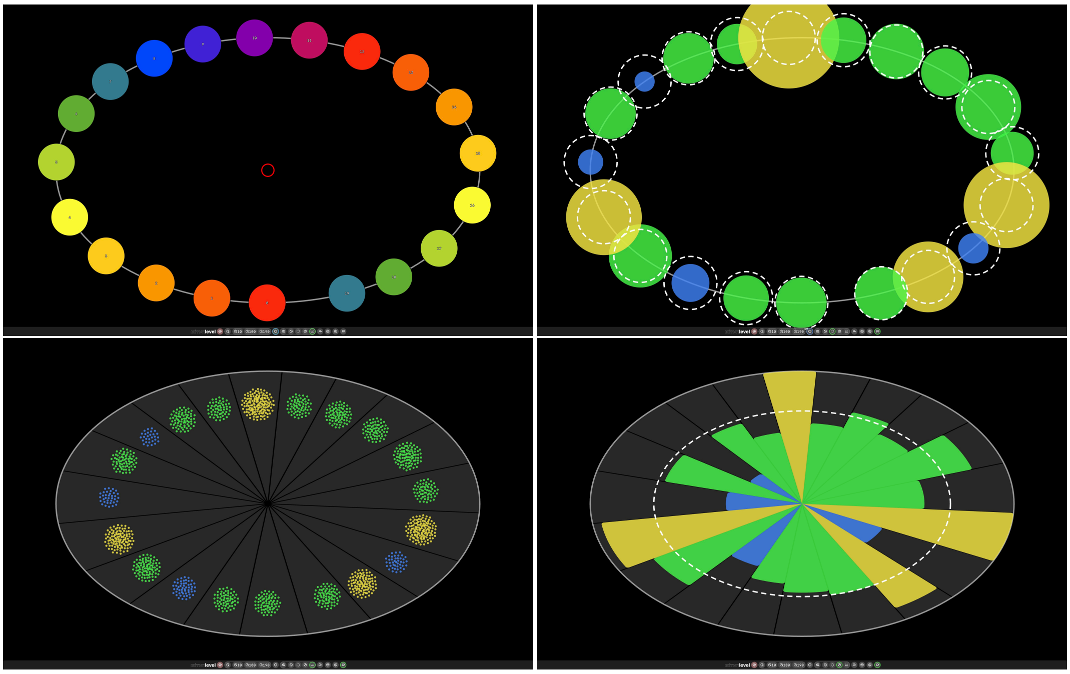

Figure 42: Screenshots of the front end with test data for 21 users (3024×1890 px)

As seen in figure 42, trials with up to 20 users are possible with the current front end at higher resolutions before the relative scaling starts to overlap the reference values of CIRCLES. The SLICES visualisation seems to work efficiently with higher numbers of users and might, adjusted to P4's suggestions as a perfect circle with connecting lines, prove useful in larger committees or settings of political discussion.

7.4. Tracking Issues and Interface Design

The issue with one user's position not being set correctly could have been prevented by design, simply returning the set angle measured by the back end and displaying the number or a direction in the placed circle. Of course, further steps could be taken, like concurrent feedback displaying the raw microphone input during the calibration phase, or checking inter-user-distances mathematically and warning of a possible error when distances measured for purportedly adjacent users cross a certain threshold; given, for example, user 5's position is at 170°, one would expect user 6 sitting clockwise to be somewhere between 180° and 220° and could warn the moderator when 10° are returned instead. Even further, tracking and readjusting positions throughout the recording could be implemented as well as verification of directional data with another dimension, like machine learning-powered voice recognition, which can verify speakers in near real-time (Dhakal et al., 2019). As mentioned previously, the current interface was developed as a tool for debugging and following a specific study design. It could, next to improving robustness in general, serve to detach it from the visualisation window and instead display it on a separate monitor for the moderator, using the Broadcast Channel API[12]. In such a setup, raw microphone data could be displayed permanently, affording swift response to errors. An external control interface would also offer a simple solution to the issue raised by the expert in her review, allowing for a manual pause of tracking or a shortcut to automatically set a person's mirror to ideal levels after a longer, but important contribution.

7.5. Expert review

The expert's review of the system indicates promising potential in not just changing the participant's speaking time, but also in supporting the moderator in their decision making. Of course, as a tool to be used in a very sensitive context, this exploration does not amount to more than a jumping-off point for in-detail studies, but the system has nonetheless shown some promise in integrating group mirror technologies into compatible therapy sessions. The technical issues faced in the study are all addressable and—in the case of the calibration error—also demonstrated an emotional investment the affected student had towards the system, which is corroborated by other observations made by the expert and focus group results.

7.6. Summary and Future Work

To answer RQ1, the list of requirements and concepts derived from it and related work resulted in an abstract and neutral, but engaging and communicative set of visualisations in both PARTICLES and CIRCLES, which could also support future back end solutions with more differentiated input, like qualitative aspects of participa-

[12]https://developer.mozilla.org/en-US/docs/Web/API/Broadcast_Channel_API

tion. Regarding RQ2, the statistical results from our three disconnected groups can not be generalised without limitation, but qualitative feedback points to the group mirror motivating some participants, braking some others, and having potential for application in group therapy sessions.

Several steps could be taken from here; firstly, remaining in the application space for group therapy, larger, long-term studies, preferably with patients, using a slightly improved version of the current PARTICLES visualisation could indicate its potential for the application at hand with greater assurance. Further research on iterations of the preferred PARTICLES and CIRCLES could find ideal levels for sizing, responsiveness, hue, and crossover points of different states. The back-end could be replaced to use either more accurate user tracking or an entirely different quality of participation, possibly even semantic analysis using NLP to assign a contribution value to statements in therapy sessions.

Secondly, the three described visualisations might also have potential in even larger groups given a multi-projector setup to reach appropriate size and luminance levels. Here, possible applications could include large political discussions or committees.

Bibliography

Alker, H. R. (1965). *Mathematics and politics*. The MacMillan Company.

Bachour, K., Kaplan, F., & Dillenbourg, P. (2010, July). An Interactive Table for Supporting Participation Balance in Face-to-Face Collaborative Learning. *IEEE Transactions on Learning Technologies*, *3*(3), 203–213. Retrieved 2025-04-10, from `http://ieeexplore.ieee.org/document/5518762/` doi: 10.1109/TLT.2010.18

Dhakal, P., Damacharla, P., Javaid, A. Y., & Devabhaktuni, V. (2019). A near real-time automatic speaker recognition architecture for voice-based user interface. *Machine learning and knowledge extraction*, *1*(1), 504–520.

DiMicco, J. M., Pandolfo, A., & Bender, W. (2004, November). Influencing group participation with a shared display. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work* (pp. 614–623). Chicago Illinois USA: ACM. Retrieved 2025-11-25, from `https://dl.acm.org/doi/10.1145/1031607.1031713` doi: 10.1145/1031607.1031713

Ihaka, R., & Gentleman, R. (1996). R: a language for data analysis and graphics. *Journal of computational and graphical statistics*, *5*(3), 299–314.

Jermann, P., & Dillenbourg, P. (2008, August). Group mirrors to support interaction regulation in collaborative problem solving. *Computers & Education*, *51*(1), 279–296. Retrieved 2025-04-10, from `https://linkinghub.elsevier.com/retrieve/pii/S0360131507000541` doi: 10.1016/j.compedu.2007.05.012

Jermann, P., Soller, A., & Muehlenbrock, M. (2001). From mirroring to guiding: A review of the state of art technology for supporting collaborative learning. In *European Perspectives on Computer-Supported Collaborative Learning* (pp. 324–331). Retrieved 2025-05-16, from `https://infoscience.epfl.ch/entities/publication/fc01eca1-d198-4956-afcd-3da30219d85c`

Kim, T., Chang, A., Holland, L., & Pentland, A. S. (2008, November). Meeting mediator: enhancing group collaborationusing sociometric feedback. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work* (pp. 457–466). San Diego CA USA: ACM. Retrieved 2025-04-15, from `https://dl.acm.org/doi/10.1145/1460563.1460636` doi: 10.1145/1460563.1460636

Praharaj, S., Scheffel, M., Drachsler, H., & Specht, M. (2018). Multimodal analytics for real-time feedback in co-located collaboration. In V. Pammer-Schindler, M. Pérez-Sanagustín, H. Drachsler, R. Elferink, & M. Scheffel (Eds.), *Lifelong technology-enhanced learning* (pp. 187–201). Cham: Springer International Publishing.

Praharaj, S., Scheffel, M., Drachsler, H., & Specht, M. (2019). Group coach for co-located collaboration. In M. Scheffel, J. Broisin, V. Pammer-Schindler, A. Ioannou, & J. Schneider (Eds.), *Transforming learning with meaningful technologies* (pp. 732–736). Cham: Springer International Publishing.

Praharaj, S., Scheffel, M., Schmitz, M., Specht, M., & Drachsler, H. (2022). Towards collaborative convergence: Quantifying collaboration quality with automated co-located collaboration analytics. In *Lak22: 12th international learning analytics and knowledge conference* (p. 358–369). New York, NY, USA: Association for Computing Machinery. Retrieved from `https://doi.org/10.1145/3506860.3506922` doi: 10.1145/3506860.3506922

Roman, F., Mastrogiacomo, S., Mlotkowski, D., Kaplan, F., & Dillenbourg, P. (2012, October). Can a table regulate participation in top level managers' meetings? In *Proceedings of the 17th ACM international conference on Supporting group work* (pp. 1–10). Sanibel Island Florida USA: ACM. Retrieved 2025-04-10, from `https://dl.acm.org/doi/10.1145/2389176.2389178` doi: 10.1145/2389176.2389178

Schiavo, G., Cappelletti, A., Mencarini, E., Stock, O., & Zancanaro, M. (2014, February). Overt or subtle? Supporting group conversations with automatically targeted directives. In *Proceedings of the 19th international conference on Intelligent User Interfaces* (pp. 225–234). Haifa Israel: ACM. Retrieved 2025-04-15, from `https://dl.acm.org/doi/10.1145/2557500.2557507` doi: 10.1145/2557500.2557507

Schwind, V., Resch, S., & Sehrt, J. (2023). The hci user studies toolkit: Supporting study designing and planning for undergraduates and novice researchers in human-computer interaction. In *Extended abstracts of the 2020 chi conference on human factors in computing systems.* New York, NY, USA: Association for Computing Machinery. Retrieved from `https://doi.org/10.1145/3544549.3585890` doi: 10.1145/3544549.3585890

Streng, S., Stegmann, K., Hußmann, H., & Fischer, F. (2009, November). Metaphor or diagram?: comparing different representations for group mirrors. In *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7* (pp. 249–256). Melbourne Australia: ACM. Retrieved 2025-04-10, from `https://dl.acm.org/doi/10.1145/1738826.1738866` doi: 10.1145/1738826.1738866

Tausch, S. (2015, February). Investigating the Different Characteristics of Group Mirrors. In *Proceedings of the 18th ACM Conference Companion on Computer Supported Cooperative Work & Social Computing* (pp. 109–112). Vancouver BC Canada: ACM. Retrieved 2025-04-10, from `https://dl.acm.org/doi/10.1145/2685553.2699333` doi: 10.1145/2685553.2699333

Tausch, S. (2016). *The Influence of Computer-Mediated Feedback on Collaboration* (Unpublished doctoral dissertation).

Tausch, S., Hausen, D., Kosan, I., Raltchev, A., & Hussmann, H. (2014, October). Groupgarden: supporting brainstorming through a metaphorical group mirror on table or wall. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational* (pp. 541–550). Helsinki Finland: ACM. Retrieved 2025-04-10, from `https://dl.acm.org/doi/10.1145/2639189.2639215` doi: 10.1145/2639189.2639215

Tausch, S., Ta, S., & Hussmann, H. (2016, May). A Comparison of Cooperative and Competitive Visualizations for Co-located Collaboration. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 5034–5039). San Jose California USA: ACM. Retrieved 2025-04-10, from `https://dl.acm.org/doi/10.1145/2858036.2858072` doi: 10.1145/2858036.2858072

Weisband, S. P., Schneider, S. K., & Connolly, T. (1995). Computer-mediated communication and social information: Status salience and status differences. *Academy of management journal*, *38*(4), 1124–1151.

A. Appendix

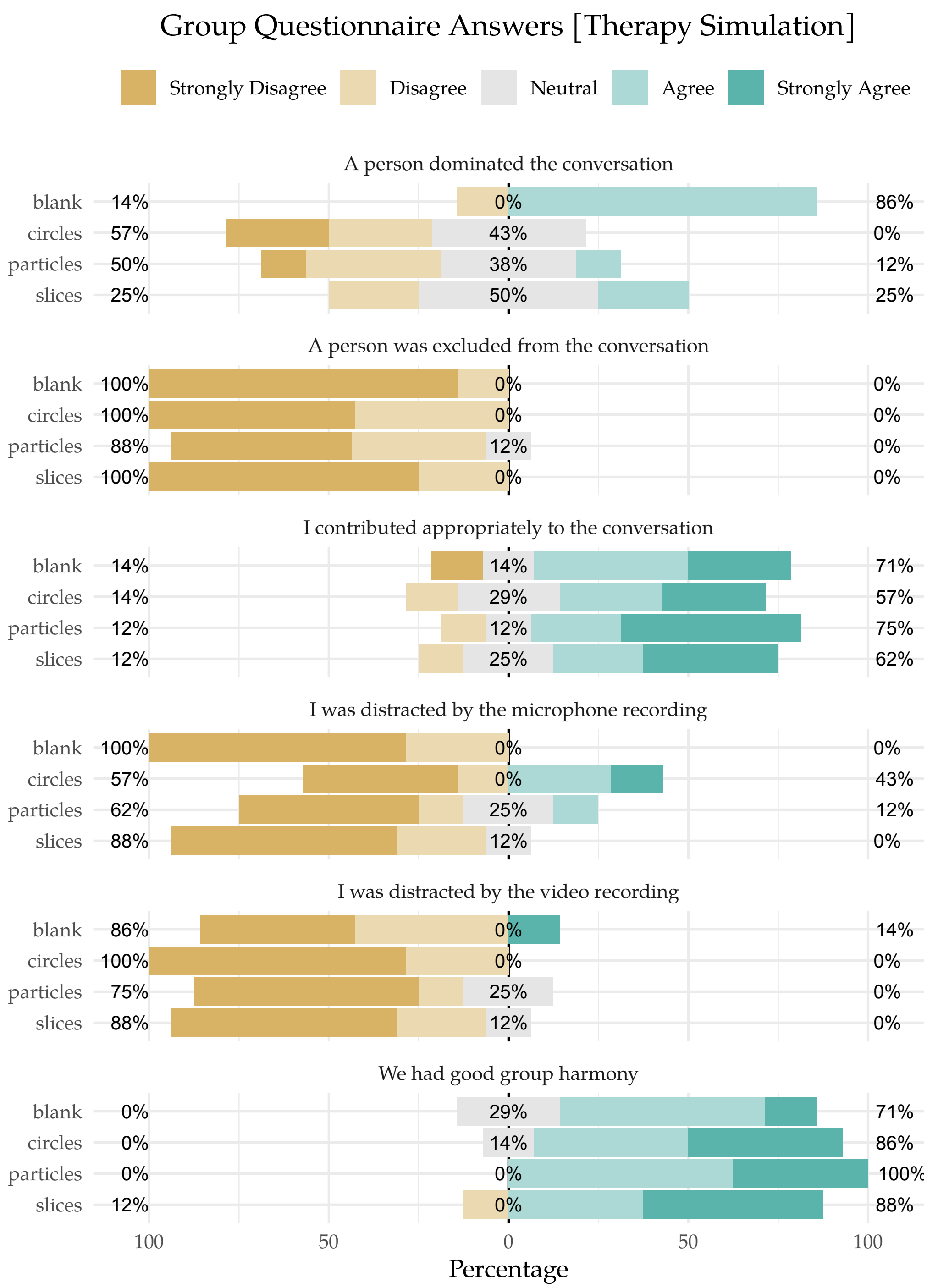

Figure 43: Group Questionnaire Results for Study 1.

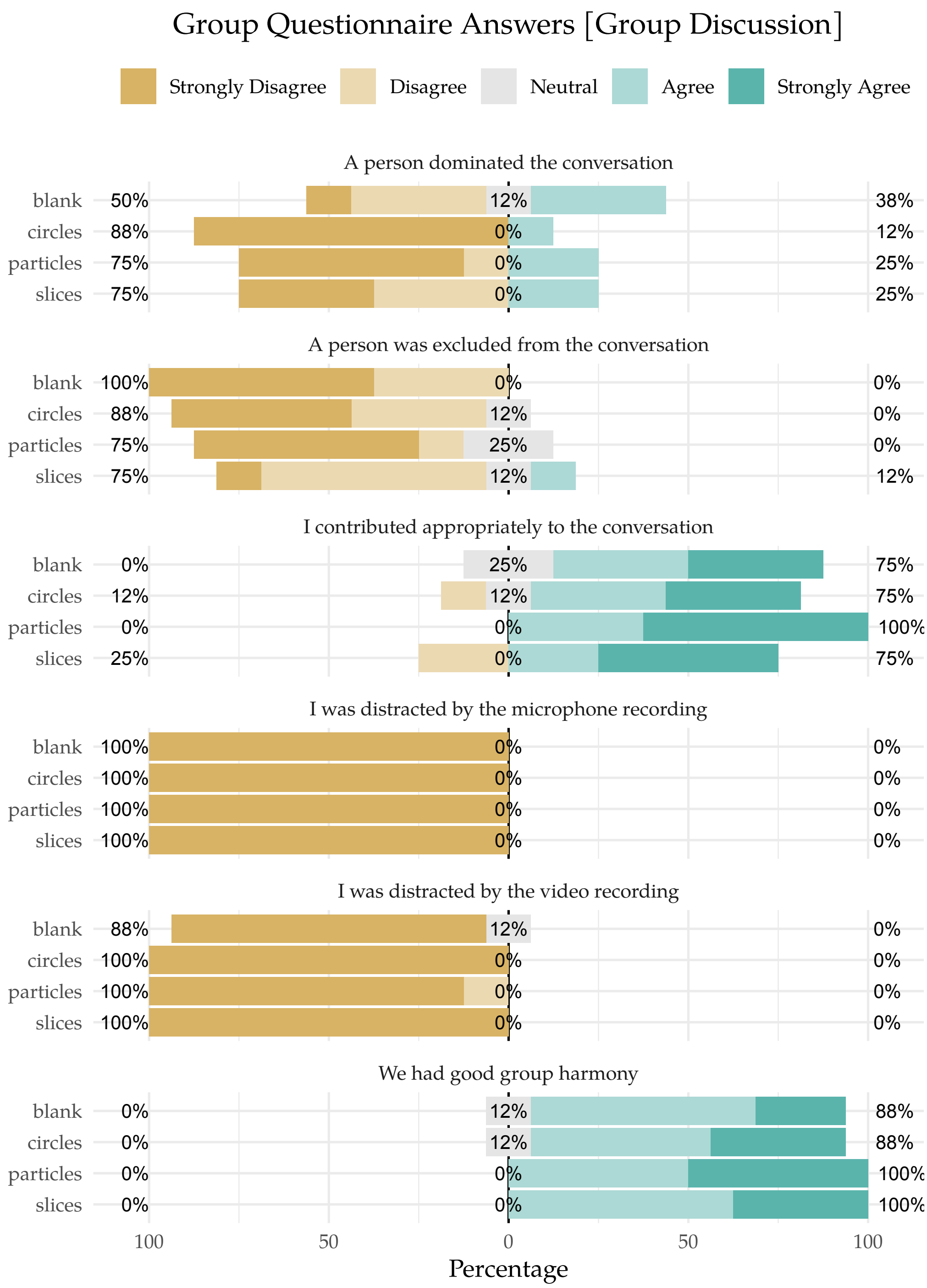

Figure 44: Group Questionnaire Results for Study 2.

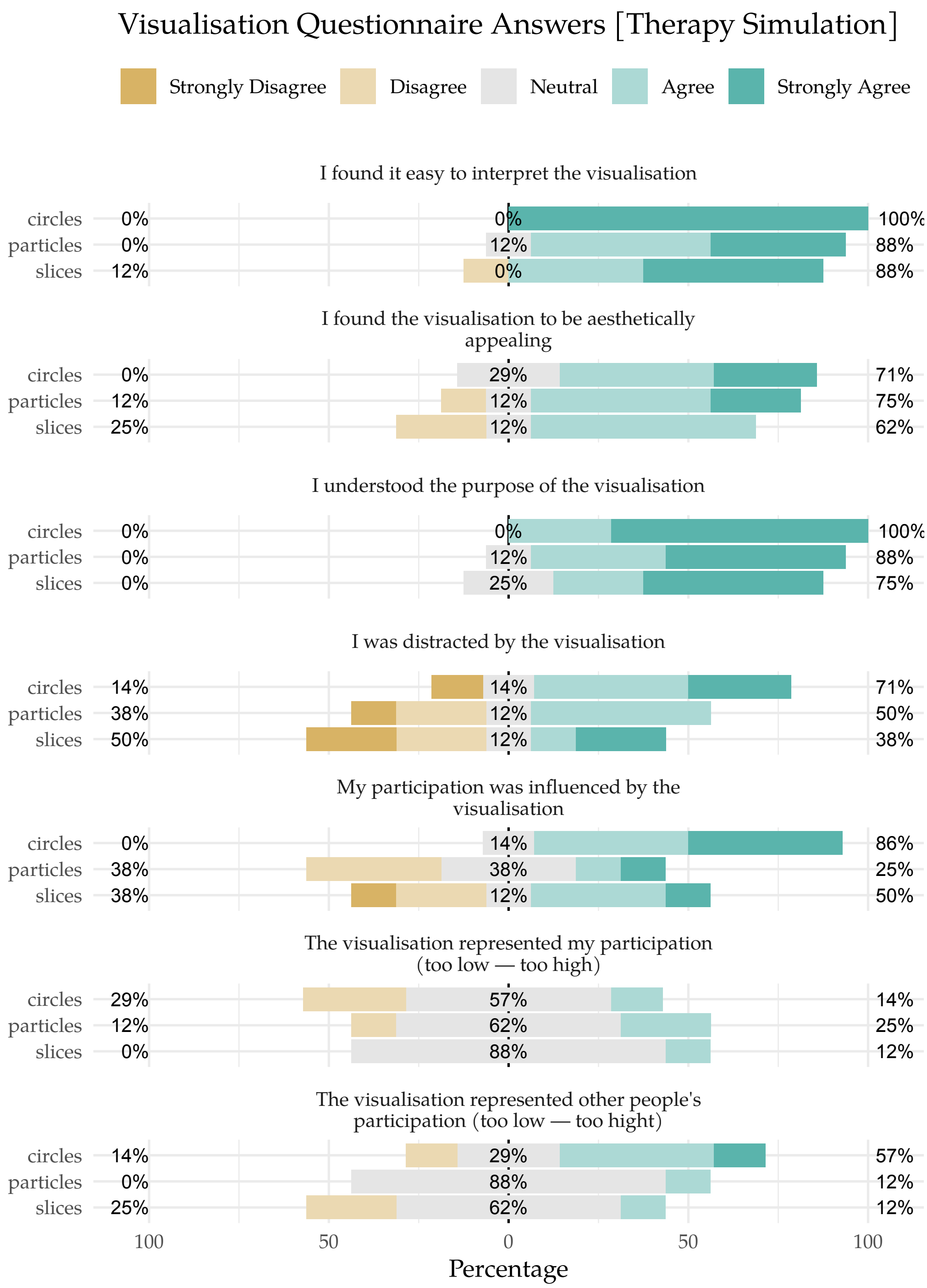

Figure 45: Visualisation Questionnaire Results for Study 1.

Figure 46: Visualisation Questionnaire Results for Study 2.

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B. Inhalt des beigefügten Datenträgers

`/1_Ausarbeitung`	Schriftliche Ausarbeitung als PDF und LaTeX-Ordner mit verwendeten Grafiken
`/2_Konzepte`	Anforderungsliste, Konzepte und Transkript der Anforderungsbesprechung
`/3_Code`	`/mirrorlevel`: Quellcode von *mirrorlevel*, `/validierung`: Tonspur, Audacity-Projekt und Auswertung der Validierung
`/4_Studie`	Informed Consent, Demografie und Fragebogen für die Studien
`/5_Artefakte`	Rohdaten der Studie im CSV-Format, R-Projekt und R-Markdown der Auswertung, sowie Transkript von Fokusgruppe und Moderationsfeedback
`/6_Quellen`	Alle in der Arbeit zitierten Quellen im PDF-Format
`/7_Vorträge`	Folien von Antritts- und Abschlussvortrag im PDF-Format