SoundXY4: Supporting Tabletop Collaboration and Awareness with Ambisonics Spatialisation

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ABSTRACT

Co-located tabletop tangible user interfaces (TUIs) for music performance are known for promoting multi-player collaboration with a shared interface, yet it is still unclear how to best support the awareness of the workspace in terms of understanding individual actions and the other group members actions, in parallel. In this paper, we investigate the effects of providing auditory feedback using ambisonics spatialisation, aimed at informing users about the location of the tangibles on the tabletop surface, with groups of mixed musical backgrounds. Participants were asked to improvise music on "SoundXY4: The Art of Noise", a tabletop system that includes sound samples inspired by Russolo's taxonomy of noises. We compared spatialisation vs. no-spatialisation conditions, and findings suggest that, when using spatialisation, there was a clearer workspace awareness, and a greater engagement in the musical activity as an immersive experience.

Keywords

ambisonics, spatialisation, auditory feedback, interactive tabletops, tangible user interfaces, *The Art of Noise*, musical improvisation

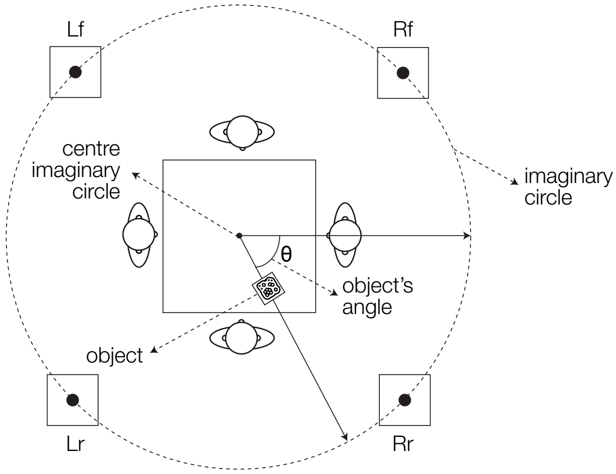

Figure 1: Imaginary circle representing ambisonics on a tabletop system. The sound source is dependent on the angular position and distance of the object on the sphere in relation to the position of the loudspeakers.

1. INTRODUCTION

Tabletop tangible interfaces are especially suited for real-time collaboration. At the same time, such interfaces allow for a better analysis of collaboration issues such as awareness. Technically, real-time collaboration refers to the support of concurrency or parallel actions and interactions in interactive systems, not necessarily based on a tabletop interface (e.g. network music or collaborative writing using individual interconnected mobile devices). Particularly in a context of digital musical instruments, apart from supporting parallel processes, real-time collaboration involves supporting multiple musicians (cf. [9]) and complex interactions or the 'artist spec' [2]. Workspace awareness (referred to later as just awareness) is a term widely used in tabletop studies, which refers to "the up-to-the-moment understanding of another person's interaction with a shared workspace" [5, p. 412]. During the performance of collaborative tasks on tabletops, it becomes difficult to identify simultaneously individual actions (or voices in music) from other participants' actions happening on the workspace. Addressing this issue is a challenge in tabletop studies [7, 17, 19, 25], as well as studies in sound and music computing [1, 6, 27].

In collaborative interactive systems, awareness issues are generally addressed by using mechanisms such as real-time feedback. With the advent of tangible user interfaces (TUIs), particularly tabletop TUIs, visuals have been often used as a mechanism to provide feedback about people's actions. The role of the tangible objects is to both control and represent digital data [8], and so features of the objects such as position, orientation, identity, or relationships between objects are digitally augmented in the form of projection or display. In the case of tabletop TUIs for music, the manipulation of objects produces audio feedback generally in combination with visual feedback, as exemplified by systems such as the AudioPad [18] or the Reactable [10].

Our approach is to explore the possibilities that auditory feedback, in combination with visual feedback, bring to teamwork processes in musical tabletop interaction, focusing on the overall group experience. In particular, this study investigates the effects, when using ambisonics spatialisation, on group collaboration and awareness during musical improvisation with a tabletop system (see Figure 1).

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We designed a study with co-located small groups using SoundXY4, a basic tabletop TUI prototype for music performance that implements ambisonics spatialisation [4] for 4 loudspeakers. Our hypothesis was that the spatialisation condition, compared to the no-spatialisation condition, would result in higher awareness in terms of space territoriality and themes about awareness emerging from verbal communication. The sounds used for this research were based on Russolo's 1913 taxonomy of noise sounds [21]. We conducted the experiment with 8 groups of 4 people, and findings revealed that, using spatialisation, there was a clearer awareness of individual vs. group actions, sounds, and filters; and a greater association of the musical task to an immersive and realistic experience. With these results, we expect to inform tabletop research on potential uses of ambisonics auditory feedback, in particular how to cope with collaboration and workspace awareness on musical tabletops for co-located small groups.

In the following sections, we first introduce the SoundXY4 system, we then describe the study, present the findings, and end with the discussion and conclusions.

2. SOUNDXY4: "THE ART OF NOISE"

2.1 Motivation

SoundXY4 is designed to facilitate collaborative musical performance using a surround sound system with 4 loudspeakers, providing information on the location of tangible objects on a tabletop surface where each performer receives information from all of the speakers. We aimed at promoting a group experience in contrast with a more individualistic experience of using individual speakers or headphones for each of the listeners. This approach can be useful to support awareness of both individual and group actions on the tabletop surface using the same soundfield for everybody with no disruptions as it would happen when using headphones. It can also permit musicians to explore and discover together a set of sound categories during a music performance. Finally, it aims at supporting collaboration across people with different musical backgrounds.

"Soundxy4: The Art of Noise" is a celebration of the centenary of Russolo's 1913 "The Art of Noise" [21] and his taxonomy of sounds, which includes urban, noise and industrial sounds. We believe that Russolo's material can be useful for music performance by users both experienced and inexperienced in music making when using suitable technologies. On the other hand, everyday sounds such as the noises proposed by Russolo are traditionally associated to *everyday listening* [3], which implies a greater attention to the spatial dimension than traditional musical listening (see [26] for an exploration of everyday listening in electroacoustic music). Russolo's ideas have influenced the NIME community such as in The Croaker system [23] or aesthetic reflections on using the loudspeaker as a musical instrument [15]. However, as far as we know, exploring Russolo's taxonomy of sounds on a tabletop system is novel.

2.2 Implementation

We developed a tabletop tangible interface for music performance using open source technologies[1]. The design approach is based on the Reactable [10] principles of a collaborative interface based on constructive building blocks with physical objects that trigger or modify sounds, and a lack of division of the interface into territories as a mechanism for promoting self-regulation of spaces [27]. However, SoundXY4 focuses on i) using only sound samples (i.e. no sound synthesis is used) and ii) delivering audio using ambisonics with 4 speakers for supporting an overall group auditory experience.

[1]The SoundXY4 code is publicly available at: `http://github.com/axambo/soundxy4`

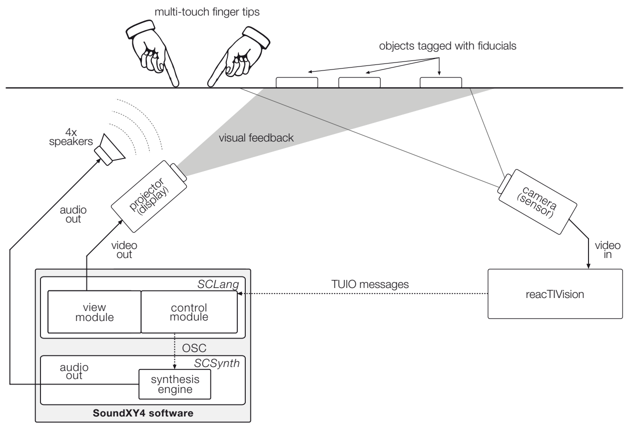

Figure 2: System overview of SoundXY4.

We built a low-cost wooden tabletop based on the commonly used diffused illumination (DI) technique [16] and inspired by the Reactable approach. The tabletop measures 87x89x100cm with an inner square frame of 58x58cm that has an acrylic sheet for projection and object detection. The size was designed to keep a balance between mobility and multi-player capabilities. The object tracking was processed using reacTIVision [12], a computer vision engine for object tracking, based on fiducial markers.

The software was written in SuperCollider [14]. We used SETO Quark[2], the implementation of the TUIO protocol by Till Bovermann, which allows SuperCollider to communicate with reacTIVision. Figure 2 overviews the system.

SoundXY4's implementation follows a Model-View-Controller pattern. The Controller module classifies the objects between sound player objects and effects, and tracks their behaviour in terms of presence, location, or rotation. The Model module manages the buffers to play the sound samples, operates the relation between sound player objects and effects according to their vicinity, and controls the order of execution of the synth nodes on the server including synths for sound samples, effects, and spatialisation. The View module manages a visualisation of sound player objects and effects.

SoundXY4 tracks the identity, position and orientation of tangible objects tagged with fiducial markers and maps them to sound players or effects. In this version, there is a subset of 36 different fiducials that are mapped to 36 different sound samples. Sounds are grouped in 6 categories inspired by Russolo's 6 families of noises (see Section 2.3). We used physical cubes with a unique marker on each side of the cube. Thus, each side represented a sound, and each cube represented a sound category. For this version of SoundXY4, we used another group of 4 different cubes with 6 different filters repeated in each. Filters used are a band pass filter, a resonant low pass filter, a high pass filter, a comb delay, a pitch shifter, and an amplitude modulator. For each tangible object of the collection explained above it is possible to modify one parameter: volume for sound player objects, and a relevant parameter for each of the effects. Sounds are looped.

The application maps sounds and filters to a 2D plane using ambisonics spatialisation [4] for 4 loudspeakers. The

[2]`http://sourceforge.net/p/quarks/code/HEAD/tree/seto/`

ambisonics technique is founded on theories of psychoacoustic perception, centred on how the listener perceives sound when decoding an audio signal. We opted for a surround sound system because it offers an integrated group and individual musical experience: headphones could disrupt the group experience. Particularly we chose the ambisonics technique because, among low-cost systems, it is the most sophisticated in terms of realism compared to other systems such as quadraphonics or stereo panning. We implemented the technique in the basic horizontal surround using 4 speakers as it remains an easy and cheap setup, and keeps a direct mapping with the tabletop interaction: loudspeakers at 90° each from the table, and positioned facing a corner of the table each, as illustrates Figure 1. In SoundXY4, we used a SuperCollider implementation of ambisonics, which is divided into two unit generators: the 2D encoder PanB2, which analyses the soundfield; and the 2D decoder DecodeB2, which synthesises the soundfield.

2.3 Taxonomy

The choice of the sounds followed the six families originally proposed by Russolo. From the original text, it can be interpreted that the second level of the taxonomy is formed with characteristic sound types: "we have included in these 6 categories the most characteristic fundamental noises, the others are hardly more than combinations of them" [21, p. 10]. We seeked examples of these categories from Freesound[3]. The main criteria were to find iconic sounds for each of the definitions in the text, but at the same time avoiding overlaps that could be easily produced. Following this idea, we extended our search when necessary in order to have six sounds per category, trying to find sounds that were clearly distinct and yet all representative of the main category[4]. A summary of the sounds used can be found in Table 1.

2.4 Usage

Sound players are represented by white cubes, and filters are represented by black cubes. Each white cube represents one of Russolo's categories. Each filter modifies the sound of the nearest white cube. Visual feedback informs users about the position of the objects, the sound category, and what sounds are being affected by which filters. When a sound player cube is on the tabletop surface, it is highlighted by a coloured square. There is a different colour for each category of sound players, and the nearest filter will be highlighted in the same colour to indicate the sound that it is affecting. It is possible to change the volume for each cube by rotating clockwise (volume up) or counterclockwise (volume down). There is a mark of the volume value in the range (0–100), and also a number for each of the six sounds (1–6). Rotation of the black cube modifies a parameter of the filter. The rotation and position of a white cube on the table surface defines the position of the sound source in the room, related to the position of the loudspeakers[5].

3. THE STUDY

3.1 Study design

The overarching research question was: What are the effects of ambisonics spatialisation on group collaboration and awareness on a tabletop system for music performance? Our main hypothesis was that spatialisation with ambisonics supports tabletop collaboration and awareness better than no-spatialisation, that is, same sound output from the 4 loudspeakers. Different aspects of group collaboration and awareness were compared between the two conditions of spatialisation with ambisonics (SP) versus no-spatialisation (NSP). In particular, we were interested in looking at events related to space territoriality; events related to the themes of identification of sounds, filters, and categories; realistic scenes; and musical immersion.

Figure 3: 360° panoramic photo of SoundXY4 experiment setup. Photo by Dave Perry (2013).

3.2 Participants

8 groups of 4 participants, 32 people in total, participated in the study as volunteers from local recruitment. There was a total of 13 females and 19 males, aged from 15 to 57 (M = 33.13 years old, SD = 11.91). All groups were gender mixed groups. Participants were also mixed in terms of years of musical training, including 8 beginners ("none"), 12 intermediates (8 with "1–2 years", 2 with "2–4 years" and 2 with "4–6 years"), and 12 experts ("more than 6 years"). All groups were mixed level groups: 1 group with beginners (B), intermediates (I), and experienced (E); 3 groups with B and I; 3 groups with I and E; and 1 group with B and E. Some of them knew each other (7), others new some of their group (8), and some didn't know each other at all (17). Participants were international (26 from Europe, 4 from Asia, 2 from North America). Groups and participants were anonymised to G# for groups and to P# for participants (e.g. G1 P4 refers to participant 4 of group 1), which is the nomenclature used from here on.

3.3 Setup

We built a closed room made of display screens in the middle of a multipurpose lab space, below 4 dome cameras, which could see the centre of the closed area from 4 different extremes of it. In order to improve the acoustics of the closed area, we positioned the display screens to avoid a perfect square. Instead, we created irregular, random, acute and obtuse angles at the joints of the display screens. The tabletop system was positioned in the middle of the closed space, with 4 loudspeakers at a distance of 1.2m from the table, facing each one of the corners of the tabletop surface, at 90° from each other, and with two additional floor standing cameras on tripods. Figure 3 shows the setup.

3.4 Procedure

The study used a within-subjects design (groups being 'subjects'), in which all groups took part in both conditions of spatialisation and no-spatialisation. The order was randomized to control possible learning effects. After a short introduction to the activity, participants were asked to improvise music with the tangible objects by playing with the sounds and filters in coordination with the group for 15 minutes. Before starting the trials, each group performed two rehearsals of the trials in the same randomized order as in the experiment, so that participants could familiarise themselves with the interface, in line with Hancock et al. [6]. After completing the experiment, participants were asked to

[3] `http://www.freesound.org`

[4] For a full list of tracks used see: `http://github.com/axambo/soundxy4`

[5] A video demo of this version is available here: `http://vimeo.com/user15175243/soundxy4-the-art-of-noise`

Table 1: Used sounds by category

Category	Used sounds
explosions	boom rumble, car crash, gun shot, thunderstorm, war boom explosion, water splash
percussion	ceramic impact, falling metal, metallic impact, rocks smashing, tom drum, wood impact
screeches	fire crackle, howl, lamp buzz, metallic whine, metallic-ceramic friction, plastic rustling
voices	cat howling, groan, kid laugh, man laugh, scream, tibetan chant
whispers	cat purring, crowd murmur, group whispering, stomach gurgling, wind mouth gurgle, wind mouth whisper
whistles	air escaping hiss, boat whistle, leaking gas hiss, long snort, tunnel short whistle, water pipe hiss

fill in a background questionnaire. Before this study took place, we did a pilot with two groups to test the procedure.

3.5 Methods of data analysis

We collected video recordings of all the sessions. We used a qualitative approach to thoroughly analyse 4-hours of video data and identify themes. Qualitative analysis is inspired by the interaction analysis framework [11], and also more broadly by a social science approach to qualitative analysis [13]. We analysed video using informal note-taking first and subsequently formalising the transcripts with Elan[6]. Figure 4 shows a view from one of the dome cameras.

4. FINDINGS

We identified qualitative differences between groups regardless of the conditions. For example 2 out of 8 groups tended to be non-talkative. We relate these variations to different group dynamics with a different understanding of musical improvisation from story-telling to music performance, and a different understanding of producing music with noise-type of sounds. If we had a continuum, on one extreme G2 and G4 adopted a story-telling approach, on the other extreme G3 and G6 adopted a mostly non-talkative music performance approach, whilst, in the middle, the rest of groups used both verbal and nonverbal communication with no apparent predominance of any of the two approaches. We analysed the video data focusing on space territoriality, and the types of conversations around tabletop collaboration and awareness. Findings show how ambisonics is explored differently between groups, and for some of them (G1, G2, G4, and G6), it made them discover areas of the tabletop surface and transition fluidly from individual to shared spaces; and for some others (most of the talkative groups), it explicitly helped them to identify more easily the different sounds and filters. Findings also indicated a greater association of sounds to realistic scenes for story-tellers (G2 and G4), and a greater immersive group experience using spatialisation in some groups (G2, G4, G5, and G8).

[6]See: `http://www.lat-mpi.eu/tools/elan`, developed by the Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands [24].

Figure 4: G5 interacting with SoundXY4.

4.1 Space territoriality

We observed that the use of territories was similar to the social protocols established in tabletop studies on territoriality [22] of personal (next to the person), group (centre of the tabletop surface), and storage (rim area) territories. However, we noticed differences in some groups about transitioning from individual to shared spaces and exploring the tabletop workspace. Here we give example vignettes to illustrate these findings.

Vignette 1 (G2, SP): The 4 members build a story together using discrete gestures of positioning on-off sound player objects on different parts of the tabletop surface, including the centre and corners, while explaining a collective story using turn-taking.

Vignette 2 (G6, SP): The group members are working individual voices in their personal spaces, and at some point they position a set of objects at the centre of the workspace and build in parallel, all together, a shared voice.

The above vignettes reveal that, for G2 and G6, ambisonics spatialisation helped them to discover certain areas of the tabletop surface. For G2, the SP condition promoted them to use not only individual spaces and the central shared space, but also in-between spaces. For G6, ambisonics spatialisation helped them to discover the centre of the tabletop surface as a shared area and to explore in team the tabletop surface, which indicates the approach supports fluid transitions between personal voices and group voices.

Vignette 3 (G1, SP): After individual explorations, group members build together in the central shared space different configurations with the tangible cubes, in a playful and active manner.

Vignette 4 (G4, SP): The group starts with all objects in the centre of the tabletop surface, then they choose cubes for themselves to play. P1 and P2 keep manipulating cubes next to themselves, whilst P3 and P4 build in collaboration by positioning the cubes in the centre.

These vignettes illustrate how ambisonics spatialisation supported versatility in the use of territories and roles. For G1, the SP condition helped to transition from individual to shared spaces. For G4, the SP condition supported versatile roles of two musicians collaborating in the middle shared space, whilst the other two musicians where manipulating tangible objects in their individual spaces.

4.2 Sounds, categories, and filters

We found several strategies for the identification of sounds, categories, and filters by different groups, regardless of the condition. We provide exemplar vignettes of these results.

Vignette 5 (G1, SP): The group is trying to identify the category of a cube [explosions category]. P4 manipulates the cube and says "so red is ..." [we hear a loop of a water splash] and P2 continues "gat sounds", and P4 seconds "gat sounds and gunshots and stuff". P3 contributes "that's why red is danger..." [we hear now a car crash] "... warning".

Vignette 6 (G8, NSP): The group decides to try cube by cube to have a clearer idea of the categories. P2 chooses a cube [voices] and starts trying different sounds of it [we hear a cat howling, a tibetan chant, a man groaning, a kid laughing, a cat howling again, a man laughing]. P2 says "Ok, so quite a lot of animal noises on that one".

Vignette 7 (G4, NSP): P2 is operating a cube [screeches category] with no visual feedback [the tabletop system is momentarily not tracking it], then P2 turns the side of the cube and drags it left to right [we hear a subtle metallic-ceramic friction, while others' cubes are heard louder], and says "mine is very inconsistent".

Using cubes that represent categories of sounds seems useful for both individual and group awareness in the two conditions: individual awareness is connected to a relation between identity of the tangible object and personal ownership; whilst group awareness is connected to a relation between the tangible object and the collective experience of discovering its identity, a situation supported by using 4 speakers where everybody can listen to the sounds because listeners share the same soundfield.

Vignette 8 (G2, NSP): P3 changes the side of the cube [we hear a man laughing]. P2 asks "oh, who's got that one?", and P2 replies "it's me".

Vignette 9 (G6, NSP): P2 puts a tangible cube he was playing from the tabletop surface to the rim area, and adds another cube [the tabletop system is momentarily not tracking it]. The other team members are manipulating cubes as well. P2 changes the side of the cube [we hear a car crash very loud]. P2 lifts the cube up and down again [we hear again a car crash very loud]. P2 says "that's me?", and P1 replies "yes".

As shown in the above vignettes, in most groups we found explicit questions about awareness issues of individual and group actions related to identifying who is manipulating a particular sound, and also related to identifying own sounds. Identifying the own voice as well as others' voices is relevant here as an aspect of musical tabletop collaboration and awareness. For these groups, these issues happened less in the SP condition.

Vignette 10 (G8, SP): P3 proposes to try whether changing the side of the "modifier" [filter] matters. P2 replies "no, it is very subtle". P1 asks "are all the blacks [filters] the same?", and P3 replies "no". P2 adds "they modify the sounds slightly differently" [from previous experience in the NSP condition]. P1 suggests "this black is the same than this black one?", and P3 comments "shall we try it?" [they try a couple of black filters]. P2 affirms "that's different!", and P3 confirms "that's better". P4 seconds "there is difference" while lifting up and down a filter next to a sound player.

This vignette illustrates how a few groups (G1 and G8) explicitly commented about the subtlety of the filters, but in SP, they noticed greater changes in the sounds being modified by different filters, which points to greater awareness of the filters in the SP condition.

4.3 Realistic scenes

Groups tended to associate the music to films, particularly horror films, regardless of the condition (G2, G4, and G7). In SP, P2 in G4 said "it's like the soundtrack of some movie", and P2 in G7 described it as "noises from film"; in NSP, P1 in G2 and P2 in G7 referred to a "horror film". Also in both conditions, we find description of or associations to situations: "a supermarket" (P2 in G4, SP), or "that's horrible like the computer humming back in the background" (P2 in G2, NSP). However, we discovered that in SP, the 2 groups who adopted a story-telling approach, attributed the musical output as more realistic, and associated the location of the sound player objects on the tabletop surface to the location of speakers. Particularly, we found comments about the realism of the musical events, which signals a greater immersion and awareness of the group experience, as illustrated in the following example vignettes.

Vignette 11 (G4, SP): All participants are manipulating tangible cubes. Then, P2 explains "when we manipulate this, all I can think of is scenes of places, and things happening".

Vignette 12 (G2, SP): After having built a story all together using sound player objects, P2 says "we don't have the time or patience to create another scene, have we?".

In these examples we can see an association of the musical activity to the creation of scenes, which only appears in the SP condition. This involves a connection of musical sequences to places and situations, which points to a greater immersion and awareness of the group musical activity. We also found evidence in the SP condition of associating the sounds to realistic "scenes", and of associating the position of the sound sources (cubes) to where the sound was located in the soundfield, as shown in the following vignettes.

Vignette 13 (G2, SP): Previously, the group positioned a sound of a fire [fire crackles] in the corner referring to "a campfire in the corner". A few minutes later [we hear the sound of a thunderstorm], P1 turns his head to the speakers, then he turns back his head looking at the tabletop surface, points to his back left speaker, and says "the fire sounds really nice, it sounds as it is actually fire". Later, P2 says "it seems realistic at least in terms of urban noises".

Vignette 14 (G2, SP): The group is listening to a "scene" they have created by looking at the objects [a sound of fire crackles in one corner of the tabletop surface, a sound of a thunderstorm in another corner]. P2 says "I wonder whether it is interesting where we put these [tangible cubes] cause we wanted the fire in the corner, if it had some significance, we created a geographical representation as well as the sound one". P1 adds "it could be a suggestion [to be added to the software]... geographical representations that change something".

Vignette 15 (G4, SP): P4 turns his head looking at the speakers, then turns it back and asks about the 4 speakers and whether it is stereo. P1 replies "it could be 4 channel, you could actually orient the proximity of the cube to the speakers, which channel to use".

The above vignettes show how some groups (G1, G2, and G4) had conversations about the perception of ambisonics effects, although non-explicit, such as the mapping of the location of tangible objects on the tabletop surface to the location of speakers, which indicates workspace awareness.

4.4 Musical immersion

We found differences in describing the musical outcome, pointing to a greater association of producing enjoyable music in the SP condition. In the NSP condition, there were a few comments (G1, G4, G6, and G8) about the musical outcome such as "for a moment something nice" (G4 P2) or "we are very close to a preview performance, aren't we?" (G4 P3); whilst in the SP condition, we identified more comments in more groups (G2, G3, G4, G5, G6, and G8) about engaging with the group musical output such as " I think we have reached some musical plateau" (G4 P2), "it's music now" (G8 P3), "we should record a song like this" (G6 P3), or "we've arrived, we are doing Stockhausen now" (G5 P1).

5. DISCUSSION AND CONCLUSION

Findings showed how the use of ambisonics spatialisation in tabletop collaboration is "beyond one-size-fits-all", as group dynamics are different, and so it is explored differently. Rick et al. [20] recognised these differences in group dynamics and highlighted the importance of supporting them on interactive tabletops for promoting collaborative learning. For those groups where using ambisonics spatialisation had a greater impact to space territoriality, it allowed them to discover and use individual vs. shared spaces distributed respectively next to themselves and in the centre and corners of the tabletop surface. Our study shows, in contrast with Hancock et al.'s study [6] in the context of auditory icons, in that case using localized sound with individual speakers vs. mixed sound with one shared speaker without spatialisation, that simultaneous support of awareness for both individual and group actions is possible.

This study also showed how mixed groups engaged with the music performance process using different working styles from story-telling to music improvisation. Blaine and Perkis [1] experimented with audio delivery to mixed groups of people with different musical backgrounds, and found that the best choice was to combine individual speakers with a surround sound system. We here highlighted a more ecological approach, using only a surround sound system to support the overall group musical experience with no detriment of the individual musical experience. Whilst non-talkative groups tended to have an immersive experience in any case, using ambisonics spatialisation, we found evidence of a greater engagement with the musical activity as an immersive experience for the most talkative groups, including associations to realistic situations for those strictly story-tellers. This approach seems thus promising for investigating further how to best deliver immersive musical experiences using auditory feedback with tabletop systems that can inform users at both individual and group levels in a democratic setting.

6. ACKNOWLEDGMENTS

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