Chapter 11
Computer Musicking: HCI, CSCW and Collaborative Digital Musical Interaction

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Abstract We are interested in the design of software to transform single user devices such as laptop computers into a platform for collaborative musical interaction. Our work draws on existing theories of group musical interaction and studies of collaboration in the workplace. This chapter explores the confluence of these domains, giving particular attention to challenges posed by the auditory nature of music and the open-ended characteristics of musical interaction. Our methodological approach is described and a study is presented which contrasts three interface designs for collaborative musical interaction. Significant results are discussed, showing that the different interface designs influenced the way groups structured their collaboration. We conclude by proposing several design implications for collaborative music software, and outline directions for future work.

11.1 Introduction

Novel systems for group musical interaction such as touch surfaces (Jordà et al. 2007) and multi-player instruments (Fels and Vogt 2002) represent an exciting insight into the future of music technology; however many of these systems rely on bespoke hardware which prevents them being widely available. An alternative to developing new physical interfaces is to design software that transforms single user devices such as personal computers into a platform for collaboration. We believe that there are wide and under-explored possibilities for such environments; however at present the majority of music software is designed for single user operation, and there are few readily available technologies to support musical collaboration beyond the synchronisation of single user devices. MIDI and NINJAM are examples of

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S. Holland et al. (eds.), *Music and Human-Computer Interaction*, Springer Series on Cultural Computing, DOI 10.1007/978-1-4471-2990-5_11,

synchronisation-based technologies. MIDI is a serial communication protocol that enables multiple devices to be slaved to a single timing source, while NINJAM enables audio to be synchronised over the Internet to facilitate geographically distributed collaboration (Mills 2010).

Systems for musical collaboration can extend beyond synchronisation by allowing more complex sharing of musical contributions, ideas and representations within a group of musicians. For instance, distributed graphical interfaces can allow multiple users to interact simultaneously with a collection of shared on-screen virtual instruments, or collaboratively arrange items on a shared timeline. In addition to facilitating more complex interrelations between musicians' contributions, a distributed software environment could provide support and scaffolding for collaboration by, for instance, displaying information about the authorship of specific contributions, allowing annotations to be attached to the shared workspace or allowing individuals to work with varying degrees of privacy. The technical challenges of this approach have been explored by laptop and mobile phone orchestra projects (Dannenberg et al. 2007; Wang et al. 2009; Trueman et al. 2006) and geographically distributed software environments such as the Daisyphone (Bryan-Kinns and Hamilton 2009), LNX Studio[1] and Ohm Studio[2]. However less attention has been paid to the way people use these environments, or to the effect different interface designs have on collaborative group processes.

Our research deals with co-located interaction where groups of musicians create music using a shared software interface distributed across multiple computer terminals. Some of the issues we are particularly interested in are illustrated by the following examples. Firstly, when musicians can edit each other's musical contributions the issues of ownership, territory and privacy become important. Questions arise such as whether users should be able to edit each other's work at any point or should the interface provide mechanisms that give authors control over sharing and access to their musical contributions? Secondly, in a shared interface where musicians are not tied to specific instruments or equipment, the roles they play within the group may become more fluid. How does this freedom impact on the way groups structure their collaboration? Third is the issue of awareness, or knowledge of others' activities within the shared workspace. If musicians can work on musical ideas privately, or transition between different roles and activities, how do they maintain awareness of each other's actions and how might an interface support maintenance of such awareness. These issues are fundamental to the design of group musical environments as they define the way groups collaborate, however at present there is limited research investigating the way groups of people engage in musical collaboration using computers, and consequently there are few existing guidelines for the design of future systems.

We propose the term Collaborative Digital Musical Interaction (CDMI) to describe the phenomenon of technologically supported group musical interaction.

[1] http://lnxstudio.sourceforge.net/

[2] http://www.ohmstudio.com/

This term bounds the concept in three ways. Firstly, it stresses the collaborative nature of group musical interaction. Secondly, it emphasises the process of musical interaction rather than concentrating on a particular musical activity such as performance, composition or improvisation. Finally, CDMI focuses on the use of digital technology to support collaboration, but does not commit to a specific device or platform. This chapter outlines CDMI by drawing on research from within Human Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW). Our understanding of music is informed by studies of conventional musical interaction, the theory of Musicking (Small 1998) and studies of group creativity (Sawyer 2003). Our methodological approach to studying CDMI is described, and illustrated through the presentation of an experimental study. We conclude with a number of design concerns for CDMI and more general reflection on how studying CDMI can contribute to HCI and CSCW.

11.1.1 Music and Collaboration

Computer Supported Cooperative Work (CSCW) is a specialised branch of HCI focused on understanding the nature of group work and designing appropriate technology to support collaboration between people (Bannon and Schmidt 1991). Although generally not concerned with musical interaction, CSCW represents a substantial body of research into the nature of group-work and the design of technology to augment collaboration. CSCW can be viewed as an umbrella term for all HCI research concerning multiple users, however Hughes et al. (1991) stress that all work, no matter how individual, occurs within a wider social context, and therefore CSCW might usefully be regarded as a paradigm shift within the Computer Science community away from the view of HCI as interaction between individual people and computers, and towards a social view of work and interaction as a collective phenomena.

Key research themes for CSCW are the design and evaluation of collaborative and multi-user software termed ‘groupware’, and the study of group interaction in workplaces. Workplace studies often employ ethnographic techniques (Heath et al. 2002) and draw on frameworks such as distributed cognition (Furniss and Blandford 2006; Hutchins 1996) to develop rich accounts of group work activities in work settings which feature intense group coordination. These studies typically present detailed analysis of a number of specific incidents within the observed interaction to characterise the relationships and processes that take place. Controlled experimental studies in CSCW typically investigate specific aspects of group activity by presenting work teams with simplified tasks such as completing jigsaw puzzles (Scott et al. 2004) or work-like activities such as designing a post-office (Dourish and Bellotti 1992). This type of study environment provides more flexibility in data collection and control over the activities participants engage in. Groupware evaluation is often based on an experimental approach where groups engage in an activity using interfaces with different features or support for collaboration. Typical observations are time to complete the task, quality of the solution, ease of collaboration and user satisfaction. Gutwin and Greenberg (1999) describe these features as *Product* (the result or outcome of a task), *Process* (the activity of the group while developing their solution), and *Satisfaction* (feelings about the work and interaction with the system).

Workplace studies in CSCW often base observations in high-risk environments such as control rooms. In these environments full concentration is needed, and peoples' activities are time-critical, highly interdependent and potentially life threatening. While musical interaction is clearly a lower risk activity, for the musicians involved the interaction may exhibit similar attributes to those found in other workplace activities. Real-time musical interaction is typically time-critical, and musicians are especially sensitive to timing accuracy on many different musical time scales. Group musical interaction can also be highly interdependent, with musicians using and broadcasting cues for changes and transitions (Gratier 2008; Healey et al. 2005), adapting their own contributions in response to what they hear from others in the group (Sawyer 2003) and helping each other recover from mistakes (Gratier 2008).

As well as similarities, there are existing points of confluence between CSCW and music technology research. Gates et al. (2006) uses the theory of Workspace Awareness (Gutwin and Greenberg 2002) to discuss the ways in which DJs maintain awareness of their audience while performing. Merritt et al. (2010) explore visualization techniques to promote awareness in collocated musical interaction. Bryan-Kinns and Hamilton (2009) and Fencott and Bryan-Kinns (2010) draw on aspects of CSCW to explore interface design issues for collaborative music software. Gurvich (2006) discusses privacy and awareness in an online music environment and Klugel et al. (2011) draws on studies of co-located collaboration to inform the design of a tabletop music interface.

The aspects of CSCW research we apply to CDMI are those associated with awareness, coordination, and the analysis of communication. Our research takes the Workspace Awareness framework (Gutwin and Greenberg 2002) as a starting point for understanding the interrelationship between people engaged in co-located musical interaction using a shared software environment. Their framework is informed by observational studies of co-located workplace activities, and identifies the types of information people hold or may attempt to gather while collaborating in work tasks.

11.1.2 Musical Interaction

This section draws on theories and observational studies of musical interaction to highlight the ways in which group musical interaction can be regarded as distinct from other forms of group work and collaboration. This in turn leads to implications for both design and evaluation of new CDMI systems.

Small (1998) proposes that music is constructed by those who engage in the act of 'Musicking', a social ritual through which participants explore their identity and relation to others. Small argues that activities such as listening to a personal stereo, playing in a rock band, dancing and attending a classical music concert can all be regarded as acts of Musicking. Musicking is an activity commonly associated with Flow (Csikszentmihalyi 1990) and Group Flow (Sawyer 2003), while the acknowledgement that all Musicking is a social and cultural phenomenon parallels the assertion that all work activities are social (Hughes et al. 1991).

Small argues that traditional philosophies and theories of music mistakenly value musical artifacts such as scores and recordings, while ignoring both the actions of creation and perceptions or responses to it. Sawyer (2003) illustrates the importance of the creative process by stressing that artists frequently modify their work, that inspiration does not always precede execution, and that creators do not share all their acts of creativity with the world. For this reason music has been described as a problem-seeking activity (Holland 2000) where the product is the process (Makelberge 2010; Sawyer 2003) and those involved are concerned with exploring the medium, discovering new ideas and finding a creative problem to resolve. In a group context the individuals may also be interested in exploring their creative relationship to others in the group.

An association has frequently been drawn between musical interaction and face-to-face conversation (Healey et al. 2005; Gratier 2008; Small 1998; Bryan-Kinns and Hamilton 2009). Healey et al. (2005) identifies a turn-taking process used by participants to introduce new musical themes. Sawyer (2003) argues that improvisational music making exhibits many of the same properties as everyday conversation, including emergence, contingency, and a reliance on intersubjectivity. Sawyer (2003) also notes that while musicians frequently use conversation as a metaphor for describing improvisation, in musical improvisation there is no turn-taking as all musicians perform simultaneously.

Although there are traditions for which notation is a central aspect of musical culture and understanding, music is primarily an auditory domain. This represents a key distinction between CDMI and research in CSCW concerned with the generation of visual artifacts such as documents, drawings and diagrams. We believe working with sound has a number of implications for the way people collaborate. One crucial implication relates to Clark and Brennan's theory of communicative grounding (Clark and Brennan 1991), where it is noted that 'indicative gestures' such as looking, pointing and touching are important means by which interlocutors arrive at an understanding that they are both referring to the same object. In a purely auditory situation these visual gestures may not be as useful as it is not possible to point at sounds.

Coughlan and Johnson (2007) identify many forms of representation used by musicians to convey ideas and refer to aspects of the music. These include playing their instruments, vocalising, gesture and verbal communication. This illustrates the idea that a musical gesture is both an act of communication and an aesthetic product in its own right (Gratier 2008; Bryan-Kinns and Hamilton 2009). Coughlan and

Johnson (2007) argue that an understanding of how musicians represent and convey ideas is crucial to the design of new musical interfaces and software environments, while Nabavian and Bryan-Kinns (2006) note that musicians often successfully collaborate while holding entirely different cognitive representations of the music they are co-creating.

Healey et al. (2005) describe the way musicians use the physical space around them as a collaborative resource, arguing that musicians use the orientation of their bodies and musical instruments towards the physical 'interaction space' as a sign of their (dis)engagement with the ongoing improvisation. However the role of this physical interaction space may be reduced when musicians are seated at computers using a shared software interface, as the musicians may be less free to move while still in reach of their computer. Compared to acoustic instruments, the abstracted nature of the shared software interface and generic physical input devices may provide less opportunity to gesture.

To summarise, our conception of music draws on the theory of Musicking, and views music as an activity in which the participants may be equally concerned with the process of creating and exploring as they are with arriving at a musical outcome. As a domain, music is in many ways distinct from visual and spatial mediums, and this has implications for the way people go about discussing, referring to and representing ideas within and about it. CSCW provides some insights into observable features of collaboration, however the tasks used in CSCW research are often more aligned to product outcomes.

11.2 Approach

We use a controlled experimental approach to investigate interface design considerations for CDMI. During experiment sessions groups of musicians make music using collaborative music software developed specifically for our research. We present the groups with different software interface designs and observe how this impacts on the way they use the software, their approach to organising collaborative activities and their subjective preferences. This approach is inspired by studies such as Gutwin and Greenberg (1999), where interface based awareness mechanisms are manipulated to assess their impact on group collaboration usability. Our additional focus on qualitative measures extends the traditional CSCW approach to account for some of the distinct experiential properties of CDMI. Typical research questions driving our studies are:

- How does manipulating the degree of privacy individuals have in a shared musical interface alter the way they work together?
- How do different forms of audio presentation influence the way groups coordinate and organise the shared workspace?
- How do mechanisms for gathering authorship information alter the way groups discuss the music they are creating?

We collect and analyse interaction features using log data captured by the software. We use video observation to study participants' discussions during the interaction, and we hold group discussions with the participants to discover their interpretations of the experience. Finally, we employ multiple choice questionnaires to capture demographic and preference information. Observations include:

- The amount of musical contributions participants make during the interaction
- The amount of editing and participants perform on contributions
- The degree musical contributions are co-edited by multiple participants
- The topics of conversations participants engage in
- Spatial use and arrangement of the software interface by participants
- The emergence and negotiation of roles within the interaction

As illustrated by the study presented subsequently in Sect. 11.3, these features can tell us a lot about the way participants used the software and structured their collaboration. Many of the quantitative log measures can be directly compared between different interface conditions to reveal the effects brought about by different interface designs, although features such as roles and conversation require analysis of video and audio recordings.

The software used in our studies has been designed specifically for our research, and our approach is therefore in line with others who develop musical interfaces specifically to conduct experiments, rather than applying posteriori evaluation techniques to previously developed artifacts of new musical technology (Marquez-Borbon et al. 2011). Creating software specifically for performing research has several advantages over attempting to apply evaluation techniques to existing software. Primarily, as noted in Sect. 11.1, there are few existing collaborative music making applications which support the type of interaction we are interested in studying. Secondly, using bespoke software provides us with complete control over every aspect of the functionality, appearance and behavior of the software. This is beneficial as it allows us to implement multiple interface designs for the same underlying software model, and enables us to explore interface and interaction possibilities that might not be present in existing third party applications. Furthermore, using bespoke software allows us to limit the capabilities of the software so as to be suitable for short experimental sessions. This is important as the sessions are time-constrained and it is essential for participants to reach a competent level with the software in a short amount of time. Finally, using novel software introduces control over the influence of participants' previous experience by ensuring that all participants are using the software for the first time.

However, there are several considerations to using bespoke software. One such concern is that participants need to be trained in the use of the software. Where appropriate using interaction metaphors from existing music software may help people familiarise themselves, although time must still be allocated to training in each experiment session. Secondly, the design and affordances of the software will direct participants towards specific interactions, and generalisations about study findings must be balanced against the idiosyncrasies of the experimental software. Thirdly, ordering effects may be introduced as participants become more experienced and familiar with the software over the course of the experiment session.

We use mailing lists and forums to recruit participants. Our recruitment seeks to find people with an interest in making music and/or experience using computer music software. While social and musical rapport are important aspect of group musical interaction (Sawyer 2003; Small 1998) several factors have motivated us to study groups of people who have not previously worked together. Firstly, established groups will arrive with a history of experiences to draw upon, a shared musical repertoire and established working strategies. These working strategies and means of communication may be obtuse and difficult to interpret or study. Secondly, studying musicians who have previously worked together may introduce bias between groups, as not all groups will have an equal level of experience working together. Thirdly, the group's musical repertoire, group musical knowledge and established working strategies may be stronger than or resilient to the effects brought about by the experimental conditions under investigation. Studying groups of individuals who are not familiar with each other introduces control over differences in the level of group experience, as all participants will have an equal level of familiarity with one another. We acknowledge that participants will need to build a social and musical rapport and although it is less common for musicians to play with people they have not previously worked with, this is not an entirely unnatural situation. Finally, recruiting groups of strangers simplifies the process of recruitment and allows us to use a larger sample of participants.

11.3 Study

To demonstrate the practical application of the methodology outlined above, this section describes a study focusing on how varying the amount of privacy and awareness provided by a software interface impacts on the process of musical collaboration. The study design uses three experimental conditions, each providing participants with different level of privacy. This design is intended to reveal the different approaches taken by collaborators when given varying degrees of information about each other's activities. For instance introducing the ability for someone to work in isolation from the group creates a situation where collaborators have potentially heterogeneous representations of the music, with each participant listening to a mixture of personal and group-level contributions. Given this situation, participants may need to work harder to maintain awareness of one another, or may develop alternative strategies for managing the collaborative process. Specific features addressed in our analysis are how awareness information is gathered and exploited by collaborators, the emergence of roles, and how musical contributions are introduced to the group.

Participants used a bespoke software environment that allows for the creation of 'electronica' style music based on synthesised sounds, drum beats and melodic loops. Music is made by deploying 'Music Modules' within an on-screen workspace

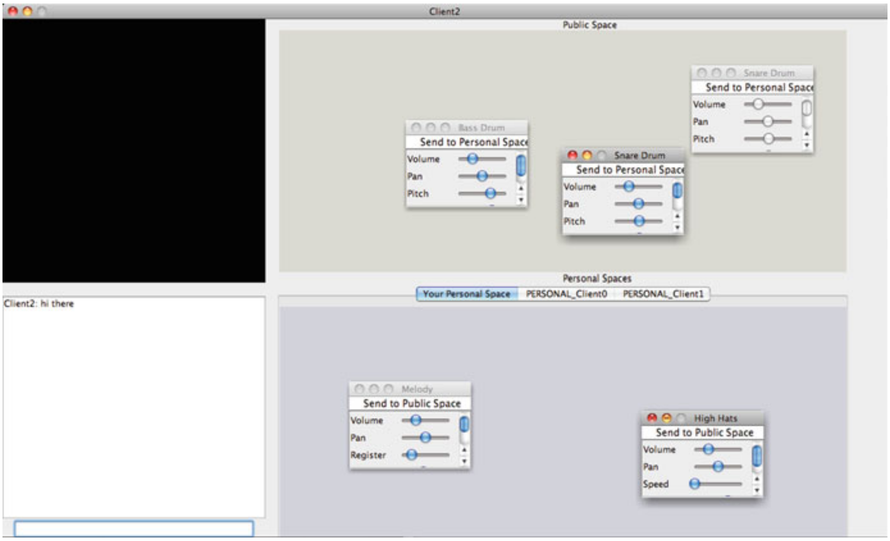

Fig. 11.1 User interface for condition C2

mirrored across multiple computers connected via a local network. Music Modules are windows containing controls to manipulate their musical behavior (see Fig. 11.1). Changes to module controls are immediately reflected to all connected clients via a server application which logs all events and maintains a database of the music being created. Each module offers control over volume and stereo pan position, plus a number of module specific controls. By using the 'music module' metaphor the software is similar to commercial music applications which feature 'virtual instruments', however it is important to stress that our software does not use the timeline metaphor common to digital audio workstations. Although the software presents participants with a shallow learning curve it does require a degree of domain knowledge, for instance an understanding basic music technology terminology.

The study had three experimental conditions. In the first interface condition (C0), participants worked in a shared and public workspace where all music was audible to their collaborators and all changes in the graphical interface were immediately visible to others. In the second condition (C1), each participant was provided with a private workspace in addition to the public workspace. The private workspace could not be accessed by their collaborators. In the third condition (C2), an additional interface feature allowed participants to view and listen to the contents of their collaborators' private workspaces. Switching workspace 'views' was achieved using a tabbed window that allowed users to select either their own personal space or the personal space of one of their collaborators. C2 therefore weakened the level of privacy provided and increases the potential for participants to gather information about the activities of their collaborators. Table 11.1 summarises the interface conditions. Participants received a personalised audio mix of the modules currently

Table 11.1 Summary of interface conditions

Condition	Description
C0	Public space only. Music modules are audible and visible to all participants at all times
C1	Public space + Private space. As C0, plus participants are able to create or place modules in their own Private space. Modules in a participant's Private space cannot be seen, edited or heard by other users
C2	Public space + Personal space. As C1, except participants can view and hear each others' Private spaces using a tabbed window. For this reason the Private space is referred to as a Personal space

in the Public space and the modules in their Private space (in C1) or in the case of C2 the modules playing in the currently selected Personal Space. Figure 11.1 shows the software interface for C2.

Music Modules could be deployed in Public or Private workspaces and could be freely transferred between the spaces. When modules were placed in the Public space they were editable, visible and audible to all collaborators, while modules within a user's Personal space were only editable by the owner of that space.

Participants were given 15 min with each condition plus an initial training session. The presentation order of conditions was permuted to control for ordering effects. Audio was presented individually to each participant through headphones, thus ensuring that private audio was not audible to others. The software included a text-chat tool for communication, although participants were free to communicate verbally. Participants were each seated around a table and provided with a personal computer.

11.4 Results

Twenty seven participants were recruited into nine groups of three people. Participants received financial compensation for taking part in the experiment. A multiple choice questionnaire was used to collect demographic information. Twenty-four participants could play a musical instrument. Two participants described their level of proficiency as 'beginner', eight participants described their level of proficiency as 'intermediate', nine participants described themselves as 'semi-professional', four described themselves as 'professional' and four gave no response. Twenty-four had written musical compositions by themselves and 19 had written musical compositions with other people. When describing their level of computer literacy 2 participants selected 'beginner', 12 participants chose 'intermediate' and 13 chose 'expert'. Sixteen participants had previously used multi-user computer software such as collaborative document editors or online games.

Table 11.2 presents a simplified summary of the interaction log data collected automatically during the participants' interaction with the software. To save space the totals have been summed across groups for each experimental condition. Column C0 contains n/a for features which were not observable in that interface condition.

Table 11.2 Log file data grouped by feature

Feature	C0	C1	C2
Total module creations	220	339	333
Public module creations	220	43	59
Private/personal module creations	n/a	296	274
Public module deletions	138	51	97
Private/personal module deletions	n/a	103	101
Total module edits	3,752	4,527	4,497
Public module edits	3,752	2,152	2,277
Private/personal module edits	n/a	2,375	2,220
Module transfers to public	n/a	237	232
Module transfers to personal	n/a	74	96

The Friedman Test was applied on per-participant totals to compare the absolute amount of module creations, deletions and edits:

- Significantly more Public Creations occurred in C0 than in C1 or C2 ($p < 0.0001$, $df = 2$ $csq_r = 25.8$).
- Significantly fewer creations occurred in total for C0 ($p = 0.0029$, $df = 2$, $csq_r = 11.69$).
- Significantly less Editing in total took place in condition C0, compared to conditions C1 and C2 ($p = 0.0344$, $df = 2$, $csq_r = 6.75$).
- Significantly more Public Module Deletions took place in condition C0 than in conditions where participants also had a Personal Space ($p = 0.0293$, $df = 2$, $csq_r = 7.06$).

Co-editing was counted where one participant edited a module they had not initially created, and was calculated per participant as a proportion of all edits made by that participant. Significantly more co-editing took place in condition C0 (where participants only had a Public Space) compared to conditions C1 or C2 ($p = 0.0019$, $df = 2$, chi-squared $= 12.57$).

The Wilcoxon Signed-Ranks Test was used to compare between conditions where a Private Space was made available to participants (Conditions C1 and C2):

- In C1 and C2 significantly more module creations took place in the Personal Space than in the Public space (for C1 $p = 0.0001$,$w = -331$, $z = 3.97$, for C2 $p = 0.0002$, $w = -307$, $z = -3.68$).
- There was no significant effect on the number of times modules were transferred between workspaces in either C1 or C2.

A post-test questionnaire was used to collect quantitative preference data from participants. Participants were asked to choose which condition they felt most applied to a series of statements. Bold indicates statistically significant statements using the Chi-test (Table 11.3).

Dialog was transcribed from video recordings. Space prevents us from presenting entire transcripts, however the following vignettes demonstrate typical exchanges between participants while working together. In these extracts individual participants are identified by a letter.

Table 11.3 Questionnaire responses

Statement	C0	C1	C2	Total	Chi-test P value
The best music?	5	12	8	25	0.23
I felt most involved with the group	6	9	10	25	0.59
I enjoyed myself the most	5	13	8	26	0.07
I felt out of control	12	2	8	22	**0.04**
I understood what was going on	6	10	7	23	0.51
I worked mostly on my own	3	10	13	26	**0.05**
We worked most effectively	6	11	9	26	0.16
Other people ignored my contributions	10	6	4	20	0.22
The interface was most complex	7	3	14	24	**0.01**
I knew what other people were doing	8	2	11	21	0.06
I felt satisfied with the result	5	9	9	23	0.5
We edited the music together	4	11	8	23	0.2

Participants sometimes ran into problems identifying the cause of specific features within the music:

B: it's really difficult to single out what's doing what
A: exactly, yeah
C: yeah
A: there's someone somewhere that's, there's one of them there that's making the
A: *repeatedly clicks mouse* how about this one down here?

There are two points to draw from this extract. Firstly, B expresses the problem of identifying the music module responsible for a certain sound within the musical mix, stating it is difficult to single out what is doing what. B is attempting to gather awareness information about the source of a sound, and in doing so draws attention to the way graphical interfaces for music detach the means of visually defining a musical event from the auditory result; the two operate in different modalities. The second point about this incident relates to the way A draws Bs attention to a specific item within the interface. Participant A uses both the spatially consistent workspace layout across all users' screens and the knowledge that his actions are immediately reflected on all other screens as a resource to make an indexical reference to a music module by repeatedly modifying a parameter (the repeated mouse clicks) and verbally referring to the module as 'down here'.

It is important to note that B is not at this stage trying to ascertain who created the music module he is searching for, and this highlights a situation that the Workspace Awareness framework (Gutwin and Greenberg 2002) cannot fully describe, as it does not take into account awareness of authorship by non-human entities. It would therefore be feasible to suggest a What-Authorship element to account for an awareness of which non-human agent is responsible for which sounds within the unfolding music.

Participants rarely moved around the table or attempted to view each other's screens, except when assisting each other in the use of the software interface. The following excerpt provides such an example:

B: *Removes headphones from one ear.* "How do you"
B: *Places headphones around neck.* "get it into the public space?"
A: *Looks over and removes headphones.*
C: *Looks over and removes headphones.* "How do you what?"
B: "How do you get your thing into the public space?"
C: *while replacing headphones.* "Click on send to pub. Send to public space"
A: *Pointing with finger but looking at own screen.* "Erm, click on Personal space"
C: "Below the title there"
C: l*eans over and points to something on B's screen.*
A: *leans over to point at B's screen.*
B: "Oh, ss, yeah, yeah."
A: *Replaces headphones*
B: *Replaces headphones*

Group interviews were conducted at the end of each session. The discussions were structured around a set of pre-prepared topics including the use of personal, private and public spaces, approaches to gathering awareness of others and the emergence of roles. To save on space, extracts from the group discussions are incorporated into the following section.

11.5 Discussion

Video of the interaction suggests participants engaged in improvisation type activities, as there was rarely any initial discussion about the musical direction of the piece or formulation of an overall plan for how the music should sound. This suggests that their style of working, and the music they created, was emergent and contingent on the group interaction. During group interviews some participants described the activity as like a 'jam', although the majority of participants did not describe the nature of the activity or liken it to other musical experiences.

The log analysis reveals that participants made extensive use of the Private Space and Personal Space when they were made available. When a Personal Space or Private Space was included in the interface (conditions C1 and C2) music modules were almost always created within it, rather than in the Public space, and significantly more editing took place when participants had a Personal or Private space. Participants noted working least on their own in condition C0, which did not feature a private or public workspace. In interview the public space was described as the 'actual composition' or the 'main space', while participants often described the Personal and Private spaces as places to experiment, test ideas and formulate contributions, as illustrated in the following statement:

> I quite liked to try things out there, so instead of just adding a [music module] in, I'd try it out and then tweak it a little bit and then move it up, afterwards

Post-test questionnaire responses show that the C2 interface was seen as the most complex, however during interviews participants did not express concern over it being too difficult to use. One frequently raised issue was the problem of distinguishing between audio in the public and private spaces. The interface provided no explicit mechanism for separating audio from the two spaces, leading to confusion about which music modules were responsible for which sounds and which sounds were audible to other participants. This is demonstrated by the dialog extracts in Sect. 11.4, and statements made in group discussions, such as:

> and it's, and it's, it's hard to , you can't isolate, a element, or a sound

The groups adopted a variety of working strategies, which appeared to be influenced by the inclusion of Personal and Public spaces. For instance some groups exploited the ability to create contributions in private by agreeing initially to work individually and then share their ideas with the group. One participant suggested during the interaction:

> why don't we, erm, like start off just a simple little thing looping at the top, and then we each build a little section each and then, to bring in

The results of this study pose a number of design implications for CDMI. Firstly, the plurality of approaches to collaboration adopted by the groups suggests that interfaces should not enforce a particular style of working, but instead should be flexible and adaptable to the working style of the group. Secondly, where interfaces offer degrees of privacy this needs to be balanced with mechanisms to provide appropriate levels of awareness to others, or the increased potential for private work may interfere with the group members' ability to formulate coherent musical contributions. Given the extent to which participants exploited the private and personal spaces to formulate contributions, and the role this played in shaping the way groups collaborated, we argue that this is a key design consideration. Thirdly, the way audio is presented, and the ways in which it can be interrogated need to be considered by designers. In particular interfaces could provide an auditory means of distinguishing between music contributions that are shared and private, and interfaces could provide mechanisms for identifying or highlighting specific contributions within the audio mix. These features may aid individuals in identifying specific musical elements, and may also contribute to collaborative activities such as establishing indexical references.

11.6 Summary

Our research draws on CSCW literature and studies of group creativity in musical improvisation to compare software interface designs for Collaborative Digital Musical Interaction. We have identified a number of distinctions between CDMI and CSCW type activities. Some of these distinctions are related to the problem seeking nature of musical interaction. Other distinctions are due to the auditory nature of music, and the implications this has for the design of collaborative systems.

A study was presented in which nine groups of three musicians used three software interfaces to make music together using networked computers. Each interface variant provided users with different degrees of privacy. Changes in the interface design caused significant differences to the way the participants used the software and the way the groups worked together. Specifically, when given the opportunity, participants made extensive use of the ability to work individually and control access to, and release of their musical contributions. When made available, the ability to work privately was exploited by participants from all groups to formulate ideas in isolation before making them available for others in the group to hear and edit. This impacted on the way the groups worked as a whole by facilitating more varied working strategies, for instance the inclusion of privacy allowed groups to adopt a strategy that encouraged isolated work initially, followed by a period where ideas from different people were combined.

While the graphical interface made a clear distinction between private and public contributions, our design did not reflect this distinction through the way audio was delivered to users. This caused a breakdown in awareness at individual and group level, as participants encountered difficulties establishing which musical elements were publicly available, which were personal to them, and which graphical interface elements were responsible creating these sounds.

Questionnaire based measures produced statistically significant results. Participants consistently identified C2 as the most complex, and C0 as least conducive to individual work. In interview some participants stated preference for interfaces that incorporated aspects of privacy, however subjective preferences are difficult to attribute to any single experimental factor, as they may be associated with many aspects of the experience, such as the music being made or the flow and coherence of the group.

We believe there are many ways the study of CDMI can inform our understanding of work and collaboration. The auditory nature of musical interaction distinguishes it from the visual and spatial activities typically studied in groupware evaluation, and therefore an understanding of this distinction may inform the development of collaborative systems for less spatial or visually oriented tasks. Compared to primarily visual domains, there is at present limited research directed towards human interaction and collaboration in auditory domains, and this is clearly an area music interaction research can contribute to. Additionally, Sawyer (2003) posits that group creativity in music is in some ways similar to group activities in the workplace, and consequently studying the design of technological support for group music making and understanding the human interaction associated with CDMI may have implications for the design of real-time groupware to support activities that involve problem-seeking creativity or the generation of novel ideas and design solutions.

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