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The Effect of Prototyping Material on Verbal and Non-verbal Behaviours in Collaborative Design Tasks

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Abstract: This paper reports a study of 23 controlled experiments, with a total of 99 individual tasks, between pairs of designers collaborating to solve a simple design task using four different types of prototyping media. The aim of the study was to correlate verbal and non-verbal behaviours across different types of media with a range of measurement indicators. Using innovative movement trail images we show how collaborative sketching activity results in attenuated use of interpersonal collaborative space when compared with cardboard, clay, and Lego, which provoked intensive collaboration. Furthermore, the sketching (control) condition resulted in pre-conceived ideas being executed when compared with the three-dimensional media, where ideas emerged through collaboration. This finding suggests that increased creativity in design can result through the careful choice of prototyping media at the beginning of the design process.

Key words: Prototyping, Collaboration, Discourse, Gesture, Interpersonal Space,

1. Introduction

Although studies into the social, collaborative and conversational aspects of designing are becoming increasingly popular, few studies have looked at the close relationship between the physical materials of a design process and the kind of talk that those physical things enable. While there have been both detailed studies analysing design talk and studies looking at the physical artefacts produced during a design process (including sketches, drawings, gestures, and prototypes), the interactive relationship between the two things – conversation and artefacts – has not been looked at in detail. Ferguson's [2] general typology regarding the different functions for sketches produced during designing as being thinking, talking, and communicating has usefully pointed the way for further research about the different types of interaction between design talk and artefacts produced while designing.

In previous studies [11] we have looked at the role that prototypes play in conversation and interaction during professional design practice, exploring the amount and quality of talk enabled by prototypes. The present study, however, has a much narrower and controlled focus. This investigation focuses on the role of physical prototyping media on the verbal and non-verbal interaction between designers collaborating in developing a solution for a simple design task. It examines how different prototyping media influence the collaborative design process, specifically the type of talk and gestures as well as the use of interpersonal space.

There is a strong view in the literature that any practical activity, and perhaps especially designing, embodies different types of thinking and that in achieving a particular goal these types of thinking can interact with one another. Lloyd, Lawson and Scott [8] found that certain types of thinking, for example planning, are more amenable to verbalization, while other types, for example sketching, are not. Similarly, McNeill [10] argues that gestures have a complex relationship with speech while at the same time reflecting "visible thinking in the form of action" and such a view is held elsewhere [4, 5, 6, 12].

Research has suggested that different kinds of hand gestures can elicit neural activity in regions that are also activated during the mental performance of tasks, as well as language and motor imitation [3]. Echoing this finding, Lloyd [7] reports that information represented in the visual system stimulates areas in the brain that would be active if one would actually be embodied in a real life situation. Drawing from various studies, Lloyd [7] summarises that: "the evidence suggests that proxemic behaviour is regulated by our beliefs about the agency of the other person in the social interaction". This indicates that gestures may play a key role in controlling interpersonal behaviour in design collaboration.

The relationship between gesture and speech is further complicated by the fact that the space in which a gesture occurs in collaborative activity is not neutral. Sweetser and Sizemore [15] identify an important aspect of co-located design collaborations suggesting that: "speakers reach into the shared space to mark shared social goals and shared affect as the basis for the accompanying utterance". Gestural movements shouldn't then be seen as simple indicators of the spoken word, and perhaps the reverse might even be the case.

This paper looks at the relationship between different thinking modes in the design process and how they find their expression. We are particularly interested in how measures of talk in designing correlate with measures of other types of activity, for example gesture, and how they mutually influence one another.

2. Method

2.1 Experimental setup and participants

The data studied comprised material collected from 23 controlled experiments with designer participants collaborating in pairs to complete a product design task using four types of prototyping material: clay, Lego, cardboard, and sketching (the control condition).

Figure 1. Experimental setting for video recording of design activity.
The four boxes are for the four different types of prototyping materials

The experiments were carried out at Central Saint Martins College of Arts and Design in London, UK. Prior to the main design task, participants were asked to complete between three and four 'skills building' tasks using only one of four prototyping materials offered at a time. This resulted in 76 separate skills building tasks for analysis. For the main design task participants were free to choose between any of the three materials available in producing a prototype to respond to a design brief. In total the skills building tasks and experiments lasted approximately 1 hour each with participants being paid for their time. All sessions were videoed and fully transcribed. For each experiment the observer was present, with a camera being positioned in front of the participants. Figure 1 shows the experimental setup.

Table 1. Overview of different tasks accomplished

	Total number of experiments		
	23		
Number of main design tasks	Number of skill building tasks		
	Cardboard	Lego	Clay	Sketching
	22	20	22	12
23	**76**		

The task given in the 'skills building' part of the experiments – which represents the focus of this study – was to build a square cube. The participants had five minutes to complete the task and were free to build the cube in any way they wished. In addition to the videos and transcripts, the participants were also asked to fill out a brief questionnaire, indicating the number of years they had studied design, their familiarity with the other participant, and the prototyping materials provided, as well as their familiarity with the English language.

2.2 Data Analysis

The study used a number of quantitative and qualitative methods to look at various aspects of collaborative behaviour and their interaction, specifically (1) hand movements, (2) interpersonal space, (3) gestural type, (4) verbal rate, and (5) the use of language.
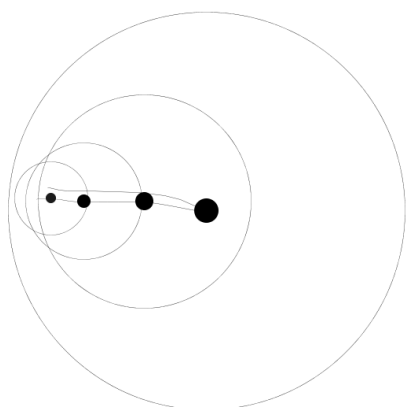

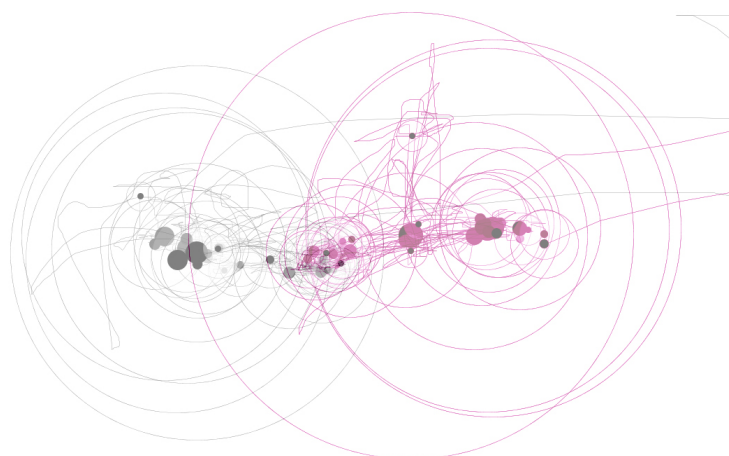Figure 2. Dots and circles indicating stops of 3, 5, 10, and 20 seconds.

Figure 3. Combination of two motion paths of participant's hands.

In order to plot the hand movements of both participants occurring during the experiment, a software programme, IOGraph, was used. The programme was used to record the movements of each participant

individually with movements indicated by a line, and stops plotted as dots and circles. Depending on the length of the stop, the size of the dots and circles sizes increased (Figure 2). The lines represent the location in the middle of both hands when resting or when equally active. When one hand was active and the other inactive, the line followed the hand executing an action. The two images resulting from recording each participant's movements were superimposed with an image editor and a colour code was used for better distinction of the two motion paths (Figure 3).

To record the use of the interpersonal space between the study participants, a grid indicating different spatial zones was laid over the video recordings (Figure 4). The red area marked the space that lay between the two participants and represented the 'hot zone' for design interactions. The yellow area indicated an extended interpersonal space. Blue indicated the space which use could be characterised as least interpersonal in nature. In order to reduce the distractions from the movement in individual zones, a soft-focus effect was applied.
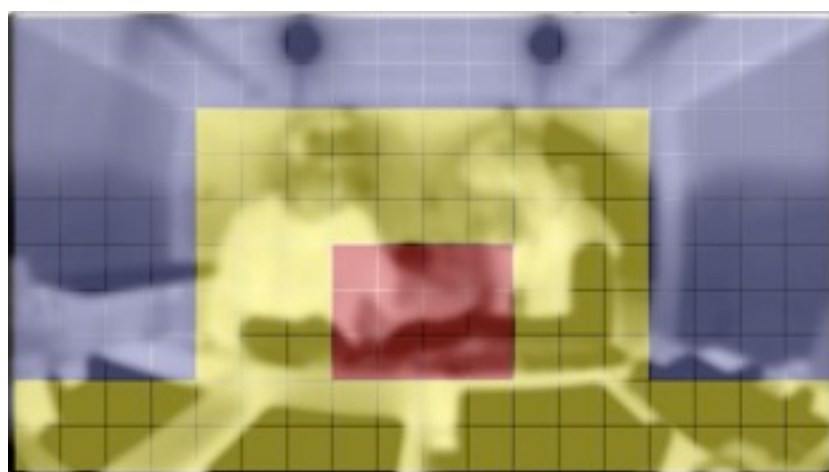

Figure 4. Video recording combined with spatial grid to identify
the use of different zones of the interpersonal space.

Using the video grid, the majority of time, for each 5 second period, where each participant was active in one of the interpersonal spatial zones was plotted on a timeline (Figure 5).
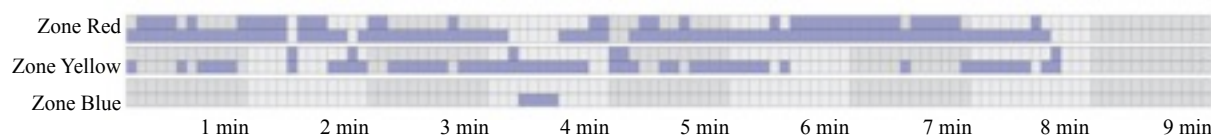

Figure 5. Nine minute time line showing hand movements for both participants in three
interpersonal zones. (top two rows indicate time in the red zone, the middle two rows indicate
time in the yellow zone, and the bottom two rows indicate time in the blue zone

While there are different kinds of categorisations of types of gestures, according to Cutica and Bucciarelli [1] most gesture types, identified in current typologies, can be attributed to one of three main categories: *deictic* gestures, which comprise indicative or pointing acts; *representational* gestures, which represent actions, characteristics, forms, or relationships between people and objects; and *motor* gestures, which are rhythmic or repetitive hand movements that do not refer to the semantic content of the accompanying talk.

These three distinct kinds of gestures were again plotted along the timeline allowing a comparison of what types of gesture occur at different stages of the prototyping process (Figure 6).
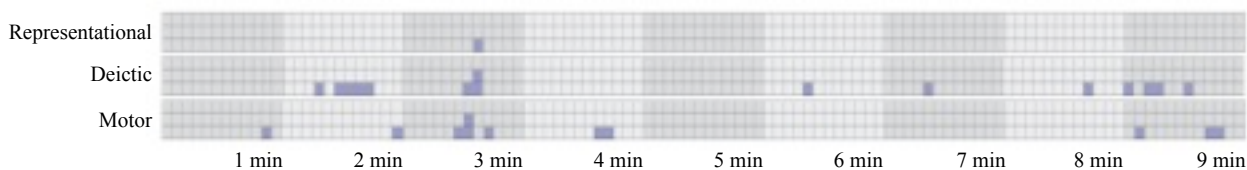

Figure 6. Occurrence of gestures plotted along the timeline. Representational gestures (top), deictic gestures (middle), motor gestures (bottom)

The rate of talk was measured by recording the number of words of both participants for each 5 second period. Figure 7 shows an example timeline of verbal rate for an eight minute session.
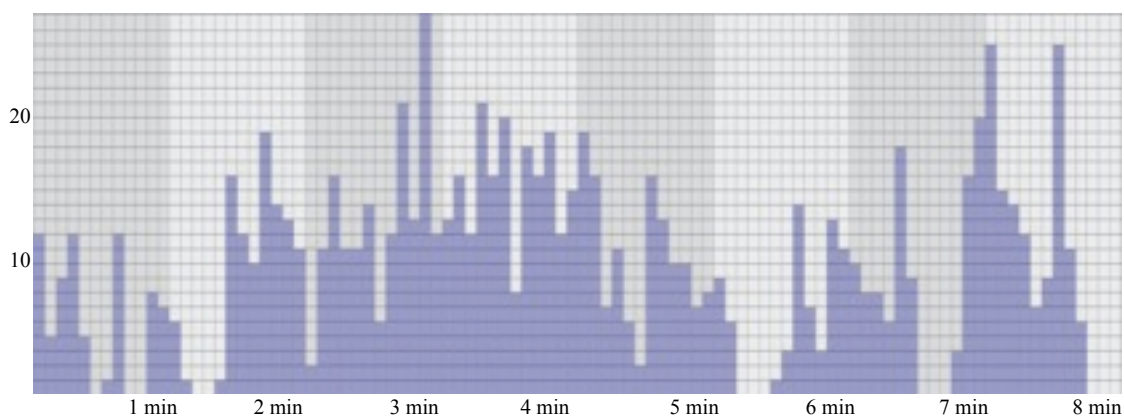

Figure 7. The rate of talk by word count for each 5 second period.

A qualitative approach was used to focus on specific instances of the conversation using the approach of Conversation Analysis [13, 14]. By attending to what the participants 'perform' within their conversation, the observer does not need to make claims about what is in the participants' minds. Instead it tries to unpack how the individual events of the conversation are organised and ordered, to discern how social actions are structured and achieved. The aim is to analyse the data by assuming that each turn-at-talk represents the speaker's understanding of the discourse. McDonnell states that when working in the context of qualitative data "turn-at-talk is a relatively objective unit of analysis for spoken interaction." [9]

3. Results

3.1 Prototyping media versus intensity of movement

Recording the hand movements in 20 selected experiments, a visual analysis shows that the interpersonal space between participants was used significantly more when employing a three-dimensional prototyping material than when using sketching. Figures 8-10 show comparisons of hand movements between one of the prototyping materials and sketching for three different subjects. The interpersonal space, marked as zone red in the spatial grid used, is indicated in the images by the square outline. It is also noticeable that the individual participants paused more in their design process when using sketching.

In the sketching tasks, the dots and circles seem to be larger and located significantly wider away from each other than in the experiments using Lego, clay, and cardboard as prototyping media.
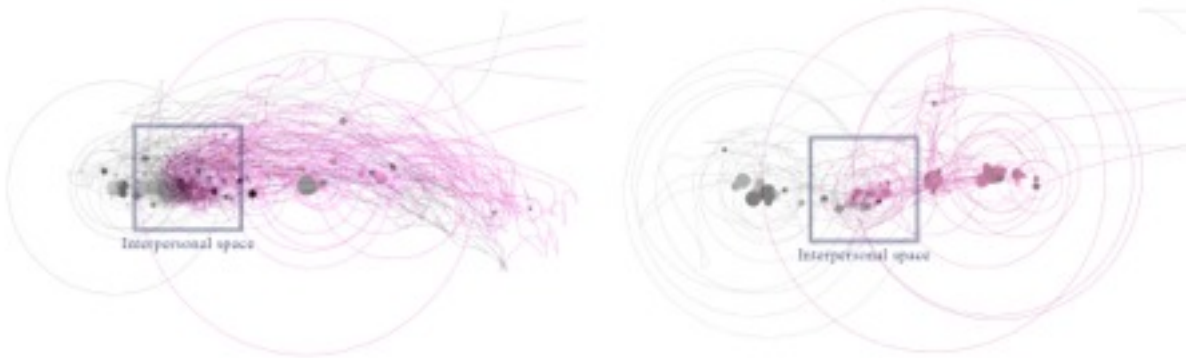

Figure 8. Comparison of the use of interpersonal space with Lego (left) and sketching (right).
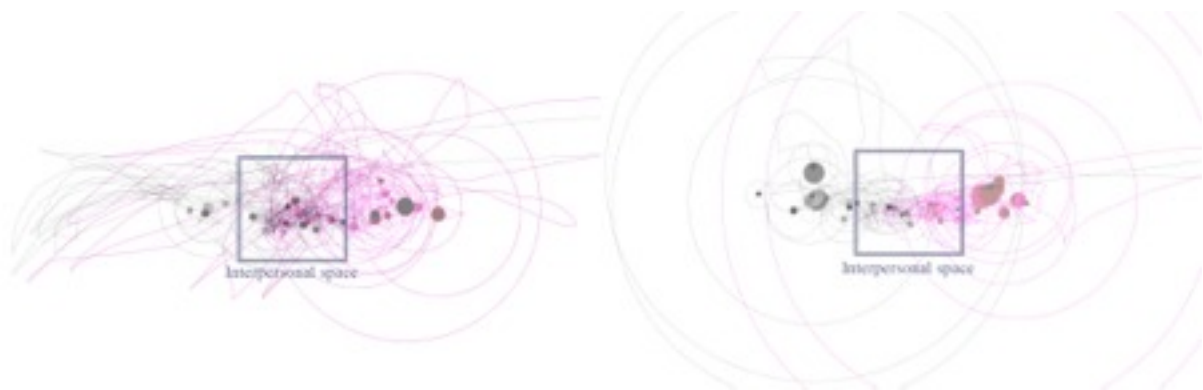

Figure 9. Comparison of use of interpersonal space with clay (left) and sketching (right).
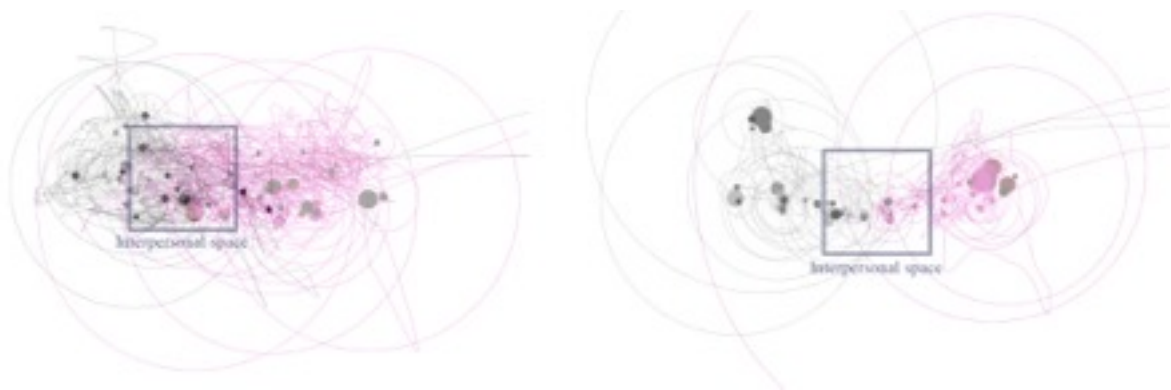

Figure 10. Comparison of use of interpersonal space with cardboard (left) and sketching (right).

Comparing the motion trails generated in the individual experiments reveals some consistent patterns. The sketching experiments, shown in Figure 11, demonstrate only a limited use of interpersonal space with more activity taking place individually and long and frequent phases of inactivity.
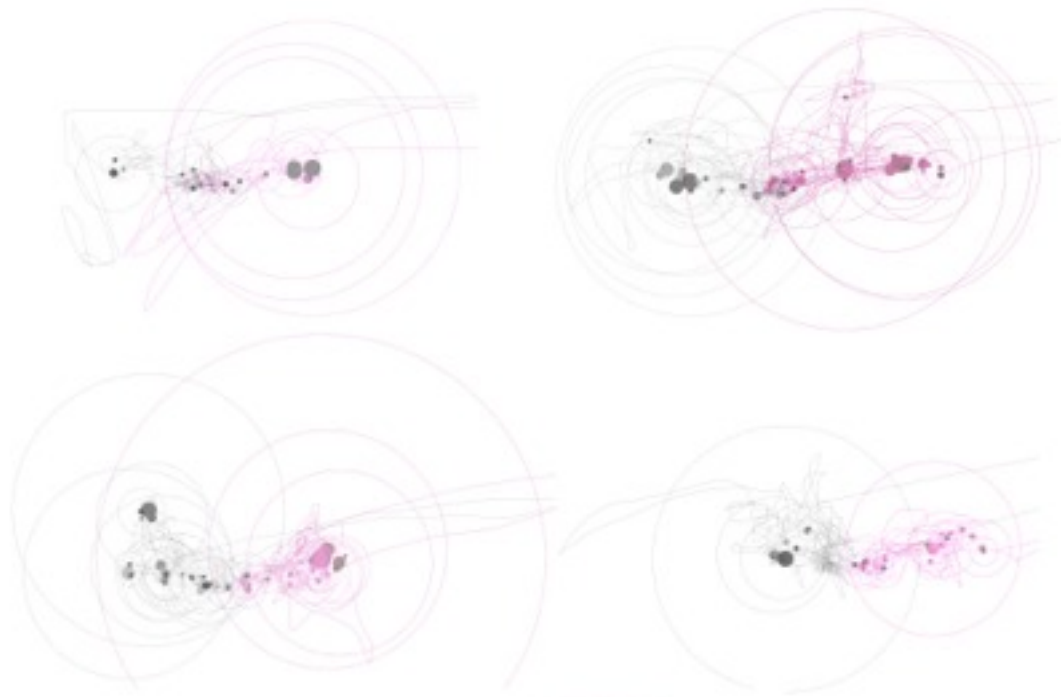
Figure 11. Motion trails in the sketching condition.

Figure 12. Motion trails in the Lego condition.

In contrast to the sketching (control) condition, the movements in the Lego, cardboard, and clay experiments produced trails with much stronger intensity in the interpersonal area. Figure 12 shows the Lego motion diagram and reveals an intense use of the shared space in between the two participants, as

well as the frequent use of the box containing the Lego bricks provided in the experimental setup. In general, the participants spent more time completing the Lego task than the sketching task.

The clay and cardboard conditions revealed a similar pattern to the Lego regarding the use of the shared space between the participants, though slightly less intense than with the Lego condition. The number and sizes of the dots and circles indicating stops and phases of inactivity remain significantly lower and smaller compared to the sketching condition. Strong use of interpersonal space and shorter phases of inactivity are also a feature of the cardboard condition, though of all the three-dimensional materials this appears to be the least intensive. Due to the limited space we have in this paper, from now on we concentrate on the Lego condition and the sketching (control) condition in showing further results, as both clay and cardboard conditions produced similar outcomes to the Lego condition.

A closer examination of the individual participant's hand movements reveals the differences in the use of the interpersonal space in more detail. Figure 13 shows that in the Lego condition the individual frequency of use of the shared space is very high. There are dots indicating pauses, but they tend to be short and located often within the interpersonal space.
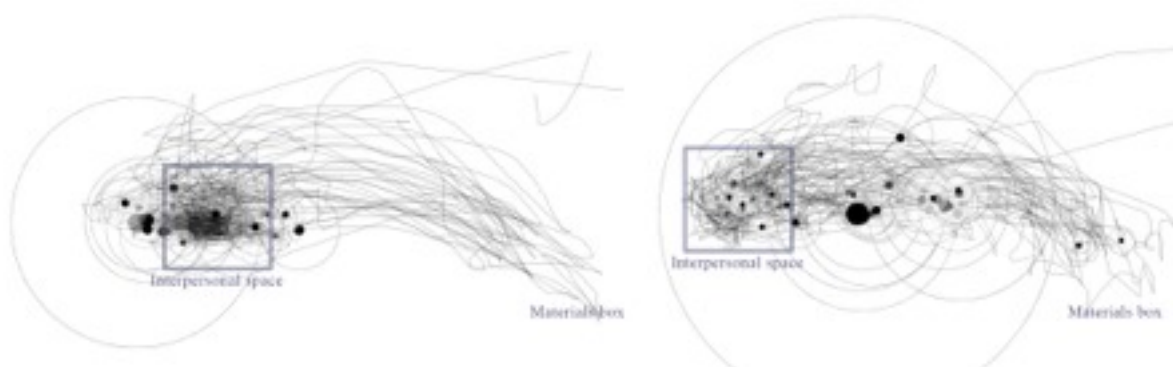

Figure 13. Individual hand movements of participants A1 (left) and A2 (right) using Lego.

In contrast, Figure 14 shows individual hand movements in the sketching condition. There is much less activity here, more centred on the individual, with the use of interpersonal space restricted. The activity here is less obviously collaborative, with the trails seeming to indicate more static individuals.

Figure 14. Individual hand movements of participants A1 (left) and A2 (right) using sketching.

3.2 Rate of talk

Why does sketching appear such an attenuated form of collaborative activity in this context? The findings thus far show a form of collaborative behaviour, but looking in more detail both at the content of what is exchanged, as well as the form of other types of behaviour, reveals some deeper patterns in the experiments. Figures 15 and 16 show how verbal rate varies against the use of interpersonal space for sketching (Figure 15) and Lego (Figure 16), the most widely contrasting collaborative activities.

Both figures show that verbal rate, although changing, doesn't seem to depend on the locus of collaborative space. Figure 15 reveals that participants are rarely in the same collaborative space (be that red, yellow, or blue) and this contrasts greatly with Figure 16 which shows participants much more often matched in terms of using the same collaborative space. The concentrated activity in minutes 5, 6, and 7 in Figure 16 seem to correlate with a slight decrease in verbal rate, which might indicate that collaboration has switched to a more visual or three dimensional nature, less accessible to a verbal discussion or commentary. This would support the findings of Lloyd, Lawson and Scott [8].
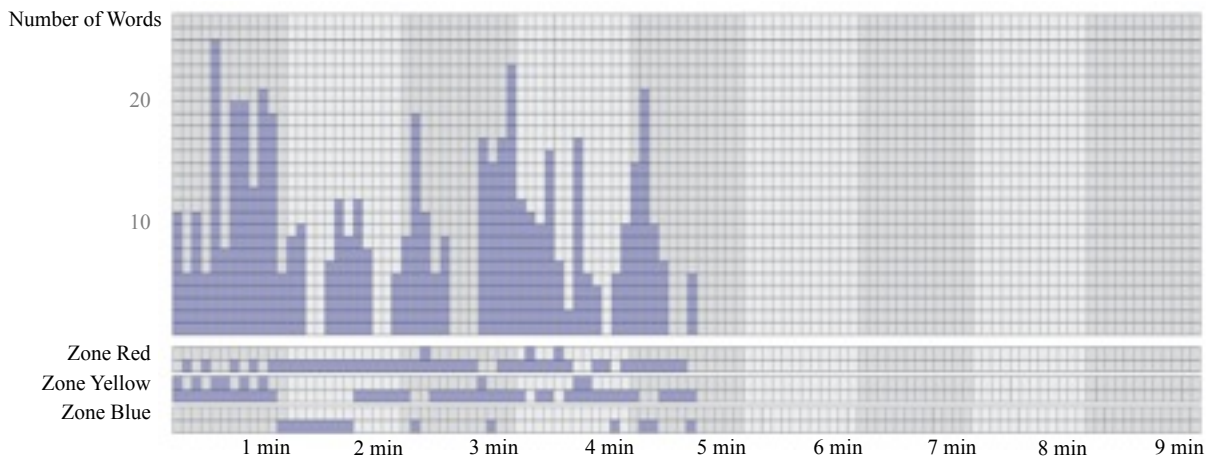
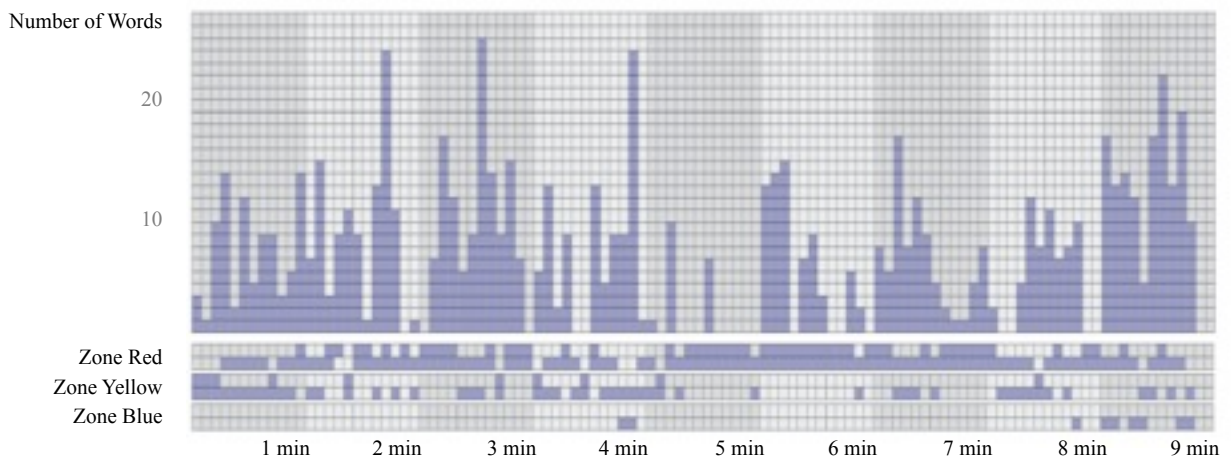Figure 15. Rate of Talk and use of interpersonal space using sketching.

Figure 16. Rate of Talk and use of interpersonal space using Lego.

9

3.3 Gestural type

Figures 17 and 18 again contrast the Lego condition with the sketching condition, this time in terms of gestural type. Figure 17 shows that when sketching, representational gestures seem to be used at the beginning of the task, followed by deictic gestures. In contrast, Figure 18 shows the reverse to be the case when using Lego. First deictic gestures are used, and only later in the prototyping activity do representational gestures occur. One way to interpret this observation might be that gestures are used in the sketching condition to communicate a preconceived idea about what *should* be drawn, while in the Lego condition the participants used representational gestures to classify what *emerged* from their collaborative activity.
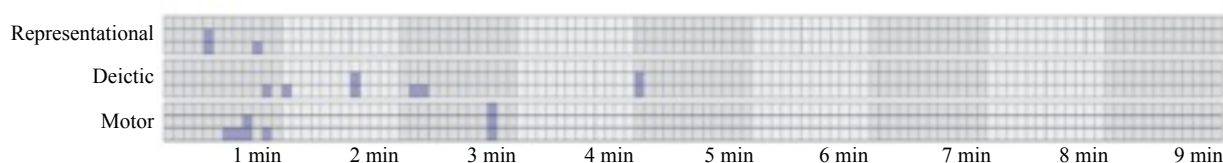

Figure 17. Representational, deictic, and motor gestures recorded during the sketching condition.
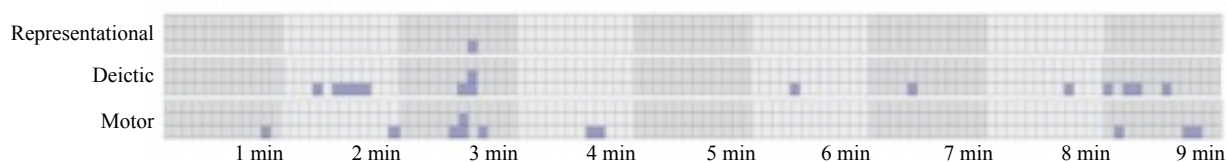

Figure 18. Representational, deictic, and motor gestures recorded during the Lego condition.

3.4 Transcript analysis

Looking at the transcription of discussions taking place during the Lego and sketching conditions provides further evidence for the differences in approach. The first segment of transcript comes from the sketching condition:

```
A1    yeah so I think we've got a number of ways of doing that haven't
      we? we can do a net [opens hand as if to illustrate a flat sheet
      of paper] of a box plan a box plan that opens out [gestures a plan
      unfolding] so +
A2    yeah yeah + yeah
A1    yeah?
A2    yes
A1    or we can just do it as a sort of axonometric
A2    mmmm
A1    projection
```

Segment 1. Transcript Excerpt at the beginning of the Sketching condition.

Participant A1 proposes two different possibilities for how the cube could be drawn (box plan and axonometric drawing). To illustrate his suggestion, he uses his hands as if unfolding a cube. The discussion is, however, about agreeing to do something that both participants understand. Right at the

beginning of the process, then, the outcome is known. This contrasts with segment 2, which comes from one of the Lego transcripts:

```
A2:   but what are we building?
A1:   I have no idea + a cube isn't it?
A2:   yeah what are you doing then? +
A1:   making a base +++ a very classical and then not having one
      [gestures to a missing plinth in a setup made by A2]
A2:   yeah
A1:   I like it ++
```

Segment 2. Transcript Excerpt at the beginning of the Lego condition.

In the Lego condition the participants start building right away but they do not know what they will make ('what are we building?'). What seems to be happening echoes what Figure 18 shows. The collaboration is about finding out what emerges from joint activity, rather than agreeing a plan and then executing it, often asymmetrically. The Lego material supports a more explorative, and perhaps more creative, design process. The idea that participants then arrive at what emerges from their collaboration, rather than being an embodiment of it.

4. Discussion and Conclusions

This paper reports a study attending to features of collaboration, interpersonal space, and gestures observed in a series of 23 experiments conducted with pairs of designers in an experimental setting. We investigated how different kinds of prototyping materials might affect the collaborative design process, especially how gestures, talk and shared space are used differently when using three-dimensional and two-dimensional media.

The analysis revealed significant differences in collaboration between a sketching (control) condition and three other conditions using: Lego, cardboard, and clay. We found that the intensity of movement and use of interpersonal space was attenuated in the sketching condition, while of strong intensity in all other conditions, though strongest in the Lego condition. We didn't find a significant effect between the verbal rate and the locus of collaboration, though there was a slight effect of decreasing verbal rate when collaborative activity was most intense in the Lego condition.

A closer look at the kind of gestures used in the experiments revealed that in the sketching condition representational gestures were used at the beginning of the process, whereas for the Lego condition representational gestures only emerged through the process of collaboration. This provides evidence that in collaborative sketching designers may only be rehearsing pre-conceived ideas, whilst the Lego and other three-dimensional conditions provide much more of an exploratory process. The skill level associated with each media will, of course, be a factor, but if so, it implies that an equal level of skill in any media may provide more potential for creative exploration.

Further research is now looking at how the analysis of the skills building tasks presented in this paper correlate with the main design tasks that participants were given in our experiments.

5. Acknowledgements

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