Characterizing tangible interaction during a creative combination task

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Tangible user interfaces change the way we interact with digital information, with physical affordances that are distinctly different from pointing and keyboard/mouse interaction. As a precursor to studying the impact of tangible interfaces on design cognition, this paper presents a coding scheme for measuring the difference between two types of user interfaces: tangible and pointing. We perform a case study, using data collected from an experiment in which participants are asked to make word combinations from a set of six nouns and give them meaning. The task is presented as a design task with references to function, behavior, and structure of the word combination meanings. The case study shows large differences in gesture and action between the two conditions. We conclude with hypotheses on how interaction modalities that afford more body movement may have an impact on creativity and design cognition.

Introduction

The affordances of design tools facilitate specific aspects of designing. As we move away from the traditional WIMP (Windows, Icons, Menus, and Pointer) interaction, we encounter new kinds of affordances in interactive digital design tools [1]. In this paper we focus on how to characterize the distinction between tangible and pointing interactions, as a precursor to studying the influence of tangible interaction on design cognition.

Tangible user interfaces (TUIs) are a type of human computer interaction design based on graspable physical objects, that shift the sorts of ac-

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tions required for interacting with digital information from pointing and clicking to holding, grasping and moving physical objects. TUIs are the coupling of physical objects and digital information, and eliminate the distinction between input and output devices, such as mouse and display [2]. For example, Figure 1 illustrates Sifteo^{TM} cubes, a type of TUI. Tangibles can trigger various gestures (spontaneous gestures or intentional actions), and have potential for exploring design alternatives through novel forms of interacting and discovering.

Figure 1. Sifteo^{TM} Tangible User Interface cubes

Previous studies of tangible user interfaces have shown an effect on designers' cognition during a design task [3,4,5]. Kim and Maher [4] found an increase of epistemic actions, and through a protocol analysis were able to observe an increase in the cognitive processes typically associated with creative design. The potential affordances of the TUIs, such as manipulability and physical arrangements, may reduce cognitive load associated with spatial reasoning, thus resulting in enhanced spatial cognition and creative cognition. Brereton and McGarry [5] studied the role of objects in supporting design thinking as a precursor to designing tangible interaction; they found that design thinking is dependent on gesturing with objects, and recommend that the design of tangible devices consider a tradeoff between exploiting the ambiguous and varied affordances of specific physical objects.

In this paper, we study how graspable tangible devices differ from pointing, in a creative task of combining words and giving the combination a meaning. Ultimately, our goal is to study how interfaces based on physical objects (i.e. TUIs) engage human cognition differently than traditional computer interfaces that do not include grasping within a design context. We claim that the developments in user interaction toward tangible devices have significant implications for computational support for designers. In this first step, we want to better understand how graspable and pointing interactions differ. We describe the results from a case study carried out to better understand how to measure the differences in gesture and action in an existing corpus of experimental data. We show a difference in the presence of gesture and action between the TUI and control conditions; while this was an expected result of the experiment, here we are reporting a case study on how to segment and code the data.

Gesture and Thought

Gesture has been associated with thought and speech production. There is evidence that gesturing with our hands promotes learning [6], and aids problem solving [7], but few studies have explored actions with objects [2, 3] and none have compared tangible object and intangible interaction within a creativity context.

Research on gesture in psychology and cognitive science considers the different types of gestures and the roles that gestures play in communication, problem solving, and learning. McNeill [8] describes four gesture categories when gesture is associated with speech, that he adapted from Efron [9] and others: "iconics", when the gesture depicts an object or event; "metaphorics", when the gesture presents an image of an abstract concept such as knowledge or language; "deictics", when the gesture is a pointing movement; and "beats", hand actions linked to speech rhythm. These categories were developed assuming that the person is speaking to another person, and suggest that gesture is relevant to language and therefore important for communication.

There is evidence that gesturing aids thinking. When children are learning to count, the learning is facilitated by touching physical objects [9, 10]. More specifically, Kessell and Tversky [10] show that when people are solving and then explaining spatial insight problems, gesturing facilitates finding solutions. Goldin-Meadow & Beilock [11] summarize findings as "gesture influences thought by linking it to action", and "producing gesture changes thought" and can "create new knowledge". These studies show that gesture, while originally associated with communication, is also related to thinking. Tangible interaction design creates an environment that encourages actions on objects, and therefore affords more gestures and actions than traditional GUIs. We posit that the affordances of graspable tangible devices, when present during a creative task, may affect cognition.

Case Study

We use a case study approach as an early exploration of the differences between tangible interaction and pointing interaction in a collaborative task [12]. In this paper we present a subset of the data from an experiment designed to study the effect of tangible interaction on creative cognition [13]. The experiment design uses a conceptual combination task, which for the purposes of this study is similar to a design task: a synthesis of prescribed components (words) and the creation of a meaning for selected combinations. The conceptual combination task in this experiment is an adaptation of Wisniewski & Gentner [14], for the purpose of investigating tangible interaction and its effect in a creative cognition task.

In the experiment the participants are asked to combine words from a given set of 6 words, and then describe meanings for the combined words. In the instructions the participants are asked to think about the function, behavior, and structure of the combined word when creating its meaning. The visual display features of the words were maintained across the two conditions, but varied across conditions in terms of the affordances for interacting with the words: words were displayed on tangible user interface cubes (Cubes Condition, Figure 2 right) or printed on a poster board (Poster Condition, Figure 2 left).

Pairs of participants worked together in the conceptual combination task [15]. A within-subjects experimental design enabled comparison of the graspable interaction when compared to pointing for each pair of participants.

Participants

Forty 6th-grade children (aged 11-12) participated in the experiment, providing data for 20 pairs of participants. For our case study, we arbitrarily selected results from 5 pairs of participants. We chose 6th grade children because of their ability to compose creative meanings while engaging them in a task that would be received as age-appropriate.

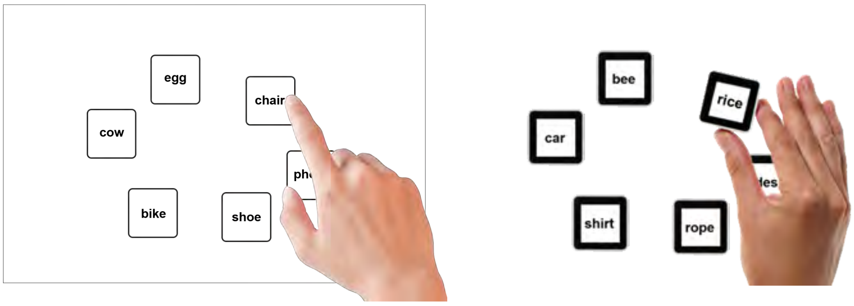

Figure 2. Schematic of Stimuli

Words as Design Elements

Considering the conceptual combination task as a design task, the words provided the requirements of the design, and the task is similar to a design synthesis problem. The two-word sets comprised six words each. Each word is a single-syllable noun representing a concrete basic-level category object [13]. Each noun represented one of six disparate semantic categories: food, furniture, tool, clothes, vehicle, and animal, shown in Table 1. This prevented word combinations from forming same-category meanings, thus promoting creative thinking. Each set of six nouns was constructed such that the 30 possible pair-wise combinations (e.g. rice desk) would not form conventional lexicalized N-N compounds.

Table 1. Word Set Stimuli by Semantic Category

Category	Word Set 1	Word Set 2
Animal	cow	Bee
Artifact-Tool	phone	Rope
Clothes	shoe	Shirt
Food	egg	Rice
Furniture	chair	Desk
Vehicle	bike	Car

Materials

Six Sifteo cubes were programmed to display one word per cube. The display did not change, and no other cube sensors or capabilities were active. The display screen of Sifteo cubes is housed in a square frame with rounded corners. The printed poster stimuli were designed to match cube displays on task relevant perceptual attributes: text font and size; words appeared centered in a rounded square; and initial spatial arrangement of the cubes and printed squares matched.

Procedures

The within-subjects procedure consisted of an instruction phase followed by two experiment conditions: Poster Condition and Cubes Condition in two counterbalanced blocks. The two Word Sets were counterbalanced with condition type (Poster, Cubes) and block order (Block 1, Block 2). The duration of the experiment was approximately 20 minutes, consisting of the instruction phase followed by two experimental blocks of 5 minutes each. Participants were instructed to “combine words and come up with as many creative meanings as you can”. The instructions included an example: “the word fish and the word car are things everyone knows about, but nobody knows about a fish car”. Three questions based on function, structure, and behavior [16] encouraged creative thinking: Who can tell me what a fish car might look like? —what a fish car is for, or what it does? —how a fish car works? In the experimental phase each participant pair sat at a table with a poster paper (Poster Condition) or Sifteo cubes (Cubes Condition) (Figure 3). Participants self-selected their choices of word combinations and how they took turns presenting their creative ideas to their paired partner. Experimental sessions were video and audio recorded.

Figure 3. Experimental Design. Left: Cubes condition / Right: Poster condition

Exploring hypotheses for characterizing the effect of graspable interaction on design creativity

In this case study we explore methods of measuring the difference in gesture and action between the two interaction conditions, in ways that are relevant to previous studies on creative cognition, a core component of creative design. As a means to defining relevant measurements, we present potential hypotheses on the impact of tangible interaction on creative cognition.

Epistemic actions improve creativity

We are interested in the argument that interfaces based on physical objects may offer more opportunities for epistemic (i.e. exploratory) actions than pragmatic (i.e. direct) actions [17]. Epistemic actions are exploratory motor activity aimed at uncovering information that is hard to compute mentally. An example of epistemic action is the way novice chess players find it helpful to physically move a chess piece when thinking about possible consequences. Epistemic actions offload some internal cognitive resources into the external world by using physical actions [18]. In contrast, pragmatic actions are motor activity directly aimed at a final goal. If tangible interactions offer greater opportunity for epistemic actions, then they may improve creativity by affording mental exploration through physical action [3]. This leads to hypothesis H1.

- H1: Tangible interaction increases epistemic actions when compared to pointing interaction.

Fluid movement leads to creativity

We expect that bodily movement can influence cognitive processing, with fluid movement leading to fluid thinking. Slepian et al. [19] explain the effect of fluid body movement on creativity. Creative thought is often contrasted with analytical thought: creative thought is associated with a more relaxed, open and playful approach where analytical thought is more rigid and precise; a fluid can move in multiple directions with ease, and the ability to fluently and flexibly generate multiple thoughts is essential for creativity. Fluid thinking, thus, is a metaphor for certain elements of creativity [20]. This leads to hypothesis H2.

- H2: Tangible interaction encourages more fluid body movement than pointing interaction.

Collaboration drives creativity

Tangible interactions enable the development of sharable interfaces that provide a unique collaboration environment [21]. Tangible interactions can impact children's collaboration and facilitate engagement and motivation that increase attention to tasks. We expect that the higher the interest in the experiment, the more active and collaborative their behaviors, which is expected to enhance the ability to think of creative and novel meanings. This leads to hypothesis H3.

- H3: Tangible interaction draws more collaborative actions than pointing interaction.

Abstract concepts enhance creativity

Abstract concepts may help people solve problems in more creative ways, and encourage people to think "outside of the box." [22]. We have expectations that the participants might engage in more abstract thinking when they explain function-behavior, and this abstract thinking will lead to creative meanings. This leads to hypothesis H4.

- H4: Tangible interaction elicits more function and behavior exploration than pointing interaction.

Bimanual interaction facilitates creativity

We propose that bi-manual tangible interaction may improve creative output, because manipulating cubes with two hands may facilitate interhemispheric interaction [23]. This leads to hypothesis H5.

- H5: Tangible interaction induces use of both hands.

Data Analysis for Case Study

Segmentation and Coding

Our analysis of the video stream for each session involves segmenting the video into discrete elements defined by a start time and end time, and assigning a code to each segment. We started by segmenting the verbal stream according to speaker, and then segmenting it into smaller segments so that a segment is formed around the utterance of a word combination or around the definition of a word combination. In order to associate the gestures and actions with design issues, we had an additional stage of segmentation in which each segment is associated with one "FBS" code using the FBS coding scheme described below. Segmentation and FBS coding were done simultaneously. We then coded each segment using a gesture/action coding scheme described below. We coded a gesture for each of the two children's left and right hand for each FBS segment. Two of the authors performed the coding together for 3 of the sessions, to ensure agreement on the coding scheme. Then a single author coded all sessions twice, separated by a period of several days, followed by an arbitration process to identify and resolve differences in coding.

FBS Coding Scheme

Function-Behavior-Structure (FBS) is a schema for analyzing design activity. The definitions of FBS [16] originally proposed are listed in Table 2.

Table 2. The FBS Definitions by Gero [16].

Function	The intentions or purposes of the design artifact
Behavior	How the structure of an artifact achieves its functions
Structure	The components which make up an artifact and their relationships

When instructing the participants to create a meaning for word combinations, they are asked to describe its function, behavior, and structure.

- R: Requirements. This is when the participant makes a verbal reference to one of the six words printed on the poster or cubes.
- F: Function. This is when the participant talks about the purpose, use, or function when describing the meaning of the word combination.
- Be: Expected behavior. This is when the participant talks about an expected behavior in the meaning of the word combination.
- Bs: Behavior from structure. This is when the participant talks about whether the structure in the meaning of the word combination can actually achieve the expected behavior.
- S: Structure. This is when the participant talks about the appearance, the form, the spatial qualities, and the material properties of the meaning of the word combination.
- O: Other. This is used when a participant repeats a phrase or talks about something that is not relevant to the task.

For example: shirt car (coded as requirements), the participants talk about how it behaves: "you wear" (coded as expected behavior), what it looks like: "car made out of shirt" (coded as structure), and what it is for: "that you can drive" (coded as function).

In addition to the FBS codes, we coded when the F, B, or S segment introduces a new or surprising idea for that pair of participants. The meaning of surprising is derived from the distinction between novel and surprising in [24, 25]. Surprising ideas are unexpected issues associated with the function, behavior or structure of the meanings the participants ascribed to the word combination. For example, when explaining chair egg in a particular session, Child 2 said "a chair and an egg what if there is like a whole cracked up egg and you can just sleep on it like a vampire or just like be in the egg." A vampire in this context is unexpected and was coded as surprising.

Gesture/Action Coding Scheme

Gestures are expressive, meaningful body motions involving physical movements of the fingers, hands, arms, head, face, or body with the intent of conveying meaningful information or interacting with the environment. Gestures vary in form, function, and in how they relate to language. Bodily experiences play an integral role in human cognition [8, 11]. Gestures help people link words to the world (e.g. deictic gestures) or help a person organize spatial information into speech (e.g. iconic or metaphoric gestures). When we code the gestures in this case study, we distinguish between gestures and actions where actions are body movements associated with the intention to hold or move a physical object. Our intention in developing this coding scheme is to explore potential correlations between the gesture or action, and the cognitive issue (a cognitive issue is F, B, or S). For example, does a grasping gesture correlate with thinking about structure, or thinking about behavior? We coded gestures and actions in five categories, shown in Table 3.

Table 3. Gesture/Action Coding Scheme

G	Grasping
P	Pointing
OG	Other Gesture
NG	No Gesture
NV	Not Visible

Although the tangible cubes afford many different actions (grasping, rotating, stacking, picking up, and rearranging), we coded all actions on the cubes as Grasping. This is distinctive to the Cubes condition and allowed us to compare the impact of the words on cubes to words on the poster. When the participant used a finger or hand to point to a word on a cube or poster, we coded that segment as Pointing. All other body movement was coded as Other Gesture (OG). An example of OG is when a participant said "it happened over and over again" while gesturing by repeatedly tracing a circle with one hand. If the participant's hand was on the table but not moving, it was coded as No Gesture (NG), and if a hand was below the table so that it could not be seen, it was coded as Not Visible (NV).

Coding Analysis

In this paper, we report on the coding and analysis of 5 of the 20 pairs of participants for a total of 10 sessions. We are using this smaller set of data to explore our hypotheses about the differences in body movement in the two conditions, and as the basis for developing hypotheses for a more complete analysis of the entire corpus of data. Our notation to refer to the session is pair number-condition, e.g. P01-POSTER is the pair of participants labeled P01, and the condition is the poster condition.

Figure 4 shows an overview of the coded data for one pair of participants. Each bar in the figure is one of the FBS segments, plus NT which we used to code a time segment in which the participants were not talking. Each code is indicated in a different color. This pair is typical of all 5 pairs: Grasping dominated in the Cubes condition and Not Visible dominated in the Poster condition.

Figure 4. Gestures on FBS codes. Top: P05 Cube Condition, Bottom: P05 Poster Condition

Table 4 shows the percentage of new words and surprising words for each session along with the Total Segment number and which condition was first in the Order column. In all cases, there were more FBS segments in the Poster condition than in the Cubes condition, yet the number of new and surprising words is higher in the Cubes condition in 3 of the 5 participant pairs in this case study.

Table 4. New and Surprising words in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

	Order	Poster					Cubes				
		Total Segment	New (%)		Surprising (%)		Total Segment	New (%)		Surprising (%)	
P01	Cubes	205	9.8		1.5		143	18.2	▲	2.8	▲
P02	Poster	194	13.9		2.6		180	16.1	▲	2.8	▲
P05	Poster	243	25.5		4.5		200	28.5	▲	6.5	▲
P04	Poster	205	24.9	▲	4.4	▲	194	21.1		1.5	
P03	Cubes	228	34.6	▲	9.2	▲	176	31.8		6.8	

Table 5 shows the total number of gesture segments as a percentage for each pair in each condition, indicating whether the Poster or Cubes condition was larger. For example, the NV and P code in the poster condition is larger than the NV and P code in the cubes condition for all 5 pairs, which is displayed in red column. And the G code is dominated in the cubes condition for all 5 pairs, which is displayed in blue column.

Table 5. Gesture Percentages in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

		G (%)		P (%)		OG (%)		NG (%)		NV (%)		Total (Count)
Poster	**P01**	0		2.6	▲	7.9		11.1		78.4	▲	820
	P02	0		1.2	▲	7.5		1.4		89.9	▲	776
	P03	0		3.2	▲	52.2	▲	16.9	▲	27.7	▲	912
	P04	0		3.0	▲	13.9		4.8		78.3	▲	820
	P05	0		0.2	▲	26.5	▲	20.1	▲	53.2	▲	972
Cubes	**P01**	37.3	▲	0.7		17.0	▲	31.7	▲	13.3		571
	P02	51.7	▲	1.0		8.9	▲	12.1	▲	26.4		720
	P03	37.4	▲	0.3		40.9		12.5		8.9		704
	P04	56.4	▲	0.9		16.5	▲	16.4	▲	9.8		776
	P05	68.8	▲	0		20.9		5.0		5.3		796

G: Grasping, P: Pointing, OG: Other Gesture, NG: No Gesture, NV: Not Visible

We observed the actions performed with the cubes, such as: making word combinations by changing the arrangement of cubes, holding the cubes without meaning, and actions performed to make word combinations by adding or taking out cubes from word combinations. We observed gestures not related to actions on the cubes, such as: gestures to explain meanings of a word combination, gestures to describe the behavior or the appearance of a word combination, gestures to repeat a certain pattern, and habitual stroking of the hair and patting around the lips. In all cases, the cubes condition had more gestures + pointing + action and the poster condition had more no gesture + not visible. This means that the participants exhibited a relatively higher proportion of using their hands in the cubes condition than the poster condition.

Table 6 shows percentages of segments based on FBS code, with an indication of when the percentage is greater in the cubes or the poster condition. For example, the segments coded R (Requirements) refer to the task to be performed. Thus, the number of segments coded R is correlated with the number of word combinations the pair came up with during the session. The remaining segments code when the pair explained meaning(s). All of the total number of requirement segments as a percentage, for each pair in cubes condition is larger than poster condition. This means that cube condition produces more word combinations per total number of segments, which is displayed in the blue column in Table 6.

Not Talking (NT) is not typically included in the FBS coding scheme, but is in this case study. It is meaningful to code NT because the participants were gesturing or grasping while not talking. Figure 4 shows percentages for gestures based on FBS. It shows a high portion of gestures using cubes during 'no talking' time. This result can be used as a clue to how a series of gestures which appear while they do not talk, develop thoughts in performing design tasks and what effect they have on cognition.

Analysis of Table 6 shows that, of all FBS codes, structure has the highest proportion. Structure issues address the object(s) and their relationships while explaining the meaning of word combinations. Table 6 also shows that in all 5 cases, the percentage of Requirements segments is always higher in the Cubes condition.

Table 6. FBS segment percentages in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

		R (%)		**S** (%)		**F** (%)		**O** (%)		**Be** (%)		**Bs** (%)		**NT** (%)		**Total** (Count)
Poster	**P01**	19.5		52.7	▲	2.4		8.3		11.2	▲	0.5		5.4		205
	P02	17.0		20.6		0.5		39.7	▲	7.2	▲	6.2	▲	8.8		194
	P03	5.3		44.3	▲	3.9		17.1		23.2	▲	6.1		0.0		228
	P04	13.2		46.3		3.9	▲	15.6	▲	11.7		4.4	▲	4.9		205
	P05	4.1		34.2		2.5	▲	27.2	▲	16.0		2.9		13.2	▲	243
Cubes	**P01**	25.9	▲	45.5		3.5	▲	8.4	▲	4.2		3.5	▲	9.1	▲	143
	P02	21.1	▲	23.9	▲	1.7	▲	28.9		5.6		4.4		14.4	▲	180
	P03	15.9	▲	33.0		4.5	▲	19.9	▲	20.5		6.3	▲	0.0		176
	P04	16.5	▲	47.9	▲	3.6		11.9		11.9	▲	0.0		8.2	▲	194
	P05	9.5	▲	38.0	▲	0.5		18.5		18.5	▲	3.0	▲	12.0		200

R: Requirements, S: Structure, F:Function, O:Others, Be: Expected Behavior, Bs: Behavior from Structure, NT: No talking

H1: Tangible interaction increases epistemic actions when compared to pointing interaction.

Epistemic actions are counted as the number of segments in which the participant is pointing at a word or grasping a cube. As seen in Table 7, the percentage of segments coded as epistemic actions is higher in cubes condition than poster condition for all 5 pairs, which is displayed in the blue column. In the case of P05, epistemic actions (grasping) are 59.7% of the segments in the cubes condition. In the cubes condition, participants are changing or realigning the positions of the cubes but in poster condition, percentage of epistemic action (pointing) is negligible at 0.2%. Participants rarely took pointing actions.

Table 7. Epistemic Actions in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

	Poster				Cubes			
	Pointing		Total (%)		Grasping		Total (%)	
	C1 (Count)	C2 (Count)			C1 (Count)	C2 (Count)		
P01	0	17	2.1		51	137	33.3	▲
P02	9	0	1.2		96	206	41.9	▲
P03	16	13	3.2		98	165	37.4	▲
P04	25	0	3.0		188	214	51.8	▲
P05	0	2	0.2		259	216	59.7	▲

H2: Tangible interaction encourages more fluid body movement than pointing interaction.

Where H1 focuses on epistemic actions, considering only those segments in which the participants are searching the words for a word combination to give meaning, H2 focuses on body movements during all phases of the design task. Hence all the gestures with the cube and other gestures were included in this comparison. There is diverse range of fluid body movements. Movements made with cubes show continuously repeating patterns of behavior. For example, there is the pattern of back-and-forth movement on the surface on the desk with a cube held in one hand, or the pattern of keeping on turning the cube in one direction.

Overall, the percentage of segments with body movements is higher in cube condition than poster condition. In Table 8, P03 and P05 show the highest proportion of body movements in both conditions. When compared with Table 4, P03 and P05 expressed more surprising meanings. Though the data is not sufficient to say this increase in body movement and increase in new and surprising ideas are related, it highlights that this is a hypothesis to explore further.

Table 8. Body Movement in Poster and Cube Condition (Number of Segments)
(▲ indicates the higher value in the two conditions)

	Poster						**Cubes**					
	P		**OG**		**Total** (%)		**G**		**OG**		**Total** (%)	
	C1 (Count)	**C2** (Count)	**C1** (Count)	**C2** (Count)			**C1** (Count)	**C2** (Count)	**C1** (Count)	**C2** (Count)		
P01	0	22	20	45	10.6		54	157	52	96	62.9	▲
P02	9	0	3	55	8.6		119	253	25	64	64.0	▲
P03	16	14	184	292	55.5		98	165	133	288	97.2	▲
P04	25	0	76	38	17.0		207	231	83	128	83.6	▲
P05	0	2	163	95	26.7		300	252	60	166	97.7	▲

H3: Tangible interaction encourages more collaborative actions than pointing interaction

In order to determine if the tangible objects create a more collaborative environment in performing tasks, we counted how many segments a participant speaks before being interrupted by the other participant in each condition. It was assumed that if the two participants speak alternately, it means that they cooperate to make developments by sharing thoughts to perform the tasks, and that both participants are engaged in the activity.

In Table 9, the number for each participant in the row labeled 1 is a count of how many times that participant spoke for 1 segment before the other participant spoke, row 2 is how many times that participant spoke for 2 segments before the other participant spoke, and so on. We indicate when the cube condition is greater than the poster. Our analysis shows that subjects generally spoke more times alternately in the poster condition. In Table 9, by this analysis, P03 is the most collaborative. In the cube condition, child 1 spoke 33 times and child 2 spoke 24 times while in the poster condition, child 1 spoke 41 times and child 2 spoke 27 times.

The percentage of abstract concepts for each pair under each condition is shown in Table 10. For participants P03 and P05 function and behavior segments were a higher percentage of the segments when explaining meanings compared to the other pairs of participants. When compared with Table 4, participants expressed more surprising meanings in P03 and P05.

We observed that there may be a correlation in the participants explaining function or behavior in the segments before and after coming up with a surprising meaning. For example, in the word combination car rice, a concrete representation refers to the shape and color or something that describes structure related to its most common use. An abstract representation refers to car rice as a food like “if you are hungry, you can eat the car while you are driving, they cheap too because they’re edible.” This meaning is about function and behavior. These more abstract thoughts might lead the participants to contemplate other, less common uses or structure descriptions.

Table 9. Hold the Floor in Cube and Poster Condition (▲ indicates the higher value in the two conditions)

Poster																				
Seg	**P01**				**P02**				**P03**				**P04**				**P05**			
	C1 (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)	
1	24	▲	20	▲	31	▲	20	▲	41	▲	27	▲	29	▲	33	▲	23	▲	24	▲
2	4		6	▲	8	▲	7	▲	3		13		6	▲	1		9	▲	6	
3	1		1	▲	2		9	▲	1		4		1		3	▲	6	▲	2	
4	-		1		-		5	▲	-		2	▲	1		1	▲	-		-	
Cubes																				
Seg	**P01**				**P02**				**P03**				**P04**				**P05**			
	C1 (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)		**C1** (Count)		**C2** (Count)	
1	13		17		27		18		33		24		23		17		14		9	
2	6	▲	3		6		6		7	▲	13		4		8	▲	8		8	▲
3	1		0		2		5		-		4		3	▲	1		2		2	
4	1	▲	1		-		4		-		-		1		-		-		2	▲

H4: Tangible interaction elicits more function and behavior exploration than pointing interaction.

Table 10. Abstract Concept in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

	Poster				**Cubes**			
	F (%)	**B** (%)	**Total**		**F** (%)	**B** (%)	**Total**	
P01	2.4	11.7	14.1	▲	3.5	7.7	11.2	
P02	0.5	13.4	13.9	▲	1.7	10.0	11.7	
P03	3.9	29.3	33.2	▲	4.5	26.8	31.3	
P04	3.9	16.1	20.0	▲	3.6	11.9	15.5	
P05	2.5	18.9	21.4		0.5	21.5	22.0	▲

H5: Tangible interaction induces use of both hands.

We measured bimanual interaction in two ways: alternate uses of each hand and simultaneous usage of both hands. Table 11 shows how many times hand gestures were used for each participant. In order to investigate whether participants used both hands when making explorative gestures, we counted the number of segments with gasping and pointing. As there were no pointing or grasping gestures in P01 child 1, P05 child1, P02 child 2 and P04 child 2, they were excluded from comparison. In the remaining sessions, the number of times when both hands are alternately used was larger in the cubes condition. In the poster condition, participants did not use pointing gestures at all except in P03, and even when using pointing gestures they used only one hand.

Table 11. Bimanual interaction, number of times, in Poster and Cube Condition

	Poster						**Cubes**					
	P						**G**					
	C1		**Index***	**C2**		**Index***	**C1**		**Index***	**C2**		**Index***
	RH (Count)	**LH** (Count)		**RH** (Count)	**LH** (Count)		**RH** (Count)	**LH** (Count)		**RH** (Count)	**LH** (Count)	
P01	0	0	-	22	0	0	49	5	.1	89	68	.7
P02	0	9	0	0	0	-	100	19	.2	114	139	.8
P03	4	12	.25	8	5	.6	65	33	.5	73	92	.7
P04	0	25	0	0	0	-	116	91	.8	118	113	.9
P05	0	0	-	2	0	0	151	149	.9	142	110	.7

* Bimanual index: 0 if they only used 1 hand and 1 if they used both hands an equal amount of time. Index = smaller divided by larger.

Table 12 shows the number of segments for each child where the LH and RH are both coded as G, P, OG. Bimanual interaction occurred more frequently in the cubes condition than the poster condition.

Table 12. Bimanual interaction, number of segments, in Poster and Cube Condition (▲ indicates the higher value in the two conditions)

	Poster				**Cubes**			
	C1	**C2**	**Total**		**C1**	**C2**	**Total**	
P01	4	4	8		13	80	93	▲
P02	0	16	16		25	119	144	▲
P03	53	127	180		78	151	229	▲
P04	14	11	25		108	116	224	▲
P05	21	24	45		169	166	335	▲

Discussion and Future Work

This paper presents a coding scheme used in a case study, to measure the influence of the grasping affordances present in tangible user interfaces, in the context of a design task. Our gesture/action coding scheme connects gesture to the segmentation and coding of the verbal utterances of FBS issues. Our coding scheme includes Grasping, Pointing, Other Gesture, No Gesture, and Not Visible. The case study reported in this paper shows that the cubes condition served as an environment that has more gesture and action than the poster condition. Although this is to be expected given the different affordances in the two conditions, our coding scheme identifies a way to measure this difference in a design context.

Using our gesture/action coding scheme applied to 5 case participants, we measured the differences between actions in the cubes condition (tangible interaction with the design elements) and poster condition (no tangible interaction) to explore 5 hypotheses, derived from the literature on creativity, that relate body movement and creativity. Of the 5 hypotheses, our case study shows that the 3 that are directly related to body movement (H1, H2, and H5) should be further explored. The two hypotheses that relate to collaboration (H3) and abstract thinking (H4) are not strongly associated with tangible interaction when compared to pointing interaction. Specifically, our case study supports further analysis of the following hypotheses; alternately, non-tangible interaction my have a negative influence on these hypothesized factors.

1. Tangible interaction encourages more epistemic actions.
2. Tangible interaction encourages more fluid body movement.
3. Tangible interaction encourages the use of both hands.

This exploration of the data and hypotheses is a starting point for understanding the influence of TUIs on gesture and action in a design task, with the potential for developing similar studies that show the impact of this kind of body movement on creativity and design. Our study results are consistent with the idea that participants produce more gestures when allowed to manually manipulate physical objects.

The contributions of this paper include: a coding scheme specifically for gesture and action in a design task, and the exploration of hypotheses relating gesture and action to creativity. While the affordances of different kinds of user interfaces are taken into consideration in designing new interaction technologies [4], few studies consider their impact on cognition [6, 7, 8]. In this study we focused on characterizing TUI affordances on cognitive design issues (FBS), that ultimately can inform the design and analysis of new TUI technologies and applications. Currently we are coding and analyzing the full set of experimental participant data in two coding scheme methods: FBS (as in this paper) and psycholinguistics and semantics [13]. In our future work, we plan to apply the gesture/action codes to the remainder of the participants in the experimental data, and to further explore hypotheses that posit correlations between our gesture/action codes and cognitive issues in designing.

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