Tactile Reasoning: Hands-on vs Hands-off – what's the difference?

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ABSTRACT
This study investigates tactile reasoning in relation to sense making in the context of designing a new non-traditional information environment. We define tactile reasoning as an interaction technique that supports analytical reasoning by the direct manipulation of information objects in the graphical user interface (GUI). When people directly manipulate data, for example, by moving individual pieces of information to create temporary groups or sequences, or eliminating pieces of information from a group. We hypothesise that this can enhance their sense-making and analytical reasoning ability by helping them discover new explanatory relationships created by the re-arranged pieces of information. Our study used a card sorting type of task where participants were either allowed or not allowed to touch and manipulate the cards to look for information or to construct groups of information that could provide meaningful explanations. The results showed that manipulation has a positive effect on analytical reasoning performance. In the more difficult task conditions, participants who were allowed to use their hands were observed to invoke sense-making strategies 99 times in comparison with the 50 by participants who were not allowed to use their hands.

KEYWORDS
Tactile reasoning, analytical reasoning, sense-making.

INTRODUCTION

In this paper we briefly report on our observation of sense-making strategies invoked by participants in a study that investigates how tactile reasoning affects the sense-making task. We define tactile reasoning as an interaction technique that supports sense-making by the direct manipluation of information objects in the user interface. We believe that when one is presented with a set of information that can be freely moved, manipulated, grouped or re-arranged in a visuo-spatially manner, this interaction method can help us discover meanings or relationships. Such actions are externalisations of our mental processes, and have been referred to as epistemic actions (Kirsch and Maglio, 1994). By off-loading cognitively demanding mental computations in appropriate ways, we can obtain insight by '… organising intelligence that places the full set of clues in a unique explanatory perspective' (Lonergran, 1957, page ix). In this study we used a card sorting task as where participants were either allowed or not allowed to touch and manipulate the cards to look for information or to construct groups of information that could provide meaningful explanations. We believe this is a close enough parallel of the electronic index cards that can be individually manipulated in the user interface we have developed in our research for investigating novel user interfaces. This research prototype, called INVISQUE – Interactive Visual Search and Query Environment – was originally designed to support information search and discovery in electronic library resources (Wong, et al, 2010). INVISQUE is being extended for use in a variety of complex information analysis and sense-making tasks such as intelligence analysis. Other studies found that it improved the information search and sense-making performance of low literate users (Kodagoda, et al, 2012). As part of this research, we wish to investigate how the generation of insight can be facilitated by aspects of the user interface and interaction design that create the ability to manipulate information objects in a user interface. In the study reported here, we investigate the aspect of being able to freely manipulate information.

BACKGROUND

In this study we were interested in understanding the differences in the sense-making task that may arise from the ability to manipulate, re-organise and move the cards. Sense-making has been defined as '… a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively' (Klein et al, 2006). It is a cyclic process that does not have a clear start and end point as sometimes suggested where data => information => knowledge => understanding (Ackoff, 1989).

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There are several models of sense-making (e.g. Pirolli and Card, 2005; Weick, 1995), but for reasons of brevity, we will briefly describe Klein et al.'s (2007) Data-Frame Model of Sense-making. They propose a non-linear model comprising four main cognitive activities that can happen at any time and can transition fluidly between activities: (i) Connect, when new data, say representing a situation, connects with our frame, it enables us to understand what the situation is about. We may hear explosions, and part of our current frame (understanding) is that it is New Year's Eve, so those explosions followed by the bright flashes in the sky suggests it is a fireworks display; (ii) Elaborate refers to the activity of finding out more information to improve our understanding of the situation or issue; (iii) Questioning refers to the activity of determining the accuracy or validity of one's conclusions or assumptions about the situation; and (iv) Re-framing refers to the activity of changing our understanding given new data or a new understanding of the data. Can the physicality of interaction affect this sense-making process ? We briefly review some of these studies next.

Kirsch and Maglio (1995) describe how complementary strategies, i.e. the complementary use of external elements to support cognitive process, reduce cognitive load in mental computations. For example, the use of pencils, paper or hands can reduce cognitive load to make a task easier. In the study they showed participants a set of cards depicting currency coins, i.e. quarters, dimes and nickels. The participants had to compute the total amount in dollars and cents. In one condition they were allowed to use their hands to organise the cards, while in the second condition they were not. The results showed that the complementary strategy of using hands improved performance. The notion of complementary strategies as used by Kirsh supports the view that when we off-load cognitive work into the environment, we can improve mental computation performance (Wilson, 2002).

Kirsch and Maglio (1994) also explain that the external actions that accompany these complementary strategies are known as epistemic actions, i.e. '… physical actions that make mental computation easier, faster, or more reliable, … and performed by an agent to change his or her own computational state' (p513-514). These epistemic actions have developed and are used in order to uncover information that is hidden or hard to cognitively compute. For example, sorting nuts and bolts before assembling a piece of furniture, or in more abstract tasks such as algebra and arithmatic, we simplify the mental computation by manipulating external symbols where intermediate results '… which could in theory be stored in working memory, are recorded externally to reduce cognitive loads' (p514).

Antle et al (2009) differentiates even further in a study where she analysed children's hands actions when solving a jigsaw puzzle. She described three types of manipulation: First direct placement actions, which basically means moving information in the correct position. Second she describes indirect placement actions as a complementary pragmatic action that are usually '...part of a trial and error approach to visual search' (p2); and third, exploratory actions*,* where information is being manipulated to facilitate the simplification of a task by changing the environment such as rotating information to the correct orientation. These are epistemic actions. These studies explore and describe the ways people use external elements to simplify tasks.

Maglio et al. (1995) used tiles from the game Scrabble to see if epistemic actions aid in the discovery of anagram solutions within two different sets of seven tiles. The study showed that the use of hands to manipulate the tiles provided people an edge over those who did not use hands. However, the former only applied in the conditions where the sets of tiles had a low frequency of anagram solutions. This implies that there might be a threshold on the applicability of complementary strategies in making sense of information. Manipulation might aid in situations where the information is ambiguous and patterns are difficult to discover. This threshold is, however, not the focus of our study. We are interested in the differences in how people make sense of data and how complementary strategies influences sense making.

METHODOLOGY

Participants

There were 24 participants (13 males and 11 females) with ages ranging from 20 to 58 years with a mean of 30 (SD = 9.29). All participants were PhD students, minimising variation in reasoning skills.

Materials and apparatus

Five sets of cards were used in the experiment, one set with 10 cards for a practice session and four sets with 22 cards each for the main experiment. The four sets were used in a counter-balanced way to minimise learning effects. The cards depicted animals, living environments and vegetation. For example, one set would consist of 16 animals, 3 kinds of vegetation and 3 living environments.

Design

The experiment was based on a 2 x 4 within subjects, related samples design. The primary dependent variable was the number of cards found; other dependent variables were the time to complete the task (in seconds) and the quality of categories. The first related measures independent variable is the problem type, with two levels (an easy 'known-item search' to a hard 'ill-formed query') with a total of four questions divided in these two levels. The second related measures independent variable is physical manipulation, either hands could be used or they could not. The conditions were counterbalanced between participants.

Tasks

There were two types of tasks, a 'known-item search' task and an 'ill-formed query' task. Due to the nature of the known-item search task, being a visual search on a small number of features, we regarded the known-item search as a low difficulty task. This task consisted of two questions where participants were first asked to find information on two and then three features. For example, "*Identify carnivore mammals.*" (E1) and "*Identify carnivore mammals in warm climates*" (E2).

The ill-formed query tasks were intended to be higher difficulty due to the large amount of possible groupings and categories. This task also consisted of two questions "*Construct one or more food chains*" (D1) and "*In how many ways can you categorize the cards*" (D2). As these tasks have a higher degree of difficulty we expected the use of hands to improve performance.

Figure 1. The experiment setup.

Procedure

Each participant performed a practice session to get familiar with the experiment setup and method. This trial was identical to the actual experiment but used a smaller card set (i.e. 10 cards) and an easier task (i.e. one feature search). Participants carried out the experiment individually, they sat at a table and were provided with a brief introduction to the experiment on a laptop. From hereon in separate subsequent screens the participant saw, **a)** which set of cards to lay out on the table which were then provided by the experimenter, **b)** whether they could use their hands or not and **c)**, the time limit for every task (120 seconds). The participant was asked to think out loud during the trials and was not allowed to take notes.

Table 1. Observed cognitive strategies hands-on, hands-off

	Sense-making strategies observed (*n* = 24)	**Hands-on number of observations**	**Hands-off number of observations**
D1	Exploration of and experimenting with data	20	8
Construct one or more food chains	Create, fill and finalize	8	3
	Task immersion	12	0
D2	Exploration of and experimenting with data	19	10
In how many ways can you categorize the cards?	Create, fill and finalize	19	8
	Create and illustrate	3	13
	Inverted pyramid categorisation	14	8
	Task immersion	4	0
	Total number of observations	99	50

RESULTS

After transcribing the video and audio data, we employed the Emergent Themes Analysis approach (Wong, 2003) to analyse the data. Drawing from Grounded Theory, ETA seeks to discover higher level activities, behaviours and critical cues of individuals, and to then identify common patterns and interesting themes that may emerge across the 24 participants. The results are summarised in Table 1, focusing on the more difficult tasks (D1 and D2).

Exploration of and experimenting with data

In the hands-on condition, when participants were asked to construct a food chain, participants tended to explore and experiment with the data. Participants appear to use the ability to manipulate the data to search for relationships in the dataset. For example participants seem to search for relationships in the card set by moving cards together. Visually indexing the dataset gives them a general indication of what data is available; they then can start to search for relationships in the dataset.

> "*Maybe, the bird eats the spider*" [moves the parrot and the spider to the top of the workspace]
>
> (Participant 22)

In the hands-off condition participants were observed to be less likely to explore the dataset and came up with conclusions early on in the task. Stating findings early on in the task suggests that participants are less concerned with experimenting and exploring as in the hands-on condition. Though there might have been a form of mental experimenting and exploring participants seldom verbalized this process and merely stated their findings. Participant 3 for example spend some time thinking in silence for a few moments and then came up with a few conclusions. This first part of the excerpt "Ok, I think I have some" indicates the participant to have made an initial 'rough idea' of the groups. After this initial connection is made the groups then get elaborated and finalized.

> "*Ok, I think I have some... The fly, spider, frog... frogs eat spiders, they can also eat flies so I guess you can put the frog as top of the chain being, fly, spider, frog and also frog, eh sorry, spider, frog. So that's two*"
>
> (Participant 3)

Create, fill and finalize

In D2, participants were asked to categorize the dataset any way they found meaningful. In the hands-on condition participants seem to explore the data set by creating categories. They then gradually assign cards to those categories and meanwhile create additional categories. However this is not a consistent behaviour across all participants. Some create a category and then fill it completely with all the cards they consider to be a member of that category.

> *"Mammals would be easier but that's quite a big category I think"* [moving the panda, fox, lion, monkey, tiger, mouse and rhino to the bottom of the workspace] [adds horse]
>
> (Participant 14)

Create and illustrate

The 'Create and illustrate' strategy is a variation of the 'Create, fill and finalze' strategy. In the hands-on condition, categories are created and then illustrated with a few cards that belong to that category as if to test if that category is valid. Once deemed valid, participants continue adding cards to previously created categories to update or finalize them.

> [moves shark and killer whale together] [adds fish] [adds polar bear] [3 other actions]
> [adds penguin to the group with shark, killer whale, fish and polar bear] [2 other actions]
> [adds crocodile to the 'water' group]
>
> (Participant 2)

In the hands-off condition, participants tend to create categories and illustrate them with a few examples without finalizing that category (i.e. filling it with all cards that belong to the category).

Again there seems to be a relationship with the 'explore and experiment' strategy of the D1 task. The 'create and illustrate' strategy seems to be a simplified version of the more elaborate strategies in the hands-on condition.

> *"Okay so there's sea creatures, there are birds, ehmmmm.... animals that live in North America naturally. And then I guess there's this picture that looks like the plains of something, in Africa or wherever. So some of them will live there, so you can group them by area where they live, environment where they live, whether or not they fly ehmmm.."*
>
> (Participant 22)

Inverted pyramid categorization

Participants tend to begin with categorizations that can be applied to large portions of the card set. Afterwards the categories get increasingly more specific and usually have fewer members. For example, starting the task by separating plants from animals and then breaking the animal category down into more specific categories like: mammal, reptile or birds. This behaviour can be explained by using Klein's Data-Frame model. When participants visually index the data set they seem to primarily identify a limited number of over arcing frames that fit the data. Subsequent these frames can then be subdivided into smaller and more specific frames. The card set, for example, can be divided in two large categories: animate and inanimate entities. The animate category can subsequent be divided in animals and for example, plants.

> *"Animals and plants"*
> *"Mammals and reptiles, mammals and reptiles. And bird and beast"*
> *"and also herbivore, and carnivore"*
> (Participant 11)

Task immersion

Participants were asked to use the Think Aloud Protocol (TAP) during the tasks. They are expected to verbalize what they think, what conclusions they draw, how they are solving a particular problem or just how they are interpreting the data. This helps us understand how the process of task completion progresses. Participants in the Hands-off condition were only allowed to point to cards in case they did not know how to identify them. Since they were not allowed to physically move the cards the participants in general talked more and used some occasional pointing. We observed that participants in the Hands-on condition tended to forget to verbalise their thoughts. They seem 'immersed' in the task. Not being able to manipulate the data (Hands-off) might put less strain on the cognitive load of participants, and who are in general more likely to verbalize their thoughts.

CONCLUSION AND DISCUSSION

Although not statistically conclusive, we have observed differences between how Hands-on and Hands-off participants work with the cards, and in particular, in the more demanding D2 task. Hands-on participants showed a greater tendency to explore, try out assumptions and play around with the data than Hands-off participants. While the exploration behaviour itself does not appear to correspond directly with the activities of the Data-Frame Model, we suggest that exploratory actions are part of the process of seeking data to match one's frame. This would be part of the process of CONNECT as defined by the Data-Frame model: attempting to see what data is relevant and how they might be organised to make sense. The shuffling around of cards is a trial and error process of testing the conceptual or meaningful fit between cards and categories or thematic organisation. Some of this activity is CONNECT, as they attempted to make a 'FRAME' in order to understand what is present in the data set in order to therefore direct one's searches for that particular type of data (e.g. this set of cards is about vegetarian animals and not carnivores). The actions can also be ELABORATE actions as they search for other possible amplifying relationships, e.g. supportive of other cards in that category such as by placing more of the same type of animals in the carnivores category. Finaly there were REFRAME actions where participants decided a category or a member of the category is wrong and then re-organised or created a new category.

In the hands-on conditions our participants had off-loaded what would have been a demanding mental computation – setting up several 'lists', identifying commonality and assigning cards with the common features to the respective mental list – to an external representation of the physical placement and grouping of the cards. This is in line with findings that epistemic and complementary strategies (Kirsh and Maglio 1994; Kirsh 1995) can minimise mental computation workload. In designing systems for aiding the sense making process we can then start to identify several guide lines. Exploration of data is an important aspect in the process of solving a problem. It therefore is vital for users to being able to manipulate data and organize it in such a way so the system can function as an external memory. Designs should facilitate the transfer of mental idea's into the world. Besides functioning as a external memory to decreasing the cognitive workload it also serves as a platform to test hypotheses, setting aside intial unfitting data to simplify the dataset and play with data to facilitate serendipitous discoveries and subsequent possible solutions to the problem being worked on. A highly adaptable environment that affords manipulation in a constraint-free workspace would, so we suspect, greatly increase the ability to solve problems and possibly decrease the chances to err.

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