Comparison of Visual and Haptic Spatial 2-back Tasks within Interruption Recovery

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Abstract*— It is well-known that Interruptions are disruptive because they lead to longer resumption time and induce more errors. Several previous researchers have demonstrated these phenomena by performing only limited sensory experiments (e.g. visual and auditory tasks). In this study, we compare two kinds of cognitive tasks, which employed visual and haptic sensory modalities, especially through a spatial 2-back task during the task interruption and resumption process. The purpose of our experiment was to understand how the performance of each interrupted task is differentiated by the modality it uses. Participants were given both visual and haptic spatial 2-back tasks as primary tasks and were interrupted by a virtual needle penetration task. Our experiment confirms that, within a dynamic environment, both visual and haptic cognitive tasks are negatively affected by the interruption, but haptic-spatial information requires more time to be recognized in both non-interrupted and interrupted situations. These results suggest a way of understanding the recovery process within a complex modality.

Index Terms*— Haptic memory, Interruption recovery, Multitasking, Spatial 2-back task, Working memory.

I. INTRODUCTION

It is well known that interruptions are disruptive. In everyday life, people face various cognitive tasks that require their attention to shift frequently. The ability to multitask is a common capability that allows most people to deal with interruptions without many problems. However, complex situations and potential interruptions that divide people's attention have rapidly increased with advances in technology. In the last decade, understanding the cognitive control and role of interruptions has received much attention, especially in human-computer interaction (HCI) and psychology.

Numerous observational studies [1]-[3] have worked on identifying how interruptions affect task performance and how people resume their original tasks after interruptions within the usual workspace. Recent studies have also focused on what makes interruptions disruptive; they have confirmed that it requires time to recover from interruptions and that they increase the likelihood of errors [1], [4]-[6]. Especially within the "resumption lag," the time taken to resume the task, the mechanism of reverting to the primary task is still being studied. In order to fully understand the cognitive process, researchers endeavor to integrate their studies into a perceptive theory [7].

Memory-For-Goals (MFG) theory is one of the most popular frameworks to convey the effects of interruptions [8]. This theory explains the resumption processes with the idea that human memory has an activation level for each task. When the task is interrupted, its information is transferred to declarative memory, and the activation of the task decays over time. Several studies support this framework by proving that longer interruption induces longer resumption lag and more errors after interruption [6], [9]. However, some issues related to retrieving (strengthening and priming) tasks within the MFG model remain unclear [10].

Another issue in the literature is that tasks used in the experiments involved limited senses, primarily relying on vision and audition. Most studies employed simple visual tasks by using monitors, and furthermore, relatively little research used a dynamic task environment [10]. Because real world tasks occur in complex sensory circumstances, it is important to consider the recovery process within dynamic tasks.

In this study, we investigated the difference in task performance arising from the difference in modality during task interruption and the resumption process. In particular, we focused on two kinds of modalities: visual and haptic sensory. Tactile sensation is often used as a contextual cue that alerts individuals to interruptions or indicates spatial location of the task [5], [11], [12]. The role of haptic memory during a multi-sensory cognitive task interruption was implemented [13]; however, direct comparison of those two modalities has not been well studied.

Although touch sensation is a relatively unconscious process compared with visual or auditory sense, it is important to understand the precise cognitive process of a complex modality. For instance, in a real-life work situation,

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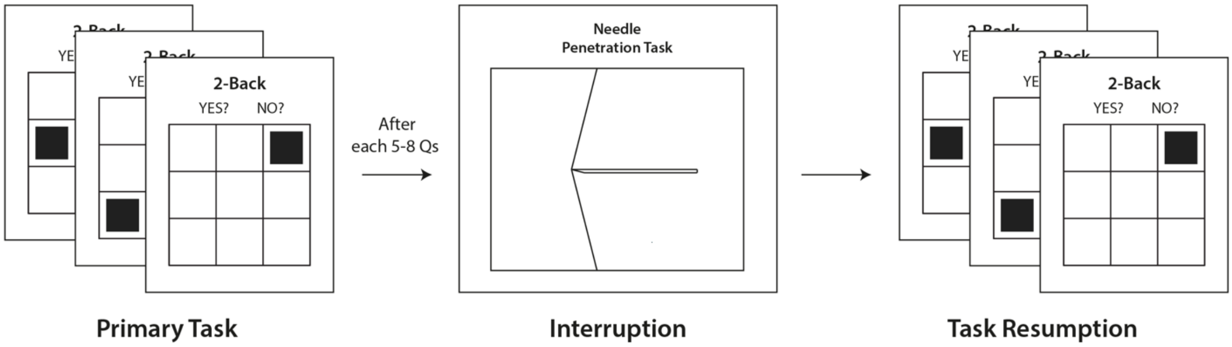


Figure 1. Brief diagram of our experimental process
A spatial 2-back problem is given to subjects as a primary task and interrupted by a needle penetration task

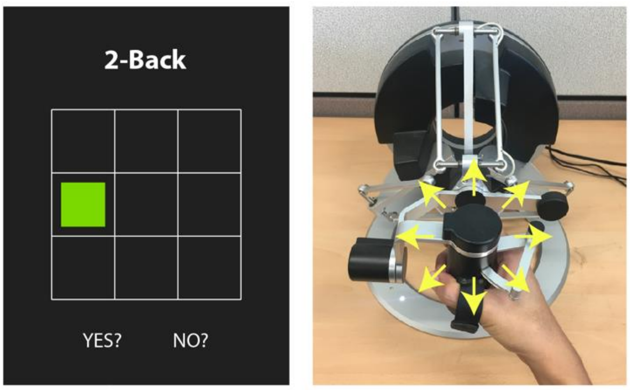
while I write an e-mail using my laptop, my phone suddenly starts to ring. After I answer the phone, I return to my laptop, putting my hands on the keyboard and seeing the display. The transition of my tactile feeling, from the phone to the keyboard, may affect the resumption process and help me become aware of what I was doing just before the phone call.

This study investigated two kinds of modality-based cognitive tasks. In order to prevent the effect of dissimilar processing codes (spatial vs. non-spatial) for each cognitive task, we implemented the spatial 2-back task as a primary task within both visual and haptic conditions. In order to provide a haptic task environment, one 7 Degrees-of-Freedom haptic device (Force Dimension, "Omega.7") was used along with one personal computer (PC). A virtual needle penetration task, which also requires both visual and haptic feedback, was used as an interruption. The accuracy of the 2-back task and reaction time from each condition with and without haptic feedback were measured.

The main goal of this experiment was to understand how the performance of each interrupted task is differentiated by the modality they use, especially through spatial-working memory demanding tasks.

II. Method

Our experiment was planned within a 2 x 2 within-subject factorial design. The main factor of the modality of the primary task (visual vs. haptic) was used to evaluate the impact of different sensory modality on task performance.



(a) visuo-spatial 2-back (b) haptic-spatial 2-back

Figure 2. Brief design of each spatial 2-back task

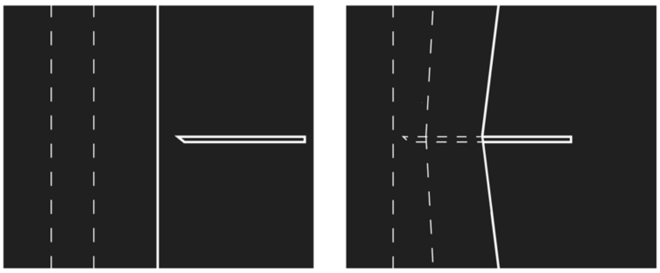
Whether the task is interrupted was also used as an additional factor to investigate how the resumption process is affected in dynamic task environments.

The experimental system was composed of one haptic interface, which is grounded with 7 degrees of freedom device, and a PC. This haptic interface can be connected and accessed through the Haptik Library [14]. The dynamic task environment including haptic feedback was developed using CHAI3D, an open-source set of C++ libraries for real-time haptic simulation and driven by Windows 8.1 OS.

A. Experimental Task

We simulated a dynamic task environment concentrating on evaluating the working memory, comparing the performance of task using haptic sensory with visual sensory. The N-back task has been widely used in cognitive science and task-interruption studies [6], [7] to evaluate working memory. We developed each visual and haptic spatial 2-back task. For using the spatial working memory, spatial information (eight cardinal directions) was given as a 2-back problem (Fig. 2). In the visual condition, eight directions were defined by markings placed in each area. On the other hand, in the haptic condition, subjects were given each directional force feedback from a haptic device. Before the experiment, all the visual items and force feedbacks were shown to the subjects in order to familiarize them with the information.

A virtual needle penetration task was developed as a short interruption task, which demands both visual and haptic cognitive resources. This secondary task was adapted from a needle insertion simulation toward haptic-rendered soft tissue [15]. This task involved finding an invisible vessel



(a) before contact (b) after puncture vessel

Figure 3. Brief design of the virtual needle penetration task

using a virtual needle by penetrating the virtual skin and soft tissue of the vessel (Fig. 3). The location of the vessel was randomly assigned in every interruption.

The primary task was interrupted after 5–8 (randomly assigned) problems and both visual and haptic conditions of the entire task consisted of 60 problems. Before the experiment, subjects were fully trained for each task both with and without haptic conditions.

B. Dependent Variables

Our primary variables of interest were time-on-task and task accuracy. These two variables were measured in four conditioned environments: visuospatial task with-and-without interruption and haptic-spatial task with-and-without interruption. The time-on-task was computed as an average period to complete one question of the primary 2-back task, and the task accuracy was assessed as a percentage of correct answers.

C. Procedure

Our half-hour per person experiment was conducted in a laboratory environment. Prior to the assessment of the variables, a training period was given to subjects in order to help them be adept in handling the haptic interface and experimental tasks. All trials were conducted within both visual and haptic conditions. In order to reduce the learning effect from repetitive execution, the execution orders were randomly assigned.

III. Result

Fig. 4 shows the time-on-task according to the regulated conditions. According to our assessment, reaction time was measured under the four conditions by recording the time interval before the participants responded in the primary task. Between the four conditions, a two-way repeated measures analysis of variance (ANOVA) was used to determine the significant impact of two factors: modality and interruption. The time-on-task increased significantly when the primary spatial 2-back task was interrupted; $F(1,4) = 215.57$, $p < 0.01$. In comparison with the visual 2-back task, the haptic task significantly induced increased reaction time; $F(1,4) = 9.89$, $p = 0.035$. However, there was no significant interaction between interruption and modality in terms of reaction time on the task, according to the 5-percent-standard level; $F(1,4) = 1.68$, $p = 0.265$.

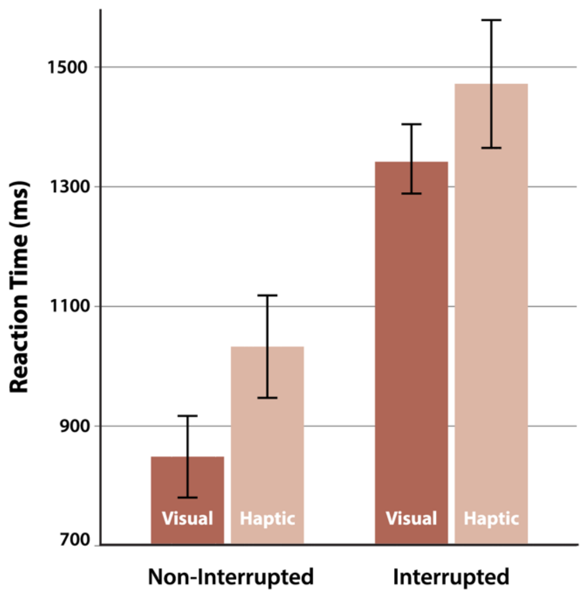


Figure 4. Reaction time (ms) for each condition

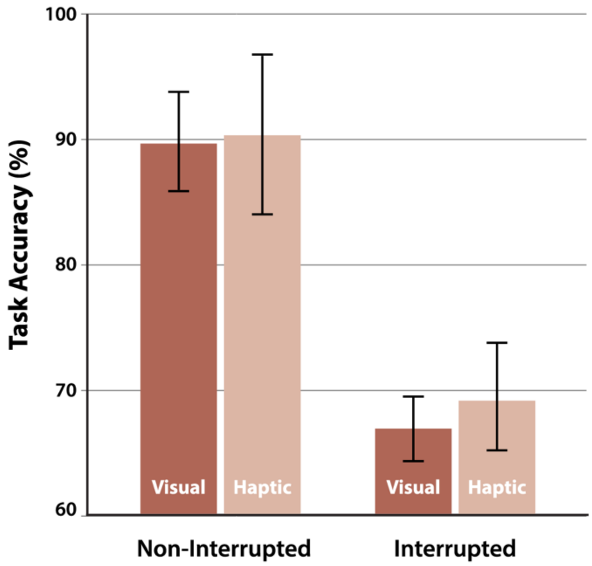


Figure 5. Accuracy (%) of each condition

The accuracy of the primary task was also measured (Fig. 5). As previous studies fully confirmed and MFG model predicted [6], [8], [9], subjects made more errors after interruption than otherwise. According to the two-way repeated measure ANOVA, the accuracy of the primary 2-back task was reduced significantly when it was interrupted; $F(1,4) = 66.91$, $p = 0.01$. However, there was no significant main effect by modality; $F(1,4) = 0.61$, $p = 0.477$. Moreover, no significant interaction was found between interruption and modality; $F(1,4) = 1.279$, $p = 0.321$.

Our ANOVA analyses confirmed that within a dynamic environment, 1) visual and haptic cognitive tasks are negatively affected by the interruption in terms of both reaction time and accuracy, 2) however, haptic-spatial information requires more time-on-task in both non-interrupted and interrupted situations.

IV. Discussion

Haptic sense is an integral part of our daily tasks, but most previous studies have focused only on visual and static tasks. The utility of tactile modality has only been dealt with as a contextual cue, and only a few studies have used a dynamic task environment. In this study, we propose a dynamic task experiment focusing on the haptic modality under task interruption, which has not been well studied. Our results also support previous studies on the effect of interruption. Regardless of visual or haptic modality, subjects need more time to recover and demonstrate less accuracy when they are interrupted, as we expected based on the MFG theory.

In our main assessment of interest, there was no difference in the accuracy but the task-on-time increased when subjects performed the haptic task. It can be inferred that haptic-spatial information requires more time to be recognized than visual information does. In another perspective, the distribution of humans' attention also can result in extra time. Some studies have emphasized the role of attention, especially in a dynamic task environment [10]. Another study presented the possibility of a personal task strategy with the trade-offs between speed and accuracy in task resumption [16]. Moreover, in a complex-modality environment, subjects may use specific strategies for improving task-accuracy. Therefore, it is unclear how the resumption process is composed in a dynamic task environment.

Our results had some implications regarding the experimental design. The complexity of the interruption task may be tolerable. However, from the perspective of a problem-state, which contains the necessary information to perform a task [4], the needle penetration task is only used to divert both haptic and visual attention and not for using multiple problem-states. This might lead to an insufficient display of the resumption process. Another implication is the limit of haptic reproduction. As seen in the above examples, in daily life people touch various materials and objects of different shapes, such as a phone and a keyboard. However, with the haptic interface, we implemented only the haptic force feedback.

Previous attempts to deal with task interruption in a dynamic task or complex modality environment have been rare. Our study, focusing on tactile modality, can be a stepping-stone to understanding the resumption process in terms of combined sensory cues. It also indicates the necessity of a novel theory to better specify the use of each modality within task interruption.

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