AUDITORY PREEMPTION VERSUS MULTIPLE RESOURCES: WHO WINS IN INTERRUPTION MANAGEMENT?

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We examined the effects of modality (auditory versus visual) and spatial separation when a simulated vehicle control (tracking) task (the ongoing task: OT) was time shared with a digit entry task (the interrupting task: IT), contrasting the predictions of auditory preemption theory with that of multiple resource theory. Participants performed the tracking task with auditory display of the phone numbers, or with visual display at eccentricities ranging from 0 deg (overlay) to 45 deg. Auditory input improved IT performance relative to visual, but disrupted OT performance, thereby supporting the role of auditory preemption. This cost did not grow with longer messages. In contrast, at eccentricities above 15 deg, auditory superiority emerged for both tasks, highlighting the role of multiple resources, and separation produced greater costs to the OT than to the IT. Therefore, both discrete tasks, and auditory delivery have inherent preemptive effects on the continuous visual OT. The results are also interpreted in the context of the non-linear costs to dual task performance with increasing separation from the eye-field to the head-field, and the support for different visual hemi-fields for concurrent processing of verbal and ambient spatial information.

INTRODUCTION

Attentions switching and task interruptions have seen a recent growth of interest in the human factors and HCI community (e.g., Altman & Trafton, 2002; Freed, 2000; Monk, Boehm-Davis & Trafton, 2004; McFarlane & Latorella, 2002; Iani & Wickens, 2004). This growth was preceded by a more enduring program of research on attention switching within basic psychology (e.g., Rogers & Monsell, 1995). A descriptive model shown in Figure 1 captures both aspects of interruptions and attention switching in the context of an **ongoing task (OT)**, which may be periodically interrupted by an **interrupting task (IT)**. Within this model, we can consider some of the properties of the OT that resist interruptions, such as the degree of "engagement" (Iani & Wickens, 2004), properties of the IT that attract attention to itself (its attentional capture properties, Yantis, 1993), and properties of both tasks that delay the return of attention to the OT. The latter measure – return time has two components: the duration of performance on the IT before attention is switched, and the time required to "re-activate" the OT after attention has been re-directed (Monk et al., 2004).

The many influences on these processes are complex, and not yet well modeled, but can be divided into three partially overlapping classes. (1) **Strategic influences** are decisions in task management that may be related to individual differences and skill learning. For example the skilled operator may be more calibrated as to the relative importance of the IT and OT, and thereby manage switching in a more optimal fashion. (2) **Task influences** are properties of the task demands, such as the above mentioned "importance" factor, or the working memory demands. Here strategic and task influences may interact. For example an OT with greater working memory demands may lead a strategically optimal manager to be more resistant to abandoning the OT in the face of an interruption (Monk et al., 2004). (3) **Physical properties** refer to properties of the interface itself that can effect switching. For example it is likely that close spatial proximity between the display of a visual IT and OT will encourage more rapid switching. Of particular interest in the current research is the modality (auditory versus visual) with which IT information is presented.

The role of modality in attention switching has a long history in human factors, given the emergence of the auditory channel as the preferred modality for issuing important warnings and alerts. Yet in a multi-task context, there is some concern that audition offers a two edged sword: an auditory IT will capture and demand attention, *at the expense of a visual OT*, to a degree that a visual IT will not (Wickens & Liu, 1988; Latorella, 1998). Such auditory capture could impose serious consequences on an OT with high safety implications, such as monitoring the trajectory of a ground or airborne vehicle. (Note that we focus here exclusively on a visual OT, given our interest is in the safety of visually guided vehicle control). Psychological analysis offers two different reasons for such **auditory preemption**. **Onset preemption** refers to the greater attention capturing properties of the auditory channel (Spence & Driver, 1997), that property which underlies its popularity as a warning system.

In contrast, what we label **strategic preemption,** characterizes the human's desire to keep attention focused longer on an auditory IT of some complexity, because to do otherwise would risk the loss of information from working memory. This tendency would not be reflected for a visual IT given that its display will typically be enduring (e.g., printed text), and not requiring working memory for retention. Latorella (1998) has found some evidence to support strategic preemption in an aviation simulation, while a few recent studies in driving (e.g., Horrey & Wickens, 2004) have supported the role of onset preemption in driving simulations.

In design applications, it is important to note that auditory pre-emption has very different implications from multiple resource theory (Wickens, 2002), from which emerges a prediction that performance on both the IT **and** a visual OT will be superior with an auditory display of the former task. Ample support for this view has been provided in both basic (e.g., Wickens, 1980, 2002) and applied (e.g., Wickens, Goh, Helleberg, Horrey, & Talleur, 2003; Horrey & Wickens, 2004) research. However benefits of auditory presentation of an IT for both tasks, are most likely to be found when the sources of visual input are widely separated, adding a scanning or peripheral vision cost to visual presentation, on top of whatever central processing mechanism (pre-emption, multiple resources) may exist.

The primary goal of the current study is to carefully examine pre-emption versus multiple resource predictions in a well controlled experiment in which an auditory versus visual IT are presented concurrently with a visual tracking task (simulating continuous vehicle control). In order to examine the possible contributions of onset versus strategic preemption, IT message length is varied, to impose a range of working memory demands. If strategic preemption is manifest, then the auditory cost to the visual OT should be increased (or an auditory benefit reduced) as message length increases.

As a secondary goal, we explore a range of visual separations in the visual conditions, to examine the contribution of scanning costs to overall dual task costs. In particular, we are interested in testing a model of visual information access costs (Wickens, 1993) postulating smaller costs with increasing eccentricity within the eye field, compared to those costs within the head field where head movement is required.

A third goal is to evaluated predictions related to the compatibility of display of OT (vehicle control) information in either the right left visual field (hemispherically compatible; Wickens & Sandry, 1982), or in the upper visual field (ambient incompatible, Previc, 1998, 2000).

METHODS

Thirty-six paid undergraduate volunteers participated in the 1 hour study. Participants sat in front of the work station (two CRT displays, and a joy stick), shown in Figure 2. They tracked (the OT) a first order two axis compensatory tracking task (quasi-random input with 0.5 Hz bandwidth), while periodically performing the IT: a cell-phone number entry task, in which they received (auditorally or visually) 4, 7, or 10 digit phone numbers at unpredictable intervals averaging 10 seconds, and were required to "voice dial" those numbers as soon as they heard or saw them. Equal emphasis was placed on both tracking and voice dialing. Participants carried out 9 trials, each of 3 minutes duration, during which they received a random order of IT message length. Each trial used a different interface layout: auditory, or one of several visual displays, which, as shown in Figure 2, varied in eccentricity from an overlay (simulating a HUD), to 7.5 degrees (adjacent to the tracking display), to 15 degrees, 32 degrees and 45 degrees), the latter a separation that clearly enters the head field (Bahill, Alder, & Stark, 1975).

RESULTS

Modality Analysis: Pre-Emption Versus Multiple Resources

Response time to the IT in the HUD and visual adjacent (7.5 degree) condition did not differ, and the latter was used as the baseline with which to compare auditory performance and was 0.90 sec. RT for the auditory display was 0.62 sec, a difference that was highly significant ($F_{1,34} = 23.7$, $p<.01$). Importantly, a significant display X load interaction ($F_{2,68} = 7.53$, $p<.01$) indicated that this auditory advantage was greatest with the shortest (4 digit) IT.

In contrast to IT performance (RT), tracking (OT performance) showed two sorts of costs for auditory delivery of IT information (relative to visual adjacent delivery): an increase in control activity just after arrival of the IT ($F = 4.64$, $p<.01$), and a 10% larger tracking error during the period when the voice response was articulated ($F = 8.83$, $p<.01$). This auditory preemption effect did **not** grow with longer messages, thereby suggesting that a strategic preemption was not manifest in the current data. It is important to note that the performance effects on the IT and OT were observed with the same magnitude in the visual overlay condition as in the adjacent condition, and therefore the visual costs to IT response time cannot be attributable to visual scanning.

Eccentricity Analysis

The second portion of the analysis focused on the effects, within the visual modality, of increasing lateral eccentricity relative to the adjacent-overlay conditions, through the range of the eye field, where visual scanning was involved, out to the region of the head field (at 45 degrees) where head movements were necessary to bring the IT digits into foveal vision, as well as to foveate the tracking cursor. These results revealed significant decreases in both IT performance (RT: $F = 17.4$, $p<.01$), and tracking performance (RMS error: $F = 156$, $p<.01$), as eccentricity increased. Furthermore, at separations of 15 degrees, performance reached a level on both tasks that was inferior to auditory delivery.

For both tasks, the error increase with eccentricity was non-linear, with the greatest cost encountered when the separation entered the head field (Bahill et al., 1975). That is, head movement costs were greater than eye movement costs. This tracking cost with increased eccentricity within the eye field (15-32 degrees) was 2.5 [tracking error units]/degree, half the eccentricity cost within the head field ((32-46 degrees: 5 [tracking error units]/degree). Importantly, the total costs of eccentricity were substantially greater for tracking (70% error increase) than for the IT (30% error increase).

Visual Field Analysis

This analysis compared displacement of the IT rightward with downward. Importantly, this places the spatial tracking display in peripheral vision, where tracking can still be accomplished, but, respectively, in a hemispherically compatible location (left visual field feeding to the right cerebral hemisphere), and in an ambient incompatible location (Previc, 1998, 2000). Consistent with these predictions, tracking error was better with the lateral than the vertical displacement ($F_{1,33} = 9.07$; $p<.01$). The effect was of marginal significance, but in the same direction, for IT RT ($F_{1,33} = 3.59$; $p=.07$).

DISCUSSION

Auditory delivery of information is often advocated as a design tool to offset visual resource competition in high workload settings, and therefore avoid some of the task management costs of, for example, looking downward at an IT display while driving. The current data offer two main messages in this regard. First, the benefits of auditory offload may, under some circumstances, be offset by the pre-emptive nature of the auditory delivery, producing a cost to the ongoing tracking (e.g., vehicle control) task, when this cost is assessed relative to a visual display location that requires little or no scanning (e.g., a HUD, or a display located high on the dashboard of a vehicle). In the current study, this cost appeared to be more related to an abrupt shift of attention at the onset of the auditory message, than to a strategic effort to maintain attention away from tracking while rehearsal was ongoing, since this cost did not increase, but actually decreased with increasing message length. Such a cost of a purely auditory task is quite consistent with the concerns offered by Strayer and Johnson (2001; Strayer, Drews & Johnston, 2003), and others regarding hands-free cell-phone interference with driving.

The conditions under which auditory (cross modal) delivery of information remain superior to visual (intra-modal) when visual scanning in the latter case is not required, remain somewhat of an enigma, just as they were in the original review by Wickens and Liu (1988).

Second, we note that even within purely visual delivery, increasing eccentricity of an IT imposes a greater cost on the continuous manual control task (OT), than on the discrete IT, in spite of instructions to give them equal priority. Thus, in the context of the model offered at the outset, both modality and visual separation may represent classes of physical variables that can influence the overall task switching/interruption parameters. Such influences have important consequences when the costs of neglect of the OT are serious (automobile crashes), and certainly speak positively for the benefits of adjacent visual (i.e., HUD) displays.

Third, we note that the non-linearity with increasing eccentricity is prominent. This suggests that, when display separation must be imposed, particular caution should be exercised to keep this separation within 25 to 30 degrees, so that head movements are not required for information access.

Fourth, we note the emergence of compatibility effects, supporting the notion of separate visual fields that might be more, or less supportive of spatial processing necessary for continuous control (Previc, 1998, 2000). These findings suggest that a rightward display of digital information may be ideal (as is often the case in positioning automobile displays--- to the right of the steering wheel). However they also suggest that digital information, perhaps on a HUD, might be better positioned above, than below the source of primary tracking information.

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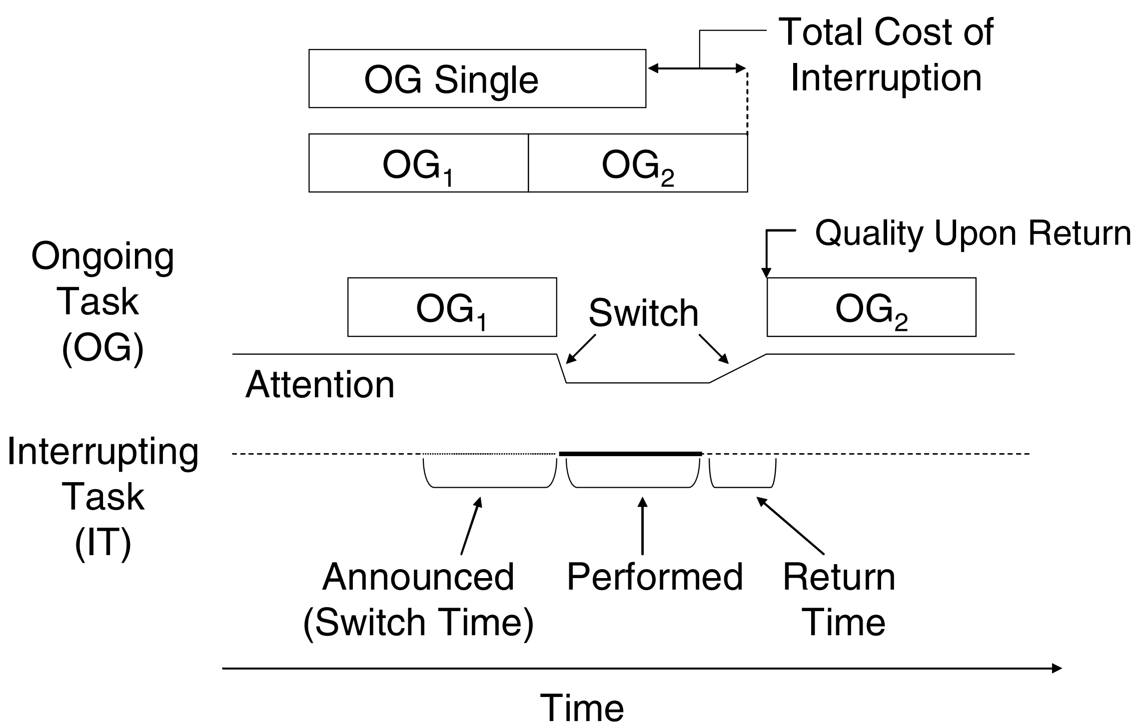

Figure 1. A model of attention switching.

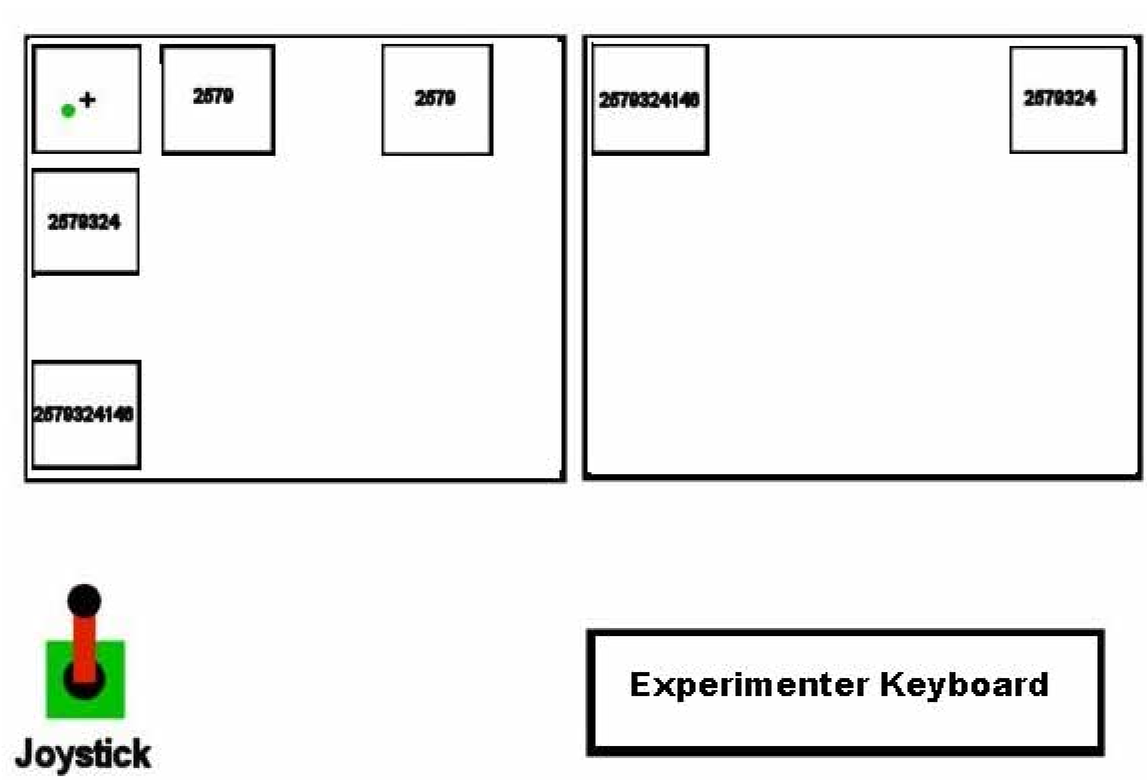

Figure 2. Different layouts employed for positioning of the interrupting task. Although only one layout was employed at a time, the current rendering shows several of these, and illustrates the different interrupting task lengths. An additional layout superimposed the digits on the tracking task display at the upper left.