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When Available Resources Become Negative Resources

The Effects of Cognitive Overload on Memory Sensitivity and Criterion Bias

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This study uses signal detection measures and secondary task reaction times (STRTs) to examine the effects of structural complexity and information density on processing television messages. Of particular interest are results pertaining to cognitive overload experienced while processing structurally complex and informationally dense messages. When required resources exceed available resources—that is, when a state of cognitive overload is reached—both memory sensitivity and criterion bias drop dramatically while STRTs get faster. The results provide support for the contention that secondary task reaction times are often very fast during highly complex messages because the system is overloaded and therefore resources are shifted from the primary task to the secondary task. Also of interest, the liberal shift in criterion bias starts before overload has occurred, suggesting that criterion bias may be tracking available resources.

Keywords: *limited capacity; signal detection; secondary task reaction time*

A paradox that has troubled communication researchers for years concerns the speed of secondary task reaction times (STRTs) during complex mediated messages. In the STRT methodological paradigm, participants perform a primary task (e.g., watching and remembering mediated messages) while at the same time they are told that from time to time they will hear or see a signal (e.g., a beep or color bars) and when they do they should press a key or button as fast as possible. In this paradigm it is believed that when the primary task requires many resources there will be few resources left over to perform the secondary task and as a result the STRT will be slow. When the primary task is easy on the other hand and requires few resources, there will be many resources left over and the STRT will be fast. Applying this paradigm to media, one would theorize that as messages become more complex they should require more cognitive resources to process, resulting in fewer leftover resources and slower STRTs.

However, a number of studies have found that STRTs are faster during viewing of complex compared to simple messages (Britton & Tesser, 1982; Britton, Westbrook, & Holgredge, 1978; Lang, Schwartz, Chung, & Lee, 2004; Reeves & Thorson, 1986; Reeves et al., 1985; Reeves, Thorson, & Schleuder, 1986; Schleuder, Thorson, & Reeves, 1988; Thorson, Reeves, & Schleuder, 1985, 1986). This has left researchers searching for an explanation for this unexpected result. Initially, some researchers suggested that simple messages fill up cognitive capacity more than complex messages do (Thorson et al., 1985). Another explanation was that complex video messages are more arousing, which causes reaction times to be faster (Reeves et al., 1986). But these do not seem to be the simplest or most parsimonious explanations, and neither do they account for the poorer memory (primary task) performance that often accompanies the fast STRTs for complex messages (Lang & Basil, 1998; Reeves et al., 1986; Thorson et al., 1986). The declining memory performance found in these studies suggests that processing the complex messages suffered. As noted, faster STRTs were generally thought to indicate plenty of leftover resources. But for complex messages, the fast STRTS cannot indicate superfluous resources given the accompanying decline in memory performance. Rather, limited capacity theory suggests that the fast STRTs and poor recognition performance for the primary task likely indicate an automatic shift of limited cognitive resources from the increasingly difficult primary task to the relatively simple secondary task when overload occurs. The study reported here uses limited capacity theory and signal detection measures to test this explanation for the paradox of fast STRTs for complex messages.

Literature Review and Study Hypotheses

Secondary Task Reaction Times and Limited Capacity

The secondary task methodological paradigm is rooted in the theoretical assumption that people have a limited pool of cognitive resources with which to process information. Cognitive researchers have long considered people to be limited capacity information processors with a finite pool of resources that puts an upper bound on how much information can be attended to or processed at a time using active or working memory (Baddeley, 1999; Duncan, 1999; Miller, 1956). Generally, STRTs have been considered to be a measure of unused or leftover resources. That is, as more cognitive resources are used up by the primary task, fewer resources are left over to respond to the secondary task. Thus, STRTs are thought to slow down as primary tasks become more complex and use more resources.

Recently, Lang and Basil and their colleagues have been testing a new conceptualization of secondary task reaction times as a measure of resources available at encoding rather than leftover resources (Lang & Basil, 1998; Lang, Bradley, Park, Shin, & Chung, 2006; Lang, Park, Sanders-Jackson, Wilson, & Wang, in press). Lang and Basil (1998) suggested that as perceiving and responding to the secondary task reaction time probe is essentially an encoding task, STRTs are actually indexing the resources that are allocated to the encoding subprocess but not required by it.

This conceptualization was developed using Lang's (2000) limited capacity model of mediated message processing, which posits that successful processing of a mediated message consists of the simultaneous operation of three subprocesses—encoding, indexed by recognition; storage, indexed by cued recall; and retrieval, indexed by free recall—all of which draw on the same pool of limited resources. When sufficient resources are allocated to all the subprocesses involved in mediated message processing, then the message will be thoroughly processed; however, if insufficient resources exist to provide sufficient resources to the subprocesses, then a state of cognitive overload is said to have occurred and some aspect of message processing will suffer (Lang, 2000). Declining recognition performance is an indication that message encoding has suffered as cognitive overload has occurred (Fox et al., 2004; Lang, 2000; Lang, Potter, & Bolls, 1999).

Within this theoretical perspective, resources are thought to be allocated to message processing through both controlled and automatic mechanisms. Viewers can and do allocate their limited cognitive processing resources in a conscious or controlled manner as a result of decisions about what to pay attention to, how hard to try, and so on (Lang, 2000). At the same time, however, many structural features in messages (e.g., cuts, edits, sound effects, etc.) elicit an orienting response from viewers, which is a type of automatic attentional response to novel or signal stimuli that increases the automatic allocation of resources to the subprocess of encoding the message (Lang, 1990, 2000; Lang, Geiger, Strickwerda, & Sumner, 1993; Reeves & Nass, 1996; Thorson & Lang, 1992). Thus, increasing the number of structural features in a message increases the automatic allocation of resources to encoding the message (Lang, Bolls, Potter, & Kawahara, 1999; Lang, Potter, et al., 1999; Lang, Schwartz, & Snyder, 1999; Lang, Zhou, Schwartz, Bolls, & Potter, 2000).

Interestingly, whether the additional resources that are automatically allocated in response to certain structural features enhance encoding of the message depends on the difficulty of the message content to which viewers are giving their controlled attention. Cognitive overload can occur, even with greater automatic and/or controlled resource allocation, if the additional resources are still insufficient to process the increased resource demands of the message. When messages are simple, familiar, or easy, increasing the number of structural features and hence the resources automatically allocated to encoding tends to result in increased recognition memory for the messages. However, for less familiar, complex, or more difficult messages, the reverse occurs; although increasing the number of structural features increases automatic allocation of resources to encoding, it results in decreased recognition memory for the messages, indicating poorer encoding of the message (Bolls, Muehling, & Yoon, 2003; Lang, Bolls, et al., 1999; Lang et al., 2004; Lee, Angelini, Schwartz, & Lang, 2003). This is because the resources allocated are not sufficient to process the resource demands of the difficult or unfamiliar content and the changing structure of the complex messages.

Similarly, when an edit occurs within the same visual scene, the edit elicits an orienting response and an accompanying automatic allocation of additional processing resources to message encoding. Because the edited visual remains within the same scene, however, the newly introduced information does not require many new resources to encode and the additional resources are superfluous. However, when there is a cut to a new visual scene there is generally much more new information introduced with the camera change. In this case, the additional processing resources elicited by the orienting response to the camera change may not be sufficient to encode all of the new information introduced with the camera change, and message processing may suffer. Indeed, studies have found recognition to increase linearly with message pacing for related cuts but curvilinearly for unrelated cuts (Lang, 2000). That is, recognition always improved as pacing increased the number of related camera changes, suggesting that the additional automatic allocation of processing resources elicited by those related camera changes helped message encoding. For the unrelated cuts, increasing pacing also initially helped message encoding through the additional automatic allocation of processing resources. But at some point the pacing got too fast, and even though additional resources were automatically allocated to the message with each camera change, there were insufficient resources to process all of the new information introduced before the next camera change occurred.

This means that when deciding whether a media message is complex one must consider both structural and informational components of the message. If one conceptualizes STRTs as resources available at encoding, it is necessary to separate complexity due to structure from that due to the content because increasing structural complexity increases resources automatically allocated to encoding, whereas increasing content complexity only increases the resources required. The combination determines whether or not there are resources available at encoding, which in turn determines the speed of the STRT.

Two recent studies (Lang et al., 2006, in press) manipulated both the complexity of the structure (i.e., resources allocated to encoding) and the information content (i.e., resources required at encoding) in television messages while measuring STRTs and recognition memory. Structural complexity was manipulated by the number of camera changes per second, with two levels (low and high). Informational density was manipulated by the amount of information introduced by the camera changes, with three levels (low, medium, and high). They found that increasing structural complexity (i.e., resources allocated) at low levels of information density (i.e., resources required) resulted in improved recognition and no change in STRTs as would be expected because available resources should be high as the processing demands of the messages are quite low. At medium levels of information introduced, increasing structural complexity resulted in slower STRTs and good memory performance, indicative of fewer available resources given the slower

STRTs—but still a superfluity of resources given the recognition scores. At high levels of information density however, increasing structural complexity resulted in poor recognition, as would be the case if cognitive overload had occurred. In other words, there were insufficient resources allocated to encoding, indicated by the declining recognition. But, performance on the secondary task improved, as indicated by faster STRTs.

So, if structural features introduce simple, familiar information, then the structural features result in an increase in resources automatically allocated to encoding, but the simplicity of the information makes those resources superfluous as only low levels of resources are needed to process the message. Thus, there are many resources available (that is, allocated but not required) at encoding so recognition performance is good, and there are plenty of available resources to allocate to a secondary task so STRTS are fast. On the other hand, if structural features introduce difficult, unfamiliar, or complex information—or introduce unrelated or increasing amounts of new information with increased pacing of structural features—then even though additional resources are automatically elicited by the structural features, additional resources are also required to encode the content and changing structure of the information. Thus, there may be fewer available resources at encoding. If there are fewer but still sufficient resources available for encoding, recognition should remain stable but STRTs should be slower because there are fewer available resources to allocate to the secondary task. In the case of cognitive overload, resources required to encode the message exceed the resources allocated, and thus there are insufficient resources available at encoding and recognition suffers. The fast STRTs accompanying the declining recognition memory performance when overload is experienced suggest that encoding resources are being shifted from the too difficult primary task to the secondary task when overload occurs. But how can we be sure that this shift in resources from the primary to the secondary task is happening? Signal detection measures may provide the answer.

Signal Detection

The use of signal detection should significantly add to our knowledge about the cognitive processing of complex media messages by providing measures for examining both recognition memory strength and recognition memory decision criterion (Fox, 2004; Macmillan & Creelman, 1991; Murdock & Dufty, 1972; Shapiro, 1994; Wickens, 2002). Generally, media secondary task reaction time studies have relied on recognition accuracy to provide an indicator of how well the encoding subprocess or the overall processing of the message is going. This study proposes to use signal detection measures rather than simple recognition accuracy to further explore what is happening when viewers process messages that increase and decrease in both structural complexity and information density or difficulty.

In signal detection theory, a measure called sensitivity is used to indicate recognition memory strength (Fox, 2004; Murdock & Dufty, 1972). From its roots in radar detection studies from the 1950s, signal detection uses sensitivity to measure how well people distinguish between signals and noise (Fox, 2004; Macmillan & Creelman, 1991). Memory researchers have adopted this measure to compare how well study participants distinguish between old and new information when making recognition judgments (Fox, 2004; Macmillan & Creelman, 1991; Murdock & Dufty, 1972; Shapiro, 1994). To measure memory sensitivity, the recognition memory test includes both target items that were actually presented in the mediated messages and foil items that were not. The hit rate for correct recognitions of targets and the false alarm rate for incorrect recognitions of foils are used to calculate memory sensitivity (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). As sensitivity is a measure of recognition memory strength, sensitivity can be used to index message encoding in much the same way that recognition accuracy has been used in previous research. Thus, we can examine sensitivity and STRTs together as an indication of available resources. When resources available at encoding are plentiful and superfluous, then sensitivity is good and STRTs are fast. When resources available at encoding are fewer but still sufficient to perform the primary task of message encoding, sensitivity remains stable but STRTs are slow. When overload has occurred, sensitivity drops significantly and STRTs get faster.

In addition, as previously noted, in signal detection there are two parts to recognition—sensitivity and criterion bias, or our willingness to say we detect a signal or recognize information (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). Hit rates and false alarm rates are also used to measure this decision-making aspect of recognition judgments (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). Its distinction from memory sensitivity reflects the other roots of signal detection theory in statistical decision theory (Fox, 2004; Macmillan & Creelman, 1991). In signal detection theory, signals and noise, or targets and foils, vary in their individual familiarity values, though usually signals or targets have higher familiarity values than noise or foils (Fox, 2004; Macmillan & Creelman, 1991). The criterion value is the level we set for how familiar an item must be for us to consider it a signal or say we recognize it (Fox, 2004; Macmillan & Creelman, 1991). The more liberal our criterion is, the lower the level of familiarity we will require before saying that we recognize some piece of information, and vice versa, the more conservative our criterion is the higher the level of familiarity we will require before saying that we recognize information (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). Thus, when we have a more conservative criterion bias, we will have fewer false alarms but also fewer hits, whereas when we have a more liberal criterion bias we will have both more hits and more false alarms (Fox, 2004; Macmillan & Creelman, 1991).

This decision-making aspect of recognition judgments may offer some insight into viewers' encoding of complex messages. More difficult information may seem less familiar and thus viewers may adopt a more conservative criterion bias in determining how familiar the information must seem before they say they recognize it, even when they are still able to process the increasingly difficult information. A previous study using signal detection to examine memory for typical and atypical information supports this suggestion. Shapiro and Fox (2002) found participants were more conservative in their recognition decisions regarding atypical, schema-consistent information than they were in their recognition decisions regarding more familiar typical, schema-consistent information, even though their memory sensitivity for the atypical information was just as good if not better than their sensitivity for the typical information. Because schema activation facilitates message processing (Alba & Hasher, 1983; Bartlett, 1932; Hawkins & Daly, 1988; Mandler & Johnson, 1977; Meadowcroft & Reeves, 1989; Schank & Abelson, 1977; Thorndyke, 1977), the liberal criterion bias Shapiro and Fox found for typical, schema-consistent information may indicate a larger surplus of available resources at encoding, whereas the more conservative criteriofi bias for atypical information may indicate fewer resources available when encoding the schema-inconsistent information. Similarly, as messages increase in complexity and viewers have fewer resources available for encoding, indicated by slower STRTs, but have not yet reached cognitive overload, indicated by stable recognition performance, their criterion bias may become more conservative compared to when they more easily processed the simpler messages. That is, for complex compared to simpler messages, viewers may become more stringent and look for a higher level of familiarity given the increasingly difficult but still accomplishable task of processing the more complex messages.

On the other hand, once overload occurs and the primary task of message processing suffers, viewers may do considerably more guessing on the recognition test of primary task performance, particularly if they switched some of their limited resources from the compromised primary task to the secondary task to maintain that performance. This increased guessing would be reflected in a more liberal criterion bias. Therefore, a liberal shift in criterion bias accompanied by significantly declining memory sensitivity and faster STRTs could provide evidence that viewers shifted resources from the primary task of message processing to the secondary task during cognitive overload. Thus, this study predicts:

Hypothesis 1: Secondary task reaction times will increase as structural complexity and information density increase up to the point of overloading viewers' limited cognitive resources, defined by a drop in memory sensitivity; when viewers reach overload, their secondary task reaction times will get faster.

Hypothesis 2: Recognition memory criterion will become more conservative as message complexity increases, up to the point of overloading viewers' limited cognitive resources. When viewers reach overload with highly complex messages their criterion bias will become more liberal, indicating that resources have shifted from the primary to the secondary task.

Method

Design

The design of this experiment is a Structural Complexity (2) x Information Density (3) x Valence (2) x Arousing Content (2) x Message (3) x Half (2) mixed A NOVA design, although the results involving the emotional factors of message valence and arousal are reported elsewhere.

Stimuli

The half factor refers to which half of the total message pool participants viewed. A total of 144 messages, which were either 30 or 60 seconds in length, were selected from a pool of video clips from television messages and feature films. From the pool of video clips, 144 messages were chosen to manipulate the structural complexity, information density, and emotion of the messages. For each category of Structural Complexity/Second x Information Density/Second x Valence x Arousing Content, 6 messages were chosen. Then the 144 messages were separated into two groups of 72 messages, balanced by the length of total presentation time (equal number of 30- and 60-second clips in each half). Each of those two groups contained 3 messages for each category of Structural Complexity/Second x Information Density/Second x Valence x Arousing Content. Each participant was randomly assigned to view one set of 72 messages. This is the only between-subjects factor in the study; all others are within-subject factors.

Independent Variables

Structural complexity. The first factor, structural complexity, is the structural component of message complexity manipulated in this study. Structural complexity was manipulated by counting the number of camera changes in each message and dividing it by the length of the message, resulting in the number of camera changes per second. The average camera changes per second for the two levels of structural complexity in this study were low = .22 (*SD* = .173) and high = .45 (*SD* - .83). The difference between these levels was statistically significant, jp(l, 142) = 5.17, p = .02.

Information density. The second factor, information density, is the content component of message complexity manipulated in this study. Information density for the messages was measured using the Information Introduced (I-squared) measure developed by Lang and colleagues (Lang et al., in press). I-squared measures the amount of information introduced by each camera change in the message. For each camera change, I-squared ranges from 0 to 7, depending on the number of informational dimensions present for the new information introduced by each camera change.

recordings of all statements and responded either yes or no that they had heard the statement. Given the high accuracy of visual recognition only audio recognition was tested.

Based on Macmillan and Creelman (1991), parametric measures were used to compute sensitivity and criterion bias. These measures assume that familiarity distributions for old and new items are normal and have equal variance and include adjustments in cases of perfect accuracy. Using the following procedures outlined by Macmillan and Creelman, signal detection measures of sensitivity and criterion bias were calculated for each participant.

Sensitivity (d'). The proportion of false alarms, converted to a standard score, is subtracted from the proportion of hits, also converted to a standard score, to calculate sensitivity, denoted by *d'* (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994; Shapiro & Fox, 2002). The more sensitive the participant is at discriminating between target and foil items, the larger the *d'* value will be (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). If a participant is unable to discriminate between target and foil items the hit rate will equal the false alarm rate and *d'* will equal zero (Fox, 2004; Macmillan & Creelman, 1991).

This sensitivity measure is unbounded and thus can be infinite in the case of perfect accuracy (Fox, 2004; Macmillan & Creelman, 1991). When this happens, it is usually because of statistical or sampling error (Macmillan & Creelman, 1991), although if there are several instances of perfect accuracy the experiment should be redesigned (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994). In cases of perfect accuracy, proportions can be converted from 0 to 1/(2N) and from 1 to 1 - 1/(2N) (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994; Shapiro & Fox, 2002).

Criterion bias (c). The parametric measure for criterion bias, denoted by c, is calculated by multiplying the sum of the standardized scores of the hit rates and the false alarm fates by -0.5 (Fox, 2004; Macmillan & Creelman, 1991; Shapiro, 1994; Shapiro & Fox, 2002). When the false alarm rate for foil items equals the miss rate for target items, a participant is just as likely to say yes as to say no in making recognition judgments (Fox, 2004; Macmillan & Creelman, 1991). When this happens, the value for c is zero and the criterion is considered unbiased (Fox, 2004; Macmillan & Creelman, 1991). When the false alarm rate is greater than the miss rate, the bias is toward answering yes, indicating a liberal criterion bias with a negative value (Fox, 2004; Macmillan & Creelman, 1991). On the other hand, when the miss rate is greater than the false alarm rate, the bias is toward answering no, indicating a conservative criterion bias with a positive value (Fox, 2004; Macmillan & Creelman, 1991).

Participants

For the study, 94 students, 45 women and 48 men with 1 participant gender unidentified, were recruited from telecommunication courses at a major Midwestern university and given extra credit for their participation. The average age of study participants was 20.1 years old (*SD* = 1.83). Technical problems rendered the STRT data of 13 participants and the recognition test data of 1 participant unusable, resulting in 80 participants in the STRT analysis and 93 in the signal detection analysis.

Procedure

After giving informed consent, participants were randomly assigned to view one set of 72 messages. Participants were instructed to pay close attention to the messages as their memory would be tested. Participants were also told that they would hear occasional beeps and that when they heard a beep they should push a button on their keyboard as fast as they could. Following a practice session with two video clips and several recognition questions, participants viewed 72 messages presented via a laptop computer and headphones and responded to the STRT probes. Participants then performed a distractor task before completing the auditory recognition test.

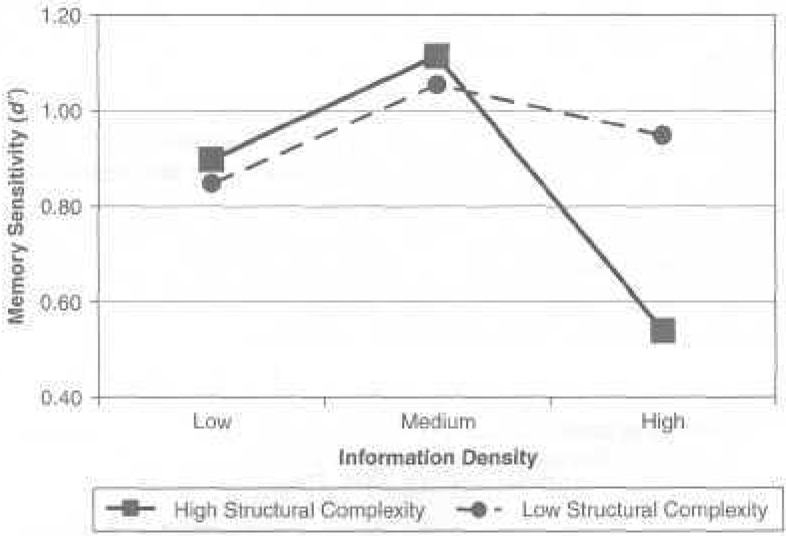
Results

Memory Sensitivity and Secondary Task Reaction Time

Hypothesis 1 predicted that secondary task reaction times would increase as message complexity increased up to the point of overloading viewers' limited cognitive resources but that when viewers reached overload their secondary task reaction times would get faster. Based on the memory sensitivity results, this means that STRTs should be fastest for messages high in structural complexity and information density as this is where the memory sensitivity data indicate that overload occurred. Specifically, recognition memory sensitivity was considerably worse for clips with both high structural complexity and high information density (d' mean = .540) compared to all the other conditions, as indicated by the significant interaction of information density and structural complexity on recognition memory sensitivity, $F(2, 184)$ — 4.615, p = .011, partial n^2 = .048 (see Figure 1).

In the other conditions, STRTs should get slower as information density and structural complexity increase. This prediction is tested by the significant interaction of information density and structural complexity on STRTs, $F(2, 158) = 19.362$, $p <$ .001, partial $r]^2$ - .197 (shown in Figure 2). As predicted, when structural complexity is low, increasing information density results in decreasing but still positive available resources and slower STRTs. However, when structural complexity is high, increasing information density decreases available resources, eventually reaching negative available resources or cognitive overload. Thus, STRTs for structurally complex messages slow from low to medium information density as fewer but sufficient resources are available to complete the primary task but then return to the fast level seen in simple messages at the point of overload, suggesting a shift of resources from the primary to the secondary task. Hypothesis 1 is supported.

Figure 1
Information Density × Structural Complexity Interaction Effect on Memory Sensitivity (d')

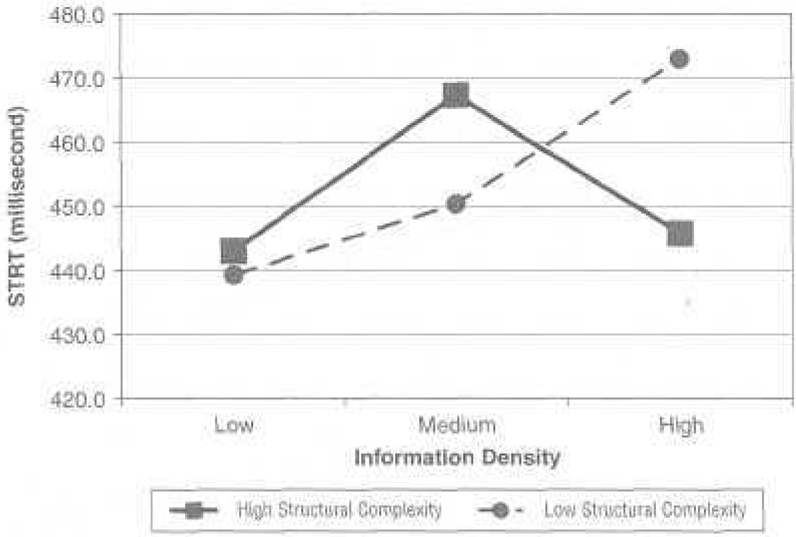


Memory Decision Criterion Bias

Hypothesis 2 predicted that if resources shift from the primary task to the secondary task at overload then criterion bias should decrease significantly for messages where cognitive overload occurred—that is, in messages high in both structural complexity and information density. This prediction is tested by the significant interaction of information density and structural complexity on recognition memory criterion, F(2, 184) = 8.348, p < .001, partial n = .083 (shown in Figure 3). As expected, criterion bias is lowest, or most liberal, for messages high in structural complexity and information density. Interestingly, criterion bias is equally low, or liberal, for messages low in structural complexity but high in information density. This may suggest that information density drives criterion bias. Indeed, there was a significant main effect of information density on criterion bias, $F(2, 184) = 13.50$, $p < .001$, partial $n)^2 = .128$ (see Table 1). When information density was high, the criterion became more liberal regardless of the structural complexity.

However, the significant interaction of structural complexity and information density on criterion bias means criterion bias responds to both task difficulty and available resources. Thus, it is also worth noting the differing patterns in criterion bias for high and low structural complexity. When structural complexity is high,

Figure 2
Information Density × Structural Complexity Interaction Effect on Secondary Task Reaction Times (STRTs)

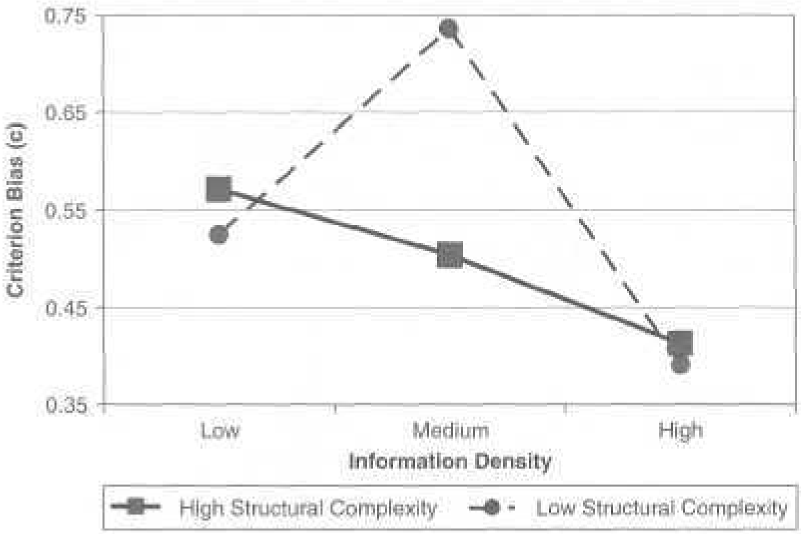


there is a linearly decreasing relationship between information density and criterion bias. That is, when structural complexity is high, criterion bias becomes more liberal as information density increases. However, when structural complexity is low, a moderate level of information actually leads to an increase, that is, a conservative shift, in criterion bias, as predicted. In Figure 2, we can see that in the medium information density condition, STRTs are faster for low structural complexity than they are for high structural complexity. This combination of faster STRTs and a more conservative criterion suggests that there are more available resources for medium information density messages in the low compared to the high structural complexity condition. Interestingly, memory sensitivity is the same for these conditions as seen in Figure 1. Hypothesis 2 is partially supported.

Discussion

The data tell an interesting story about processing mediated messages. For messages with low structural complexity, increasing information density does not induce cognitive overload; although there was a decrease in available resources, resulting in

Figure 3
Information Density × Structural Complexity Interaction Effect on Criterion Bias (c)



slower STRTs, memory sensitivity was stable. On the other hand, when messages are high in structural complexity, increasing information density reduces available resources precipitously and eventually overloads the system, resulting in drastic reductions in memory sensitivity and fast STRTs. These results suggest that the increased allocation of processing resources automatically elicited by the structural changes is insufficient to thoroughly process the increased processing demands of the content and structure in those messages.

Of particular interest are the criterion results, which offer further support for the prediction that when viewers process complex messages that produce cognitive overload, they shift resources from the primary task, freeing up available resources for the secondary task. Criterion bias was most liberal for the high density information. Viewers hit overload, and STRTs became faster for the high information density messages with high structural complexity, suggesting a shift of resources from the primary task of message encoding to the secondary task. Looking at the medium level of information density shows the story is a bit more complex however as the shift to a more liberal criterion for high structural complexity messages seems to precede actual overload, suggesting that criterion bias may actually be tracking the decrease in available resources.

Table 1
Differences in Means for Information Density Conditions

	Low Density		Medium Density		High Density		Significance Test		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*
d'	$0.87^{1,2}$	0.081	$1.08^{1,3}$	0.09	$0.75^{2,3}$	0.07	8.14	2, 184	< .001
Hypothesis 1: Secondary task reaction times (ms)	$441.21^{4,5}$	11.22	458.86^{4}	12.13	459.41^{5}	10.88	12.55	2, 158	< .001
Hypothesis 2: Criterion bias	$0.55^{6,7}$	0.07	$0.62^{6,8}$	0.07	$0.40^{7,8}$	0.08	13.50	2, 184	< .001

Note: Means sharing a common superscript are significantly different beyond $p = .001$ by the t test.

Examining results for the three dependent variables together further supports this contention. For messages with low structural complexity, as information density increases, STRTs get slower and memory sensitivity stays the same. As previously noted, this indicates no cognitive overload. Criterion bias however shifts at medium levels to a more conservative criterion and then at high levels shifts to a very liberal criterion. This may mean that from low and medium levels of information density there are fewer but still plenty of available resources, but at high levels of information density—though overload has not occurred—there are very few available resources remaining, which may lead to the more liberal criterion.

For high structural complexity messages, the shift from low to medium information density again results in slower STRTs and stable memory sensitivity. However, the slowing in STRTs is much greater for the structurally complex messages than it was for the less complex messages from low to medium information density, and this is coupled with a liberal shift in criterion bias rather than the conservative shift seen for less structurally complex messages. This may mean that there are far fewer available resources for medium information density messages that are structurally complex than there are for medium information density messages that are structurally simple. So, the liberal shift indicating the approach of cognitive overload is already occurring at the medium level of information density for structurally complex messages. At high levels of information density and structural complexity, overload has occurred and criterion is even more liberal.

Although sensitivity is actually best for medium information density messages with high structural complexity, those messages take considerably more resources to process, as indicated by the slower STRTs compared to both medium information density messages with low structural complexity and messages with high structural complexity but low information density. Despite viewers' ability to still process these messages thoroughly, available resources are decreasing, thus the shift in criterion bias may indicate that available resources are fast approaching zero.

This suggestion that for recognition judgments decision criterion bias is tracking available resources makes an important contribution to the signal detection literature. Signal detection theory posits that criterion is based on rewards for correct judgments and punishments for incorrect judgments (Fox, 2004; Macmillan & Creelman, 1991). Another way to think of this is the type of error we are willing to make (Fox, 2004). When we have a conservative criterion bias we are more willing to miss a signal, which for recognition would be failing to correctly recognizing old information. When we have a more liberal criterion bias we are more willing to falsely identify noise as a signal, which for recognition would be incorrectly recognizing new information (Fox, 2004). For certain judgments there are obvious rewards and punishments associated with hits, misses, false alarms, and correct rejections. For example, there are obvious rewards associated with correctly identifying a blip on a radar screen as an enemy aircraft (destroying it before it attacks) or a suspicious area on an X-ray as a tumor (treating the cancer and saving a life). Likewise, there would be obvious punishments associated with missing those signals. Similarly, there would be obvious benefits to correctly rejecting noise when there is no incoming enemy aircraft or when the tissue is healthy, just as there would be obvious penalties associated with falsely identifying a blip on a radar as enemy aircraft (friendly fire) or falsely diagnosing healthy tissue as cancerous (unnecessary worry and medical procedures). However, the data from this study suggest that for recognition judgments, criterion bias may not be indexing rewards and punishments so much as it is tracking available resources. When resources are taxed but still superfluous, criterion becomes more conservative, but as available resources become exhausted, criterion becomes considerably more liberal, heralding the onset of cognitive overload. In addition to these important theoretical contributions, the findings in this study make an important methodological contribution by suggesting that signal detection measures are valuable tools for measuring resources available at encoding.

One of the limitations of this study is the number of categories used to examine effects of information density and structural complexity on message processing. Future studies could examine greater, more finely grained categories of these variables to more precisely pinpoint where overload occurs and the exact point at which the liberal criterion shift begins.

Another limitation of this study is that only video information introduced was coded for each camera change. This study stems from a line of research that manipulated complexity of television messages, and thus presumably the cognitive load or resources required to process those messages, through pacing of camera changes. The method used here improves on previous studies by acknowledging that not every camera change introduces an equal amount of new visual information. However, although camera changes are visual changes, audio information can also change at the same time, requiring additional processing resources (though also bringing additional automatic allocation of resources through orienting responses to changes in audio). Given the multiple messages used in this study design, it is unlikely that they all have the same audio complexity. But although audio complexity is not manipulated here, it should at least be controlled through the use of multiple messages in the study design. Nevertheless, audio complexity is certainly an important feature of television messages that warrants further investigation, particularly as the secondary task is an auditory task and the measure of performance on the primary task is audio recognition.

A system has been developed for coding the amount of audio information introduced during changes in auditory structural features in radio messages that identifies two common sets of auditory structural features—voice change and structural onsets (e.g., sound effects, music, silence)—and quantifies the amount of information to be processed by the resources allocated to those structural feature onsets (Potter et al., 2006). Voice changes are coded for seven different types of information introduced, such as whether the voice had been heard previously in the message, whether it introduces unrelated content, and whether there is a change in emotion across the voice change. Structural onsets are coded for four types of information introduced, including whether the sound had been previously heard in the message and whether it is an emotionally intense sound. A recent study using this system found increasing information density from low to medium levels improved recognition for radio messages with high structural complexity but led to overload for high structural complexity messages with high information density; for low structural complexity radio messages, increasing information density did not affect recognition (Potter et al., 2006). Future studies could incorporate this audio information introduced system developed for radio messages into the coding of information introduced by cuts and edits in television messages.

Despite these limitations, the study results reported here suggest that variations in structural and informational complexity elicit predictable automatic changes in the pattern of resource allocation, memory sensitivity, and criterion bias. Perhaps paramount is that this study strongly supports the theoretical premise that STRTs are likely indexing available resources, which are the result of both structural complexity and information density, once again pointing to the need for media researchers to consider the impact of both content and structure on message processing. These findings offer practical value to media practitioners by showing that messages that are too complex will overload viewers, and both processing and memory for the information will suffer. The findings offer theoretical value to researchers by using signal detection measures to help explain a paradox about STRTs and message complexity that has plagued researchers for decades. The findings suggest that cognitive processing automatically adjusts to message and task demands. The liberal shift associated with dwindling available resources may be the signal that viewers are pushing their cognitive limits, even though they are still able to allocate sufficient resources for message processing at that point. Once overload hits, sensitivity declines, criterion becomes considerably more liberal, and STRTs get much faster, indicating viewers have reallocated resources to maintain secondary task performance while message processing suffers. That is, when the primary task can no longer be performed, ,a shift in resource allocation occurs to maintain performance on the secondary task in spite of the primary task overload.

Note

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