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REVIEW ARTICLE



The limited capacity model of motivated mediated message processing: looking to the future

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ABSTRACT

In a companion piece (Fisher, Keene, Huskey, & Weber, 2018), we reviewed the foundations and current state of the Limited Capacity Model of Motivated Mediated Message Processing (LC4MP). In this manuscript we return to the three areas investigated in our review: cognitive load, motivation, and memory. In each domain, we: (a) outline areas in which the LC4MP has produced unexpected or ambiguous findings; (b) look broadly at literature from biology, cognitive psychology, and neuroscience to inform and clarify definitions of key terms; (c) develop an updated, cohesive framework of assumptions and predictions of the LC4MP; and (d) propose a roadmap for testing the proposed framework. We conclude with a discussion of the LC4MP's continued relevance for understanding dynamic, interactive, multimodal communication phenomena.

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attention; memory;
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The truth is that we must be constantly critical; self-critical with respect to our own theories, and self-critical with respect to our own criticism; and, of course, we must never evade an issue.

– Karl Popper, 1985¹

A prominent philosophy of scientific inquiry advocates for specifying models and theories such that they can be demonstrated as false through the accumulation of empirical evidence; this is known as falsification (Popper, 1959/2002). Within a falsification framework, no theory is necessarily true. Rather, theories are approximations of truth that should be abandoned when a better approximation is formulated. At the time of its initial development, the Limited Capacity Model of Motivated Mediated Message Processing (Lang, 2000, 2009) was unique in its efforts to develop a novel framework through which the 'black box' of cognitive processing could be pried open – creating a more informed and biologically plausible approximation of the complex, nonlinear, dynamic processes involved in communication.

Almost two decades have passed since the original publication of the model, and a large quantity of extant research supports its central assumptions and predictions (Fisher, Keene, Huskey, & Weber, 2018). However, there are several specific areas where model predictions and recent empirical findings do not align. If we understand falsification as a guiding principle of communication science (Slater & Gleason, 2012), then we are forced to ask: are these observed inconsistencies sufficient to falsify the LC4MP? More directly, is it time to abandon the LC4MP in favor of a better approximation of reality? In short, our answer to this question is 'no.'

We propose that the observed inconsistencies can be made consistent within the LC4MP framework through a process of model clarification (DeAndrea & Holbert, 2017). More specifically, we argue that progress toward resolving these inconsistencies can be achieved by elucidating mechanisms underlying key processes such as resource allocation and memory as well as clarifying a selection of conceptual issues in the model. In this manuscript, as in (Fisher et al., 2018), we turn to three broad domains within LC4MP research: cognitive load, motivated processing, and memory. In each domain we undertake several tasks. First, we outline areas in which the model has produced ambiguous or inconsistent findings, as well as areas in which the model would benefit from further conceptual or operational clarification. Next, we review the literature that informs the LC4MP, synthesizing recent theories and data from biology, cognitive psychology, and neuroscience in order to address observed conceptual and operational issues in the model. Finally, we develop an updated, cohesive framework of assumptions and predictions for the LC4MP, discussing how each of these changes contribute to the utility of the model for testing questions of interest for communication scholars (for a summary of these changes see Table 1). In each section, we generate a selection of hypotheses and present a roadmap for their testing. We conclude by situating the LC4MP within the milieu of modern communication science.

Cognitive load

The LC4MP proposes that the human processing system is capacity limited – an idea with a long history of support (Bjorklund & Harnishfeger, 1990; Chandler & Sweller, 1991; Kahneman, 1973; Posner, 1978; Schneider & Shiffrin, 1977; Zechmeister & Nyberg, 1982). The LC4MP argues that cognitive resources exist in a single, central pool (Lang, 2000, 2009). This proposition is in contrast to many other theories and models that propose that cognitive resource limitations are not monolithic, choosing to consider resources in a modality-specific or task-specific manner (Baddeley, 1992; Basil, 1994a; Wickens, 1991). The LC4MP discusses cognitive resources using the metaphor of a ‘pie’ with four slices: *resources required*, *resources allocated*, *resources available*, and *resources remaining* (Lang & Basil, 1998; Lang, Bradley, Park, Shin, & Chung, 2006).

In the LC4MP, it is proposed that the human processing system dynamically allocates resources to encoding, storage, and retrieval processes and that these resources are required (consumed) at a rate commensurate with message complexity (Lang, 2000, 2009). Message complexity in the LC4MP is conceptualized as the availability of processing resources (Lang et al., 2015; Lang, Kurita, Gao, & Rubenking, 2013) and can be measured as information introduced per second (ii/sec) or per camera cut (ii/cc; Lang et al., 2006). A key prediction of the LC4MP is that message complexity interacts with pacing, individual cognitive differences, and emotional content to load the processing system and thereby reduce the available cognitive resources. Decreasing resources available for processing is reflected in lengthening secondary task reaction times (Lang & Basil, 1998; Lang et al., 2006) and reduced memory for presented content. On the whole, the LC4MP’s predictions in the area of cognitive load have found broad experimental support (Fisher et al., 2018). A selection of recent results, though, are not well characterized by the current model, necessitating clarification of the model’s assumptions and predictions.

Unexpected findings and inconsistencies

As mentioned above, the LC4MP assumes that audio and visual information both draw from a central, unitary resource pool. The LC4MP holds that audio and visual information load the processing system with different speed and in different amounts, but does not allow for the idea that auditory and visual information may require different resources to process (Lang, Potter, & Bolls, 1999). A subset of LC4MP research suggests, though, that the resource pool may be meaningfully separable by modality. For example, a study by (Bolls, 2002) found that audio processing only interfered with a visual task when the audio messages were high in imagery. These findings are corroborated by

Table 1. Comparing the current LC4MP to proposed updates.

Domain	Extant LC4MP	Proposed Updates	Utility of Proposed Update
Cognitive Load	No delineation between cognitive and perceptual resources.	Cognitive and perceptual resources are considered as meaningfully separable, each having unique effects on message processing.	Can account for increasing evidence suggesting that cognitive and perceptual load interact to influence message processing outcomes rather than both drawing from the same pool.
	The LC4MP does not currently specify a physical mechanism for resource limitations.	Resources are conceptualized as relating to chemical, spatial, and temporal constraints.	'Resources required' by a message processing task can be specified in a more precise fashion.
	Visual and auditory processes draw from same central pool, although differences in quantity of resources required and processing speed allowed between modalities.	Visual and auditory resources are also separable, but only for perceptual processing.	Explains and provides a path forward for inconsistent and sometimes contradictory findings regarding audiovisual redundancy and resource availability.
Motivated Processing	Reward learning and controlled resource allocation in relation to individual goals are theoretically characterized in the model, but further conceptual / operational clarity is needed.	Motivation is proposed to be related to rigid or flexible associations with reward/threat magnitude, likelihood, and proximity. These associations drive a response competition process wherein particular stimuli are 'biased upward' or downward based on their relevance	Introduces a mechanism through which stimuli in the environment can acquire motivational relevance in a task-specific or contextual manner and allows for better characterization of individual differences in motivational relevance.
	Cognitive overload is characterized as related to an imbalance of resource requirements and resource allocation resulting in decrements in message processing effectiveness.	Cognitive overload is reconceptualized as motivationally-driven <i>cognitive offload</i> . It is proposed that resources are allocated away from the message processing task when effort is mismatched with rewardingness or when messages induce excess negative affect or threat.	Parsimoniously explains behavioral / physiological findings from the cognitive overload literature and the defensive processing/avoidance literature regarding resource allocation away from a message task.
Memory	No structural model of memory is proposed in the model, although general discussion of mechanisms (spreading activation, Hebb's rule) are assumed.	Henke's (2010) processing-based model is proposed as a structural model of memory in the LC4MP. Memory is said to consist of rapid encoding of single or unitized items, rapid encoding of flexible associations, and slow encoding of rigid associations.	Allows for increased clarity and structure concerning memory in the model, including cognitive vs. perceptual processing and formation of flexible/rigid associations with reward/threat.
	Encoding memory has been primarily measured using percent correct, although a substantial amount of recent studies utilize signal detection.	Signal detection is proposed as a necessary tool for understanding encoding performance.	Assists researchers in understanding both accuracy and criterion bias of memory recall measures, contributing to further clarity regarding resource allocation patterns in relation to message structure and content.

brain imaging research showing that mental imagery activates visual processing brain regions, but leaves auditory processing regions comparatively inactive (Ganis, Thompson, & Kosslyn, 2004; Kosslyn et al., 1993). This suggests that the auditory process (listening to radio advertisements) relied on auditory processing resources until a visual process was required as well (mentally picturing high-imagery ads). Additionally, other research has shown that decreasing audiovisual redundancy – which should increase total resource requirements if audio and visual processing draw from the same resource pool – only seems to affect message processing performance at certain levels of resources required, and for certain patterns of arousal and valence (Keene & Lang, 2016; Lee & Lang, 2015). This suggests that visual and auditory resource requirements may load the processing system in a separable fashion with differentiable message processing outcomes.

Other studies using video game stimuli (Huskey, Craighead, Miller, & Weber, 2018) have shown that STRTs follow the predicted patterns in relation to resource requirements when the distractor task and the primary task shared the same modality, but that this pattern deteriorates for modality-inconsistent distractors. This is further supported by early research finding that message complexity seems to lead to different outcomes depending on both the channel in which information is introduced and on the channel in which the STRT is measured (Thorson, Reeves, & Schleuder, 1985). Neuroimaging results also indicate that resources are split by visual and auditory modalities (Keitel, Maess, Schröger, & Müller, 2013; Porcu, Keitel, & Müller, 2014; Wahn & König, 2017).

In addition to mounting evidence for the necessity of considering resource allocation and resource requirements as meaningfully separable by modality, a growing body of research suggests that load can also be meaningfully dissociated by process (e.g. cognitive processing or perceptual processing; Lavie, Hirst, de Fockert, & Viding, 2004; Wickens, 2008). Some LC4MP work has already shown differentiable effects of perceptual and cognitive resource requirements (Stróžak & Francuz, 2016), and has found separable effects of cognitive and perceptual resource requirements on message processing performance (Cunningham & Alhabash, 2017; Fisher, Hopp, & Weber, 2018). These findings point to the need for another look at the cognitive resource pool in the LC4MP, which in its current iteration does not explicitly distinguish between the different neural requirements of cognitive and perceptual tasks (although it does assume that perceptual processing must occur in message processing; see Fisher et al., 2018). If, as these findings suggest, cognitive and perceptual load are separable, then it is likely that predictive and explanatory accuracy of the model could be improved by considering *how* – in terms of process or modality – a particular piece of information in a message loads the processing system.

Updating the model

What is a resource?

In the current conceptualization of the model, all message processing tasks are said to draw from a single, central resource pool (See Figure 1). The above research suggests, though, that the LC4MP may benefit from an updated understanding of ‘resources’ as well as a more process-dependent and modality-dependent characterization of the ‘resource pie’ in line with modern approaches that describe the human processing system as a collection of large scale, dynamic, hierarchical networks (Betzel & Bassett, 2017; Sporns & Betzel, 2016). To this end, we look to the Load Theory of Selective Attention and Cognitive Control (LTSACC; Lavie et al., 2004), Dual Mechanisms Theory (Braver, 2012; Braver, Gray, & Burgess, 2007), and Multiple Resource Theory (MRT; Basil, 1994a, 1994b) to propose an updated picture of cognitive resources within the LC4MP. Furthermore, we argue that recent LC4MP research paves the way for these updated conceptual definitions, and that these updates can be implemented using tools already familiar to communication scholars.

With that said, and in an honest effort to accurately characterize state-of-the-art scientific evidence, the cognitive resources debate is complex and far from settled within the neuroscience literature (Bays, 2015; Johnson, Simmering, & Buss, 2014; Ma, Husain, & Bays, 2014; Wei, Wang, & Wang, 2012). We believe, though, that a clear enough picture is emerging to suggest that introducing a material mechanism for resource limitations would be beneficial for communication scholars. Neuroscience research has shown that cognitive resources can be conceptualized as relating to metabolic (chemical), spatial, and temporal constraints (Buschman, Siegel, Roy, & Miller, 2011; Marois & Ivanoff, 2005; Todd & Marois, 2004). Briefly, whenever neurons fire they require energy (in the form of glucose and oxygen) and their axon terminal releases chemicals (neurotransmitters), quantities of which are limited, carried by cerebral blood flow (Kuschinsky, Suda, & Sokoloff, 1981), and have to be replenished.

The idea that resources can ‘run out’ within a given topographical area seems to explain findings from electrophysiological studies that within brain regions, neural firing increases as required effort increases, but reaches an abrupt plateau when load passes a certain point (Ma et al., 2014). From

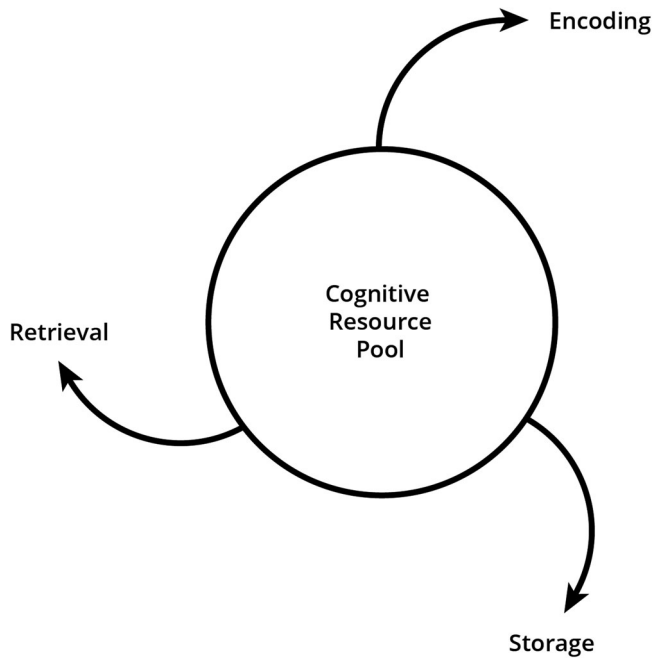


Figure 1. Graphical representation of cognitive resource allocation in the LC4MP. The central circle represents the pool from which resources are allocated to the three subprocesses. This allocation process is assumed to be modality and context agnostic.

these findings, it can be concluded that cognitive resources in form of metabolic substrates can also be considered – albeit coarsely – as spatially constrained. Finally, a wide selection of research has supported the idea that cognitive resources in form of metabolic substrates experience temporal constraints – especially in working memory (Barrouillet & Camos, 2012). Whenever an item is not held in conscious focus, it is subject to temporal decay. This decay rate limits the number of items that can be maintained as focus is shifted back and forth from item to item.

Research has revealed many large-scale, dynamic brain networks in the brain dedicated to performing various tasks, such as sensory processing, cognitive control, and initiating motor actions (Power et al., 2011). For LC4MP researchers, three of these networks are especially salient: the visual processing network, the auditory processing network, and the cognitive control network. Here we propose that the LC4MP's conceptualization of the 'resource pie' could be improved by taking into account how a message loads visual and auditory networks (perceptual resource requirements), and also how messages and other experimental parameters load the cognitive control network (cognitive resource requirements).

Perceptual and cognitive load

The Load Theory of Selective Attention and Cognitive Control (LTSACC; Lavie et al., 2004)– supported by a wealth of behavioral (Forster & Lavie, 2007; Lavie, 1995) and neural (de Fockert, Rees, Frith, & Lavie, 2001; Lavie, 2005; Rees, Frith, & Lavie, 1997; Scalf, Torralbo, Tapia, & Beck, 2013) evidence–provides a illipromising path in this direction. The LTSACC suggests that perceptual and cognitive resources should be considered independently from one another, and that each has measurable outcomes related to phenomena of interest such as primary task reaction time and accuracy, recall, resistance to irrelevant distractions, and related measures (Fitousi & Wenger, 2011; Forster & Lavie, 2007; Kelley & Lavie, 2011). In the LTSACC, perceptual load is related to three primary factors: 1) the number of items that need to be identified, 2) the number of perceptual operations that are required to identify each item (e.g. mental rotation, de-distortion,

perspective change, etc), and 3) the difficulty of the perceptual operations required (Elliott & Giesbrecht, 2010; Lavie, 2005; Lavie & Tsal, 1994). In contrast, cognitive load is related to goal-directed control of attention, sense-making, and maintenance of items in working memory (Lavie, 2010).

As perceptual resource requirements increase, more resources are required in visual and/or auditory processing networks in order to perceive, correctly identify, and encode stimuli embedded in a message. This reduces perceptual resources available. Once encoded, information must be quickly passed on to other processing networks (such as motor control or working memory), to enable an individual to rapidly react to information as it enters the processing system. This process has been described as *reactive control* – in which perceptual systems signal to other brain regions that information is worthy of conscious attention or action (Braver, 2012; Braver et al., 2007). Thus, it is proposed that perceptual resources are allocated to and consumed by two primary subprocesses: *encoding* and *reactive control* (See Figure 2).

In the LTSACC, it has been shown that initial increases in perceptual load are associated with increased performance in a primary task, but that when perceptual load continues to rise, increased load will be associated with reduced performance (Forster & Lavie, 2007; Lavie et al., 2004). Thus, it is proposed that the relationship between resource availability and perceptual load in message processing is slightly curvilinear. Increasing perceptual load should initially be associated with increased resource availability, decreased STRTs, and increased primary task performance as more resources are allocated to the task than are required. But high levels of perceptual load should be associated with reduced resource availability, increased STRTs, and reduced primary task performance as resources required by the task increase at a rate faster than resources allocated (which are, ultimately, capacity-limited). Importantly, this seems to match with LC4MP findings wherein low levels of perceptual load introduced by a structural feature seem to be associated with increased memory and shortened STRTs, but as more perceptual operations are required (perspective changes, identifying new objects, etc) STRTs lengthen and encoding drops (Fox, Park, & Lang, 2007; Lang, Kurita, et al., 2013).

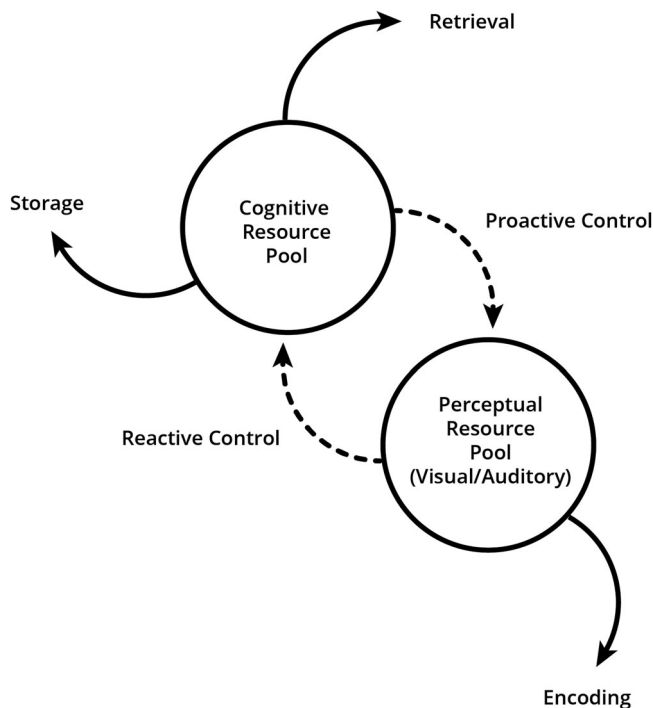


Figure 2. Graphical representation of resource allocation in the proposed conceptual update to the LC4MP. Note separate, but interacting cognitive and perceptual resource pools.

Much of the research that has taken place under the LC4MP has been aimed at investigating what are conceptualized in this framework as perceptual load processes. Indeed, within the model, messages are frequently defined as ‘continuous variably redundant streams of audio and visual *perceptual information* [emphasis added]’ (Lee & Lang, 2015, p. 601). Furthermore, five of the seven dimensions of the ii measure relate to the number or difficulty of perceptual identification processes (object change, new object, distance change, perspective change, form change; Lang, Kurita, et al., 2013). In incorporating cognitive load as meaningfully separable from perceptual load, the model presented here provides a clear way forward for refining LC4MP predictions and enabling it to predict and explain message processing outcomes of interest in novel contexts.

In order to further refine our conceptualization of cognitive load, we draw from the Dual Mechanisms of Cognitive Control framework (Braver, 2012; Braver et al., 2007). In this framework, the cognitive resource requirements of a particular task are related to two primary factors: the amount of information that must be held in working memory, and the extent to which the current processing task involves errors, conflict, or uncertainty in relation to a given goal (Botvinick & Cohen, 2014). This can be thought of as exercising control over what ‘bubbles up’ from perceptual processing to conscious cognitive processing, a process called *proactive cognitive control*. Proactive cognitive control is essential for focused attention, learning, and goal attainment (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miller & Cohen, 2001). As the amount of information that must be retained in working memory increases or becomes more conflicting, uncertain, or error-prone, activation in cognitive control networks increases, requiring more resources (Botvinick & Braver, 2015; Botvinick & Cohen, 2014; Westbrook & Braver, 2015). As resource requirements increase in these networks, reaction times are increased and task performance is reduced – thus increasing levels of cognitive load should be reflected in lengthened STRTs, reduced memory storage, and increased frustration (for graphical predictions regarding the effects of perceptual/cognitive load on STRTs and primary task performance see Figures 3 and 4).

Importantly, in the model presented here, the impetus that directs the processing system to allocate resources to a message remains largely unchanged from the original LC4MP. It is proposed that resources are allocated to a message due to the presence of orienting eliciting structural features (OESFs; Lang et al., 2006) or motivationally relevant content. Increases in the number of OESFs should increase the allocation of resources (both cognitive and perceptual) to the message processing task in a phasic fashion, and motivationally relevant content should increase resource allocation across longer periods of time.

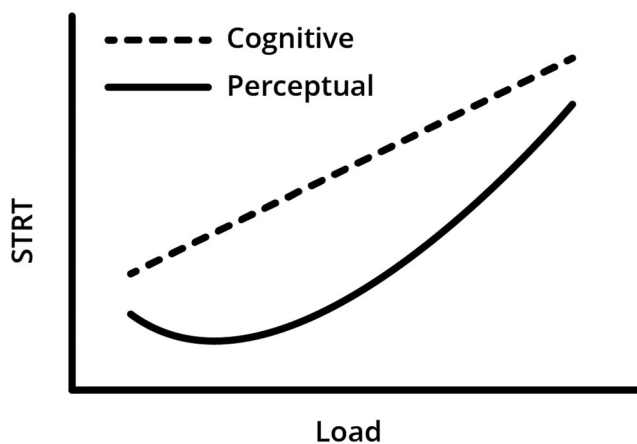


Figure 3. Graphical predictions regarding the effects of cognitive and perceptual load on Secondary Task Reaction Times. Initial increases in perceptual load should be associated with reduced STRTs (an index of greater resource availability), but further increases should be associated with lengthened STRTs. Cognitive load should be positively associated with STRT’s length. Note that this does not take into account resource reallocation as a result of overload.

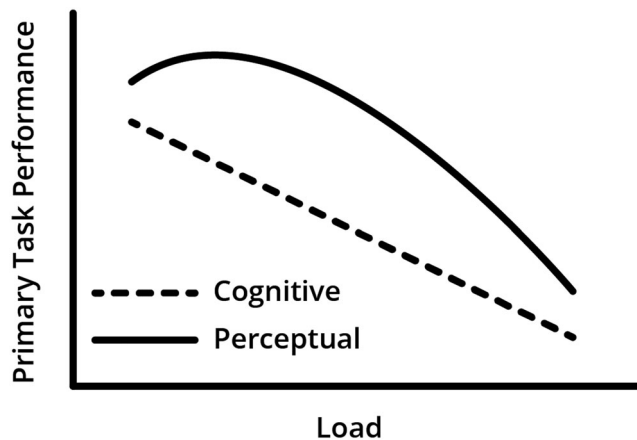


Figure 4. Graphical predictions regarding the effects of cognitive and perceptual load on primary task performance (recall or other measures). Initial increases in perceptual load should be associated with better performance, but further increases should be associated with reduced performance. Cognitive load should be negatively associated with performance. Note that this does not take into account resource reallocation as a result of overload.

To complete the updated conceptualization of cognitive resources proposed in this manuscript we now discuss the role of modality. For this, we return to Multiple Resource Theory (Basil, 1994a, 1994b), from which the LC4MP heavily draws. In this theory, resource availability in environments containing both visual and auditory information is conceptualized as somewhat separable by modality, but also dependent on redundancy between modalities. The MRT proposes that allocated resources are consumed by three primary tasks: attention, encoding, and memory. Although some studies testing MRT did not show modality specific effects – as when asking participants to focus on a particular modality while responding to probes in another (Basil, 1994b) – other studies seem to support modality-specific effects, especially when considering the load induced in each modality (Basil, 1994a; Bolls, 2002; Reeves & Thorson, 1986; Thorson et al., 1985). Research in the field of multisensory integration has consistently found that processing resources are separable between modalities at the perceptual level but not at the cognitive level (Alais, Morrone, & Burr, 2006; Koelewijn, Bronkhorst, & Theeuwes, 2010). Thus, we propose that for message processing, perceptual load exhibits modality-specific effects, but that the effects of cognitive load should be much less separable between modalities.

These findings are echoed in recent neuroscience research finding that modality-independence of load depends on the type of task and also the level of perceptual load in the system (Keitel et al., 2013; Konstantinou, Beal, King, & Lavie, 2014; Porcu et al., 2014). This literature also reveals that modality specific effects of resource load are largely constrained to perceptual processing tasks (for a review see (Wahn & König, 2017). Additionally, recent work investigating the intersubject correlation of brain regions during a message processing task has shown that perceptual processing of stimuli only loads modality-specific processing regions, but that when the same messages are consciously processed, brain activation spreads across modalities and into higher order processing areas (Regev et al., 2018). Taken together, this evidence suggests that the LC4MP's predictions regarding message complexity, recognition, and attentional engagement could be improved by separating load in each modality, proposing specific predictions for information processing in visual and auditory modalities, and testing visual and auditory memory separately.

To summarize, our updated model proposes two key delineations: between cognitive and perceptual processing, and between visual and audio processing (See Figure 2). Importantly, our model proposes that cognitive and perceptual processes are meaningfully – but not completely – separable. This means that perceptual resource allocation does not necessarily reduce resources allocated for cognitive processing. What this does not mean, though, is that cognitive and perceptual processes

rely on completely separable pools of resources. The exact nature of resource sharing between processes and modalities is a topic of open debate in the literature (Fitousi & Wenger, 2011; Giesbrecht, Sy, Bundesen, & Kyllingsbaek, 2014). Current theorizing suggests that brain networks can be considered as semi-modular (Bassett & Sporns, 2017). These networks can meaningfully – but not completely – be considered in isolation from one another (Sporns, 2014; Sporns & Betzel, 2016). Task-specific brain networks can be parcellated and examined for their unique characteristics and contributions to human processing (Bassett & Sporns, 2017; Power et al., 2011) but all brain networks share certain processing resources in certain ways (e.g. through their mutual connection to large ‘hub’ nodes; Bassett & Bullmore, 2006).

Updated predictions and avenues for testing

Predictions of the updated model are as follows: (1) Low levels of perceptual load will be associated with fast reaction times and high performance (as encoding, primary task reaction times, etc). (2) Higher levels of perceptual load in one modality will be associated with lengthening STRTs and reduced performance in that modality. (3) For information which is presented in multiple modalities, perceptual load will be separable between the modalities and STRTs/performance will vary depending on the modality in which load is introduced and the modality in which they are tested. (4) Cognitive load will reduce cognitive resources available. This will be reflected in lengthened STRTs and reduced performance regardless of prompt modality – these changes should occur in a linear fashion. These predictions refine and clarify the associations between message complexity, load (both cognitive and perceptual), and processing performance. Importantly, these predictions do not yet consider overload, which should result in resource allocation away from the message processing task and toward another task (responding to the secondary task, internal processing, mind wandering, etc). Considerations regarding overload will be incorporated in the next section.

These predictions can be tested using an experimental paradigm in which perceptual load and cognitive load are manipulated independently from one another. Perceptual load can be manipulated in three primary ways—changing the number of items that need to be identified at any given time, increasing the number of perceptual operations that need to be performed to identify an object (focusing, flipping, de-distorting, perspective change, distance change) and introducing visually salient, but task-irrelevant audiovisual stimuli (Elliott & Giesbrecht, 2010; Lavie, 1995, 2005). As discussed earlier, five of the seven dimensions of the ii/cc or ii/sec measures may also be used as indicators of the perceptual resource requirements of a message. STRT’s and performance should be tested in a modality specific fashion (using both tones and visual prompts for audiovisual stimuli) along with encoding (audio and visual forced choice recognition tasks). Storage and retrieval (indexed using cued/free recall tasks) are not expected to show modality specific effects.

Cognitive load may be introduced by a) requiring that more information be held in working memory or b) increasing the extent to which message content involves errors, conflicting information, or uncertainty. Methodologically, cognitive load may be manipulated using classic paradigms such as a digit span task (Wechsler, 1974) or through introducing complex or discordant semantic or episodic information which must be integrated and maintained in working memory (such as presenting scenes out of order in a narrative, or presenting unfamiliar or complex information in an educational message). For mediated messages such as PSAs, the cognitive load of a message could be assessed using computational measures of linguistic complexity or interpretability (such as the Dale-Chall index; Dale & Chall, 1948) or by pretesting stimuli using well-validated self report measures of cognitive load (Paas, Van Merriënboer, & Adam, 1994).

A particularly promising example of a stimulus that can be used to manipulate cognitive load and perceptual load independently is *Asteroid Impact* (https://github.com/medianeuroscience/asteroid_impact) when using this stimulus, cognitive load can be introduced through increasing game difficulty and perceptual load can be manipulated through increasing visual and auditory complexity (Fisher et al., 2018; Huskey et al., 2018). Updating the model to incorporate separable effects of

cognitive and perceptual load allows for more refined predictions regarding how stimulus features (cuts, edits, etc) interact with perceptual and cognitive information to facilitate message processing outcomes.

Motivated processing

Motivation, the the fourth 'M' of the LC4MP, although not present in the original version of the model (Lang, 2000), has become a core focus of LC4MP research, serving as a question of interest in over 150 published studies (Fisher et al., 2018). These studies have revealed much about the nature of individual differences in motivational activation, how appetitive and aversive content interact with arousal to facilitate processing outcomes, and how physiological indices of cognitive and affective processing can increase our understanding of the information processing system.

Recently, though, it has become clear that this portion of the model needs updating in several key areas. First, a recent set of studies investigating coactivation have produced unexpected findings that merit further clarification. Next, although the LC4MP is primarily a bottom-up model (Lang, 2017), many studies have used the LC4MP to make predictions – with varying success – regarding the role of motivation in top down (controlled) resource allocation processes. Current conceptual definitions and operationalizations in the model warrant updating to more effectively incorporate these findings and predictions. Finally, we propose that the LC4MP benefits from a new look at the psychology and neuroscience of motivation and emotion to facilitate more precise predictions and incorporate modern methodological tools.

Unexpected findings and inconsistencies

As research into the mechanics of emotional and motivational processing has become more advanced, inconsistent results have emerged between the LC4MP's predictions and observed data. The LC4MP does not provide a clear prediction as to how coactivation – when both the appetitive and aversive systems are active at the same time – should affect processing in respect to resource allocation, memory, and emotional reactions. Emotional frameworks upon which the LC4MP is based would seem to predict that activation in the appetitive and aversive motivational systems at the same time should lead to additive effects (Norris, Gollan, Berntson, & Cacioppo, 2010). However, the arousal findings – both psychophysiological and self-reported – do not match this additive prediction for coactivation. Instead, both skin conductance (Hohman, Keene, Harris, Niedbala, & Berke, 2017; Keene & Lang, 2012; Wang, Morey, & Srivastava, 2012) and self-reported arousal (Keene & Lang, 2016; Lang, Sanders-Jackson, Wang, & Rubenking, 2013) are lower than would be predicted for messages that elicit coactivation in the motivational systems.

Another key area in which the model needs further consideration is in the interaction between message complexity and motivational activation in facilitating resource allocation and processing outcomes. All other things being equal, the model predicts that more resources will be devoted to the most motivationally relevant stimuli (Lang, 2000, 2009). This, though, exposes an interesting point of ambiguity within the model. According to extant cognitive processing theories discussed above, STRTs (an index of resource availability) should exhibit a U-shaped pattern as perceptual load increases and should increase monotonically for cognitive load (see Figure 3). The observed pattern of resource availability and load, though, tends to be in the form of an *inverted-U* for STRTs and neuroimaging data (Fox et al., 2007; Huskey et al., 2018; Lang, Kurita, et al., 2013; Ulrich, Keller, & Grön, 2016; Ulrich, Keller, Hoenig, Waller, & Grön, 2013), as well as psychophysiological measures (Harris, Vine, & Wilson, 2017; Park & Bailey, 2017).

The current explanation for this pattern is that as resources available to process the stimulus diminish, the individual enters a state of cognitive overload. What seems to occur, though, is not necessarily 'overload' in the classic sense (Chandler & Sweller, 1991; Kahneman, 1973; Schneider & Shiffrin, 1977), which should simply be reflected in low performance on the primary task and no

resources available for the secondary task. Instead, what seems to be occurring is that resources are *reallocated* from the primary task to the secondary task (Fox et al., 2007). Indeed, recent LC4MP theorizing has suggested that ‘cognitive overload’ may be a misleading moniker (Lee & Lang, 2015). The role of motivation in the resource reallocation process has been alluded to in several studies (Clayton et al., 2017; Fox et al., 2004; Huskey et al., 2018; Leshner, Clayton, Bolls, & Bhandari, 2018), but the model has not yet been updated to satisfactorily predict and explain when and why resources are allocated away from the primary task towards a secondary task.

Some studies in the LC4MP literature propose that stimulus features can interact with individual difference variables to manipulate the relative motivational relevance of the primary and secondary task, leading to a state in which the secondary task becomes more motivationally relevant than the primary task (Fox et al., 2007; Huskey et al., 2018; Park & Bailey, 2017). We propose that conceptually clarifying cognitive overload as a motivation-driven process can assist in predicting and explaining resource allocation in a way that takes into account both goal-driven and stimulus-driven resource allocation.

In addition to these considerations, a disparity must be addressed between the LC4MP and other theoretical frameworks in modern motivation and emotion research. In the framework employed by the LC4MP, both emotional and motivational experience are the result of activation in appetitive or aversive subsystems (Bradley, 2007; Lang, 2000, 2009). Within this framework, motivation is characterized as survival-based ‘disposition to action’ elicited in response to particular stimuli in the environment (Lang & Bradley, 2008, p. 52). Other frameworks (Berridge, Robinson, & Aldridge, 2009; LeDoux, 2012; Pessoa, 2009) also emphasize the role of activation in approach and avoid subsystems, but propose a separable role of emotion in modulating how and when these systems activate and how their activation is reflected in processing. Accordingly, motivation can be thought of as relating to judgments of value/threat of *particular* stimuli in the environment. These stimuli are associated (in a rigid or flexible manner) with threat or reward. These associations bias the planning and execution of specific cognitive processes and behaviors (e.g. approach or avoidance) in relation to a given outcome (Pessoa, 2009). Emotion, on the other hand, is characterized as a domain-general state that predisposes the processing system toward or away from certain *types of actions*, not necessarily toward or away from specific stimuli (Chiew, 2011). As the next section shows, a consideration of the separable influences of emotional and motivational judgments in media processing helps refine predictions of the LC4MP and affords increased utility to the model in a variety of applications.

Updating the model

In order to propose a mechanism by which we can understand motivated resource allocation in the LC4MP and integrate it into the conceptual and operational language of the model, we turn again to the cognitive control literature (Braver, 2012; Braver et al., 2007; Miller & Cohen, 2001), specifically response competition theory (Desimone & Duncan, 1995; Pashler & Sutherland, 1998) and arousal-biased competition theory (Lee, Itti, & Mather, 2012; Mather & Sutherland, 2011). As in our updates to the LC4MP’s treatment of cognitive load, we argue that these theory-driven conceptual and operational updates do not conflict with core assumptions of the model, and can be investigated using largely familiar tools and approaches.

The first proposed update to the model’s treatment of motivation is aimed at clarifying how and when judgments of motivational relevance are made and how these judgments affect processing. The human information processing system dynamically estimates reward/threat *likelihood*, reward/threat *intensity*, and reward/threat *proximity* for stimuli in the environment and seeks to initiate cognitive and behavioral responses that maximize reward while minimizing threat and effort (Braver et al., 2014; Westbrook & Braver, 2015). These assessments happen rapidly and continually, and are associated with activation in well-characterized neural substrates (Gottfried, O’Doherty, & Dolan, 2003; Hauser, Eldar, & Dolan, 2017; Pessoa, 2010).

Some associations between stimuli and reward/threat likelihood, intensity, and proximity have likely been passed down over evolutionary time – resulting in valuations that are rigid, inflexible, and context-agnostic – such as in the processing of threatening stimuli like snakes, spiders, or large predators (Lang, Bradley, Cuthbert, & Simons, 1997). Here, we will call these *rigid associations*. Importantly, though, a wealth of evidence suggests that the associative process can also operate in a flexible and context-specific manner for the completion of a specific goal (see (Gottfried et al., 2003; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005). Objects that are relevant for the completion of an individual's goals can elicit resource allocation in a manner similar to those which have direct relation to genetic survival, hedonic pleasure, or pain (Anderson, Laurent, & Yantis, 2011). Importantly, the influence of these goal-specific associations is largely limited to a particular context or a particular task (Pessoa, 2010; Schultz, Dayan, & Montague, 1997). The introduction of a different set of rules or different contextual information modulates goal-specific reward and threat associations in order to maximize outcomes in scenarios with rapidly shifting parameters. Thus, we will call these *flexible associations*.

A useful framework for understanding how these rigid and flexible value representations bias cognitive processing can be found in Response Competition Theory (RCT; Desimone & Duncan, 1995; Pashler & Sutherland, 1998); a precursor to the modern cognitive control literature. RCT proposes that numerous responses to the environment compete for capacity-limited cognitive resources in parallel, and that each response is activated ('biased upward') or inhibited ('biased downward') by inputs from sensory processing regions, memory, and other brain areas. The response that 'wins' (e.g. maintains the highest threshold of excitatory inputs over inhibitory inputs) is chosen, leading to a particular cognitive or behavioral outcome. Motivational relevance serves as an important bias signal in this process, leading the brain to prioritize stimuli that are motivationally relevant over those that are less relevant. This upward bias increases the strength of the signal associated with a particular response, making it more likely to 'win' the response competition process (Lee et al., 2012)

Reconceptualizing resource allocation as contingent upon a dynamic value-assignment process also helps rectify confusing and sometimes contradictory findings regarding cognitive overload in LC4MP research. In this framework, it is proposed that cognitive overload is more accurately conceptualized as a reallocation process rather than 'overload' per se. This reallocation process prioritizes the secondary task or other alternatives (e.g. internal processing, mind wandering) over the primary task when the tradeoff between reward and effort or threat becomes imbalanced. This can be due to the message processing task becoming too challenging, as in traditionally conceptualized cognitive overload, but it can also be due to defensive processing (Bradley, Angelini, & Lee, 2007; Clayton, Lang, Leshner, & Quick, 2018; Leshner et al., 2018; Liu & Bailey, 2018), fear (Leshner, Bolls, & Wise, 2011; Rhodes, 2017), or other internal processes (such as social comparisons; Clayton, Ridgway, & Hendrickse, 2017). We propose here that a more accurate term for this phenomenon is *cognitive offload* – more accurately capturing the idea that cognitive resources are reallocated from the primary to a secondary task rather than truly being overloaded.

This conceptualization parsimoniously explains findings from both the cognitive overload literature (Fox et al., 2007; Lang, Kurita, et al., 2013; Park & Bailey, 2017) and the defensive processing literature (Clayton et al., 2016; Clayton, Leshner, Bolls, & Thorson, 2017; Leshner et al., 2018; Liu & Bailey, 2018). When message processing difficulty (as cognitive/perceptual load) is optimally matched to the rewardingness of the message processing task (as activation of the appetitive system), STRT's should be long, tonic heart rate should decelerate, and performance (as indexed in encoding, storage, and retrieval) should be high. When the primary task is either (a) unrewarding, frustrating, boring, or otherwise aversive, or (b) requires too much effort to process, then primary task performance should be low. During the resource reallocation process, heart rate should increase (or decelerate less). Other measures, such as STRTs and memory (discussed later), can provide clarity as to the secondary task to which resources were reallocated (e.g. responding to the STRT probe, counterarguing, mind wandering).

What, then, is the specific role of emotion (as arousal and valence) in the proposed model? A way forward can be found in an extension of RCT known as Arousal-Biased Competition Theory (ABC; Mather & Sutherland, 2011). ABC theory argues that an individual's arousal level can modulate the relative incentive salience of objects in the environment, increasing competitive advantage of certain neural/behavioral responses while diminishing others. Thus, arousal can be conceptualized as a domain-general, energizing process that prepares the cognitive or physical system for performing a certain action or set of actions, such as fighting or fleeing. This is largely reflective of the theorizing of Cacioppo, Lang, Bradley, and colleagues regarding the adaptive role of motivation and emotion in the human processing system (e.g. Berntson & Cacioppo, 2008; Cacioppo & Gardner, 1999; Lang & Bradley, 2010). ABC theory, then, provides a first step for considering the role of emotion in facilitating responses that occur in relation to reward-associated/threat-associated stimuli.

ABC theory proposes that arousal is a domain-general psychophysiological state that biases perceptual response competition processes in favor of salient (e.g. bright, loud) stimuli against those that are less salient – increasing the signal to noise ratio in the sensory field (Lee et al., 2012; Mather & Sutherland, 2011). Anecdotally, this can be seen in the extreme salience of neutral sounds or visuals (such as the creaking of a door or motion at the visual periphery) in situations when arousal is high. These aspects would, in situations of low arousal, be expected to be relatively less attended to or noticed. LC4MP research has also shown that emotion (both arousal and valence) can 'spill over' from one message to the next, supporting our proposition regarding the more domain-general nature of emotion as opposed to motivation (Yegiyani, 2015a). The ABC, then, allows for predictions about the relationship(s) between arousal, context, message content, processing, and memory for particular portions of a situation (Dolcos, Wang, & Mather, 2014). To integrate this framework into the LC4MP, it can be said that variation along traditional emotional dimensions—such as arousal or valence—modulate flexibly and rigidly held representations of value in message processing, leading to differential prioritization of behavioral responses to stimuli.

The predictions and evidence given for ABC (Mather & Sutherland, 2011) would seem to match, and more importantly, explain, certain findings related to coactivation in the LC4MP (Hohman, Keene, Harris, & Niedbala, 2016; Keene & Lang, 2012, 2016; Lang, Sanders-Jackson, et al., 2013; Liu & Bailey, 2018; Wang, Solloway, Tchernev, & Barker, 2012). If arousal and valence modulate value representations, then coactivation would be expected to could lead to ambiguity in the value assignment and updating process, especially in situations of high arousal. This phenomenon is especially salient considering recent research investigating the inclusion of substance cues (such as cigarettes or needles) in fear and disgust appeals. This research has shown that including a substance cue (typically seen as an appetitive cue) within an aversive message induces defensive processing when the message is arousing (Clayton et al., 2018; Leshner et al., 2018; Liu & Bailey, 2018) but that inclusion of a substance cue in a low-arousal message increases automatic resource allocation to the message (Liu & Bailey, 2018).

ABC theory proposes that increasing levels of arousal in the message bias the processing system toward action. If a message contains coactive information (such as substance cues) and is low arousal, the processing system may seek to resolve coactivation through information intake mechanisms, increasing attention to the messages. In contrast, coactive information in high arousal messages drive the processing system seek resolution for conflicting motivational signals by (a) avoiding the message and withdrawing resources (flight response) or (b) initiating approach toward the coactive stimulus (fight response). Extant work has made progress toward understanding how individual differences in motivational system activation interact with message features to facilitate fight or flight responses (Clayton et al., 2018).

Updated predictions and avenues for testing

Updated model predictions for the role of motivation and emotion in biasing message processing are as follows: (1) Message content with rigid value associations (those related to survival or deeply

learned association with reward or punishment) will elicit motivated processing (as ‘upward bias’) in encoding, storage, and retrieval, leading to orienting and resource allocation. When these objects are presented, they are predicted to result in longer reaction times for competing tasks (e.g. STRTs), shorter reaction times for the primary task, decelerating heart rate, and enhanced memory for relevant objects (expanded in detail in the below section). (2) Message content with flexible value associations (those related to task-relevant goals) should elicit motivated processing, but only within the context of the task – these associations may be rapidly replaced or modified when task parameters change. (3) Resource reallocation (cognitive offload) will be observed in two situations: (a) when effort is mismatched to reward (e.g. the message is too complex), or (b) when the message induces defensive processing. (4) Emotion (as arousal and valence) will modulate behavioral responses in relation to the relative salience of message content in a more general fashion (i.e. modulating groups or collections of stimuli or behavioral responses rather than particular stimuli or responses).

Memory

In the LC4MP, memory is conceptualized as encoding, storage, and retrieval (Lang, 2000, 2009). At the time of writing, there were 73 studies in the LC4MP literature investigating memory processes in some way (Fisher et al., 2018). The LC4MP does not subscribe to a particular structural model of memory, but does include discussion of specific memory mechanisms. The first of these is spreading activation –that is, activation of a particular representation in memory tends to result in similar conceptual representations becoming activated as well (Anderson, 1983; Collins & Loftus, 1975). The second is Hebb’s rule–neurons that ‘fire together wire together’ (Bradley, 2007; Hebb, 1961). We propose that the introduction of a formalized model of memory function will increase conceptual clarity and allow for more refined predictions. Specifically, these updated predictions integrate the modality-specific and process-specific effects of motivation and cognitive load outlined previously in this article, providing a substrate which enables the formation of flexible and rigid value associations.

Unexpected findings and inconsistencies

Although LC4MP research has uncovered several theoretically and practically relevant considerations regarding memory for mediated messages, there are several instances in which the LC4MP’s predictions regarding memory are not borne out in observations. The first of these is found when considering the exact relationship between the orienting response (OR) and the encoding and storage of presented messages. For example, (Diao & Sundar, 2004) presented participants with animated or non-animated ads in either a pop-up or banner position within a web browser. Based on the LC4MP’s prediction that ORs generally lead to better encoding (pending that content following the OR is not drastically different than content before the OR (Potter, Jamison-Koenig, Lynch, & Sites, 2016)), the authors hypothesized that animated pop-up ads would elicit ORs, resulting in higher performance on a forced-choice recognition task. These ads, although they were shown to elicit ORs, were not remembered better than static ads—which did not induce ORs. This is in contrast to other research (e.g. (Lang, Borse, Wise, & David, 2002; Potter, Lang, & Bolls, 2008; Potter et al., 2016)) which found that ORs do result in a boost in recognition for presented content.

Additionally, the exact relationship between STRTs, cognitive load, and memory is, as of yet, unclear. A general trend has been observed wherein more complex messages lead to lengthening STRTs and slight increases in memory performance (as measured using recognition and recall tasks) up until the point at which resources are allocated away from the message. This pattern, though, is far from consistent. For example, Lang, Kurita, and colleagues ((Lang, Kurita, et al., 2013) found that STRT’s remain short even as memory drops, up until all but the most complex messages are presented (Fox et al., 2007)., using signal detection measures, found that the shifting of cognitive

resources away from a primary task seems to be reflected in an increasingly liberal criterion bias, followed by *shortening* STRTs and *reduced* memory. In addition, (Lang et al., 2006) demonstrated that memory increases as messages require more resources, with highly complex messages recalled better than simpler ones (when messages inducing cognitive overload are removed). Additionally, although the main effect of information introduced on STRTs was significant, this effect did not hold when considering differences in response times at the individual level—suggesting that the relationship between STRTs and memory may be more complex. An additional study found increases in recognition accuracy (as percent correct) for certain types of message features (e.g. old and new voices) without corresponding changes in STRTs (Lang et al., 2015).

Updating the model

The sometimes mixed findings observed in LC4MP research regarding memory are likely a result of the parsimonious conceptualization of memory within the model. Measuring a concept as multidimensional as memory using a narrow scope of recognition and recall tasks does not encapsulate the broad landscape of mechanisms by which the brain encodes, stores, and retrieves information. Memory is infamously complex (Squire, 2004; Squire & Zola-Morgan, 1991) and the exact neuropsychological underpinnings of memory formation and retrieval are still far from completely explicated. However, a clear enough picture is emerging from this literature to suggest that a more nuanced treatment of memory would benefit the LC4MP. In this section, we propose two primary updates to the LC4MP's treatment of memory. The first update is theoretical, incorporating a modern structural model of how memory operates in the brain, and how different memory processes uniquely enable processes that are central to the LC4MP in its canonical form as well as the updated form presented in this manuscript. Our second update is methodological, highlighting signal detection analysis as a methodological tool that has been used with great utility in the literature, suggesting its broader use in LC4MP research.

An optimal starting point for discussing memory for messages can be found in a processing-based model proposed by (Henke, 2010). In this model, it is posited that memory processes can be sorted into three broad categories— (1) rapid encoding of single or unitized items, (2) rapid encoding of flexible associations, and (3) slow encoding of rigid associations.

Importantly, this model uses the term 'encoding' in a slightly different fashion than does the LC4MP. In the LC4MP, encoding only refers to the initial process of noticing, and identifying a stimulus, whereas in Henke's model encoding encompasses both initial perception (rapid encoding of single or unitized items) and an associative storage process (encoding and concurrent retrieval of flexible and rigid associations).

We propose that Henke's (2010) model is an ideal candidate for a structural model of memory in the LC4MP in that it does not rely on machine-based metaphors or rigid separations between different types of memory. Instead, this model posits that memory is a flexible, dynamic, and associative process that enables and undergirds human information processing. Each of the three processes occurs dynamically and continuously, and has extensive feedback with other processes. As such, each of these processes has both serial and parallel components. It is argued that an explication of the three processes outlined in Henke's model can provide a unifying framework for cognitive load, motivated processing, and their respective roles in message processing and outcomes. We now review each encoding process in turn, discussing the relevance of each for understanding message processing and memory.

When a piece of information first enters the processing system, it is briefly encoded as a pattern of neural activity in sensory processing regions (Jäger, Mecklinger, & Kipp, 2006). This process corresponds to 'encoding' as traditionally discussed in the LC4MP. Information encoded in this fashion can be said to exist in a precategorical state – largely devoid of associational information. In Henke's (2010) model, this memory process is called 'rapid encoding of single or unitized items.' A unitized item is one that has been 'chunked' into one unit in memory (e.g. remembering a string

of isolated numbers as one unit—such as a phone number, or remembering three interconnected lines as a triangle (Gobet et al., 2001; Mathy & Feldman, 2012).

Rapid encoding of single or unitized items is largely modality- and process-specific (Tulving & Schacter, 1990). Although some cross-modal effects have been observed, these effects are often attributed to semantic representations of either auditory or visual information (e.g. speaking a word which has been presented in print; see (Carlesimo et al., 2004). We propose that this mechanism undergirds perceptual processing as outlined in our updates to the model. As items are encoded, they are rapidly utilized by other processes which guide their longer term storage and enable the motivation-driven biased competition mechanisms proposed above (Lisman & Grace, 2005). When this reactive control mechanism is overloaded in either auditory or visual streams, efficiency of these biased competition processes is likely compromised.

When a piece of information is encoded, it is quickly associated with other, previously stored information that might be relevant for understanding and acting upon the information. This process is referred to as ‘rapid encoding of flexible associations.’ Whenever an individual encounters new information in a message, the brain quickly associates this information with contextual, emotional, or motivational ‘tags’ related to information which have previously been stored in working or long term memory (Redondo & Morris, 2011). In LC4MP parlance, this mechanism can be said to undergird encoding and storage of information that may be context specific or flexible. Consistent with the understanding of motivational influences on processing outlined in this article, these tags inform the response competition process, biasing neural processes and their associated responses upward or downward depending on associated goals, states, and other information.

Both expectations and outcomes adaptively guide what is transferred from working memory to longer term memory, facilitating learning of motivationally relevant information or behaviors, allowing individuals to carry out actions that are optimal in a given situation (Shohamy & Adcock, 2010). An individual’s associations between particular stimuli and their reward/threat magnitude, likelihood, and proximity are dynamically updated as these expectations are upheld or violated (Ablner, Walter, Erk, Kammerer, & Spitzer, 2006; Schultz et al., 1997). The difference between the expectation and the outcome (prediction error) is a signal that alerts the processing system to update representations of effort, reward, and threat for particular stimuli in the environment (Dunn, Inzlicht, & Risko, 2017; Westbrook & Braver, 2016). This means that motivationally relevant stimuli that elicit a large prediction error should be encoded more robustly than those for which expectations and outcomes are more predictable. Within the LC4MP, this serves as a potential explanation for why message content surrounding orienting responses is more memorable than other content. A ‘cut’ in a message can be thought of as violation of the expectation that a scene will be characterized by continuous motion, leading to greater resource allocation and higher encoding and storage.

The final, and most permanent memory process proposed is ‘slow encoding of rigid associations.’ Memories which are rigidly encoded can be either conscious or unconscious. These memories are, for the most part, initially formed as flexible associations, but are abstracted, encoded, and stored in longer term memory stores as a result of repetition, rehearsal, or updating in relation to prediction error. Some of these associations are likely innate – brought about by genetic influences on neuro-cognitive development across evolutionary time (LeDoux, 2012, 2000). This echoes Lang’s assertions in the LC4MP that certain stimuli are motivationally relevant because they are survival relevant – stimuli which have direct associations with bodily threat, nutritive value, potential mates, etc. It is worth noting that under this framework, associations do not necessarily have to be a result of firsthand experience with relevant stimuli. Importantly, flexible or rigid associations can also be formed as a result of vicarious learning processes (such as a mother telling her child about the dangers of guns). This is especially relevant for communication scientists, as messages form a vast repository of stimuli which can drive these learning and reinforcement processes, contributing to formation of flexible or rigid associations between concepts which can drive habit formation, classical conditioning, and procedural learning outcomes.

Broadly speaking, the more that flexible associations are accessed and associated with new experiences, the more rigid they become (Berridge, 2000; Dayan & Balleine, 2002). In the LC4MP, these associations can be thought of as contributing to the motivational relevance of a behavior or piece of information in the communication environment. These rigid associations are not likely to change as specific goals or context changes, although they are likely influenced by shorter-term flexible associations—especially as flexible associations become more rehearsed (and thus solidified). Notably, motivational activation is ongoing throughout these processes and thus both rigid and flexible associations result in either appetitive or aversive activation. So, taken together, motivational coactivation could result from four different combinations of associations across the appetitive and aversive systems (rigid appetitive with rigid aversive; rigid appetitive with flexible aversive, flexible appetitive with rigid aversive, and both flexible associations).

In addition to the incorporation of a more detailed model of memory in the LC4MP, we argue that much progress can be made in incorporating signal detection analysis into measures used to index encoding and storage. Signal detection was integrated into the LC4MP toolkit in response to concerns with using accuracy as the sole measure of recognition memory and to better understand the dynamics of resource reallocation processes, (Fox et al., 2007). In this measure, percent accuracy is replaced with two separate measures, *sensitivity* and *criterion bias* (for an overview of signal detection analysis as applied to tests of memory see (Macmillan & Creelman, 1991; Shapiro, 1994; Stanislaw & Todorov, 1999).

Signal detection analysis has been used to great utility in the literature to understand the nature of declines in memory performance due to resource reallocation processes in response to message complexity (Fox et al., 2007), and due to defensive processing (Clayton et al., 2018; Clayton, Leshner, Tomko, Trull, & Piasecki, 2017; Leshner et al., 2011, 2018; Liu & Bailey, 2018). Recent work in this area suggests that signal detection analysis may be used to differentiate resource reallocation that occurs due to ‘flight’ responses (message avoidance) from that which occurs due to ‘fight’ responses (counterarguing; Liu & Bailey, 2018). Criterion bias due to cognitive overload and due to flight responses tends to be quite liberal – meaning that participants are willing to ‘guess’ about the content that was seen (Clayton et al., 2018; Fox et al., 2007; Leshner et al., 2011) but that criterion bias due to fight responses tends to be more conservative (Clayton et al., 2018; Clayton, Leshner, Bolls, et al., 2017; Leshner et al., 2011, 2018; Liu & Bailey, 2018).

The signal processing approach has also been used to understand encoding of central or peripheral details (Yegiyani, 2012, 2015b; Yegiyani & Yonelinas, 2011), video games (Chung & Sparks, 2016; Sparks & Chung, 2016), speech rate (Rodero, 2016) and many other phenomena. Despite this, well under half of the studies considered in our review that dealt with memory conducted signal detection analyses (Fisher et al., 2018). We suggest that future tests of recognition memory for messages should utilize signal detection measures – especially if cognitive resource reallocation is expected.

Updated predictions and avenues for testing

The following predictions assume that rapid encoding of single or unitized items is a *perceptual* process and is capacity limited by modality whereas encoding of associations (either flexible or rigid) is a capacity limited *cognitive* process. With these in mind, several testable predictions are proposed here: (1) Flexible associations with reward or threat may be induced by associating stimulus features with reward or threat within the experimental context (Anderson, 2016; Anderson et al., 2011). (2) Message content that is either flexibly or rigidly associated with reward or threat will elicit more resource allocation than non-motivational information. (3) Stimuli for which prediction error is the highest (much more or less rewarding or threatening than expected) will elicit higher resource allocation. (4) Perceptual load (e.g. increasing objects to be identified, inducing perspective change, etc.) will interfere with rapid encoding of single or unitized items. (5) Cognitive load (e.g.

retaining a string of numbers in working memory or keeping up with a complex plot) will interfere with the rapid encoding process for items flexibly associated with motivational relevance but not items rigidly associated with motivational relevance. This will be reflected in increased misses for flexibly encoded, but not rigidly encoded information in the affected channel.

We propose that the memory processing categories introduced here can inform not only the LC4MP, but also our understanding of the way in which humans process communication in general. Reward association processes involving both rigid, automatized memory structures and flexible, context-dependent memory structures bias cognitive patterns which facilitate processing, and approach or avoidance behaviors for motivationally relevant stimuli. In the message processing environment, the appetitive and aversive systems can often produce conflicting bias signals – such as in a public service announcement wherein a rigidly encoded appetitive cue (such as a substance cue) is presented as highly negative. This creates a conflict between a rigid association (substance cue → reward) and a flexible association (substance cue → threat or disgust). The motivated response that is chosen in response to these conflicting cues is likely contingent on contextual variables (such as magnitude of reward or threat within the message processing context) and on individual differences in motivational system activation (Clayton et al., 2018).

This approach to motivational coactivation could help to further explicate some of the previously discussed disparate findings. Specifically, by theorizing as to whether expected appetitive and aversive activation is a function of rigid or flexible associations, researchers using the LC4MP can better predict the nature of specific processing outcomes that are thought to result from coactivation (e.g. reactance, counter arguing, etc.). Consideration of each of Henke's (Henke, 2010) three subsystems of memory within the context of response competition theory and cognitive control provides a way forward for the integration of predictions of the LC4MP in a processing environment which is highly dependent on a host of context, content, structure, and individual difference variables.

Conclusion

Nearly two decades have passed since the original LC4MP article was published (A. Lang, 2000, 2006). At the onset of this paper, we asked if unexpected and sometimes inconsistent findings observed in the LC4MP literature were sufficient to warrant discarding the model in favor of an entirely different framework. We propose that the answer is 'no.' Instead, we argue that it is possible to account for these inconsistencies by incorporating recent empirical results from a diversity of literatures and updating a selection of the auxiliary hypotheses of the LC4MP. To this end, we considered three broad domains within LC4MP research: cognitive load, motivated processing, and memory. In each section, we outlined a selection of findings that suggested the necessity of another look at the assumptions and predictions of the LC4MP, updated these assumptions in light of current literature in communication science and cognate fields, and proposed a suite of falsifiable predictions and potential avenues for their testing. In doing so, we provide explanations for inconsistent findings and position the LC4MP to take advantage of new methods and illuminate new questions.

By conceptualizing communication in all of its physically and digitally mediated forms as a dynamic, fundamentally human-centered process, the LC4MP provides a framework through which to investigate processes of interest to a wide range of communication scholars. The model has already been used to great utility for understanding health messages (Bigsby, Monahan, & Ewoldsen, 2017; Clayton et al., 2018; Clayton, Leshner, Tomko, et al., 2017; Leshner et al., 2018; Leshner, Thomas, & Bolls, 2009; Liu & Bailey, 2018; Weber, Huskey, Mangus, Westcott-Baker, & Turner, 2015; Weber, Westcott-Baker, & Anderson, 2013), political messages (Bradley et al., 2007; Wang, Morey, et al., 2012), educational multimedia (Chung, Cheon, & Lee, 2015; Fisher & Keene, 2017; Lee & Heeter, 2017), fear appeals (Leshner et al., 2011; Ordoñana, González-Javier, Espín-López, & Gómez-Amor, 2009; Rhodes, 2017; Roskos-Ewoldsen, Yu, & Rhodes, 2004), social influence and morality (Read, Lynch, & Matthews, 2018; Rubenking & Lang, 2014), news (Barreda-Ángeles, Pereda-Baños, Ferrándiz-Bofill, & Costa, 2017; Bas & Grabe, 2015; Fox et al., 2004; Grabe, Yeghiyan, &

Kamhawi, 2008; Lang, Potter, & Grabe, 2003; Wise, Eckler, Kononova, & Littau, 2009), multitasking (Kätsyri et al., 2016; Rubenking, 2017; Wang, David, et al., 2012), and a wide variety of other areas. In clarifying and updating model predictions, we hone the model's utility in each of these areas, and position the LC4MP to investigate novel questions and incorporate new methodological approaches.

Of the 256 LC3MP/LC4MP articles published over the last two decades, 164 of them have been published in the last five years—suggesting that the influence of the LC4MP is yet far from waning (Fisher et al., 2018). While it may be overly optimistic to think that the ideas presented herein will have a similar shelf life as the original model, we sincerely hope that the predictions we outline – and the revised model we sketch – provide a foothold for the next wave of fruitful LC4MP research across many areas of communication science (Table 1).

Note

1. As later published in (Popper, 1985).

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