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REVIEW ARTICLE

The limited capacity model of motivated mediated message processing: taking stock of the past

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ABSTRACT

In the 15 years since its inception, the Limited Capacity Model of Motivated Mediated Message Processing (LC4MP) has contributed to understanding regarding the dynamics of message processing in a variety of domains. In this manuscript we outline the foundations and assumptions of the LC4MP, discussing salient research from biology, cognitive psychology, and communication upon which the model is built. We then conduct a systematic review of the LC4MP literature with a focus on three primary domains: cognitive load, motivated processing, and memory. In a companion piece (Fisher, Huskey, Keene, & Weber, 2018) we look to the future of the model, incorporating recent findings from communication and cognate fields to inform an updated suite of predictions.

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> It is the boldness of a conjecture which takes a real risk — the risk of being tested, and refuted; the risk of clashing with reality. –(Karl Popper, 1985)[1]

Communication science has long benefited from a knowledge brokering process wherein empirical results gleaned from other fields are used to inform assumptions and predictions about human behavior (Bushman, 2016; Ewoldsen, Rhodes, & Fazio, 2015; Johnson, Ewoldsen, & Slater, 2015; Sherry, 2015; Weber, Sherry, & Mathiak, 2008). Indeed, theories and methods in communication often draw from cognate fields such as psychology, sociology, evolutionary biology, history, and political science (Rogers, 1994). Communication researchers often deal with high-level constructs that involve numerous lower-level processes, each of which are likely the subject of vast quantities of research in their own right (Weber, Eden, Huskey, Mangus, & Falk, 2015). For the communication researcher, then, a primary challenge is to integrate this research from other fields into coherent explanations and predictions for human communication behavior in a variety of specific contexts (e.g. interpersonal communication, multimedia message processing). The Limited Capacity Model of Motivated Mediated Message Processing (LC4MP; Lang, 2000, 2006b, 2009) is a particularly notable example of this process.

The LC4MP was first conceptualized over 15 years ago as the Limited Capacity Model of Mediated Message Processing (LC3MP; Lang, 2000). Although motivation was undeniably a consideration in the original model, the fourth 'M' was not officially folded into the model until 2006 (Lang, 2006a, 2006b). The LC4MP brokers insights from biology, evolutionary psychology, and the cognitive sciences to ground its assumptions and to provide predictions regarding human communication behaviors. Since its publication, the model has been remarkably productive. The LC3MP, and subsequently

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the LC4MP, has been cited over 770 times.[2] The LC4MP provides a theoretical and methodological framework to investigate an individual's interaction with communication phenomena in real time (Lang, 2009). Rather than choosing to examine stimuli and their responses in a cross-sectional fashion, the model hones in on the mechanics of processing throughout individuals' engagement with a message. This allows researchers to make more refined predictions about the nature of information processing (Detenber & Lang, 2010).

At the time of its writing, the LC4MP was a marked change from contemporaneous models and theories within communication scholarship. In these approaches (see e.g. Bryant & Zillmann, 1986), media use patterns and individual differences were conceptualized as inputs and media effects as outputs – treating the intervening human processing system as a 'black box' impenetrable to investigative efforts (Lang & Ewoldsen, 2009; Lang, Potter, & Bolls, 2008). The LC4MP, in its turn towards an 'information processing approach' (see Craik & Lockhart, 1972; Lang & Ewoldsen, 2009; Miller & Cohen, 2001; Newell, Simon, & Others, 1972; Weber et al., 2015, 2008) has inspired a broad range of theoretical, methodological, and empirical contributions relevant for communication researchers (Lang, 2013).

In this manuscript, we argue that the LC4MP—due to its unique position at the intersection of communication research and the cognitive sciences—has been especially useful in facilitating progress toward understanding how human beings process information rich, multimodal messages. We begin by reviewing the LC4MP's central assumptions and predictions, discussing these tenets in light of current findings from communication science and cognate fields. We then conduct a systematic review of the LC4MP literature, highlighting three key domains in which the LC4MP has produced especially fruitful research: cognitive load, motivated processing, and memory. For each of these domains we discuss (1) what the LC4MP has to say about the processes involved in each domain; (2) primary methodological tools that have been used or developed to investigate empirical questions in each domain; and (3) current model predictions salient within each domain. We conclude with an overview of the current state of the LC4MP, highlighting areas in which model predictions are well established and those that need more development.

Foundations and assumptions of the LC4MP

The LC4MP is based on five theoretically-derived assumptions. First, it is assumed that human information processing is capacity limited and that these limitations place predictable constraints on how messages are processed. This assumption has a long history of empirical support across several fields (e.g. Kahneman, 1973). The LC4MP proposes that cognitive resources exist in a single, central, generic pool of a fixed size (Lang, 2000; Lang, Bradley, Park, Shin, & Chung, 2006). This notion of cognitive resources is based on findings from cognitive psychology suggesting that resource limitations are related to attention or working memory processes (Baddeley & Hitch, 1974; Bjorklund & Harnishfeger, 1990; Hasher & Zacks, 1979; Kahneman, 1973; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Zechmeister & Nyberg, 1982).

As the brain can only process a small selection of information in the environment at any given time (Baddeley & Hitch, 1974; James, 1890), some selection process must take place wherein the most salient information is chosen for processing—often to the detriment of less salient information (Handy, Hopfinger, & Mangun, 2001). Information selection decisions can take place either consciously or unconsciously based on individual goals or stimulus features (Lang, 2000, 2009). Selection decisions that are driven by an individual's goals and prior knowledge are referred to as 'top-down,' whereas those driven by attention-grabbing stimulus features are referred to as 'bottom-up' (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000; Treisman & Gelade, 1980). In the LC4MP, cognitive resources that are allocated to message processing are allocated to one of three subprocesses: encoding, storage, and retrieval (Lang, 2000, 2009). Cognitive resource limitations can inhibit the successful performance of any of these three subprocesses, reducing processing performance and influencing outcomes such as enjoyment, learning, persuasion, and many others. Individuals may vary in their ability to effectively allocate cognitive resources among these processing tasks, leading to differences in message processing effectiveness (Bailey, Potter, Lang, & Pisoni, 2015; Lang, Schwartz, & Mayell, 2015).

The second assumption of the LC4MP is that humans have two motivational systems developed over evolutionary time to facilitate survival behaviors (e.g. finding food, finding mates) and avoid harmful situations or behaviors (e.g. predators, pathogens). This notion of motivation is derived from the Evaluative Space Model (ESM; see Cacioppo, Berntson, Norris, & Gollan, 2011). The ESM proposes that two independent motivational systems – the appetitive system and the aversive system (Cacioppo & Gardner, 1999; Cacioppo, Gardner, & Berntson, 1997; P. J. Lang, Bradley, Cuthbert, & Simons, 1997)—respond automatically and pre-consciously to both pleasant and unpleasant stimuli. In the ESM, activation in these systems can be thought of as varying along three continua: arousal (intensity or excitingness), valence (positive or negative), and dominance (or control; Bradley, 2007a; Bradley & Lang, 1994; Bradley, Codispoti, Cuthbert, & Lang, 2001).

Generally, a stimulus that induces more activation in the motivational systems elicits more cognitive resources. However, each of the two motivational systems have unique patterns in response to increases in activation intensity. At rest, the appetitive system is more activated than the aversive system. This difference in activation is called the *positivity offset* (Cacioppo & Gardner, 1999; Ito & Cacioppo, 2005). Because the appetitive system is more activated at rest, the LC4MP predicts that at low levels of arousal positive stimuli will elicit more resource allocation than will negative stimuli. As activation in the appetitive system becomes more intense, resource allocation will continue to increase in a roughly linear fashion. By comparison, activation in the aversive system activates much more quickly and powerfully than in the appetitive system. Thus, at moderate levels of intensity, the LC4MP predicts that negative stimuli will elicit more resource allocation than positive stimuli. Critically, at high levels of activation in the aversive system, resources are allocated away from processing the threatening stimulus in order to avoid or combat the threat (fight or flight). This reallocation of resources at high levels of aversive system activation is known as the *defensive cascade* (Bradley et al., 2001; Cacioppo, Gardner, & Berntson, 1999; Lang et al., 1997).

The third assumption of the LC4MP is that messages can be conceptualized as continuously varying streams of information presented in one or multiple modalities (visual and/or auditory). Each of these modalities can be variably concordant (matching across modalities; e.g. correct subtitling of dialogue), discordant (conflicting across modalities; e.g. incorrect subtitling), or redundant (neither modality containing information which the other does not; e.g. a voiceover of a text presented on-screen; Lang, 1995). Incorporated into this assumption is the idea that all communication is mediated (Mangus, Adams, & Weber, 2015) and may be presented in many types of environments (e.g. face-to-face, television, mobile, personal computers, virtual reality). Streams of mediated information are assumed to be processed in largely the same way as direct, non-mediated information. This is based on the assumption that the human brain has evolved over hundreds of thousands of years and has not yet developed mechanisms to quickly and reliably discriminate unconsciously between perceptions of digitally mediated phenomena and phenomena in the 'real world' (Reeves & Nass, 1996). Said differently, stimuli that the processing system would treat as salient in the real world – such as predators, food cues, and motion – are mostly treated as salient in a mediated context (Bailey, 2015; Bradley, 2007a; Lang & Bailey, 2015).

Fourth, the model assumes that communication happens over time. As such, the dynamics of communication contain valuable information that is lost when collapsing measures of processing outcomes into post-hoc or cross-sectional variables. For example, a cross-sectional, summative sentiment score for a media message could be the same for a message which starts extremely positive but ends extremely negative as for a message which starts extremely negative and ends extremely positive. This is problematic in that each of these sentiment trajectories has been shown to lead to different outcomes (Chung, Fink, Waks, Meffert, & Xie, 2012; Keene & Lang, 2016; Nabi & Green, 2015). For this reason, the LC4MP is advantageously situated to utilize dynamic measures of message processing such as continuous response measurement, psychophysiology, and neuroimaging.

Lastly, the model assumes that communication can be defined as an ongoing interactive exchange of information via a medium (e.g. air/light in interpersonal communication, television in mass communication) that is received by an individual. Even in situations like television viewing – which would seem to be largely one-way – the individual is capable of manipulating their attentional state, thus modulating the flow of information into the processing system.

Likewise, salient features of messages are capable of eliciting attention at the automatic, 'bottom-up' level – a process which also modulates the dynamic flow of information and message transmission. This assumption further emphasizes the necessity of measuring message processing over time.

Three broad areas of research within LC4MP research are especially salient for communication scholars. The first of these, *cognitive load*, is primarily concerned with capacity limitations in the human processing system—how messages load the processing system in various ways, and how cognitive load modulates message processing. The second domain is *motivated processing*. LC4MP researchers have worked to understand how the human motivational systems are involved in communication processes, and how their activation affects encoding, storage, and retrieval throughout a message. Finally, LC4MP-driven research has characterized processes that undergird *memory* for messages and the structure and content features that affect how well a message is remembered. A solid – and rapidly growing – base of research using the LC4MP in each of these three areas warrants review. In this section of the manuscript, we review each domain in turn, emphasizing three primary foci: theoretical advancements afforded by LC4MP research, methodological advancements which have animated investigation in each area, and core predictions that have arisen as a result of research in each domain.

Review of LC4MP research

For the purposes of this review, we systematically collected articles and chapters from journals and books in communication, media, advertising, and psychology that met one or more of the following criteria: a) the article or chapter explicitly tested a prediction based on the LC4MP or LC3MP; b) the article or chapter utilized the LC3MP or LC4MP to scaffold hypotheses or research questions; c) the article or chapter called upon the LC3MP or LC4MP in a discussion section to explain results; d) the article or chapter was a theoretical overview of the LC3MP or LC4MP. Searches were completed using the Communications/Media and Psychology/Sociology databases of EBSCO Academic Search Complete. The following terms were used in searching the database: 'LC4MP,' 'LC3MP,' 'Limited Capacity Model,' 'Motivated AND Message Processing,' and 'Motivated OR Mediated AND Message Processing.' In addition, a search was conducted on Web of Science™ for articles that cited the original LC3MP (Lang, 2000) or the LC4MP (Lang, 2009) manuscripts. This resulted in 669 articles. Following initial article collection and removal of duplicates, articles were filtered according to their titles and abstracts (see Figure 1). Article collection and filtering was conducted in accordance with the PRISMA guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). Three trained coders reviewed the articles for their relevance to each of the domains considered in this manuscript.[3] This resulted in a final selection of 256 articles.

Cognitive load

A core area of research within the LC4MP is directed at understanding the limitations of the human processing system and investigating how structural and content features of messages interact with these limitations to facilitate relevant outcomes. At the time of article collection, there were 103 articles in the LC4MP literature that directly investigated cognitive load. The LC4MP discusses cognitive load in terms of resource allocation, echoing many other information processing theories (Kahneman, 1973; Wickens, 1991). In the model, cognitive resources are primarily discussed using the metaphor of a 'pie' consisting of four pieces: resources required to successfully process the message, resources allocated to the message, resources remaining in the system while the task is

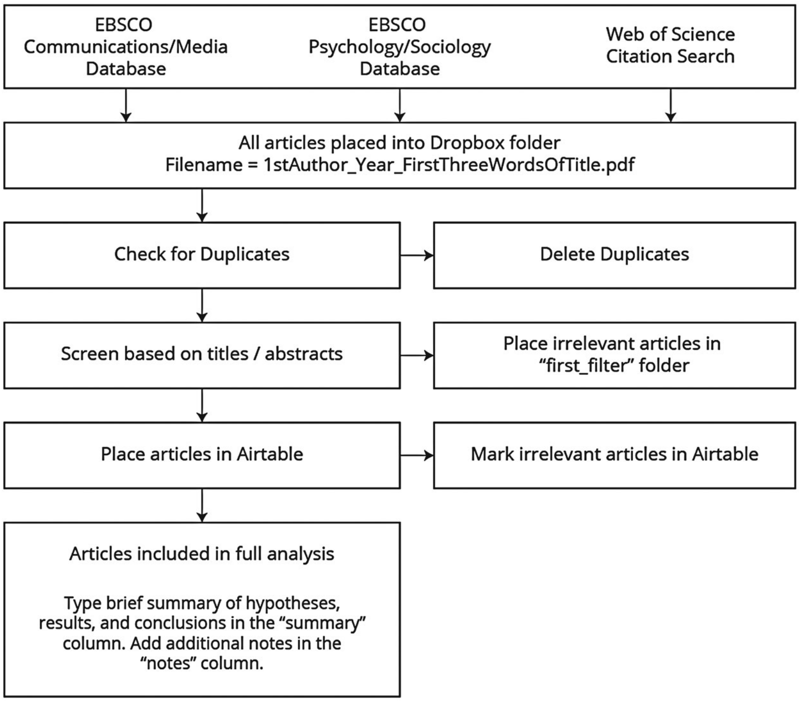

Figure 1. Document acquisition and selection process.

being performed, and available resources (Lang et al., 2006; Lang & Basil, 1998). We will use the metaphor of the resource pie to structure our review of the LC4MP's contribution to our understanding of cognitive load, discussing theoretical advancements and methodological contributions that have increased knowledge in this area as well as areas in which the LC4MP in its current state produces unclear or unexpected findings.

Resources required

LC4MP research has revealed that the resources required to process a message depends on the information introduced over time within a message (Lang et al., 2006, 2015; Lang, Kurita, Gao, & Rubenking, 2013). This understanding has led to the development of a measure to capture the information density of messages (*i^2 or ii*; Lang et al., 2006; Lang, Park, Sanders-Jackson, Wilson, & Wang, 2007). Information is conceptualized as any of seven changes that can be introduced by a camera cut (cc) or edit within a message: namely object change, novelty, relatedness, distance, perspective, emotion, and form change. For each camera cut, edit, or other structural change in the message, the amount of information that is introduced as a result of the change is counted. This results in a dynamic measure ranging from one to seven for each cut in the message.

The result of this coding can be used to estimate available resources for each cut in the message, but can also be averaged across longer time intervals or for a whole message. Both *ii* and *cc* can also be considered in relation to the pacing of the message, taking into account the amount of information introduced per second (*ii/s*) and the number of camera cuts per second in a message (*cc/s*). As a measure, *ii/cc* has been used to understand of how the information density of messages relates to processing outcomes of interest. This approach has been employed in the context of anti-smoking PSA's (Lee & Cappella, 2013) and anti-marijuana PSAs (Wang, Solloway, Tchernev, & Barker, 2012; Weber, Westcott-Baker, & Anderson, 2013), as well as prescription drug advertisements (Norris, Bailey, Bolls, & Wise, 2012) and other TV advertisements (Park & Bailey, 2017). The LC4MP proposes that audio and visual information introduced in messages load the same processing resources, but that the two modalities may require differing amounts of resources to encode message information. This has led to the development of *ii* for visual messages and *Aii* (audio information introduced; Lang, Gao, et al., 2015) for auditory messages such as radio advertisements and talk shows.

Resources allocated

Human beings allocate resources to message processing in both controlled and automatic ways. Importantly, in the LC4MP framework, individuals do not automatically allocate resources as a result of information introduced within a message. Instead resources are allocated as a result of two primary processes.The first mechanism through which resources are allocated is activation of the motivational systems (covered in the next section). The second of these is elicitation of the *orienting response* (OR)—a cascade of physiological changes by which the processing system directs resources toward the processing of novel stimuli (Graham & Clifton, 1966; Sokolov, 1963). The OR can be elicited by structural features (such as cuts/edits) or content features (e.g. loud noises, motion).

Resource allocation can be indexed over two time courses: tonic and phasic (Keene, Clayton, Berke, Loof, & Bolls, 2017; Potter & Bolls, 2012). Tonic resource allocation is measured over a relatively broad time span (e.g. an entire conversation or media message). Phasic resource allocation, however, focuses on the time that precedes or follows specific events, and is driven by the OR (Posner & Petersen, 1990). The OR has been primarily indexed in LC4MP research using psychophysiological measures such as heart rate (Keene, Clayton, Berke, Loof, & Bolls, 2017; Lang, 1994; Thorson & Lang, 1992) and skin conductance (Potter & Bolls, 2012), but other work has utilized electroencephalography as well (Francuz & Zabielska-Mendyk, 2013; Reeves et al., 1985; Stróżak & Francuz, 2017). In this literature, heart rate is the only physiological response that seems to exhibit a 1-to-1 mapping with orienting responses, as EEG and SCL responses are also elicited by other processes (Cacioppo, Tassinary, & Berntson, 2000; Potter & Bolls, 2012). Specifically, an OR is indexed by heart rate when there is a distinct deceleration following a stimulus event (e.g. a voice change; Lang, Gao, et al., 2015; Potter, Jamison-Koenig, Lynch, & Sites, 2016; Potter, Lang, & Bolls, 2008; Rodero, 2015; Rodero, Potter, & Prieto, 2017) that then leads to an acceleration back to a homeostatic baseline (Barry, 1990). This deceleration and acceleration results in a U-shaped curve called the cardiac response curve (for a review of the cardiac response curve, see Thorson & Lang, 1992).

Within the literature, cognitive resources have been shown to be elicited by camera cuts/edits (Lang et al., 2006; Lang, Kurita, et al., 2013; Lang, Park, et al., 2007), pitch changes or other structural features in audio (Lang, Gao, et al., 2015; Potter et al., 2008; Potter et al., 2016; Rodero, 2015; Rodero et al., 2017), motivationally relevant content (Clayton, Ridgway, & Hendrickse, 2017; Ordoñana, González-Javier, Espín-López, & Gómez-Amor, 2009; Potter & Keene, 2012; Potter, LaTour, Braun-LaTour, & Reichert, 2006; Rubenking & Lang, 2014; Wang, Solloway, et al., 2012), pop up banners in an online environment (Diao & Sundar, 2004; Lang, Borse, Wise, & David, 2002), content features in video games (Gangadharbatla, Bradley, & Wise, 2013), and computer controlled content presentation (Wise & Pepple, 2008; Wise & Reeves, 2007). These are often collectively referred to as *orienting eliciting structural features* (OESFs; Lang, 2009; Lee & Lang, 2015).

A current area of ambiguity within the LC4MP is the measurement of controlled, top-down resource allocation in conjunction with automatic allocation. The model has traditionally been primarily focused on bottom-up resource allocation driven by ORs and activation in the motivational systems (Lang, 2009, 2017; Lang et al., 2006) and the measure used to index resource allocation (*ii/cc*) does not take top-down resource allocation into account (although see (Park & Bailey, 2017) for work in this direction). Despite this, several studies in our review have utilized the LC4MP to understand controlled resource allocation decisions (Bolls & Lang, 2003; Clayton, Leshner, Tomko, Trull, & Piasecki, 2017; Lang, Chung, Lee, & Zhao, 2005; Park & Bailey, 2017; Sparks & Lang, 2015). Typically in these studies, resource allocation is considered as the sum of controlled and automatic resource allocation processes (Park & Bailey, 2017) and is measured using tonic heart-rate changes (Keene et al., 2017; Potter & Bolls, 2012). In general, a reduction in heart rate is a sign of increased resource allocation to the stimulus whereas an increase in heart rate (or a reduction in the amount of deceleration) is indicative of resource allocation away from the stimulus. In addition, although habituation of the OR is documented in the LC4MP (Potter, Lynch, & Kraus, 2015), little work has addressed the resource allocation ramifications of habituation or how habituative processes may interact with conscious resource allocation to influence total resources allocated to a message at any given time.

Resources available

As discussed above, an important factor within the LC4MP approach to cognitive load is the notion of *resources available*— the resources that are allocated to processing a message minus the resources required to process the message.[4] Recall that in the LC4MP resources are thought to be allocated to a message phasically in response to OESFs or motivationally relevant content and tonically as a result of individual goals. These resources are consumed by encoding, storage, and retrieval processes. As such, more complex messages (higher *ii/sec*) should be associated with lower resource availability. Thus:

$$R_{\text{allocated}} - R_{\text{required}} = R_{\text{available}}$$

Resource availability is measured using a combination of secondary task reaction times (STRTs; Lang et al., 2006; Lang & Basil, 1998) and encoding measures (discussed in the memory section below). A typical STRT task is pressing a button upon hearing a tone or seeing a particular image onscreen (henceforth referred to as a secondary task). Importantly, participants in the experiment are told to focus on the primary task (usually watching a video, listening to audio, or playing a video game) and also to respond to the secondary task when it is cued. As fewer resources are left available the time that it takes to respond to the secondary task increases.

A unique contribution of LC4MP research in this area is in investigating the nature of cognitive overload in relation to message processing (Fox, Park, & Lang, 2007; Lang et al., 2006). As available resources approach zero, resources are diverted from the primary task to the secondary task, resulting in decreasing STRTs and reduced message processing effectiveness.

The effects of cognitive overload on affective outcomes are less well understood. Lang and colleagues have suggested that certain types of overload can be enjoyable, especially for passive viewing tasks (Lang, Park, et al., 2007; Park & Bailey, 2017) but other research has reported that overload is not enjoyable, especially when processing performance is important (Ang, Zaphiris, & Mahmood, 2007; Harris, Vine, & Wilson, 2017). As such, the affective correlates of cognitive overload are still an open question within the model.

Physiological and behavioral responses indicative of cognitive overload have also been observed during intensely negative messages (such as threatening or fear-inducing appeals; Bailey, Wang, & Kaiser, 2018; Clayton, Lang, Leshner, & Quick, 2018; Clayton, Leshner, Bolls, & Thorson, 2017; Leshner, Clayton, Bolls, & Bhandari, 2018; Liu & Bailey, 2018; Rhodes, 2017), suggesting that there may be important similarities between resource reallocation patterns observed during cognitive overload and those that occur during the defensive cascade (fighting or fleeing). Recent research has begun the process of characterizing the similarities and differences between these two states, suggesting that cognitive overload may be differentiated from the defensive cascade using signal detection measures of recognition memory (Liu & Bailey, 2018).

Resources remaining

Within the LC4MP, resources remaining are conceptualized as the resources in the processing system that are not allocated to the message processing task.

Thus, resources remaining can theoretically be calculated by subtracting resources allocated from an estimate of a person's total resource capacity (assuming there is a measure for total resource capacity). Thus:

$$R_{\text{total}} - R_{\text{allocated}} = R_{\text{remaining}}$$

A certain amount of resources are allocated to the maintenance of essential bodily functions and as such are never available for allocation to a message processing task. Resources remaining in the processing system can also depend on a number of other factors, such as individual differences in cognitive capacity (Lang, Schwartz, & Mayell, 2015) and the presence or absence of other tasks competing for cognitive resources. Recent LC4MP research has begun to broach the topic of individual differences in resource capacity related to executive control (Bailey et al., 2015), age (Lang, Schwartz, et al., 2015), and disorders such as ADHD (Fisher & Keene, 2017) Researchers working in this area have worked to understand how cognitive individual differences affect total resource availability within the information processing system and how this leads to differential media processing outcomes. These findings can serve to inform the design of more effective multimedia messages for these populations (Fisch, 2017).

A summary of supported predictions

Taken together, the basic predictions of the LC4MP for cognitive load are as follows: (1) Messages that are motivationally relevant and/or contain more OESFs will elicit higher resource allocation; (2) messages which introduce more information per time unit (Lang, Kurita, et al., 2013; Lang, Park, et al., 2007; Park & Bailey, 2017) will require more cognitive resources to process thus reducing the amount of available resources; (3) this leads to lengthening STRT times as a measure of available resources, as participants with few resources available become less efficient at simultaneously managing the primary and secondary task (Lang & Basil, 1998); (4) as resources required to process the message exceed resources allocated for processing, participants enter a state of cognitive overload in which resources are allocated away from the primary task and toward the secondary task (Lang et al., 2006); (5) this state is associated with fast STRTs and poor memory. Accordingly the LC4MP predicts an inverted-U shaped relationship between resource availability (as indexed using STRTs and memory measures) and relevant outcome variables such as resource availability and recognition memory (discussed below).

Motivated processing

The LC4MP's newest 'M,' motivation, is a topic of interest across a diversity of fields. Each recognizes motivation as critical for explaining human behavior at multiple levels. It is worth noting that the LC4MP has also used a motivational framework to study emotion, particularly the complex, multidimensional emotional responses common in multimedia processing. However, the LC4MP considers emotion as the experiential byproduct of motivation (Lang, 2000, 2009, 2017), and as such, these two domains are considered together in this review. Of the studies considered here, 176 were concerned with motivational influences on message processing. This research has contributed to understanding of motivated processing in several key ways. The first of these is in illuminating individual differences in motivational system activation. Second, these studies have characterized the motivational relevance of content within messages and have developed dynamic measures to index these features (Wang, Vang, Lookadoo, Tchernev, & Cooper, 2014). Finally, these studies have developed and refined psychophysiological, neural, and self-reported measures of motivated processing, contributing to our understanding of where the 'mind meets the message' (Lang, Bradley, Chung, & Lee, 2003).

Individual differences in motivated processing

A central area of research in the LC4MP is aimed at understanding individual differences in the appetitive and aversive motivational systems and their associated effects on media selection and processing outcomes (Lang, Sanders-Jackson, Wang, & Rubenking, 2013). These differences are primarily indexed using the Motivation Activation Measure (MAM; Lang, Bradley, Sparks, & Lee, 2007; Lang, Kurita, Rubenking, & Potter, 2011). Research leveraging the LC4MP in conjunction with MAM has revealed that individual differences in baseline appetitive system activation (ASA) and defensive system activation (DSA) are associated with differences in media choices and processing (Potter, Lee, & Rubenking, 2011) and psychophysiological responses to media (Bailey et al., 2015; Hohman, Keene, Harris, Niedbala, & Berke, 2017).

The MAM classifies individuals into four main groups in regard to their relative levels of ASA and DSA; risk-takers (high ASA/low DSA), risk-avoiders (low ASA/high DSA), inactives (low ASA/low DSA), and coactives (high ASA/high DSA; Lang, Shin, & Lee, 2005). Those who are risk-taskers tend to seek out more arousing media portraying riskier choices and competitive or threatening situations, such as in horror movies, violent video games, 'adults only' entertainment, or sports (Krcmar, Farrar, Jalette, & Mcgloin, 2014; Wang et al., 2014). Risk-avoiding individuals – those who have lower ASA and higher DSA – also exhibit unique media choice patterns (Lang, 2006a; Lang & Lee, 2014), choosing to play puzzle or strategy games above violent or action-packed games and electing to watch sitcoms and soap operas over action-packed films. Coactives and inactives tend to score somewhere in between risk-seekers and risk-avoiders on sensation seeking and substance use scales (Lang, Shin, et al., 2005), and tend to exhibit less extreme responses to motivational content in messages (Krcmar et al., 2014; Lang et al., 2011; Sparks & Chung, 2016).

Individual differences in ASA/DSA have also been shown to be relevant for understanding effectiveness of marijuana, tobacco, alcohol, and prescription drug abuse public service announcements (PSAs). A core finding from this research is that individuals process, remember, and are persuaded by these messages differently depending on their baseline ASA and DSA (Hohman et al., 2017; Lang & Yegiyan, 2014; Wang et al., 2014). In the case of anti-drug PSA's, these outcomes have also been shown to be modulated by drug experience (Huskey, Mangus, Turner, & Weber, 2017; Wang, Solloway, et al., 2012; Weber et al., 2013), with those who are highly experienced with drugs exhibiting resistance to persuasion, even when the messages were matched to their ASA or DSA. Individual differences in ASA/DSA are also associated with social network usage patterns (Alhabash, Chiang, & Huang, 2014), news processing (Grabe & Kamhawi, 2006; Wise, Eckler, Kononova, & Littau, 2009), video game choice (Krcmar et al., 2014), attention to taboo products (Lang & Lee, 2014; Lang & Yegiyan, 2011, 2014; Rubenking & Lang, 2015), political extremism (Keene, Berke, Shoenberger, & Bolls, 2017), and resting heart rate variability (Bailey et al., 2015).

Motivation in the message

In addition to understanding individual differences in motivated message processing, a substantial portion of LC4MP research investigates how appetitive and aversive content, in concert with arousal, influence processing. The core prediction of the LC4MP regarding motivational content is that messages which contain appetitive or aversive content elicit more resource allocation to encoding and storage processes, leading to greater recognition and recall for these messages. At low to moderate levels of motivational system activation, negative messages elicit more resource allocation than do positive messages. If the message is too aversive (i.e. activating the aversive system beyond a certain threshold) it will elicit processes associated with the defensive cascade (Bradley, 2007a; Cacioppo et al., 1999). This prediction is supported in a wide variety of contexts, including smoking messages (Clayton, Leshner, Tomko, et al., 2017; Leshner, Vultee, Bolls, & Moore, 2010; Sanders-Jackson et al., 2011), news (Grabe, Lang, & Zhao, 2003; Lang, Potter, & Grabe, 2003), and anti-drug PSAs (Hohman et al., 2017).

Elicited arousal through messages also modulates message processing. A core finding from the LC4MP literature is that moderately arousing messages seem to be the best remembered and most persuasive overall, but that these effects depend on modality (Keene & Lang, 2016), valence (Chung & Sparks, 2016; Lang, Park, et al., 2007), the quality or strength of a persuasive argument

(Huskey et al., 2017; Weber et al., 2013), and the type of memory that is tested (Barreda-Ángeles, Pereda-Baños, Ferràndiz-Bofill, & Costa, 2017; Grabe et al., 2003; Lang, Potter, et al., 2003). According to the LC4MP, this is due to the fact that messages with low or very high arousal elicit relatively low allocation of cognitive resources as compared to messages which are moderately arousing, leading to reductions in memory, persuasion effectiveness, and related measures (Bolls, Lang, & Potter, 2001; Bradley, 2007a; Bradley, Angelini, & Lee, 2007; Lang, Bolls, Potter, & Kawahara, 1999; Lang, Park, et al., 2007; Seelig et al., 2014).

The motivational systems activate in one of three patterns in response to message content: reciprocal, coactive, or uncoupled (Keene & Lang, 2016). Reciprocal activation occurs when one system is deactivating while the other system is activating. This could occur whenever the tone in a stimulus changes from negative to positive. Coactivation occurs when both systems are active at the same time. This state is thought to be important for understanding complex emotional states often elicited by media messages (Keene & Lang, 2016). Finally, uncoupled activation occurs when the two systems are activating or deactivating without any positive or negative correlation with one another. This pattern can be observed when stimuli are monovalent (e.g. only positive or only negative).

Each of these activation patterns lead to neural and physiological changes that affect the encoding, storage, and retrieval process. Interestingly, the original predictions of the LC4MP regarding coactivation have not been supported by extant data. The LC4MP predicts that coactivation in the motivational systems should lead to additive effects on resource allocation, physical responses, and memory. Recent findings, though, have shown that skin conductance (Hohman et al., 2017; Keene & Lang, 2012; Wang, Morey, & Srivastava, 2012), self-reported arousal (Keene & Lang, 2016; Lang, Sanders-Jackson, et al., 2013), and memory (Norris et al., 2012) are lower than would be predicted for messages that elicit coactivation in the motivational systems. In addition, recent work has demonstrated that these coactive arousal responses are affected by the arousing nature of the stimuli, particularly in situations where the valence and the arousal level changes in a single viewing session (Bailey et al., 2018; Liu & Bailey, 2018).

Measuring motivational system activation

Within the LC4MP literature, there are several primary indicators and measures of motivational system activation: post-hoc self-report, continuous response measurement, and psychophysiology. Post-hoc measures of arousal or motivational activation are typically used to index complex states such as fear (Ordoñana et al., 2009; Rhodes, 2017), or inspiration (Myrick & Wojdynski, 2016). They are also used within the literature to index arousal and valence of emotional state (Alhabash, Baek, Cunningham, & Hagerstrom, 2015; Bailey, 2015; Chung, Cheon, & Lee, 2015). Continuous response measurement (CRM; Biocca, David, & West, 1994) has also been widely used in the LC4MP literature. Although most frequently used to pretest stimuli for arousal, valence, or other variables of interest (see e.g. (Keene & Lang, 2016; Rasmussen, Keene, Berke, Densley, & Loof, 2017; Sparks & Lang, 2015), CRM has also been used to index real-time dispositional states (Bailey, 2015; Keene & Lang, 2016; Lee & Lang, 2009; Rubenking & Lang, 2014; Wang et al., 2014; Wang & Bailey, 2018). These indices of emotional states, although not direct measures of motivational system activation, can be used as indicators of activation in these systems. A large suite of psychophysiological indices have also been employed to understand various aspects of motivated processing. The most commonly used measures include heart rate (HR), skin conductance (SCL), and facial electromyography (fEMG; see Potter & Bolls, 2012 for an overview of psychophysiological research methods). In our review of the published literature, 96 LC4MP studies employ psychophysiology.

As discussed earlier, HR is used as an indicator of resources allocated (Keene et al., 2017; Lang, 1994; Thorson & Lang, 1992). Specifically, increases in the interbeat interval are indicative of increases in resource allocation and vice versa for decreases in the interval.

Together, skin conductance (SC) and facial electromyography (fEMG) are utilized as measures of emotional response. SC, which measures activation in the sympathetic branch of the autonomic nervous system, is an indicator of arousal while fEMG has been used as an indicator of valence. Importantly, fEMG sensors can be used to detect facial muscle activation at several sites; however, a large proportion of the published literature in our review utilize two facial muscle groups: corrugator supercilii (Kätsyri, Kinnunen, Kusumoto, Oittinen, & Ravaja, 2016; Lang & Yegiyan, 2011; Leshner et al., 2018; Leshner, Bolls, & Wise, 2011; Potter & Keene, 2012; Rubenking & Lang, 2014) as an indicator of aversive activation or unpleasant emotion, and zygomaticus major as an indicator of appetitive activation or pleasant emotion (Bolls et al., 2001; Bradley et al., 2007; Potter et al., 2006; Wang & Lang, 2012; Z. Wang, Morey, et al., 2012).

There are also two probe-based psychophysiological measures that have been utilized within the LC4MP literature: the startle response and the post-auricular response (PAR). The startle probe is an indicator of time-locked aversive system activation (Bradley, 2007b; Bradley, Cuthbert, & Lang, 1990). In this paradigm, a startling stimulus is introduced during message viewing (such as a flash of light or a burst of acoustic noise) and physiological responses to the stimulus are analyzed. Observed increases in responsivity to the probe indicate increased activation in the aversive system. The startle response has been used to investigate reactions to negative political attack ads (Bradley et al., 2007), individual differences in responses to pictures of 'taboo' products (Lang & Yegiyan, 2011) and processing of emotional information campaigns (Lee & Lang, 2009). The post-auricular response (PAR), measured using sensors placed on the vestigial muscles behind the earlobes, is an indicator of time-locked appetitive system activation (Sparks & Lang, 2010), and has been used to investigate how sexy and humorous content is processed in media messages (Sparks & Lang, 2015).

A summary of supported predictions

Key predictions from current LC4MP research are as follows: (1) Those who are risk-takers, as characterized by high ASA and low DSA indexed by the MAM, will seek out more arousing media, be more attracted to risky portrayals, and be more resistant to persuasion. (2) Messages which contain arousing or positively/negatively valenced information will elicit more resource allocation with the caveat that (3) highly valenced or overly arousing messages will be associated with reduced resource allocation and (4) this will be stronger for negatively valenced information than for positively valenced information.

Memory

At its core, the LC4MP is aimed at understanding how cognitive load and motivation interact with the structural and content features of messages to facilitate or inhibit three primary cognitive processes: encoding, storage, and retrieval (Lang, 2000, 2009, 2017). The encoding process involves selecting information from the environment and creating a mental representation of that information. Storage is the process of relating encoded stimuli to other information held in either short term or long term memory in order to create a robust representation of the encoded information. Retrieval involves the reactivating of stored information related to the current processing task (Lang, 2000, 2009, 2017). In the LC4MP the encoding, storage, and retrieval processes are assumed to be idiosyncratic and as such successful completion of these three processes for a given piece of information does not necessarily result in a 1-to-1 mapping from the message to encoded, stored, and retrieved representations (Bradley, 2007a; Lang, 2006b).

In LC4MP research, successful completion of the encoding, storage, and retrieval process has been measured using a variety of methods. Of the 100 LC4MP studies in our review that tested memory in some way, 59 tested encoding, 40 tested storage, and 31 tested retrieval.

Although in large part the predictions of the LC4MP have been supported in this literature, several interesting incongruities warrant a discussion of how each of these processes has been measured. We also review of key findings from the literature and highlight future directions for memory research in the LC4MP.

Encoding

Encoding is defined as a perception and information selection process wherein stimuli from the environment are developed into a coherent mental representation. In the LC4MP, the encoding process is thought to be related to resource allocation. Allocation to encoding processes is typically measured using tonic or phasic heart rate deceleration (Lang, 1994; Liu & Bailey, 2018; Potter et al., 2016). These measures, though, do not necessarily indicate that a representation of the stimulus was actually created in the mind of the participant. Completion of the encoding processes is typically indexed using forced-choice audiovisual recognition tasks or multiple choice questions related to message content (e.g. Keene & Lang, 2016; Langleben et al., 2009; Rodero et al., 2017; Yegiyan, 2015b). LC4MP research has shown that messages which elicit greater resource allocation are typically better encoded than those that elicit less resource allocation (e.g. Lang et al., 2002; Potter et al., 2008).

Many of the recognition tasks in the LC4MP literature are coded and analyzed as a simple proportion of items correct or incorrect, but of the 59 studies in our review that tested memory encoding, 28 used some sort of signal detection analysis (Macmillan & Creelman, 1991; Shapiro, 1994; Stanislaw & Todorov, 1999). In these approaches, recognition performance is operationalized as both sensitivity and criterion bias. Sensitivity is calculated as the proportion of 'hits' (correct recognition of previously seen stimuli) minus the proportion of 'false alarms' (incorrect assertion that a stimulus was previously seen). Criterion bias is calculated by multiplying the sums of standardized hit rates and false alarm rates by −0.5 resulting in a positive score for 'conservative' bias and a negative score for 'liberal' bias. Conservatively biased individuals exhibit less guessing whereas liberally biased individuals guess more often. A core finding in these studies is that a liberal criterion bias seems to serve as an early indicator that resources have been allocated away from the encoding process due to cognitive overload (Fox et al., 2007) or 'flight' responses in the defensive cascade (Clayton et al., 2018; Leshner et al., 2018; Miller & Leshner, 2007; Rhodes, 2017) and that a conservative criterion bias seems to indicate resource allocation toward counterarguing ('fight' responses in the defensive cascade; Bradley et al., 2007; Clayton et al., 2018; Clayton, Leshner, Tomko, et al., 2017; Liu & Bailey, 2018). A liberal criterion bias is also associated with multitasking (Uncapher, Thieu, & Wagner, 2016), stimuli that are less personally relevant (Srivastava, 2013), and increased arousal (Yegiyan, 2012).

Although most studies in the literature have tested audio and visual encoding in isolation, some interesting modality-specific effects within the LC4MP have arisen in recent years. As an example, a study by Keene and Lang (2016) found that motivationally relevant content in audio and visual channels led to differing patterns of recognition, with visual recognition higher for aversive stimuli and audio recognition higher for appetitive stimuli. Additionally, the role of information centrality is increasingly being investigated, most notably in a series of studies by Yegiyan and colleagues (Yegiyan & Lang, 2010; Yegiyan & Yonelinas, 2011, 2015b; Yegiyan & Yonelinas, 2011). These studies have shown that arousing negative stimuli can increase encoding of central information and that arousing positive stimuli can increase encoding of peripheral information (Yegiyan & Yonelinas, 2011). These effects have also been shown to be modulated by sex (Yegiyan, 2015b).

Storage and retrieval

Successful storage of encoded information is often tested using cued recall tasks (e.g. Barreda-Ángeles et al., 2017; Bigsby, Monahan, & Ewoldsen, 2017; Fisher & Keene, 2017; Fox et al., 2004; Rodero et al., 2017). Typically, these recall measures are time-locked to points of interest within a message based on pre-testing messages for emotional valence, arousal, complexity, or other variables. Performance, then, can be considered as a time-series, and questions regarding the effects of motivation, emotion, or cognitive load on memory can be tested. These cued recall tasks can take the form of multiple choice (Grabe, Yegiyan, & Kamhawi, 2008; Myrick & Wojdynski, 2016;

Wise, Bolls, Myers, & Sternadori, 2009; Wise, Eckler, et al., 2009), or fill-in-the-blank questions (Barreda-Ángeles et al., 2017; Bas & Grabe, 2015; Chung & Sparks, 2016; Grabe & Kamhawi, 2006).

LC4MP research has revealed two key findings regarding message storage. The first of these is that activation of the appetitive system leads to increased resource allocation to encoding and storage whereas activation of the aversive system results in increased allocation to encoding but *decreased* allocation to storage, especially for peripheral detail (Yegiyan, 2015a). This is echoed in studies by Grabe and colleagues that show that arousing news stories are recalled less accurately than non-arousing news stories when cued (Grabe et al., 2003; Grabe & Kamhawi, 2006). The second finding is that when messages are difficult to process, providing a graphic, especially an animated graphic, can improve storage of the message (Fox et al., 2004). This echoes research under the Cognitive Theory of Multimedia Learning that suggests that the introduction of helpful graphical overlays for complex auditory information can decrease load and lead to more efficient storage of information (Mayer, 2014).

Retrieval is conceptualized as the process by which information that has previously been stored in the brain is activated for reuse. In the model, retrieval is related to conscious recollection, but the model also allows for more implicit associational processes which may not be consciously accessible (Lang, 2000, 2009). Free recall is by far the least investigated memory process in the model. Free recall paradigms were only used in 25 of our 247 studies.

These studies for the most part reinforced findings related to encoding and storage—namely that information presented after OESFs is better retrieved (Rodero, 2015; Rodero et al., 2017) and that emotional or arousing messages are better retrieved than neutral, calm messages (Bas & Grabe, 2015; Lang, Chung, et al., 2005; Potter et al., 2006). Although still an emerging research area, some LC4MP research has investigated differences between explicit and implicit memory for message content (Peters & Leshner, 2013; Vyvey, Castellar, & Van Looy, 2018).

A summary of supported predictions

The LC4MP has produced several predictions regarding memory for mediated messages that are supported by extant data: (1) cognitive overload will be associated with reduced recognition sensitivity and a liberal criterion bias; (2) moderately arousing content will be more encoded than calm or highly arousing content; (3) negative arousing content will elicit defensive processing, leading to reduced encoding; (4) higher arousal will be associated with greater storage of peripheral information for positive messages but reduced storage of peripheral information for negative messages; (5) information following OESFs will be encoded, stored, and retrieved at higher rates than information further from these structural features.

Discussion

In this manuscript we highlighted the basic assumptions of the LC4MP and conducted a systematic review of 247 studies from the LC4MP literature. The review was conducted with three primary foci: cognitive load, motivated processing, and memory. For each of these domains we discussed: (1) the current state of LC4MP research within the domain; (2) methodological tools that have been employed to operationalize and measure domain-specific concepts; (3) current predictions of the model; and (4) areas of current ambiguity or inconsistency between model predictions and experimental findings. Overall, evidence from these reviewed studies suggests that the LC4MP, while still providing a selection of robust assumptions and predictions, is in need of revision in light of extant data.

Cognitive load

Cognitive load research within the model has largely been conducted to illuminate one or multiple slices of the ‘resource pie.’ Resources required to process a message are related to the information density of messages and can be measured using *ii/cc*. Resources allocated to the message are primarily discussed in relation to OESFs and are indexed using a combination of STRTs, physiological measures, and tests of encoding. On the whole, predictions of the LC4MP regarding the effects of resource requirements on processing have been borne out in the data.

Ambiguity still exists, though, in several key areas. First, ambiguity must be resolved as to the response patterns that would be expected in relation to resource allocation driven by top-down processes or habituative mechanisms wherein allocation to OESFs may change over time. This is especially salient when considering individual differences in resource availability and allocation efficiency as observed in older adults (Lang, Schwartz, et al., 2015) and those with attentional processing differences (Fisher & Keene, 2017). In addition, a growing set of evidence suggests that cognitive resources are meaningfully dissociable into at least two primary pools, one expended by perceptual processing and one by higher order processes such as cognitive control and working memory (Lavie, Hirst, de Fockert, & Viding, 2004). Finally, conceptual clarification is needed as to the nature and correlates of cognitive overload especially to disambiguate or associate it with defensive processing and other related constructs.

Motivated processing

Motivation, although a late addition to the LC4MP, has become a core focus of the model. Of the studies considered in this review, 176 tested motivated processing in some way. These studies have concentrated on three main areas of research: individual differences in motivational system activation, characterizing motivationally relevant information in multimedia messages, and measuring activation in the motivational systems. Several core findings from this research were highlighted in this review. The first of these is that individual differences in activation of the appetitive and aversive system is associated with media preference and processing outcomes. The second key finding is that arousal and valence of messages have independent but interactive effects on cognitive processing that can be indexed using psychophysiological measures, as well as through testing encoding and storage of message content. Several key inconsistencies between model predictions and experimental data warrant mention in this area: (1) the role of coactivation in message processing is as yet not well characterized in the model; (2) although initial research is promising, predictions regarding how arousal and valence affect processing of and memory for specific (e.g. visual, auditory, central, peripheral) information are still unclear; (3) while top-down processes are widely discussed within the LC4MP literature, there currently does not exist a measure that characterizes when and how messages elicit conscious resource allocation.

Memory

The encoding, storage, and retrieval of message information is related to the resource requirements of the message as well as its motivational relevance. Within the LC4MP, encoding has primarily been measured using recognition tasks, storage with cued recall tasks, and retrieval with free recall tasks. Several LC4MP predictions regarding memory have been tested in the literature, most finding clear support. Cognitive overload is associated with drastic reductions in recognition and recall and is preceded by rapidly shortening STRTs and a liberal criterion bias. On the whole, messages which are more motivationally relevant are associated with greater recognition and recall. Arousing negative messages are associated, though, with drastically reduced recall. Within the memory domain as well though, several things are as yet unclear.

First, modality-specific and content-specific memory effects of cognitive load and motivation are not currently explained within the LC4MP. Second, more clarification is needed as to the message features and individual differences that facilitate or inhibit encoding, storage and retrieval processes, as well as how these processes are associated with outcomes of interest, such as persuasion or learning.

Conclusion

The LC4MP is a notable example of a knowledge brokering process wherein theoretical and methodological advancements from biology, psychology, and the cognitive neurosciences have been employed within communication research to understand human information processing. Research leveraging the LC4MP has largely been successful in beginning to pry open the 'black box' to understand how individuals process dynamic, multimodal, often interactive messages. Two decades of research has produced findings that generally support the robustness and reproducibility of model predictions, but several points exist wherein model predictions do not align with experimental findings. In a companion piece (Authors, 2018), we evaluate these findings in light of recent advancements in communication scholarship and cognate fields and propose an updated model which accounts for these findings, providing empirically testable predictions as well as future avenues for testing them. In doing so we argue for the model's utility for understanding both the mind and the message.

Notes

1. As later published in (Popper, 1985).
2. Citation metrics retrieved from Thomson ReutersTM Web of ScienceTM on September 12th, 2018.
3. A complete list of the articles and chapters considered in this manuscript is available at https://osf.io/5zs4j/.
4. As a point of clarification, it is worth noting that Lang and colleagues (2006) describe resources available as resources required minus resources allocated. This seems to be in error, as (Lang & Basil, 1998) characterize available resources as resources allocated minus resources required, as we have asserted here.

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