Journal of Applied Research in Memory and Cognition 9 (2020) 447–454

Contents lists available at ScienceDirect

Journal of Applied Research in Memory and Cognition

journal homepage: www.elsevier.com/locate/jarmac

Forum

When are Difficulties Desirable for Children? First Steps Toward a Developmental and Individual Differences Account of the Spacing Effect

Melina L. Knabe*, Haley A. Vlach

University of Wisconsin-Madison, United States

The spacing effect is one of the most robust and replicable phenomena in psychological science, and holds promise for improving children's learning outcomes in educational settings. However, there is a striking limitation in the literature: very few studies have been conducted with young children (0–5-year-olds). Moreover, most studies examine children's learning on the group level, whereas early curricula typically focus on both group and individual outcomes. We predict that developmental and individual differences in visual attention, memory, prior knowledge, and metamemory will affect children's learning on massed and spaced schedules. Thus, we argue that the next critical step in research on the spacing effect is to develop a developmental and individual differences account. Indeed, this account will address limitations in theory and barriers in implementing the spacing effect in early educational settings.

Keywords: Spaced learning, Desirable difficulties, Individual differences, Early childhood, Cognitive development

Understanding the learning conditions that promote long-term memory has been a central pursuit in psychological science (beginning with Ebbinghaus, 1885). Historically, researchers have argued that reducing task difficulty leads to stronger retention of information (e.g., Baddeley & Wilson, 1994; Skinner, 1958). However, researchers have recently countered this view, arguing that imposing certain challenges during learning improves memory (Bjork, 1994; Bjork & Bjork, 2009; Roediger & Karpicke, 2006; Smith, Glenberg, & Bjork, 1978). These challenges are referred to as *desirable difficulties*.

In the present review, we focus on the most well studied desirable difficulty: the *spacing effect* (alternatively, *spaced* or *distributed learning*). The spacing effect is the finding that distributing learning events across time, rather than massing learning events in immediate succession, promotes long-term retention (Ebbinghaus, 1885; for reviews, see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Delaney, Verkoeijen, & Spirgel, 2010). More than 1000 experiments have been published on the spacing effect, making it one of the most researched and replicated phenomena in psychology. The spacing effect has been observed across timescales (e.g., <30 s, Vlach, Sandhofer, & Kornell, 2008, to 100+ days, Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008), tasks (e.g., free recall, cued recall, recognition, motor tasks; Carpenter & DeLosh, 2005; Ren, Guo, Yan, Liu, & Jia, 2016), developmental periods (e.g., infancy, older adulthood; Kornell, Castel, Eich, & Bjork, 2010; Rovee-Collier, Evancio, & Earley, 1995), and species (e.g., drosophila, aplysia, bees, rodents; Anderson, Jablonski, & Klimas, 2008; Carew, Pinsker, & Kandel, 1972; Menzel, Manz, Menzel, & Greggers, 2001; Tully, Preat, Boynton, & Del Vecchio, 1994). Thus, the spacing effect is considered age and species invariant.

Several theories have been generated to explain the spacing effect. These include consolidation (Landauer, 1969;

Author Note

Haley A. Vlach

Funding for this work was provided in part by NSF 1561531 awarded to HV.

* Correspondence concerning this article should be addressed to Melina L. Knabe, Department of Educational Psychology, University of Wisconsin-Madison, 1025 W. Johnson St., Madison, WI 53706, United States. Contact: mknabe@wisc.edu.

Wickelgren, 1972), deficient processing (Hintzman, 1974), encoding variability (Glenberg, 1976; Glenberg, 1979), and study-phase retrieval theories (Johnston & Uhl, 1976; Thios & D'Agostino, 1976; also referred to as the time-window hypothesis in developmental psychology, Rovee-Collier et al., 1995). The most prominent and well-supported theories are theories that include a study-phase retrieval mechanism (see Delaney et al., 2010, and Greene, 1989, for arguments of supplementing study-phase retrieval theory with elements of encoding variability theory).

Given the extensive literature on the spacing effect, it is considered one of the most promising bodies of work from psychological science for improving learning outcomes in educational settings (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). Spaced learning has been implemented effectively in classrooms, promoting retention and generalization of a wide range of educational domains, such as vocabulary (Sobel, Cepeda, & Kapler, 2011), biology concepts (Gluckman, Vlach, & Sandhofer, 2014; Vlach & Sandhofer, 2012), mathematics (Nazari & Ebersbach, 2019), and history (Carpenter, Pashler, & Cepeda, 2009).

However, there is a striking limitation of this body of work: very few studies have been conducted with children (for a brief review of this issue, see Cepeda et al., 2006). That is, the spacing effect has not historically been studied in in the PreK – 12th grade population, the largest population currently being educated. Specifically, there is a paucity of studies with infants and preschool aged children (0–5-year-olds)—and those studies have produced mixed results. Spaced learning has been shown to promote children's memory for words and pictures (Childers & Tomasello, 2002), sentences (Ambridge, Theakston, Lieven, & Tomasello, 2006), science concepts (Gluckman et al., 2014), and motor skills (Rovee-Collier et al., 1995). However, other studies have shown that spaced learning is ineffective, or even disadvantageous, for young children's learning (Folarin, 1983; Goossens et al., 2016; Toppino & DiGeorge, 1984; Toppino, Fearnow-Kenney, Kiepert, & Teremula, 2009a). For instance, in a study of children's memory for category exemplars, increasing the spacing interval between exemplars deterred children's category learning (Folarin, 1983).

The lack of research on the spacing effect during early development presents several problems for theory and application. In terms of theory, it is hard to explain why we observe more mixed results with children (compared to young adults/college student samples). We also do not have enough studies to conduct meta-analyses or reviews that can answer important questions, such as: is the spacing effect truly age invariant? If the efficacy of the spacing effect varies across developmental periods, what mechanisms lead to this variation? Do the most widely supported theories of the spacing effect apply to early childhood?

In terms of application, birth to 5 years is one of the most critical periods in the human lifespan (Mustard, 2007; Kolb & Gibb, 2011). During this time, the foundations for later learning are established, which have long-lasting impacts on the learner's academic and life outcomes (Burger, 2010; Nelson, 2000). Indeed, early educational interventions are especially effective because the learner is structurally and functionally plastic and have been argued to have the most positive personal and societal impact (Cannon et al., 2018; Doyle, Harmon, Heckman, & Tremblay, 2009).

More critically, the goal of early education and intervention is not just to raise the group mean at a post-test, as what is typically the outcome measure of studies on the spacing effect. The most important goal is ensuring all children improve their learning. The need for personalized – or individualized – learning is central to early education programs (see Dockterman, 2018 for a review). To effectively customize and maximize children's learning requires an understanding of how children's developmental and individual differences interact with their learning on massed and spaced schedules. Unfortunately, the existing spacing effect literature cannot make clear, individualized, recommendations for early childhood.

In this paper, we argue that the next critical step in research is to pursue studies on developmental and individual differences in the efficacy of the spacing effect. That is, a developmental and individual differences account is needed to address limitations in theory and application of the spacing effect to early educational settings. This type of theoretical account identifies differences across age groups, and individual differences within participants of the same age. Indeed, developmental and individual differences go hand-in-hand; changes within the individual are often the mechanism(s) that explain developmental (age-related) changes. In the section below, we outline what the first steps for the field should be by reviewing the cognitive domains that will be critical for this account.

Building a Developmental and Individual Differences Account for Early Development

Historically, research on the boundary conditions of the spacing effect has focused on properties of the learning environment. Researchers have manipulated the stimuli, number of item repetitions, trial lengths, and retention intervals to reveal when spaced learning does/does not promote memory (Cepeda et al., 2006). Because of this focus, research on spaced learning has not studied internal learner characteristics that may mediate and/or moderate the effect. Thus, an account that considers developmental and individual differences will be an important next step for research with adults as well. However, we believe that an account derived from adults would not generalize well to infants and children. Unlike adults, young learners experience rapid changes in their basic cognitive capacities, such as visual attention, memory, prior knowledge, and metamemory. In the subsequent sections, we review these key cognitive capacities, and how developmental and individual differences in these capacities may affect children's learning on massed and spaced schedules.

Visual Attention

Spaced learning paradigms typically require participants to attend visually to stimuli. Presenting stimuli consecutively or spaced out in time may affect the way in which children attend to visual stimuli. In fact, a sub-class of deficient processing theories of the spacing effect (Greeno, 1967; Hintzman, 1976), inattention theory (Hintzman, 1974), proposes that massed items become increasingly familiar across learning, resulting in poorer attention to each subsequent item presentation. That is, according to inattention theory, learners pay less attention to massed items, and thus have higher performance on spaced schedules.

One key developmental change in attention during the first few years of life is the duration at which children can sustain visual attention (Betts, Mckay, Maruff, & Anderson, 2006; Lin, Hsiao, & Chen, 1999). That is, infants and young children experience rapid changes in the duration at which they can focus visual attention on a single item. This developmental difference could affect the efficacy of massed and spaced learning in several ways. On the one hand, if learning events are presented on a massed schedule, children may have more time to fixate their visual attention to the item, and thus have stronger learning than on a spaced schedule. On the other hand, children may more quickly dishabituate or look away from an item, reducing encoding and leading to weaker learning on massed schedules. Moreover, presenting learning events on a spaced schedule with lengthy intervals between repetitions may also lead to complete disengagement of all visual attention, and thus deter any learning on a spaced schedule. In brief, there are several ways in which young learners' developing ability to fixate visual attention to stimuli may differentially affect the efficacy of massed and spaced schedules.

One study (Vlach & Johnson, 2013) provides preliminary evidence that developmental differences in attention contribute to duration of looking to stimuli on massed and spaced schedules. In this experiment, 16- and 20-month-old infants participated in a word learning task where novel word-object pairs were presented on either a massed or interleaved schedule. Results from eye-tracking data revealed that 16-month-old infants' attention to massed items decreased across the learning phase, suggesting that repeated item exposure modulated attention, as predicted by deficient processing accounts of the spacing effect (Hintzman, 1976). However, the 20-month-olds did not demonstrate differences in visual attention to objects on massed or spaced schedules. Thus, future research should examine how age-related differences in sustained attention affect learning on massed and spaced schedules. Indeed, this work may in fact provide new evidence for historically discarded theories of the spacing effect, such as inattention theory (Hintzman, 1974).

Another notable difference between young children and adults is their selectivity of visual attention. Young children demonstrate poorer attentional control (Huang-Pollock, Carr, & Nigg, 2002) and differ in their selective attention to features of learning events (Plude, Enns, & Brodeur, 1994). For instance, children acquire attentional biases, or the preference to attend to certain features over others. One example of an attentional bias is children's and adults' tendency to attend to shape during object categorization, a behavior known as the *shape bias* (Landau, Smith, & Jones, 1992). The shape bias emerges around 18-24 months of age and is thought to develop from prior experience with English, which typically categorizes objects according to shape.

How might early attentional biases, such as the shape bias, affect learning from massed and spaced schedules? To date, only one study has examined whether attentional biases affect learning from massed and spaced schedules (Slone & Sandhofer, 2017). In this study, a sample of 2–3.5-year-old children were presented with a category learning task with three categories: shape, color, and texture categories. Results revealed that spacing was most beneficial for children's learning of shape categories. That is, learners' attentional biases may impact the type of information for which spaced schedules are more or less effective.

Memory

Most theories implicate memory processes as the mechanism(s) underlying the spacing effect, and thus differences in memory abilities are an important step in building a developmental and individual differences account. For instance, according to study-phase retrieval theories (Johnston & Uhl, 1976; Thios & D'Agostino, 1976), when items are distributed across time, learners rapidly forget information between learning events. A consequence of this forgetting is that subsequent retrieval of the learned information is more effortful. By engaging in effortful retrieval, future forgetting is slowed, supporting future recollection of the learned information. Thus, between-participant differences in forgetting and retrieval processes could contribute to the efficacy of the spacing effect.

Young children differ notably from adults in their maintenance and recall of previously learned information (Bauer, Wenner, Dropnik, & Wewerka, 2000; Cowan & Alloway, 2009). Specifically, children experience more rapid forgetting than adults, and this difference may affect the efficacy of massed and spaced schedules (Brainerd, Reyna, Howe, Kingma, & Guttentag, 1990; Howe, 1991; Vlach & Sandhofer, 2012). For instance, if forgetting happens so quickly that children are unable to successfully retrieve prior learning events, they may not associate new learning events with previous learning events (see time-window hypothesis; Rovee-Collier et al., 1995). Indeed, early in development, when infants forget information rapidly during even short intervals of time, massed schedules may be more advantageous than spaced schedules. Preliminary evidence for this comes from Vlach and Johnson (2013), which found that 16-month-old children were able to learn words presented on a massed schedule, but not an interleaved schedule. In contrast, 20-month-olds were able to learn words on both massed and interleaved schedules, suggesting that four months of memory development slowed forgetting enough to support learning on the same interleaved schedule. Thus, children with weaker memory abilities may benefit more from massed schedules, whereas children with stronger memory abilities benefit more from spaced schedules. As the rate of children's forgetting slows across development, the optimal amount of time between learning events on spaced schedules will also change. That is, the time interval between learning events may be increased as children's forgetting slows.

In addition to rapid forgetting, children also experience substantial changes in their ability to retrieve information.

Specifically, an extensive literature demonstrates that children have poorer recall abilities and use less effective recall strategies than adults (Ghetti & Angelini, 2008). Indeed, children have trouble generating information that will cue memory retrieval (Cole, Frankel, & Sharp, 1971; Tversky & Teiffer, 1976). These findings have important implications for studies on spaced learning, which utilize various memory tasks at test (e.g., free recall, cued recall, and recognition tasks). For instance, children may show a pronounced spacing effect on a recognition memory task, but not on a free recall task. Moreover, children with better memory retrieval abilities might show spacing effects on both recognition and free recall tasks, whereas children with poorer retrieval abilities might only show a spacing effect on a recognition task. Thus, mixed findings on the spacing effect in children may be explained by the type of post-test used, suggesting researchers should carefully design their memory tasks to account for free recall difficulties in early childhood.

Prior Knowledge

In addition to retrieval abilities, participants' storage strength – or how information is represented and associated with existing knowledge – affects memory performance (see Bjork & Bjork, 1992 for a distinction between storage and retrieval strength). That is, the prior knowledge that learners bring to the task inevitably affects their learning of new information (e.g., Bransford & Johnson, 1972; Brod, Werkle-Bergner, & Shing, 2013; Schneider, Gruber, Gold, & Opwis, 1993). For instance, studies on the spacing effect frequently use verbal stimuli (e.g., novel or familiar words), and thus differences in language abilities may affect performance on massed and spaced schedules. Indeed, children are in the process of learning language during the first few years of life (Bates, Thal, & Janowsky, 1992) and retrieval of verbal material improves across the early childhood period (see Bjorklund, Dukes, & Brown, 2009 for a review). Thus, in a spaced learning task, children may be better at retrieving words from memory that are highly familiar to them or are frequently used in their environment (e.g., baby, mama). However, if the words are unfamiliar to them or are not as frequently used in their environment (e.g., whisk, periwinkle), children may fail to retrieve words during learning, and thus benefit from a massed schedule over a spaced schedule. Moreover, one might predict that children with low language abilities (e.g., smaller vocabulary size, poorer lexical retrieval abilities) would not benefit from spaced learning in a verbal task to the same extent as a child with higher language abilities.

To date, no studies have examined links between children's language ability and performance on spaced learning tasks. Thus, it is imperative that future investigations assess how task-specific language knowledge, and prior task knowledge more broadly, impact young children's performance.

Metamemory

The understanding of one's own and other people's memory processes is broadly known as metamemory (Dunlosky & Metcalfe, 2009; Flavell, 1971). Researchers have studied the development of metamemory across the lifespan, demonstrating that children's understanding of how memory functions gradually improves in early childhood (see Karably & Zabrucky, 2009 for a review). Specifically, by age 5, children have an understanding of the variables that affect memory (e.g., characteristics of the learner and task) and can actively monitor their own learning (Johnson & Wellman, 1980; Lyon & Flavell, 1994; Schneider, 1998).

Metacognitive judgments of learning (JOLs) are one of several measures used to assess participants' active monitoring of their memory performance. Researchers have used JOLs to assess whether individuals have a preference for massed or spaced schedules during learning. When adults are asked to assess how well they learned an item and how well they would do on a future assessment of that item, they often demonstrate a massed bias: they typically prefer massed learning over spaced learning (e.g., Baddeley & Longman, 1978; Kornell & Bjork, 2008; McCabe, 2011; Simon & Bjork, 2001; Zechmeister & Shaughnessy, 1980). One explanation for the observed bias is that adults experience greater processing fluency on massed schedules as opposed to spaced schedules (Logan, Castel, Haber, & Viehman, 2012). However, when adults are asked to choose the nature of their learning experience (i.e., whether to view an item immediately or at a later time), they typically demonstrate a spaced bias (e.g., Benjamin & Bird, 2006; Toppino, Cohen, Davis, & Moors, 2009b; Toppino & Cohen, 2010). Importantly, task demands (e.g., item presentation duration) impact the preference for massed versus spaced schedules (Toppino et al., 2009b). These results suggest that adult participants alter their study strategies based on the to-be-learned material and their beliefs about how memory functions more broadly.

Interestingly, preschool-aged children do not demonstrate a massed bias (Vlach, Bredemann, & Kraft, 2019). One explanation for these results is that preschoolers have limited theories of how memory functions. As their metamemory abilities develop across early childhood, children may begin to form misconceptions about their own memory. Thus, young children may be less likely to adopt the same incorrect memory strategies as adults. Moreover, these findings suggest that early childhood may be an ideal age to begin teaching strategies for memory optimization. Informing children on the efficacy of spaced learning early may prevent them from forming a massed bias. Indeed, these results suggest that the developmental differences in metamemory may provide an advantage to the understanding and implementation of spaced learning in young learners.

Directions for Future Research on Desirable Difficulties in Early Childhood

A critical next step for researchers is to generate a developmental and individual differences account, because this research direction can inform theory and application of the spacing effect. However, there are additional next steps worth briefly mentioning. For instance, young children typically do not encounter formal, group-based schooling until kindergarten. This means that children may be primarily working one-on-one with caretakers, practitioners, or other adults. To develop more effective learning and intervention materials for this population, spaced learning tasks should be studied at the individual- and group-level, and may benefit from microlevel assessment approaches (e.g., generating a high density of observations of one child's learning).

Moreover, successful implementation will require scientists to move beyond basic research and think about effective science communication strategies for children in this age range. An important constraint in applying spaced learning to early childhood is that the individuals spending the most time with children, such as caretakers and/or parents, may not be those with formal training in science or education. How do we communicate science on the spacing effect with these individuals? After all, the willingness to implement spaced learning depends on its perceived efficacy, and many adults do not recognize the value of introducing deliberate difficulties in their own learning (e.g., Kornell et al., 2010; Miele et al., 2011Miele, Finn, & Molden, 2011; Sungkhasettee, Friedman, & Castel, 2011). This sentiment is amplified for children's learning: Adults tend to underestimate the capabilities of young children (Leippe, Manion, & Romanczyk, 1992; Miller, White, & Delgado, 1980). Initial steps could include introducing the concept/application of spaced learning in parenting forums, and explaining how learning schedules interact with changing cognitive processes.

On a final note, we would like to point out that we focused on the spacing effect because it has been studied much more than other desirable difficulties. Thus, there is a lack of developmental and individual differences research for other desirable difficulties as well, but largely just because there is not a substantive body of research studying 0–5-year-olds. Indeed, much more research is needed to implement desirable difficulties research in early childhood learning. While doing any desirable difficulties study, we encourage researchers to include measures of children's cognitive abilities. This approach will build an empirical body of research on the efficacy of desirable difficulties and provide a developmental and individual differences account that will guide effective implementation.

Author Statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content. Specifically, all authors jointly drafted, revised, and approved the manuscript. No additional persons made substantial contributions to the manuscript. Furthermore, each author certifies that this material has not been, and will not be, submitted to or published in any other publication before its appearance in the *Journal of Applied Research in Memory and Cognition.*

Conflict of Interest

The authors declare that they have no conflict of interest.

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Received 22 May 2020;
received in revised form 24 July 2020;
accepted 25 July 2020
Available online xxx