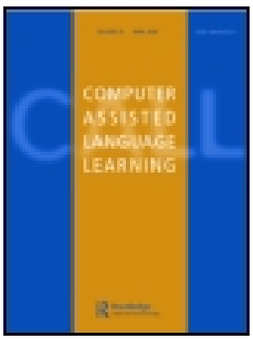

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L2 vocabulary learning from educational media: extending dual-coding theory to dual-language learners

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ABSTRACT

The purpose of this study was to examine whether technology-based learning environments have the potential to support dual-language learners' (DLLs) vocabulary learning in their less dominant language. Interrogating Dual-Coding Theory (Paivio, 1986), this study investigates whether DLLs benefit from media content that is delivered both orally and visually, and uses English language proficiency as an important contextual factor that might impact vocabulary learning on screens. Adopting a within-subjects design on 43 preschool-aged DLLs, and using eye-tracking technology to monitor children's attention, this study finds that DLLs are able to identify more words that are taught on screen when information is dual-coded, particularly if they have lower English language proficiency. Implications for the field of computer-assisted language learning are discussed.

KEYWORDS

Educational media; preschool; vocabulary; dual-language learners; dual-coding theory; eye-tracking

Children today are exposed to screens at a very young age, watching educational media programs that promise to foster early literacy skills well before they set foot in school (Lemish, 2015; Neuman, Wong, Flynn, & Kaefer, 2019). These educational programs that are marketed to provide a head start may be particularly helpful for young dual-language learners (DLLs) who come from households that speak a language other than the dominant language of school and society at home. Facilitating the bilingual development of young DLLs, media has the potential to provide children with ample exposure to new vocabulary words, using bells and whistles that draw their attention to key learning experiences (Kirkorian & Anderson, 2008; Verhallen, Bus, & de Jong, 2006). Scholars continue to explore the mechanisms that facilitate learning from screens, now extending the literature to examine how media can help children learn a new or additional language.

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A prominent theory underpinning learning from screen media in the field of computer-assisted language learning (CALL) is dual-coding theory (Paivio, 1986), which proposes that when information is transmitted through verbal (speech) and nonverbal (visual) channels, it is represented more fully, leading to stronger comprehension and greater recall (Mayer, 1997). While this theory is adopted in numerous studies with monolingual preschool populations, dual-coding theory has not been explicitly investigated among DLLs in media contexts, particularly for children in the preschool years.

Consequently, the purpose of the current study is to investigate the potential of educational media to provide preschool-aged DLLs with rich scaffolds that facilitate word learning in a second language. Specifically, this study aims to examine the importance of dual-coding theory for DLL viewers learning words in a second language. It also investigates how two key language factors for DLLs, child vocabulary in a second language (L2) and parental L2 language ability, differentially impact dual-coding mechanisms when viewing educational media.

Educational media and dual-language learners

Young children are in front of screens viewing educational media for long periods of time, leading many around the world to study educational media as a means of improving early literacy (Lemish, 2015). In the United States, DLLs are spending an average of two hours or more on screen per day (Rideout, 2014), watching programs that are marketed for bilingual learning (Wong & Neuman, 2019). Scholars document the benefits of educational media for preschoolers, demonstrating gains in early literacy, vocabulary, and problem solving (Anderson & Kirkorian, 2015). Still, others warn that toddlers who are three-years-old and under might not have the capacity to learn from screened platforms because of a *video deficit* (Anderson & Pempek, 2005), described as the discrepancy between learning from a live person and learning from a screened platform. In response, the American Academy of Pediatrics (AAP) has issued policy statements that recommend limiting television exposure to young children. Despite this recommendation, national surveys of media consumption in the United States report that 73% of 2–4 year-olds watch television every day for an average of 1.9 hours per day (Common Sense Media, 2013). As media plays an increasingly central role in the lives of young people, scholars continue to examine how media can be strategically used to support learning, particularly among vulnerable populations like DLLs.

DLLs are defined in the current study as children from the ages of birth to 5 years old who are learning two or more languages at the same time, which include a second language while still developing their first or home language (Takanishi & Le Menestrel, 2017). In the United States, DLLs are currently the fastest growing population in schools, with the largest representation of DLLs speaking Spanish as a first language and English as a second language (Capps, 2015; Connor, Cohn, Gonzalez-Barrerra, & Oates, 2013). DLLs grow up in households with varying amounts of exposure to a first and second language. In the early childhood years before formal schooling occurs, DLLs are primarily immersed in the language(s) spoken by parents, which, in the U.S. context, is often a language other than English (Hammer et al., 2014). With less English exposure than their monolingual counterparts who grow up speaking English or the dominant language of schools, preschool-aged DLLs are often more proficient in their home language (L1) than they are in English (L2). As a result, DLLs often perform below their monolingual peers in English vocabulary development (Hammer et al., 2014) because schools demand that content is learned in English. Although these differences are established in the first years of schooling, longitudinal studies suggest that English vocabulary is critical in the early years, which suggests DLLs may encounter challenges in their educational trajectory (Halle, Hair, Wandner, McNamara, & Chien, 2012; Han, 2012).

Therefore, to better understand how young children can best learn new words, a meta-analysis found that using educational media as an instructional tool was associated with significant gains in vocabulary knowledge (Marulis & Neuman, 2013). Although this meta-analysis did not specifically address word learning in a second language, these positive developments in vocabulary learning are also reported in DLL classrooms when teachers provide multimedia-rich instruction (i.e. video clips about vocabulary words or animated e-books) to young learners (Silverman & Hines, 2009; Verhallen et al., 2006). Still, the specific attributes of effective media instruction remain largely unknown. In response, scholars are now examining the pedagogical supports on screen that might facilitate vocabulary learning in young children (Danielson, Wong, & Neuman, 2019; Larson & Rahn, 2015; Linebarger & Piotrowski, 2010; Neuman et al., 2019; Teng, 2019). A more recent study that examined 200 online streamed programs found that the use of ostensive (definitional) and attention-directing cues were the most salient screen-based pedagogical supports used to promote vocabulary learning in young children's programming (Neuman et al., 2019). Similarly, a content analysis of bilingual programming demonstrated that visual supports and

repetitions were common screen-based pedagogical supports for vocabulary learning in a second language (Wong & Neuman, 2019).

Repetition in media to support vocabulary learning

Relatedly, the use of repetition and visual supports are two pedagogical scaffolds that are well-aligned with the research on learning vocabulary in a second language. Looking first at the use of repetition, scholars agree that DLLs benefit from consistent and repeated exposure to languages (Cha & Goldenberg, 2015; Hammer et al., 2014; Hammer, Lawrence, & Miccio, 2008; Quiroz, Snow, & Zhao, 2010; Thordardottir, 2011). Children's bilingual vocabulary development is closely related to the breadth of vocabulary words that they are exposed to in each language, as well as the frequency of encountering these vocabularies in each language in the home, school, or community context. While the rate of language development is related to the amount of speech monolingual children hear in that language (Hoff, 2006), bilingual infants (Hoff et al., 2012) and preschoolers (Hammer et al., 2008) develop their L1 and L2 vocabulary relative to the amount of input in each language.

Like previous studies, Uchikoshi (2006) also examined children's exposure to second language in the home and school environment, but uniquely investigated how viewing educational media in a second language affected vocabulary growth. Applying growth modeling analyses to 150 Latino-English DLLs, Uchikoshi found that children who viewed two educational media programs – *Arthur* and *Between the Lions* – at home had steeper growth trajectories than those who did not, suggesting that broad exposure to a language in media is beneficial for L2 vocabulary learning.

Visual supports in media to support vocabulary learning

Visual supports, which include visual representations of vocabulary words, illustrations, demonstrations, or multimedia, can serve as essential scaffolds for dual language vocabulary learning. The need for visuals is apparent in a number of successful interventions in early childhood settings, suggesting that visuals provide DLLs with the supports needed to make core content comprehensible (Leacox & Jackson, 2014; Silverman & Hines, 2009; Takanishi & Le Menestrel, 2017). Silverman and Hines (2009) compared DLL and non-DLL populations in preschool to second grade to understand how traditional and multimedia-enhanced vocabulary instruction differentially affected learners. Multimedia-enhanced instruction involved short, 5-minute video clips that were topically

related to the storybooks and provided rich visual representations of target words. Findings demonstrated that these visual representations scaffolded vocabulary instruction for DLLs, providing them with significant gains in vocabulary knowledge that were unique to the DLL population.

Similarly, using a within-subjects design on 24 Spanish-speaking preschoolers and kindergarteners, Leacox and Jackson (2014) used technology-enhanced e-books that pictured target words on one side of the screen and provided a short definition of the word in Spanish when clicked. These pictures appeared three times for each target word throughout the e-book, and yielded more word learning gains than in the control, adult storybook reading condition. Studies like these argue that having access to the meaning of new words through visual scaffolds helps reinforce vocabulary concepts, deepen vocabulary knowledge and support oral language development in young DLLs (Gersten & Baker, 2000; Leacox & Jackson, 2014; Silverman & Hines, 2009; Takanishi & Le Menestrel, 2017; Teng, 2019).

Many scholars agree that multimedia may be an appropriate platform to provide L2 vocabulary instruction to DLLs, using clear verbal and visual scaffolds to support vocabulary learning and deliver ample and repeated exposure to new words (Neuman et al., 2019; Silverman & Hines, 2009; Uchikoshi, 2006; Verhallen et al., 2006). The purpose of this paper is to extend this understanding of how DLLs might learn new words from educational media by closely examining dual-coding theory (Paivio, 1986). More specifically, it seeks to interrogate and establish whether dual-coding theory applies to DLLs who are acquiring vocabulary in a second language.

Theoretical framework

Dual-coding theory (Paivio, 1986, 2008) is a theory of cognition often used in CALL-related research, which asserts that the formation of mental images facilitates learning. When information is processed in the brain, activity occurs in two distinct subsystems – a verbal system specialized in processing language, and a nonverbal system specialized in nonlinguistic imagery (see Figure 1). When information is simultaneously transmitted through verbal and nonverbal channels, dual-coding theory proposes that nonverbal information can help young children comprehend unfamiliar language like vocabulary and complex grammar. Inversely, verbal information may help children process information that is presented in unfamiliar images. In other words, information is represented more fully in memory when it is coded through two channels instead of one. Early studies of dual-coding theory demonstrate the

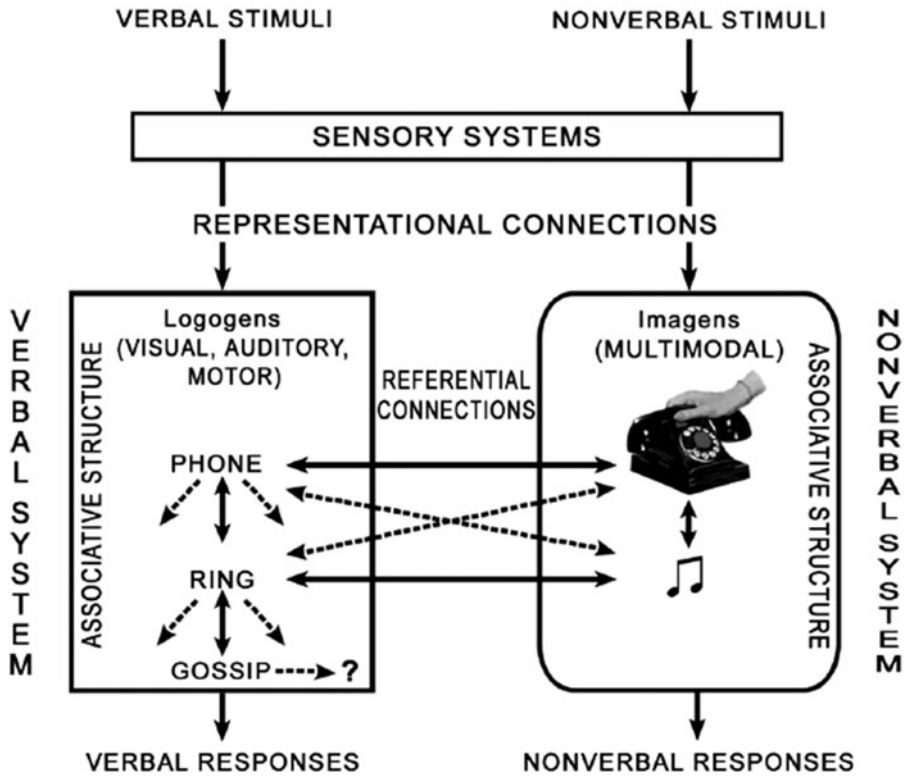

Figure 1. Dual-coding theory (Paivio, 1986).

additive effects of two sources of input on memory recall when target items are simultaneously presented with pictures and their names (Paivio, 1986). Relatively recent scholarship continues to support the theory by using functional brain evidence to demonstrate how mental representations are modality specific and multimodal (Paivio, 2010).

Dual-coding theory may be particularly applicable for DLL populations who are learning vocabulary words in a second language. When DLLs process information through two channels rather than one, they might benefit from an additional or compensatory scaffold that supports L2 vocabulary learning. Aligned with the extant literature on language learning, DLLs benefit from clear and explicit definitions of words (Carlo et al., 2004) and visual images that scaffold their understanding of vocabulary words in a second language (Gersten & Baker, 2000). Although the two systems operate independently, dual-coding proposes that the interconnections between the verbal and nonverbal systems trigger activity in one another to help build a coherent mental representation of a specific stimuli or learning experience. Providing linguistically diverse children with both verbal and nonverbal input may,

therefore, lead to stronger mental representations of information, which can influence comprehension and provide greater information recall (Mayer, 1997).

Drawing from this theory, educational screen media has the potential to support DLLs' vocabulary acquisition by offering multimodal, robust representations of information on the same topic. This means that watching educational media may facilitate learning by developing a relatively multidimensional and extensive understanding of new words and their meanings. Prior studies with bilingual learners have used dual-coding theory as a lens for understanding how children might learn from media contexts (Silverman & Hines, 2009), or how coding in two different languages (verbal) and images (non-verbal) might enhance memory recall (Paivio & Lambert, 1981). More recently, scholars consider how dually-coded or multimodal annotations that provide pictorial and verbal clarifications to viewers may also result in increased attention to the screen, which is a predictor for language learning (Boers, Warren, Grimshaw, & Siyanova-Chanturia, 2017). Yet, no studies have specifically tested how dual-coding theory applies to DLLs when learning content in media. Moreover, affordances of media demonstrate the potential to orient attention (Salomon, 1981), reduce cognitive demands (Sharp et al., 1995) and motivate knowledge-seeking (Kamil, Intrator, & Kim, 2000). Together, this suggests that educational screen media may be a powerful mechanism for cultivating vocabulary development for DLLs in the early childhood years. Still, research on learning from media primarily exists in young children learning vocabulary in their first language; no research to date examines whether dual-coding theory might be applicable to the early lexical development of young DLLs as well.

The present study

The aim of this study, therefore, was to investigate whether dual-coding theory is a key mechanism underlying learning from screens among preschool-aged DLLs. We hypothesize that because educational media are able to provide dynamic visual and auditory sources of input to DLLs, they serve as compensatory scaffolds for DLLs who may have limited experience with the language at home. To investigate this, children viewed six media clips in two different conditions: dual-coding and non-dual-coding video clips. In the dual-coding condition, vocabulary words were presented to children with visual and auditory congruence, whereby words were introduced on screen in tandem with an image or visual representation of the word. The non-dual-coding condition, on the other hand, provided new vocabulary words with visual

and auditory incongruence, where words were introduced on screen at a different time point from an image of the word. In other words, while both conditions included visual and auditory representations of the vocabulary words on screen, they occurred simultaneously in the dual-coding condition and with temporal distance in time in the non-dual-coding condition.

In addition, we were interested in understanding how specific language factors might influence vocabulary learning on screen. More specifically, we examined how two potential language factors for DLLs, child baseline vocabulary in a second language (L2) and parental L2 language ability, might differentially impact dual-coding mechanisms when viewing educational media. Finally, to more precisely understand how visual supports on screen affected children's attention and vocabulary learning, we used eye-tracking technology to examine attention to relevant vocabulary on screen. The specific research questions guiding the current study were as follows:

1. To what extent does dual-coding facilitate L2 vocabulary learning among DLLs?
2. What is the influence of child and parental language factors, as well as attention to screen, on L2 vocabulary learning in educational media?

Method

Participants

To be eligible for this study, children had to be between the ages of four to five years old from households where a language other than English was spoken. With the help of education directors and teachers, 44 DLL participants were invited to participate in the study. IRB approval was attained and consent was obtained from the children and parents. A total of 43 (97.7%) provided consent. Table 1 describes the final sample, which consisted predominantly of children from native Spanish-speaking households ($N = 35$) with an average age of 54.7 months (SDage = 6.63 months). In the sample, 46.5% were female, 81.4% were Hispanic, 9.3% were African-American, and 9.3% were Haitian. All children were enrolled in two Head Start centers in a large urban city and qualified for free and reduced lunch. The language of instruction in the Head Start centers was English, the children's L2. A home language environment questionnaire (LEQ) was provided to parents and teachers to capture children's exposure to L1 and L2 languages in the home environment. This questionnaire was adapted from the Alberta Language Environment

Questionnaire (Paradis, 2011) and a bilingual questionnaire developed by Luk and Bialystok (2013). The LEQ also served as a screening tool. Children who had home language environment scores that indicated an emergent level of receptive English (L2) language skills were eliminated from the study as they were unlikely to comprehend video clips that presented vocabulary words in English. Table 1 provides descriptive statistics of participants.

Research design

We used a within-subjects design to examine the effects of dual-coding on vocabulary learning in DLLs. In this type of design, each participant received both dual-coding (visual-auditory congruence) and non-dual-coding (visual-auditory incongruence) conditions. Children watched a total of six video clips from *Sesame Street*. Three video clips taught new words with visual–auditory congruence where a visual representation of a vocabulary word was paired simultaneously with an auditory label. Likewise, three video clips taught vocabulary with visual–auditory incongruence, whereby visual and auditory labels occurred at different time points. The condition order and clips used in each condition were counterbalanced between participants.

A within-subjects design was deemed appropriate for this study because it controls for between-subjects variability. This is particularly important because children may respond to screens differently and have visual attention patterns that vary from one child to the next. This design reduces error and increases power to detect potential differences between conditions. Second, threats to a carry-over effect are minimal because six different video clips will be examined. Lastly, because

Table 1. Descriptive statistics of sample ($N = 43$).

	Sample statistics
Gender	46.5% Female
Age (months)	54.7 (6.63)
Race	
African-American	9.3%
Haitian	9.3%
Hispanic	81.4%
Primary language of home and child's L1	
Fulani	9.3%
Haitian Creole	9.3%
Spanish	81.4%
Qualify for free and reduced lunch	100%
PPVT standard score	81.04 (11.82)
High median split	90.52 (8.31)
Low median split	71.14 (4.42)
LEQ	2.5 (1.42)
High median split	3.77 (.43)
Low median split	1.23 (.75)

participants essentially serve as their own controls, a within-subjects design will account for significant threats to internal validity.

Video stimuli

Programs were selected from a content analysis of educational media designed for young preschoolers (Neuman et al., 2019). This content analysis identified screen-based pedagogical supports for vocabulary learning on screen, categorizing these supports as ostensive (definitional) cues and attention-directing cues. The video clips for this current study used one-minute segments of the program *Sesame Street*, which taught vocabulary words using pedagogical supports common in educational media marketed for DLLs (Wong & Neuman, 2019). Using vocabulary clips from the media marketplace enhanced the ecological validity of the current study; at the same time, it limited video clip and vocabulary word options, requiring a thorough examination of available media to select comparable words across conditions. To enhance comparability across conditions, vocabulary clips included a straightforward definition of the vocabulary word with accompanying visual supports (see Table 2).

Videos were organized into two conditions: dual-coding (visual-auditory congruence) and non-dual-coding (visual–auditory incongruence). A total of six video clips, three from each condition, were obtained from the same program (*Sesame Street*) to avoid a program effect as children may pay more attention to a program that they prefer. For each condition, we selected vocabulary words that provided explicit verbal and visual input simultaneously and also with temporal distance according to the dual-coding condition (see Table 2). For example, in one clip, an athlete appeared on screen as a character said, 'That's an athlete, Elmo!' (visual–auditory congruence); In another clip, a shelter was described and talked about by a character followed by a visual support of a shelter at a later time point (visual–auditory incongruence). All vocabulary words included visual representations on screen, including 'comfort' where a woman comforted a group of chickens by putting her arms around them, and 'dusk' where the camera panned to a tranquil, empty street scene with the afterglow of a sunset that quickly darkened.

To ensure consistency across conditions, video clips were manipulated to be comparable in length, focusing on teaching one vocabulary word. These vocabulary words had a similar level of difficulty according to the CHILDES database (MacWhinney, 2014). The CHILDES database consists of more than 5000 transcriptions of adult–child spoken interactions in home and laboratory settings. With approximately 3,500,000 words in

Table 2. Description of vocabulary clips.

Condition	Program episode	Duration	Vocabulary word	Definition in media	CHILDES word frequency
Dual-coding	*C is for Cooking*	0:20	Grater	'A grater is something that you stir with.'	4
	Friends to the Rescue	0:28	Hurricane	'A hurricane is a very, very big storm with lots and lots of wind and rain.'	0
	Be a Good Sport	0:25	Athlete	'An athlete is someone who runs and jumps and throws.'	3
Non dual-coding	*Wild Words and Outdoor Adventures*	0:20	Shelter	'A shelter is a place where I can sleep, where I can stay warm and dry and protected from the elements.'	0
	Being Brave	0:24	Comfort	'Comfort is when you sit close with your arms around someone, help them feel better.'	2
	Firefly Fun and Buggie Buddies	0:20	Dusk	'Dusk is the time of day when it's getting darker outside and it's almost night time.'	0

the database, words selected in this study occurred less than five times in the utterances of 48-month-old children, indicating a word is challenging and unlikely to be known by preschool-aged DLLs. Although challenging to select words that are perfectly comparable to one another, using a within-subjects design and counterbalancing children's exposure to each condition helped account for differences in word difficulty. Videos were also manipulated so that words were repeated the same number of times in all conditions. Moreover, words were piloted before the beginning of the study and a screening measure was used to ensure children included in the study did not know the words taught in the media clips.

Measures

Screening measure

Prior to the study, children were administered a brief 10-item screening measure. This included a picture of each of the six words where the assessor asked children, 'What is this?' Children who accurately identified one or more of the words were screened and not included in the study.

Language environment questionnaire

To better understand the language environment that children are immersed in at home, we assessed parental English language ability using

an adapted version of the Language Environment Questionnaire (LEQ; Paradis, 2011). The LEQ included eight items. These questions asked about how much English children's parents spoke using a five-point scale (5-very fluent/very comfortable speaking about child to 0-not fluent/no understanding). A composite score was calculated for each LEQ.

Peabody picture vocabulary test-IV (*Dunn & Dunn, 2007*)

The Peabody picture vocabulary test (PPVT) served as a baseline for general English receptive vocabulary knowledge. It is an individually administered, norm-referenced test designed to be a valid and reliable measure of receptive language skills. Reliability of the standardized assessment ranges from .91 to .94. For this study, raw scores were converted to age-related standard scores. The PPVT has also been used as a predictor of academic skills for preschool-aged children whose primary languages are Spanish or English (Burchinal, Field, López, Howes, & Pianta, 2012; Howes et al., 2008; Lugo-Neris, Jackson, & Goldstein, 2010).

Word identification

After viewing the six videos, children were individually administered a receptive 12-item word identification posttest: six words in-context and six words in-isolation. Similar in format to the PPVT-IV, children were asked to point to the correct word among two other foils. Distractors included foils that were thematically related to the key word (e.g. key-word *grater,* distractor *spatula*; *chef*). The two contexts for vocabulary knowledge are designed to reflect vocabulary words that are learned on a continuum from simple vocabulary knowledge to greater vocabulary word understanding (Nagy, Anderson, & Herman, 1987; Nagy & Townsend, 2012). The words in-context measure captured vocabulary in their original video context (e.g. a screenshot of the *Sesame Street* monster holding the *grater*). Foils were screenshots of other thematically-related words in the same clip. The words in-isolation measure assessed images of the vocabulary words not presented in the context of the video (i.e. isolated clipart images of the target words without a background), along with two thematically-related distractors. Children received a score for correct vocabulary words, which were transformed into accuracy proportions for the analysis.

Eye-tracker fixation duration

To allow for a more precise analysis of how young children's attention is influenced by visual–auditory congruency, we used eye-tracking

technology. Eye movements were measured with a Tobii Technology T120 eye-tracker integrated into a 17 in. thin film transistor monitor. This is a remote eye-tracking system that had no contact with the child and has been used with young children (Neuman, Kaefer, Pinkham, & Strouse, 2014). After watching video clips on the eye-tracker, dynamic Areas of Interest (AOIs) were drawn around the visual representation of target words for the entire span of time the item was on screen. When, for example, an image of the vocabulary word, 'grater,' appeared on screen, an AOI was drawn around it to capture children's total fixation duration on the grater during the video clip. These were drawn for both the dual-coding and non-dual-coding conditions.

Procedure

Children were individually administered the screening measure and PPVT prior to the start of the study. Following these assessments, trained graduate student assessors escorted children to the library one-by-one to watch video clips on the eye-tracking apparatus. Assessors randomly assigned children to a counterbalancing condition. Children sat approximately 60 cm from the eye-tracking monitor. To calibrate gaze, an attention-grabber was shown at five points on the screen. Children then viewed six one-minute video clips, followed immediately by word identification assessments. The duration of the test took approximately 20–25 min to complete per child.

Analysis

We used a repeated measures analysis of covariance (ANCOVA) with the dual-coding condition as the within-subjects factor, a median-split on LEQ and PPVT scores as between-subjects factors, and age as a covariate. Accuracy proportions on the posttests served as outcome variables. To examine children's attention, we calculated the amount of time spent fixating on the target item on screen. Considering each clip was not identical in length, we created percentages for fixation duration to examine differences in attention across condition. We also ran a regression model with fixation duration (i.e. visual attention), PPVT, LEQ, and age in months as predictors, and posttest vocabulary scores in dual-coding and non-dual-coding assessments as dependent variables.

Results

In this study, the aim was to answer two primary questions: (1) To what extent does dual-coding facilitate L2 vocabulary learning among DLLs?

and (2) What is the influence of child and parental language factors, as well as attention to screen, on L2 vocabulary learning for DLLs watching educational media? Results for each question are reported in the sections that follow.

Dual-coding for dual-language learners

To answer the first research question, we examined vocabulary outcomes of DLLs in two video conditions: dual-coding (visual–auditory congruence) and non-dual-coding (visual–auditory incongruence). Using proportions of correct answers in posttest assessments, results indicated there was a main effect for dual-coding. First, a means table (see Table 3) indicates that, on average, children in the dual-coding condition selected the correct vocabulary words in posttest assessments 67% of the time, while those in the non-dual-coding condition selected correct words 52% of the time. Second, running the repeated measures ANCOVA with dual-coding as the within-subjects variable, visual–auditory congruence better supported vocabulary learning than visual–auditory incongruence, F (1, 38) = 6.07, p = .018 (see Table 4).

In this manner, when dual-coding supports existed simultaneously on screen, DLLs were more likely to learn the vocabulary word than if the visual and auditory supports occurred at different time points. For example, when a character in one clip describes the word 'hurricane' and provides a visual image of a hurricane as it is introduced, children demonstrated greater vocabulary gains. On the contrary, when a character in another clip talks about the word 'dusk' but delays the visual depiction of dusk until after the word is described, DLLs were less likely to learn the word. It appears that two modes of sensory input provided the scaffolds needed to sustain vocabulary learning after a single viewing of educational media. When vocabulary presentations did not include simultaneous auditory and visual input, DLLs were less likely to learn the vocabulary word.

Parental and child language factors

Investigating further the influence of dual-coding on DLLs' vocabulary learning, we examined whether there might be interactions between the dual-coding condition and parental or children's L2 abilities. We used a repeated measure ANCOVA with dual-coding as the within-subjects variable, a median-split on parental L2 language proficiency with the LEQ as a between-subjects variable, and a median-split on DLLs L2

Table 3. Means and standard deviations of vocabulary assessments (Proportion of questions correct) and fixation durations by dual coding group.

	Dual coding		Non-dual coding	
	M	SD	M	SD
Vocabulary*	.67	.31	.52	.31
Fixation duration	64.39	21.69	67.82	19.67

Note. $^{*}p < .05$.

Table 4. Main effects and interactions for vocabulary learning by dual-coding condition.

		Dual-coding vs. non dual-coding condition Main effects and interactions					
Dependent variable	Contrast	*F*	df	Sig.	MS_{Effect}	SS_{Error}	MS_{Error}
Percent posttests vocabulary	Dual-coding condition	6.07	1/38	.018*	.235	1.47	.039
	Dual-coding*Age	.531	1/38	.471	.021		
	Dual-coding*LEQ	6.69	1/38	.014*	.259		
	Dual-coding*PPVT	.114	1/38	.737	.004		
	Age	3.27	1/38	.079	.259	3.01	.079
	LEQ	.004	1/38	.951	.000		
	PPVT	5.85	1/38	.020*	.463		

Note. $^{*}p < .05$.

language proficiency with the PPVT as another between-subjects variable (see Table 4). Child's age was used as a covariate. Findings revealed that there was a significant interaction between dual-coding condition and parental L2 ability, F (1, 38) = 6.69, p = .014. In this sense, DLLs with low parental language proficiency or exposure to L2 in the home benefitted more from visual-sound congruence than DLLs with high parental language proficiency. In other words, children who were less immersed in an L2 environment at home particularly benefited from video clips that provided simultaneous visual-auditory scaffolds.

Examining children's L2 language proficiency, we found that there was no interaction between dual-coding condition and child PPVT scores, F (1, 38 = .11, p = .74). In other words, children's L2 proficiency did not appear to predict the importance of visual and auditory input being congruent versus incongruent. Instead, the interaction was specific to parental English language proficiency rather than child baseline English vocabulary.

Lastly, we examined the influence of children's attention to screens using data from the Tobii eye-tracker. We ran a regression analysis in both the dual-coding and non-dual-coding conditions, using vocabulary outcomes as the dependent variable, and attention (fixation duration percentage), child's L2 ability (PPVT), parents L2 ability (LEQ), and age as predictors (see Table 5). Regression findings indicated that visual attention significantly predicted posttest scores in the dual-coding, congruent condition (β = .35, p = .017). When visual and auditory cues were

simultaneously presented on screen, children's attention to screen was associated with vocabulary gains.

In the non-dual-coding condition, results demonstrated that visual attention did not predict posttest scores ($\beta = .22$, $p = .19$). This suggests that when visuals and auditory input did not match up, paying visual attention to the screen did not appear to predict vocabulary learning. Importantly, there were no differences in visual attention to screen between the congruent and incongruent videos, $F\ (1, 35) = .48$, $p = .50$, demonstrating that children attended to both types of visual representations equivalently overall.

Discussion

The present study sought to examine whether dual-coding theory – a theory often used in CALL research – is a mechanism underpinning vocabulary learning among DLLs. More specifically, we aimed to (1) understand the extent to which dual-coding facilitated L2 vocabulary learning among DLLs; and to (2) understand the influence of child and parental language factors, as well as attention to screen, on L2 vocabulary learning in educational media. Adopting a within-subjects design and assigning children to two different conditions where they were exposed to vocabulary clips that used visual–auditory congruent and incongruent input, findings suggest that a theory of dual-coding is at play for DLL populations.

Building on prior research with monolingual populations (Bus, Takacs, & Kegel, 2015; Verhallen et al., 2006), findings from this study demonstrate that DLLs are more likely to learn vocabulary words in a second language when they were presented with simultaneous auditory and visual input compared to words presented with auditory and visual input at different times. Video clips with dually coded words like 'hurricane' and 'grater' (Table 1) enhanced children's vocabulary knowledge, serving as compensatory scaffolds. Temporally congruent visuals likely provided DLLs with the supports needed to make core content comprehensible (Silverman & Hines, 2009; Takanishi & Le Menestrel, 2017). Having access to the meaning of new words through visual scaffolds helps reinforce vocabulary concepts, deepen vocabulary knowledge, and support oral language development in young DLLs (Gersten & Baker, 2000; Takanishi & Le Menestrel, 2017). Scaffolds are critical in dual-language development because they reflect students' zones of proximal development and guide learners towards deeper, more robust understandings of new words (Vygotsky, 1980). Educational media provides opportunities to learners by meeting them in their appropriate

Table 5. Regression statistics predicting vocabulary in the dual-coding and non dual-coding conditions.

Outcome	Predictor	*t*	*p*	B	*B*	*F*	df	*p*	adj R^2
Dual-coding vocabulary posttest	Age	1.87	.070	.009	.26	5.05	4, 39	.003	.29
	LEQ	−1.84	.074	−.043	−.26				
	PPVT	1.94	.060	.005	.27				
	*Fixation Duration	2.51	.017	.004	.351				
Non-dual-coding vocabulary posttest	Age	.93	.36	.006	.15	1.68	4, 39	.18	.065
	LEQ	.86	.40	.024	.14				
	PPVT	1.32	.20	.004	.21				
	Fixation Duration	1.35	.19	.003	.22				

Note. $^{*}p < .05$.

zones of proximal development and providing instruction that will deepen vocabulary knowledge.

At the same time, not all children's zones of proximal development lie within the same range. Some DLLs, for example, might have stronger L2 vocabularies and/or greater exposure to the L2 at home than others, which would facilitate learning from screens. Our second research question investigated the influence of L2 language proficiency and environment as contextual factors that may moderate the impact of visual-auditory congruence in technology-based learning environments. Using children's L2 proficiency and parents' L2 proficiency or L2 exposure in the home environment, findings suggest that the dual-coding mechanism is particularly beneficial for those with low L2 exposure in the home as they benefited more from visual-auditory congruent learning experiences than those with high L2 home exposure. By investigating DLLs who may have limited experiences with the English language and who are often underrepresented in media scholarship, this study demonstrates that educational media has the potential to build children's L2 vocabulary knowledge through wide exposure to the second language. Interestingly, this was specifically tied to children's home language environment, not their personal L2 vocabularies, highlighting the unique role of L2 use in the home.

Consequently, media appears to be an opportunistic platform for learning a second language as it can deliver ample, repeated exposures of new vocabulary words to young DLLs. The amount of language exposure and language used by individuals on a daily basis is likely to affect bilingual vocabulary development at all ages. In particular, young DLLs with daily input and output in two languages are likely to gain proficiency in bilingual language performance (Bedore, Peña, Griffin, & Hixon, 2016). In fact, research on dual-coding theory with bilingual populations suggests that the verbal processing system may be further divided into a first language and second language system. When bilingual speakers hear words in their L1, L2, and receive a nonverbal stimulus, they are more

likely to remember the information than if only one language is used with the nonverbal stimulus (Jared, Pei Yun Poh, & Paivio, 2013; Paivio & Lambert, 1981). Future studies may consider examining how verbal coding in two languages with nonverbal images might facilitate word learning in media environments.

Examining more precisely how dual-coding serves as a mechanism underlying learning from media, we used state-of-the-art eye-tracking technology to document children's visual attention to screens. Because visual attention only predicted posttest scores in the dual-coding condition, findings from this study suggest that preschoolers' visual attention to screens facilitated learning only when images and sounds were expressed simultaneously. In other words, without dual-coding mechanisms at play, visual attention to screens did not facilitate learning of new vocabulary words. Besides providing viewers with information to process in two systems, another interpretation of these findings is that dually-coded presentations may attract more attention to screens, which is a predictor of vocabulary learning (Boers et al., 2017). As Boers et al. (2017) suggest, when multimodal presentations appear on screen, learners are likely to inspect with one complex gloss than with a simple gloss, which is associated with better word retention (Al Seghayer, 2001). Extending prior research on how production techniques used in educational media affect viewing behavior (Huston & Wright, 1983; Kirkorian, Wartella, & Anderson, 2008), results from this study also suggest that the use of formal features like zooms and other attention-directing cues may be beneficial for DLL populations when they are strategically paired with nonvisual input.

The present study contributes to our understanding of how dual-coding theory can be applied to under-researched DLL populations. However, there are limitations of the study to acknowledge. First, the sample size of the study examines the experiences of 43 DLLs. While small samples might compromise the generalizability of the findings, adopting a within-subjects design limits between-subjects variability, which reduces error and increases power to detect potential differences between conditions. Similarly, not all language groups are represented in the sample. The majority of students were Spanish speakers, which limits the generalizability of results to all DLLs as children who speak another language may require different supports. Third, creating multimedia video clips that are perfectly comparable to one another with equally difficult vocabulary words is a limitation. We note that only six video clips and vocabulary words were used in the study, but recognize this was necessary to accommodate the attention spans of four-year-old children who were screened, pretested, eye-tracked, given videos to view, and

then post-tested. We attempted to manipulate clips so that they were relatively equal in video length, word repetitions, and difficulty. Again, using a within-subjects design and assigning children to condition in a counter balanced fashion allowed us to increase internal validity and wash out some of the differences between video clips. Moreover, video clips were chosen from currently available programs in the media marketplace, enhancing the ecological validity of the video clips. Because video clips were chosen from programs that are available to children, we were not able to select words that were perfectly comparable to one another. We used the CHILDES database to select words that appeared less frequently in the speech of four-year-old children. However, word frequency may not always indicate if a word is rare or indicate whether a word has polysemous meanings. Future studies would benefit from using multiple indicators to determine word difficulty. In the same vein, we used only one educational media program – *Sesame Street* – in the study, which may offer some limitations to the generalizability of this study to all educational media. Still, *Sesame Street* has been studied for decades by scholars around the globe (Fisch & Truglio, 2014) and using the same program allowed us to control for a program effect.

In sum, this CALL-situated study provides evidence to suggest that dual-coding is a key mechanism underlying L2 vocabulary learning for DLLs on screen; that this mechanism is particularly beneficial for those with low L2 exposure in the home as they benefited more from media that used visuals and sounds together, rather than those with high L2 exposure; and that preschoolers' visual attention to screens facilitated vocabulary learning only when images and sounds were expressed simultaneously. Findings suggest that congruent visual and auditory sources of input may serve as important compensatory scaffolds that facilitate the teaching and learning of L2 vocabulary on screens. Moreover, these screen-based scaffolds might support teachers in the classroom as additive tools that leverage technology to promote early bilingual development. Technology is ubiquitous in the lives of young children, with educational media in the palms of young hands all over the world. With the potential to access far-reaching households and provide DLLs with broad exposure to vocabulary words in a second language, the current study establishes that educational media has the ability to equip young DLLs with early lexical skills that promote a new or additional language, preparing them for the increasingly multilingual world.

Disclosure statement

No potential conflict of interest was reported by the authors.

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