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Chapter 4
Rapid Serial Visual Presentation: Bilingual Lexical and Attentional Processing

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Abstract This chapter examines the use of Rapid Serial Visual Presentation (RSVP) as a research method for studying reading and attention in bilinguals. Theoretical background and methodological considerations are provided for the most common ways in which RSVP is used: lexical processing, repetition blindness (RB), the attentional blink (AB), and executive control. The authors also describe and discuss relevant studies that have used bilingual participants, whether exclusively or in comparison to monolinguals. To date, there has been relatively little use of RSVP in bilingual research. However, this chapter provides rationale for its use as a well-controlled experimental method that is especially well-suited for use with bilinguals (whose reading speeds tend to vary a great deal). Suggestions for future research are also provided.

Introduction

Throughout this volume, the various methods used to study bilingual reading and related processes are presented along with discussions on how these methods inform theory and research in bilingualism. The focus of this chapter is on rapid serial visual presentation (RSVP). RSVP is a method in which letters, digits, or words are presented one at a time for a designated brief period of time. For example, Fig. 4.1, below, shows a sample experiment that uses an RSVP stream of eight items presented serially for 100 milliseconds (ms) with no pause in between (0 ms interstimulus interval; ISI). The boxes in the figure indicate what the participant would be viewing on the computer screen, proceeding chronologically from the upper left corner to the lower right corner. Stimuli may comprise a list of items or a full phrase or sentence. The greatest strength of this method is flexibility and control in manipulating...
the duration of presentation for each individual item in the series. If a full sentence or list of items were to be presented in its entirety, the relative time that the participant has to process each item could vary greatly. Reading performance can be measured in two main ways: time to read each word (or a whole passage), and comprehension of presented materials. In RSVP, time to read each word and each passage is constant for all participants so reading performance is measured by testing memory for and comprehension of presented materials. While the time it takes a participant to read a specific item can be measured using other methods, in many situations it may be preferable to directly control the amount of time the participant has to process each item. Other options could include eye-tracking (in which a camera tracks via eye movements where and how long the participant looks on the screen) or self-paced reading (in which stimuli are presented one at a time and the participant chooses when to advance to the next item). While many researchers have used one technique or another in isolation, researchers in the field of reading research have called for converging evidence amongst such techniques as RSVP and eye-tracking (Potter, 1984).

In an RSVP study, items are usually presented horizontally in the center of a computer screen. This arrangement is done given that regardless of whether the language being used is read from left to right, right to left, or vertically, most participants are faster to process words presented on the right (Smigasiewicz et al., 2010). It is best to control location and avoid a possible confounding effect on processing time by presenting all words at the center. Additionally, reading speed is fastest for
horizontal text (Yu, Park, Gerold, & Legge, 2010), so this orientation is preferred over any type of rotated or vertical text. The amount of time allotted to process each item in RSVP could vary, but it is typically held constant at a short period selected for that experiment, often between 50 and 300 ms. Given the rapid nature of presentation, Potter (1984) contended that RSVP makes equal the time that the reader has to visually perceive a word for both skilled and unskilled readers, so any differences in comprehension are likely due to language processing at a more advanced stage than vision. This balance becomes important for research on bilingualism because bilinguals often vary considerably in their reading abilities and do not always reach the level of a native speaker. Additionally, even skilled bilinguals are often much slower to read in their second language (L2) as compared to their first language (L1; Favreau & Segalowitz, 1983). Using RSVP, an appropriate duration of presentation can be applied.

As previously mentioned, converging evidence gathered with eye-tracking methodology could neatly support processing conclusions from studies using RSVP. In order to facilitate this comparison within the empirical portions of this chapter, eye-tracking methodology shall be introduced here. Eye-tracking uses cameras to identify where an individual's eyes are directed and makes assumptions about what they are attending to, based on where they are looking. The main theory behind eye-tracking is called the eye-mind assumption (Just & Carpenter, 1980) and purports that what the individual is looking at reflects what that person is attending to (Lai et al., 2013; Rayner, 1998). In the case of reading, the individual's eye fixates (remains still) at a certain point or word, and then makes a saccade (rapid physical jump) to the next point of fixation. Eye-tracking studies follow these fixations and saccades and analyze where eyes are directed at each point in time, including initial fixations, regressions (returning to a point that was fixated on earlier), and total time, among other measures (Frenck-Mestre, 2005; Lai et al., 2013). Eye-tracking has been used primarily in monolingual populations, but there are also a growing set of studies using eye-tracking with bilinguals (Altarriba, Kroll, Sholl, & Rayner, 1996; Bartolotti & Marian, 2013; Frenck-Mestre & Pynte, 1997; Libben & Titone, 2009).

A final introductory point of interest is that RSVP has been gaining attention in media and other nonpsychology fields. Recent work in design and engineering of electronics has suggested using RSVP as a method of reading on-screen displays. Part of this work has been intended for computer screens (Beccue & Vila, 2004) and for small screens such as mobile phones, PDAs, or tablets (Öquist & Lundin, 2007). Some suggest that RSVP increases reading speed without cost, especially by cutting out “unnecessary” regressions (eye movements back to look at certain words for a second time; Taylor & Taylor, 1983), though others suggest that regressions are helpful rather than harmful or unnecessary (Schotter, Tran, & Rayner, 2014). The use of RSVP for small-screen reading is based on the limited space on the display, causing users to need to scroll frequently. RSVP is suggested as a way to avoid such hand movements by the user and let them passively watch the sentence presented at a comfortable pace. As opposed to its use as a research tool, using RSVP to improve
small-screen reading would require that reading comprehension is maintained and that the user is subjectively happy with the experience. Some work has been supportive (Becque & Vila, 2004; Rahman & Muter, 1999); however, several works have suggested that there are problems with this application of RSVP (Öquist & Lundin, 2007).

Öquist and Lundin (2007) asked participants to use a touch-screen mobile phone to read text selections of comparable length and difficulty using various small-screen reading formats, including RSVP. Öquist, and Lundin (2007) found that participants read text selections (counterbalanced across presentation techniques) slower via RSVP than when using the other small-screen formats (e.g., scrolling), though this format produced equally high comprehension as the others. Finally, the perceived task load or difficulty of RSVP was slightly greater than some of the other options. Öquist and Lundin (2007) asserted based on this test that perhaps other formats should be considered in place of RSVP for small-screen reading.

Becque and Vila (2004) implemented a test of a customizable RSVP program on a computer screen. In this experiment, participants were allowed to adjust the color of the text and the background, the font, the size of the text, and the presentation rate. The RSVP group was compared with a control group that read the text presented on the screen all at the same time (traditional), using the default settings for the RSVP task (selected for commonness and ease of reading). The reading materials used by Becque and Vila came from a standardized reading comprehension test used for grades 9–16 and were made up of a number of text selections with accompanying multiple choice comprehension questions. Participants read the passages using either traditional or RSVP presentation and answered the comprehension questions. Results showed faster reading speed using RSVP for the five shorter text selections used and slower reading for RSVP than for the control group for the two longer text selections, suggesting that RSVP is best suited for shorter passages. Further, no statistically significant differences were found for comprehension question accuracy for the RSVP and traditional presentation formats. However, the results of this study should be viewed with caution, as the participants in this study were university students largely in computer focused or computer-related fields and as such may have been more familiar with a variety of presentation formats that the typical reader would not have experienced. A more compelling argument could be made with support for these results in a more appropriate group of participants with typical computer experience. Finally, given that the main task in this study was reading in English and answering reading comprehension questions, it is odd that only about half of the participants were native speakers of English (50% in the control group and 62% in the experimental group). Reanalysis of these findings should compare the monolinguals and bilinguals in this sample, and further work should seek to replicate these findings with better measures of language history. Above all, notable researchers using this paradigm have suggested that overall, RSVP’s best contribution is as a research tool, not a reading format in real life for most people, except perhaps for scanning a list for a certain item (Potter, 1984).

Before presenting research using RSVP as a research tool, it is important to address several limitations to using this method as a measure of reading and
processing. A main criticism relates to the memory demands created by RSVP performance measures and the influence of memory on measuring processing. It is known that memory span for RSVP lists varies with presentation rate, with fewer items recalled at faster presentation rates (Potter, 1999). However, due to their greater degree of structure, basic sentences are easily recalled, even sentences with as many as 14 words are easily reported with high accuracy (Potter, 1984, 1999). A large majority of RSVP studies assess performance through different questions asked after the RSVP stream has been presented (various measures are discussed below). These accuracy questions take place after online processing of the sentence, so they may not be a completely direct measure of processing time (Mitchell, 1984). It is thought that using measures such as recall tasks allows for influence by other factors besides processing, such as memory storage and retrieval (Mitchell, 1984). Despite these limitations, RSVP allows researchers to examine processing time by seeing what types of mistakes are made when presentation rates are very fast. On its own, the knowledge that individuals can read very fast and occasionally make mistakes may be less theoretically interesting than studying which processes suffer at very quick presentation rates (Potter, 1999). The remainder of this chapter will present previous research using the RSVP method to study bilinguals (and monolinguals where important for understanding the bilingual work), along with recommendations for researchers and ideas for future explorations.

**Lexical Processing**

RSVP can be used to examine lexical (word-level) and sublexical (letter or word base) effects within sentences and lists. This method has been employed in monolingual research (e.g., Andrews & Bond, 2009) because of its helpfulness in controlling how long each participant has to process individual words and sentences. One way in which RSVP has been used to study bilingualism is through the examination of language-specific sublexical effects. Previous research in this area used bilinguals whose two languages have different language families. For instance, Wong, Qu, McGugin, and Gauthier (2011) asked Chinese-English bilinguals of varying proficiency to search for specific letters or characters in a series of RSVP items. They sought to determine if expertise in reading distractor letters (defined as other letters in the RSVP stream that were not to be reported later) interfered with a target detection task (responding to the presence of a designated target letter) as compared to pseudoletters. An example of one trial type would be highly proficient Chinese-English bilinguals searching for a specific Roman letter (e.g., P) amid Chinese character and pseudoletter distractors. In Fig. 4.2, participants are presented with two possible target letters (P and S). Once they advance the computer, an RSVP stream containing one of the possible target letters along with distractors, is presented for 100 ms per item. Here, the participants see a P, along with pseudoletters and Chinese characters. Finally, the same two possible target letters are presented, and the participants indicate via key press which of the two letters was present in the
RSVP stream. They also asked monolingual English speakers to complete the same task. The two participant groups allowed Wong et al. (2011) to compare performance when searching for a familiar letter among all unfamiliar distractors (in the case of the English monolinguals) or for a familiar letter among mixed familiar and unfamiliar distractors (in the case of Chinese-English bilinguals). Other conditions in this experiment used each type of character (Roman, Chinese, and pseudoletter) as a target and a distractor, in counterbalanced blocks. Thus, the independent variables were language experience (English monolingual or Chinese-English bilingual), target type (Roman letters, Chinese characters, or pseudoletters), and distractor type (Roman letters, Chinese characters, or pseudoletters). The dependent variable analyzed was accuracy in target identification.

The results showed that for Chinese-English bilinguals, their accuracy at detecting a Roman letter declined when Chinese character distractors were present in the RSVP stream. This finding supported the notion that there was interference from Chinese distractors for the Chinese-English bilinguals when searching for a Roman letter. Surprisingly, when English monolinguals were asked to search for pseudoletter targets, they did not show a deficit if Roman letter distractors were present in the RSVP stream. This result is somewhat unexpected because the participants did not seem to be distracted by the Roman letters that they could comprehend any more than the Chinese characters that they could not understand. Wong et al. (2011) also repeated their experiment under a more difficult condition. In this case, participants were required to increase the load on their memory by rehearsing four digit sequences. Wong et al. obtained similar results under these conditions as they had
when no additional memory task was required. The results of the follow-up experiment reduce the likelihood that the effects of searching for unfamiliar pseudoletters in Experiment 1 were produced because the task required too much focus and attention (leaving no resources to be distracted by the Roman letters). Wong et al. concluded that a common expert perceptual system for recognizing known letters is being used for both Chinese characters and Roman letters for the Chinese-English bilinguals. This means that they rejected the conclusion that recognizing symbols relies on working memory and support a model in which perceptual expertise can operate under memory load, but this expert perceptual system is used when each of a bilingual’s known symbolic systems is being processed. However, the English monolinguals are only tapping this resource to process the known Roman letters. It was argued that while Roman letters hold no meaning in isolation, Chinese characters represent words, which could have an influence on this study. The authors make no further reference to this issue; however, replication of this work using languages with different alphabets, such as the Cyrillic alphabetic system and the Roman alphabetic system (whose symbols represent the same linguistic level; that of letters, not words) would add credence to the conclusions drawn here. Additionally, though Wong et al. measured the average presentation rate for each block at which acceptable accuracy could be maintained, it would be interesting to also compare reaction time for each response across condition. The time to choose the correct option from the two target letters may also be a useful measure of processing difficulty for this task.

Other research has used Hebrew-English bilinguals (Velan & Frost, 2011) as a test case of languages with different base morphologies (i.e., internal structures). Most English words have a base unit such as drive which is the base for other words such as driving, driver, drove, and driven. In contrast, Hebrew units of meaning are not orthographically near in distance. For example, the root z.k.r is used to create words that reference the concept of memory and is used to create zikaron ("a memory"), maakir ("a secretary"), and himkip ("reminded"), among others (Velan & Frost, 2011). These Hebrew words share the root concept of memory and the letters z, k, and r, but they appear in various positions relative to each other with different intervening letters.

Velan and Frost (2011) used Hebrew words with root patterns as described above, along with other Hebrew words that had been borrowed into Hebrew from languages with unified bases similar to English in an RSVP task. Thus, the authors created two groups of target words that either had Hebrew root patterns or English-like base words. Hebrew-English bilinguals completed a report task in which they viewed Hebrew or English sentences and repeated the entire sentence after the final word had been presented. The target word in half of the sentences had two letters transposed, but the participants were asked to report the word as if it had not been altered. Results were analyzed for accuracy in reporting the target word. The target words that were English showed high accuracy of report even for words with transposed letters, while the Hebrew target words with transposed letters showed a decrease in accuracy consistent with previous work (Velan & Frost, 2007). However, Hebrew words with English-like base roots were recalled with high
accuracy similar to English words. These results indicated that the fully Hebrew words with root patterns instead of base roots did not produce similar effects as previous work with other Indo-European languages, such as English and French. Letter transposition more strongly impairs processing of words with root patterns like in Hebrew than words with base words like in English. It is important to know of such cross-language differences because many experiments study effects of orthography or spelling on other processes. Given this, future research that manipulates orthography should be extremely mindful of language families, particularly Semitic languages, and seek to create frameworks that can take into account languages with root patterns as well as those with base words. RSVP is a useful tool for studying sublexical processing of isolated letters (Wong et al., 2011) and of orthographic effects (Velan & Frost, 2007, 2011) because small differences can be found by tightly controlling the amount of time in which a participant can process each item. The limited time allows very small differences in processing time and accuracy across trial conditions or participant groups to be revealed.

RSVP is also an excellent medium for examining sentence context effects in word comprehension. Altarriba, Carlo, and Kroll (1992) conducted one of the first studies to examine the effects of language dominance and sentence context on bilinguals’ word naming. The bilingual participants were Spanish dominant and proficient in English, their second and nondominant language. Altarriba et al. used sentences containing interlingual homographs, which are words that are spelled the same in two languages, but mean different things (e.g., fin is a fish part in English and means end in Spanish). These target words were embedded in sentences that were biased towards one of the interpretations of the homograph (e.g., We knew the play had reached its FIN when we saw the curtain fall, is biased towards the Spanish end interpretation of the homograph fin). Controls were created for both English and Spanish sentences that did not fit the meaning of the sentence in either language. Participants viewed each sentence presented via RSVP and named the target word (written in all capitals, e.g., FIN) aloud.

Altarriba et al. (1992) analyzed the time it took participants to name each word under the different contextual and language conditions. The homograph was either easily predictable by the sentence context or unexpected based on sentence context. Additionally, the meaning of the homograph either matched the language of the sentence context or did not. Results indicated that Spanish-English bilinguals were slower to name ambiguous homographs whenever they appeared in English (i.e., their nondominant language) than control words, regardless of whether the sentence biased the Spanish or English interpretation of the homograph. However, when naming words appeared in Spanish (i.e., their dominant language), participants were slower to name words that were biased towards the meaning of the homograph in English and showed no slowdowns for homographs consistent with the Spanish sentence context. The conclusions of this study suggest that bilinguals access the meaning of ambiguous words in both of their languages when working in their nondominant language. However, when bilinguals are reading in their dominant language, ambiguous words are only accessed in their dominant language unless the context strongly suggests a word meaning from their nondominant language.
This finding is noteworthy due to the uneven interference of the dominant and nondominant languages and implies that both language dominance and surrounding context are important for understanding how bilinguals access the meanings of words. The results taken together generally provide support for nonselective access of bilinguals' two languages; that is, both languages are activated even when they are only using one at a time. Nonselective access is a critical feature of an important connectionist model of bilingual word recognition, the Bilingual Interactive Activation Plus Model (BIA+; Dijkstra & Van Heuven, 2002). This model includes four levels of nodes: letter features, letters, words, and language (one node for each of a bilinguals' two languages). One example of the implications of this model is that because cognates share letters, they are activated whenever those letters are presented without regard for which language is the context until the final level of processing is reached (Basnight-Brown, 2014). In the case of interlingual homographs, at the final level of processing, the selection of the meaning of the word in just one language as a final interpretation takes some additional time (interference). It does seem, however, that even proficient bilinguals have more spillover from their dominant to their nondominant language. It should be noted that, while the participants were proficient in both languages, it may be a stronger argument if these findings were replicated in highly proficient speakers of both languages who are still dominant in one. This would provide further support for conclusions based on dominance separate from proficiency. Additionally, this effect could be larger or smaller when tested with two languages that share fewer homographs, so that homographs are less often expected. Further work in this area could test these empirical questions.

Based on the principle of converging evidence using multiple methods, Alcarriba et al. (1996) advanced the question of sentence constraint and its interaction with lexical features by conducting a study testing the effects of sentence constraint and word frequency. The study investigated two possible hypotheses. The first is that sentence constraint is a conceptual variable and would act similarly in either of a bilingual's languages. The alternative hypothesis would support the notion that sentence constraint is also acting at a lexical level. This would mean that constraint could interfere with processing a word that represents the same concept, but in the context inappropriate language. Alcarriba et al. conducted two experiments with the same sentence stimuli, employing eye-tracking in Experiment 1 and naming of a target word in a sentence presented via RSVP in Experiment 2. In each experiment, Alcarriba et al. manipulated the language of the sentences (Spanish or English), language of the target word (Spanish or English), sentence constraint (low or high), and the frequency of the target word (low or high). For example, a low constraint sentence with a low constraint target word (underlined) would be *The market had a new variety of pumpkin/calabaza in the fall*. The dependent variables collected were eye-tracking data (Experiment 1) and naming of the target word (Experiment 2). The participants for each experiment were Spanish-English bilinguals (Spanish L1, highly proficient in both languages).

The results showed consistent patterns across the eye-tracking and time to name the word in RSVP. Beginning with eye-tracking: low-frequency Spanish words
were initially fixated on for less time when they appeared in high-constraint sentences than in low-constraint sentences, and for high-frequency words the reverse was true. This implies that it is easier to read low-frequency words when they are highly constrained by context. For the English sentences, the bilingual participants performed like monolinguals: they looked at low-frequency, low-constraint words for more time than they did at low-frequency, high-constraint sentences, high-frequency, low-constraint sentences, and high-frequency, high-constraint sentences. These differences also appeared in the data from Experiment 2 in which participants were slower to name the target words that had been fixated on for a longer time in Experiment 1. The consistency of the results of two tasks using two methods with the same sentences provides excellent converging evidence that the processing in RSVP tasks is similar to that in eye-tracking studies. This study provides theoretical support for the effect of frequency on word processing and the notion that it interacts with sentence constraint.

Schwartz and Kroll (2006) extended the findings of Altarriba et al. (1992) and Altarriba et al. (1996) by examining the effects of different sentences on word comprehension for Spanish-English bilinguals of varying proficiency. The sentences that they presented using RSVP were either of high constraint or low constraint. Low-constraint sentences have an element (a word, phrase, or clause) that could be easily and plausibly filled in by a number of different options. In contrast, a high-constraint sentence could only be completed by one or two plausible options. For example, the high-constraint sentence, Leslie bit into the juicy red... is likely to be completed with fewer options such as apple or grape. The low-constraint sentence, Leslie bought a nice, red... has many possible options to complete the sentence, such as apple, coat, truck, ball, purse, bicycle, vase, or shirt. Schwartz and Kroll constructed high- and low-constraint sentences in which a target word appeared partway through the sentence. These sentences were matched on number of words, syntactic complexity, and length of the word that immediately preceded the target word. The cloze probability of each word was normed on a set of separate participants. The probability of the blank being filled in by the target word was approximately .66 for the high-constraint sentences and .04 for the low-constraint sentences, and did not differ across the target word conditions. The target words included, (1) cognates (e.g., band vs. banda) or words that are orthographically and/or phonologically highly similar in the different target languages; (2) cognate controls of similar English word frequency and word length to the cognates (e.g., pencil); and (3) interlingual homographs similar to those used by Altarriba et al. (1992). Finally, the fourth type of word was composed of matched homograph controls of similar English word frequency and word length to each homograph (e.g., frog). Participants viewed the sentences presented via RSVP and named the target word (printed in red) out loud into a microphone (see Fig. 4.3 for an example). Experiment 1 tested Spanish-English bilingual participants who were highly proficient in both languages and used both on a daily basis. Experiment 2 used Spanish-English bilinguals (and some Spanish-English-Valenciano trilinguals) who were more proficient in their L1, Spanish, and of moderate proficiency in English.

Cognates were named faster than matched controls by participants in both experiments when sentences were of low constraint for the target word; however,
this effect did not appear for sentences that highly constrained the target word. Interlingual homographs did not differ from controls for the highly proficient bilinguals, though error rates for homographs were slightly higher than matched control words for the less proficient bilinguals in Experiment 2. This means that the degree of constraint of the sentence context affected the relationship between cognate status and naming time. The results were interpreted by Schwartz and Kroll (2006) to support the effects of linguistic context (in this case, sentence constraint) on bilinguals' lexical access as is posited within the BIA+ model proposed by Dijkstra and Van Heuven (2002) described above. The letters shared by the cognates are processed in both languages nonselectively and so the additional activation of both cognates at the word-level means that the final level of languages is reached more quickly. Selecting just one of the cognate word representations does not impair interpretation because cognates share semantic/conceptual representations. However, one would expect that interlingual homographs would be named more slowly because their letters are shared, but word meaning is not. Further work should examine this difference, perhaps by using multiple techniques such as RSVP and eye-tracking.

Van Hell and de Groot (2008, Experiment 3) sought to extend the study conducted by Schwartz and Kroll (2006) by using Dutch-English bilinguals and varying word type within the cognates, homographs, and controls. Words in these categories were divided into two further word types: abstract and concrete. Concrete words describe things that exist in the physical world (e.g., *chair* or *cat*), whereas abstract words describe things that do not exist physically (e.g., *hope* or *heritage*). The sentences used by Van Hell and de Groot (2008) were similar to those of Schwartz and Kroll (2006), including high- and low-constraint sentences. Sentences were presented via RSVP with dashes taking the place of the target word during
Fig. 4.4 Example of a low-constraint sentence from Van Hell and de Groot's (2008) translation task presentation of the sentence, and then the missing target word was presented at the end for the participant to translate as quickly and as accurately as possible into a microphone (see Fig. 4.4 for an example). Van Hell and de Groot (2008) found that cognates were translated faster than controls when presented within a low constraint sentence only, and that while concrete words were translated faster than abstract words, this facilitation did not depend on whether the word was a cognate. Thus, the results of this study by Van Hell and de Groot (2008) using a translation paradigm support the conclusion that sentence context is important for recognizing (and translating) words, conceptually replicating the general findings of Altarriba et al. (1992), and Schwartz and Kroll (2006). However, the results from Van Hell and de Groot may not necessarily be fully consistent, as the translation method used may have involved strategic processing.

In this section, RSVP has been shown to effectively aid in the development of psychological research concerning lexical processing, both at the lexical and sub-lexical level. Some of these effects have converged with other methods with different strengths, such as eye-tracking. Future work should use RSVP to examine other possible influences on bilinguals’ ability to access words in their various languages, such as the language of the sentence context, regular and unusual word spellings, or priming effects, in addition to working to provide more converging evidence with other methods.

**Attention**

In addition to being an avenue for studying lexical processing, the RSVP paradigm is also useful when examining attention. Cognitive psychologists use many different techniques to answer questions about how humans are able to attend to and take in
information. When employing the RSVP methodology, an interested researcher will necessarily be focusing on visual attention. Huang and Pashler (2012) define visual attention as ...the selection of part of the available visual information, so that this part is admitted to consciousness (p. 30). Thus, the information to be processed must first be “available” to the individual (seen in the case of visual attention) and then selected for out of all the available options. Scientists study the ways in which specific information is selected for and reaches consciousness while other information is missed.

Typically, in this area of research, participants are asked to read a series of letters, words, or a phrase or sentence that is presented sequentially using RSVP (see Fig. 4.1 for an example of a word series). Performance measures, such as those discussed below that probe the participants’ accuracy at perceiving and comprehending the series, allow researchers to gain insight into their attentional processing. Patterns of errors can often be particularly illuminating, as shall be seen below through an in-depth look at two well-studied attentional effects: repetition blindness (RB) and the attentional blink (AB), and how they have been used to show possible differences between the attentional abilities of bilinguals and others.

Performance Measures

One way to measure performance in an RSVP task is to ask participants to reproduce the stimuli that had just been presented in that series. Using the example in Fig. 4.1, the participant would report, mold, vase, love, flower, knife, tail, pipe, yellow in the original presentation order. In the usual case, a microphone is used to record the participant’s voice as they verbally repeat the sentence or list. A scoring sheet may be used by an experimenter following along during the task as a check in case of poor recording quality, or scoring may take place only at a later point in time using the audio tape. Performance is then considered in terms of how many items/words the participant remembered and also whether they were reported in the correct order.

Another performance measure is the report or the detection of a target item. The participant will respond yes/no as to whether an item was present in a series (see Fig. 4.5). The execution of a detection task has several variations. The targets may be specified to the participant before the trial begins so that they are aware of what they are to be looking for. For instance, they may be told that they will be asked whether or not there was a word with a certain characteristic (e.g., a word printed in a certain font color, an emotion word, an animal name, a color word [e.g., yellow] or a specific word [e.g., red, happy, or elephant]). In other cases, the participant may see the whole series before they are told what the target was and then are asked to respond. It is more common for the target(s) to be specified prior to presentation of the series, and this method tends to increase accuracy and be easier for participants. In cases in which the researcher wants to ensure that the participant processes all items (including distractors), they may want to use the technique of giving the target after the RSVP stream has been presented.
Participants can also make responses about target identity rather than simply target presence (see Figs. 4.3 and 4.7 for examples). In this case, the participant would be asked about the identity of an item with a certain characteristic or in a certain position (e.g., what word was printed in red? or what word came directly after the green X?). Again, they may be told before the trial about what to be looking for. Researchers using RSVP to study attention should select the performance measure that best suits their research questions. It is important to note that it is certainly possible to use several of these tasks in combination, with several targets that may be similar or different. The empirical work in the following sections uses variations on these performance measures to examine important effects such as repetition blindness and the attentional blink.

Repetition Blindness

*Repetition blindness* (RB) refers to the effect in which participants show low accuracy in reporting the second instance of an item within one RSVP stream (Kanwisher, 1987). The effect was first shown where the second target was identical to the first. For example, when presented the sentence: *Sally wanted the ball, but the ball was lost*, participants would be less accurate at reporting the second instance of the word *ball*, as compared to the first instance (see Fig. 4.6). The second instance of the target word may appear 300 ms after the first one, for example. Control conditions
without repeated words are also used as a comparison for accuracy. These control conditions often substitute a logically consistent word for one of the instances, such as: Sally wanted the ball, but the ball was lost.

RB is generally defined as the deficit in accuracy of reporting the target word when it is repeated, as compared to the control word substitution (MacKay, Hadley, & Schwartz, 2005). There are certain procedural requirements to produce a true RB effect. In terms of presentation limits, the RSVP stream must be presented for no more than 200 ms per item as slower presentation rates reduce or eliminate the effect (Coltheart & Langdon, 2003). Additionally, the second target must appear less than 500 ms after the first target. However, limited presentation time or delay between targets is not the only procedural element required to produce an RB effect. Whittlesea and Masson (2005) conducted a study with several different types of distractors between targets. They used presentation durations that had previously produced RB, but instead of using words as distractors, they used conditions with symbol strings (e.g., *%&^%&^*), and with all fillers being the word white. The timing of each item in the RSVP stream remained constant across all these conditions, but performance was much better in the symbol strings and white filler conditions than when the fillers were random words. With distractors that lack meaning (i.e., symbol strings or repetitions of the same word), noticing the repeated words was too easy. These results imply that meaningful distractors are necessary to obtain an RB effect.

Once the effect was established, additional work sought to find the limits of how far it would generalize. Several theories variously emphasized whether repetition
blindness would be experienced when the two targets matched on lexical, phonological, orthographic, or semantic characteristics. Evidence for orthographic-based repetition blindness comes from studies that use targets that are orthographically similar, but phonologically and semantically dissimilar (Bavelier, Prasada, & Segui, 1994; Kanwisher, 1991). Stimuli from such studies could substitute one or more letters that change the phonology of the word (e.g., change-charge, rod-rid) or use subparts of the word that are phonologically distinct when presented in isolation (e.g., chunk-hunk, with-wit). However, pronounceable nonwords (e.g., gerb or sath) that are orthographically plausible do not show RB and in fact show priming effects (Coltheart & Langdon, 2003). Thus, while orthographic RB is a replicable effect, it may require real lexical stimuli. In a study demonstrating RB effects for Chinese characters, Yeh and Li (2004) also showed RB for nonidentical characters that shared sublexical repeated components (i.e., a system of lines in the same location and orientation in two different characters that do not constitute a complete character on their own). RB effects have also been obtained for word pairs that match phonologically, but not orthographically (Bavelier & Potter, 1992). This effect has been shown in several forms (e.g., 6-six, 1-eye, fancy-FANCY). An interesting way to further test the RB effect is to use a cross-modal type task, similar to that used in priming work (e.g., Stewart & Heredia, 2002; see also Chaps. 6 and 10), to present one of the repetitions in the opposite mode (i.e., a spoken word inserted in a printed RSVP sentence). Obtaining RB even when the repeated word was presented in two different modes would provide evidence that physical form is less important than phonological or conceptual similarity, though Soto-Faraco and Spence (2002) did not find evidence of cross-modal RB. This methodology could also be applied to bilingual research. In summary, RB effects are found with stimuli that occur less than 500 ms apart, are separated by meaningful distractors, and can be found with repeated orthographic elements.

Some semantic representations, such as emotionally arousing words like taboo or sexual words, may capture attention more so than neutral words and change patterns of RB. When using taboo stimuli, MacKay et al. (2005) found that if the second target was a taboo word, there was a reduction in RB; however, if instead, the first target was the taboo word, there was an increase in the effect. The results of this experiment mean that regardless of the position in which they appeared, taboo words drew the attention of the participants. This heightened attention increased the processing of that word and decreased the processing of other surrounding words. Silvert, Navetuer, Honoré, Sequiera, and Boucart (2004) examined whether a category united by an affective semantic category like negative emotional words (e.g., war or murder) would produce a greater repetition blindness effect than a neutral semantic category like animals, or neutral words not related by a semantic association. Silvert et al. (2004) supported their hypothesis that negative targets would produce a greater difference between streams that contain targets and controls. This suggests that RB is decreased for negative emotional words in comparison to neutral words.

Knickerbocker and Altarriba (2013) more clearly specified RB effects for emotional stimuli by showing that words that describe an emotional state (e.g., love,
hate) created significantly greater repetition blindness than either neutral words or emotion-laden words that evoke an emotion while not describing it (e.g., puppies, cancer). These results imply that emotion and emotion-laden words are separate categories of words that capture attention differently. Other work using emotional words should thus be conscious of this distinction. In a different semantic manipulation, Arnell, Shapiro, and Sorenson (1999) showed that under a variety of task conditions, individuals consistently showed a reduced RB effect when their own name was the target as compared to conditions where another name was the repeated target. The results here suggest that increased meaning and familiarity for one’s own name in comparison to other common names can capture attention even when repeated. Research investigating semantic repetition blindness using monolinguals supports the notion that some types of semantic items such as words that describe emotion states, words that evoke emotions, taboo or sexual words, or something as simple as one’s own name actually reduce the RB effect.

However, the most interesting examinations of semantically based RB show the valuable use of bilingual participants in research. In a number of studies, proficient bilinguals were used to test semantic RB with translation equivalents (e.g., horses and its Spanish translation caballos) instead of the within-language synonyms that had been previously used (e.g., mad and its synonym angry). MacKay and Miller (1994) used cross-language translations as a stronger test of semantic RB. They argued that although within-language synonyms like those that Kanwisher and Potter (1990) had used did not produce RB, cross-language translation equivalents would produce RB. MacKay and Miller (1994) theorized that synonyms are never exactly equivalent in meaning and may have restricted finding a true semantic RB effect. Thus, MacKay and Miller used sentences that mixed Spanish and English and contained several types of target pairs: exact matches (e.g., duck-duck), translation matches (e.g., duck-pato; pato is the Spanish translation of duck), and non-matched cross-language pairs (e.g., duck-vaso; vaso is the Spanish translation of cup or glass). An example of a sentence with a translation-matched word was, They saw horses, but caballos were prohibitir [sic] to enter, with They saw sheep, but caballos were prohibitir [sic] to enter serving as a control sentence. The sentences were mixed in terms of language and presented at 70 or 90 ms per word. The target pairs were separated by one to two words. The performance measure used here was full report and showed an RB effect for the translation pairs. The authors concluded that cross-language translation pairs can produce semantic RB. Cross-language RB would support the notion that words have very similar concepts even when translated. This conclusion is based on common explanations for RB that differentiate between “type” concepts and “token” instances (Kanwisher, 1987). When words are repeated in an RSVP stream, the concept (type) of the word is noticed and remembered, but individuals do not remember two separate instances (tokens) of that concept appearing. If cross-language translation pairs produced RB, it can be concluded that the translations were understood to be the same concept, even though their physical spelling is different. Data supporting cross-language RB would imply a strong conceptual similarity for translations across different languages.
Altarriba and Soltano (1996), however, argued that MacKay and Miller's (1994) results were driven by methodological issues. Their main criticisms targeted the low overall performance by the participants and argued that it was driven by the non-grammatical mixing of languages in the sentence stimuli. Proficient bilinguals do engage in language-mixing or code-switching (Heredia & Altarriba, 2001); however, true code-switching has consistent rules. A language switch often occurs at the boundary between two phrases or subparts of the sentence that are relatively independent. For example, a proficient bilingual might say, *My car is broken, entonces monte en bicicleta* (which translates as *My car is broken, so I ride a bicycle*). The example is a sentence that retains grammaticality in the appropriate language: English in the first phrase and Spanish in the second phrase. MacKay and Miller's (1994) materials often switched languages within a phrase instead of between phrases, and also violated grammaticality within a phrase. For example, *They saw horses, but caballos were prohibir to enter, includes an incorrect spelling (present tense of prohibit in Spanish is prohibir, not prohibir which in fact is not a real Spanish word) and also changes languages at locations other than phrase boundaries. An appropriate correction could be, They saw horses, pero caballos eran prohibidos a entrar. Additionally, caballos were prohibir to enter translates as horses were to prohibit to enter. A more appropriate translation would use “prohibidos” to replace the English “prohibited.” These violations of commonly followed language-mixing conventions and of Spanish grammar may have been difficult for participants to follow and led to the overall low accuracy.

Given these critiques, Altarriba and Soltano (1996, Experiment 1) created sentences with more naturalistic switch points, but retained the same word pair types as MacKay and Miller (1994) in addition to new cognate (e.g., *imagination-imaginación*) and noncognate translations. Altarriba and Soltano (1996) also used a full report as a performance measure. There was no repetition blindness effect obtained across languages, in contrast to the within-language identical pairs. In Altarriba and Soltano's Experiment 2, lists of three mixed-language words were presented interspersed with symbols in an RSVP sequence in order to create a condition with lower working memory load. The translation pairs with the word lists that were noncognates actually showed increased recall, or facilitation, which was unexpected based on MacKay and Miller (1994). These pairs showed 13% better recall than unrelated mixed-language pairs, implying that reading the translation of a word in another known language *facilitates* attending to it later in an RSVP stream (cf. Sánchez-Casas, Davis, & García-Albea, 1992).

MacKay, Abrams, Pedroza, and Miller (1996) disputed some of Altarriba and Soltano’s (1996) results, based on several procedural elements (see MacKay et al., 1996). These procedural choices included the unequal word length between the first and second targets and the choice to use base recall rates instead of conditional recall. Additionally, language switches were predictable because languages were switched at phrase boundaries. This predictability could be potentially problematic if it increased the salience of translations in the sentences used in Experiment 1 and reduced repetition blindness. Mackay et al. later attempted to address some of these issues specific to Experiment 2 with improved procedures (MacKay, James, &
Abrams, 2002). An additional manipulation included first targets with either many possible translations or few possible translations. MacKay, James, and Abrams (2002) found cross-language facilitation (improved performance) for the pairs that included a first target with many possible translations, but this effect did not extend to cross-language pairs in which the first target had only one possible translation. They concluded based on their conceptual replication of Altarriba and Soltano (1996) that cross-language semantic repetition blindness rarely occurs and was possibly caused in MacKay and Miller (1994) by ungrammatical language mixing in their sentences.

The specific procedural choices made by each set of authors were instrumental in narrowing down the restriction of semantic blindness effects to salient words (i.e., emotion words or one's own name, as noted above) and not merely typical word equivalents such as within-language synonyms or cross-language translations. The evidence so far does not support a general semantic RB across languages and implies that, though translation pairs share some conceptual basis, they are still maintained as separate instances in one's mental representations (unlike exact repetitions within one language). While word translations are based on similar conceptual representations, the different physical and lexical properties of the words seem to limit the RB tendency to lump two instances under the same conceptual type at the expense of storing two separate instances.

The theory and work presented in this section dealing with RB effects in monolinguals and bilinguals highlight similarities between word pairs. Within monolinguals, repetition blindness can occur for words with similar orthography and vary in relative size based on semantic factors. Bilingual research using RSVP methodology in this manner allows for strong tests of semantic RB effects based on shared concepts for the two targets, but different orthographies (i.e., different languages). Studies to date conclude that semantic blindness does not tend to occur in cross-language translation equivalents in sentences and that facilitation is actually shown when the words appear in lists. Future research should examine whether different semantic relationships, such as names or emotion words that have been shown to reduce repetition blindness in some monolingual contexts, are possible to extend in a bilingual context, in either sentences or lists.

The Attentional Blink

Another predominant use of RSVP in attention research is the attentional blink (AB) paradigm. In this method, a series of stimuli (e.g., words, letters, digits, or a mix of both) are presented quickly one at a time. In Fig. 4.7, one can see an example of possible AB stimuli. In the figure, lag describes the relative delay of the second target (T2) after the first target (T1). The performance measure in these experiments is a target monitoring task. In this task, participants are asked to detect or identify two specific targets within the series. When the second target (e.g., knife in Fig. 4.7) is presented closely after the first (love), participants are less accurate at detecting
Fig. 4.7 An RSVP stream for the attentional blink effect with targets 1 and 2 (love, knife) in red and a 300 ms interval between targets (Lag 3).

and reporting the second target, which is referred to as the AB. The name references a metaphorical eye blink in attention, causing something to be missed.

AB is revealed when Target 2 (T2) and Target 1 (T1) accuracy are compared across trials with various time delays between T1 and T2. There are specific temporal limits to the AB. The relative position in the RSVP stream, and hence the time delay, is referred to as lag. Lag is defined in reference to the first target. That is, there is a lag of two items between T1 and T2. Most previous research has used a presentation rate of 100 ms per item in the RSVP stream, though the rate can vary slightly (MacLean & Arnell, 2012). Thus, an item presented at Lag 1 is the next item after the first target (T1) and appears 100 ms after T1. An item at Lag 2 is two items after T1 and appears 200 ms after T1, etc. When the first target appears (T1), if the second target (T2) appears more than 200 ms, but less than 500 ms after the T1, individuals are less accurate at reporting T2 (see Fig. 4.8). Historically, this effect was first reported by Broadbent and Broadbent (1987), and the term was coined by Raymond, Shapiro, and Arnell (1992). Additionally, the effect has been consistently replicated (see Dux & Marois, 2009 for an extensive review). AB has been used to study attentional processes and conscious perception.

AB is an attentional deficiency that is not merely a limit of sensation, but one of conscious perception. The attentional nature of this effect has been shown through carefully controlled conditions, such as in Raymond et al. (1992). In this study, an RSVP task was presented with two targets within the stream, as is typical in the AB paradigm; however, participants were given instructions to ignore the first target (T1). The results revealed that participants showed high accuracy for reporting the
second target (T2). When an identical series was presented to other participants with the instructions to attend to and report the first target as well, accuracy was severely reduced for T2. All elements remained the same from control to experimental trials, with the exception of whether the T1 was purposefully attended to or not. If AB were based only in sensory limits, T2 would still have reduced accuracy whenever T1 was present, even if T1 was ignored. However, empirical results from Raymond et al. (1992) showed that T2 accuracy was excellent when T1 was ignored, so it is possible to conclude that the AB is caused by attentional limits (limitation of the ability to direct attention to the second target soon after the first), not by sensory limits (if sensation were limited, it would be impossible for participants to ever see the second target regardless of task instructions).

Theoretically, a general selective attention model is most useful. When the first target (T1) appears, the individual must attend to it; however, this selection takes up much of the available attentional resources from later targets. Additionally, the process of inhibition (of further distractors) magnifies this effect. The participant prioritizes processing the target and blocks subsequent stimuli from entering further processing. A model that is only based on limited-resource notions of attention cannot account for situations in which AB is diminished through experimental manipulations.

Olivers, van der Stigchel, and Hulleman (2007) constructed an experimental condition in which more than two targets appeared in succession (see Fig. 4.9 for an example with four consecutive targets) and resulted in strong attenuation of AB. The same amount of resources would have been dedicated to the first target; however, since the next items in the RSVP task were targets instead of distractors, the subsequent targets were not inhibited. Also, Di Lollo, Kawahara, Shahab Ghorashi, and Enns (2005) defined their target as a string of three digits (each presented one at a time) and also showed reduced AB as compared to trials in which the string was interrupted by a distractor (see Fig. 4.10 for an example with the target defined as three specific digits presented consecutively). This result suggests that it
Fig. 4.9  An RSVP stream from Olivers, van der Stigchel, and Hulleman (2007) measuring Aβ for consecutive targets, *love, flower, knife, and tail* (in red color)

Fig. 4.10  Example from Di Lollo et al. (2005) of an RSVP stream of digits with the target defined as a three digit sequence (*3-0-8*)
is certainly possible to continue attending to multiple items in an RSVP task, but this only occurs when the items are targets or part of a target sequence. To explain such data, one must also include the selective and inhibitory processes that are initiated in reaction to the instructions to report certain stimuli only (the targets). If another target occurs within the time window of these processes (i.e., from 500 to 600 ms), it is less likely to be reported.

The AB effect is found by comparing T2 report performance at various delays after presentation of T1. At least two targets are necessary along with distractor items; however, it is also possible to use more than two targets. In order to analyze whether AB has occurred, there must be at least two trial types that vary the T2 delay from T1. A true AB occurs when performance diminishes at short lags, but accuracy increases to near control levels at longer lags (average T2 accuracy is insufficient to show whether AB has occurred). Researchers using the AB paradigm should choose one lag that is within the time window of AB impairment (200–500 ms) and one lag that is somewhat longer for comparison. The required performance measure task for Target 1 and Target 2 do not have to be the same although it is preferable that they be the same if comparison between T1 and T2 performance overall is desired (MacLean & Arnell, 2012). These basic requirements established through work on monolinguals are critical for bilingual research, as well. To summarize, the presentation rate ought to be approximately 100 ms per item, T1 and T2 should occur with a short lag and be compared to a long lag, and analysis must be based on the relative decrease in accuracy for T2 at short lags.

Experimenters use the AB paradigm for within-subjects designs comparing different word types as stimuli or between-subjects designs to examine individual differences (Willems, Wierda, van Viegen, & Martens, 2013) such as age (Georgiou-Karistianis et al., 2007; Lahar, Isaak, & McArthur, 2001), and video game experience (Green & Bavelier, 2003) just to name a few. Of special interest here is the case of bilinguals as compared to monolinguals or comparing bilinguals of varying proficiency.

In the context of studying effects of bilingualism, researchers may treat bilingualism as a dichotomous variable (having two separate categories) and compare participants who are roughly equal in all other ways except language experience. Alternatively, one can measure bilingual experience in some numerical way (e.g., proficiency score, total years of use, age at first use of L2, etc.) and correlate the bilingualism score with a measure of AB. If the first, dichotomous conception of bilingualism is preferred, the appropriate measure of whether the AB is different for the two groups is a two-factor design and analysis should look for an interaction between lag effects on T2 performance and group. A main effect of group would merely indicate a difference in overall T2 performance without necessarily changing the AB effect. If a more numerical rather than dichotomous measure of bilingualism is preferred, correlational methods are more appropriate for analysis. Correlations or regressions may be a more appropriate choice in many cases, as speakers can range from entirely monolingual (i.e., no ability to speak or comprehend any parts of any other language other than the native language) to multilingual with high fluency and proficiency in all languages spoken (Polinsky & Kagan, 2007; see MacLean and Arnell, 2012, for a discussion of statistically appropriate measures of the attentional blink).
In relation to bilingualism, Colzato et al. (2008) compared monolinguals with bilinguals in a traditional AB task and established that bilinguals were found to have a larger attentional blink than monolinguals (see discussion below). Based on Colzato et al.'s (2008) findings, Khare, Verma, Kar, Srinivasan, and Brysbaert (2012) sought to clarify the change in AB magnitude as a function of the time course of bilingual proficiency. Khare et al. (2012) used Hindi-English bilinguals of varying English proficiency living in India, as participants and found that higher proficiency bilinguals showed a larger relative AB at short lags when compared to lower proficiency bilinguals. These results support Colzato et al.'s (2008) previous conclusions that bilingual proficiency increases AB and extend them by showing that increased AB in bilinguals is not related to age of acquisition. AB effect research in bilinguals should continue to explore the limitations and basis for differences from monolinguals. We return to this issue in the “Executive Control” section.

Emotional AB

An important manipulation of stimuli characteristics in previous research in the AB paradigm has been to systematically vary the emotional valence (positive or negative) and arousal (how intense the word is or how physiologically aroused it makes the reader feel) of the target and distractor words. This line of work has produced interesting results referred to as the emotional attentional blink (EAB; see McHugo, Olatunji, & Zald, 2013 for a review). Highly arousing words, particularly taboo or sexual words, have shown results consistent with stimulus-driven attentional capture, as a variety of studies have found that participants attend to emotional words regardless of their relevance to the task’s goal. In stimulus-driven attentional capture, features of the stimulus itself (such as valence or physical attributes like color or font) draw an individual’s attention without higher-level intention to direct their focus to that feature of the stimulus. In this case, the valence and arousal of a distractor is not relevant to identifying targets, but the emotional distractor is attended to regardless. In some instances in previous work, the emotional words appeared as distractor words and caused target words to be missed (e.g., Arnell, Killman, & Fijavz, 2007) and in others, the emotional words appeared as targets (specifically, T2s defined by ink color) and reduced attentional blink effects (e.g., Anderson, 2005). In both types of results, the emotionally arousing blink stimuli captured attention despite task irrelevance.

Several researchers have chosen the EAB task to study bilingual emotion and language processing. Specifically, previous research has examined the effect of bilingual experience on EAB (Colbeck & Bowers, 2012). Colbeck and Bowers (2012) used Arnell et al.’s (2007) methodology using taboo/sexual words as distractor words prior to the presentation of an unrelated target word defined by ink color. Results with monolinguals had shown increased AB in conditions that featured the taboo/sexual distractors as compared to neutral control words (Arnell et al., 2007). Participants in Colbeck and Bowers’ (2012) study were English monolinguals or
Chinese-English bilinguals of high-language proficiency. They found that while all of their bilingual participants had shown high proficiency, the EAB was reduced when compared to the English monolinguals. The authors concluded that length of bilingual experience, rather than proficiency, predicts the attention-capturing effects of emotionally arousing words, implying that a late-acquired L2 has less emotional strength than an L1. Clearly, additional research is required with bilingual participants of varying proficiencies, years of experience, and number of known languages. One possible confound in Colbeck and Bowers (2012) is based on the years of experience and age of acquisition among their bilingual participants. The bilingual participants not only learned English at a later age than the monolinguals but also have been speaking English for fewer years. Thus, while Colbeck and Bowers’ conclusions were based on the length of bilingual experience, the participants also had less experience with the test language (English). Additional participants could include proficient bilinguals whose first language is English (equal English experience to the monolinguals and greater bilingual experience), or those who had been bilingual from a young age (equal English experience to the monolinguals and much greater bilingual experience).

Executive Control

While linguistic and attentional factors can be assessed using the RSVP paradigm, this task has also been used by researchers to evaluate executive control. Executive control is part of working memory and Baddeley’s model of working memory is the most commonly used in cognitive psychology. It defines working memory as the system necessary for holding and manipulating information while performing a wide range of tasks... (Baddeley & Della Sala, 1996, p. 1398; see also Baddeley & Hitch, 1974). Executive control can also be conceived of as the ability to intentionally direct attention and keep relevant information to the task at hand readily available (Carlson & Wang, 2007). Thus, when we refer to information being in working memory, it refers to information that is readily available. Inhibitory control refers to the ability to control potentially interfering thought processes and actions...such as suppressing a dominant response in accordance with rules (Carlson & Wang, 2007, p. 489). Inhibitory control is important in situations in which distractors are highly salient and responses to them need to be inhibited in order to increase accuracy in responses to correct targets. Individuals select certain information from the environment to attend to (essentially at the expense of other less important or distracting information) and keep that chosen information active and ready to be used in current and future processing.

Working memory and inhibitory control are involved in efficient processing in the RSVP task. Participants must keep their attention narrowly focused on the briefly presented words, for if attention strays, they will not read words that were presented while their attention wandered. Additionally, working memory is required to keep all previously read words in the stream active in order to construct a coherent
sentence out of the individually presented stimuli. Due to working memory and inhibitory control being so closely involved, the RSVP paradigm has been used to study executive control in both monolinguals and bilinguals.

Several studies (Akyürek & Hommel, 2006; Arnell, Stokes, MacLean, & Gicante, 2010) have used RSVP methods and other executive control tasks to narrow in on the contribution of executive control abilities to RSVP performance. These studies, generally testing monolingual participants, have tested the same participants on several types of tasks and give a sense of the relative contributions of executive control and reading abilities on an individual’s performance on RSVP tasks. Akyürek and Hommel (2006) used a dual task to test the role of working memory in RSVP processing and particularly the AB effect, previously examined in this chapter. Figure 4.11 shows the procedure for this study. Initially, all of their participants were presented with a set of items prior to the RSVP task, but varied in whether they had been instructed to remember the initial set of items or ignore them (the far left stage of Fig. 4.11). All participants then completed the same RSVP task measuring the AB (the center stage of Fig. 4.11). Finally, those instructed to “remember” the initial set of items completed a memory test after the RSVP stream. Thus, half of their participants completed the RSVP task with additional memory load and half did not.

Akyürek and Hommel (2006) found a main effect of memory demands on identification of targets in RSVP, with increasing interference (i.e., decreased accuracy in target identification performance) with a larger number of things to remember, but they did not see a change in AB magnitude (i.e., the relative performance deficit based on delay between the targets). While the mean accuracy was worse when participants had to remember more items, it did not change the relative difference in performance at various delays between the first and second target. This means it is overall more difficult to perform the target identification task when one is also holding items in working memory than without memory load. However, it is no more relatively difficult to identify the second target at a given lag from the first target under the working memory load. These results led the authors to conclude that working memory storage capacity is related to general RSVP performance, but it does not change the specific time-based attentional blink effect.

Arnell et al. (2010), however, tested participants on a similar RSVP task along with three different working memory tasks requiring an increasing degree of active manipulation of the items in working memory. The first was the forward-digit span in which a set of digits was presented and after a short period of time, the participant
was asked to report the digits in the same order in which they were presented. For example, the participant may have been given the series, 2-7-8-5-3-3-9, and to answer correctly, they would respond by repeating the original digits in the same order of presentation. The second was the backward-digit span, which is similar in procedure to the forward-digit span, however, the participants were asked to report the previously presented digits in the reverse temporal order from which they were presented (e.g., 9-3-3-5-8-7-2). Finally, the Operational Span (O-Span) task was used, in which the participants were given one letter to remember after completing one math problem (Turner & Engle, 1989). For example, the participant may have been given the multiplication $8 \times 3$ and after they correctly responded 24, they received the letter $g$ for later recall. Next, they may have solved the equation $87 - 34$, and received the letter $p$ for later recall. At the end of the series, the participant was asked to recall the series of letters they were asked to remember, in the order of presentation (e.g., $g, p$). O-Span is a strong measure of working memory because participants cannot engage in strategies such as rehearsal, as they are also solving math problems typically with minimal accuracy. Arnell et al. (2010) found a similar effect of memory load on RSVP performance, but only on the working memory test requiring the most executive control. O-Span was predictive of the attentional blink magnitude. That is, these results suggest that executive control is important to the attentional blink task beyond simple memory abilities. Thus, it is clear that the relationship between the RSVP paradigm and executive control is fairly complex.

This element of executive control in the RSVP paradigm is an important tool in examining questions of differences between monolinguals' and bilinguals' executive control capabilities. A body of research has revealed that bilinguals' lifelong practice with actively selecting one language and inhibiting another increases their general inhibitory control capacity (e.g., Prior & MacWhinney, 2010). Abutalebi and Green (2007) argued that the proposed bilingual advantage occurs because bilinguals manage both languages and select one to actively use at a time. This active selection of one language and inhibition of the other is analogous to an exercise for bilinguals' general executive control skills. Essentially, selection and inhibition of language transfers to some other related, but nonlinguistic tasks.

These differences have been examined using a variety of tasks including the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Bialystok & Martin, 2004; Simon & Ruddell, 1967), in which participants are presented with one of two possible target stimuli, and are instructed to press a particular key when each stimulus is presented (see Fig. 4.12). For example, if the target stimulus is a $z$, participants may be required to press the $z$ key on the left side of the keyboard, but when a symbol such as the / (forward slash) appears, they must press the / key that is on the right side of the keyboard. The target stimuli can appear in different physical locations, either on the left side or right side of the screen. Inhibitory control is required in order to inhibit the distracting information that is given by a target appearing in the spatial location opposite of the correct response key, as the individual's inclination is to press the key that is in the same spatial location as the target. Individuals who are better able to exercise inhibitory control not only make fewer errors, but also provide the correct response quicker.
when the target appears in the opposite location of the correct key. Those results that use the Simon task to support bilingual advantages (Bialystok et al., 2004, 2008) have found quicker average reaction times for proficient bilinguals when compared to monolinguals or low-proficiency bilinguals.

The *flanker task* has also been used in several versions to investigate possible bilingual advantages (Costa, Hernández, & Sebastián-Gallés, 2008; Luk, De Sa, & Bialystok, 2011). Generally, in this task, participants should attend to a central target stimulus that has one or more “flanking” distractor stimuli (Eriksen & Eriksen, 1974). Inhibitory control is required to suppress the irrelevant information provided by the distractor stimuli and respond only with the response associated with the central target stimulus. For example, arrows are commonly used as both the target and distractor stimuli (see Fig. 4.13). The target stimulus is a centrally located red arrow. Typically, the correct response is to press the left arrow key when the red arrow points to the left, and to press the right arrow key when the red arrow points to the right. This arrow may be presented by itself, or with distractors to either side flanking it. When flanks are present, they are similar arrows; however, they are
black in color and point in a congruent or incongruent direction to the target arrow. In this case, the participant should ignore the black distractor arrows and respond according to the direction of the red arrow just as when the red arrow is presented alone during other trials. Previous research shows that participants are slower to respond when the distractor stimuli point in a direction incongruent with the target stimulus, thus creating what is called the flanker effect. In several studies (Costa et al., 2008; Luk et al., 2011), bilinguals have demonstrated a smaller flanker effect than monolinguals, or in the case of Luk et al. (2011), earlier bilinguals showed a smaller deficit than late bilinguals.

However, these positive results are not without controversy. Such differences can be difficult to replicate in multiple executive control measures (Paap & Greenberg, 2013) or do not extend to all tasks (Bialystok & Martin, 2004; Hernández, Martín, Barceló, & Costa, 2013). For example, Bialystok and Martin (2004) found that bilingual children outperformed monolingual children on a card sorting task that asked children to sort cards on perceptual features (e.g., by color), then change which perceptual feature is used to divide the cards (e.g., shape), but this advantage did not extend to semantic features (e.g., natural categories like animals or fruits). Others find consistent effects, but posit different explanations than inhibitory control differences (e.g., Colzato et al., 2008). The RSVP task may be a helpful tool to investigate these questions because the task can be customized with different executive control and linguistic demands and contribute to a full understanding of bilingual executive control abilities.

One way in which RSVP can be manipulated to test bilinguals’ executive control abilities is to use either low or high-constraint sentences, as defined above. Linck, Hoshino, and Kroll (2008) sought to compare Spanish-English bilinguals’ performance on an RSVP task with their performance on the Simon task. Linck et al. asked participants to name target words that were either highly constrained by the sentence context, or less predictable from the sentence context of a sentence presented through RSVP. Linck et al. examined the latencies to name the target word in a sentence that was entirely in the participant’s L2 in order to test whether sentence constraint had an impact on the interference from the bilinguals’ more dominant L1. The target words were either cognates of English and Spanish, or noncognates. Linck et al. found an interaction between cognate status and sentence constraint such that cognates were only more quickly named than noncognate targets in low-constraint sentences (results were controlled for baseline language proficiency). This result suggests that high constraint in sentence context minimizes the interference or at least the effect of interference from the L1 to L2 processing. Interestingly, the effect of cognate status could be predicted by participants’ scores on a reading span working memory test, but not by the magnitude of the Simon effect. These relationships suggest that reading working memory is more related to interactions with cognate status than executive control abilities.

Colzato et al. (2008) used several tasks including RSVP to test whether the proposed bilingual advantage in executive control is driven by active inhibitory systems that are in place to keep down unwanted responses, or a more general ability to focus on goal-related information instead. They employed an AB task along with
inhibitory control tasks to assess monolinguals’ and bilinguals’ executive control abilities. They found no difference in the tasks tapping largely inhibitory abilities, and a larger AB in the RSVP task. This finding may be counterintuitive based on research showing improved executive control in bilinguals; however, this result is congruent when bilinguals’ inhibitory control advantage is viewed in terms of selecting stimuli relevant to their current goal rather than avoiding irrelevant stimuli. In this experiment, the participants’ goal was to accurately report target stimuli in the RSVP task. Instead of actively inhibiting task-irrelevant stimuli (i.e., the RSVP distractors), bilinguals were better at focusing on the goal task (i.e., target report). Bilinguals’ focus on goal-relevant information is posited to explain why bilinguals performed “poorer” in terms of the AB effect: they had more effectively devoted more attention to the first target at the expense of the second target. Thus, the bilinguals may have been focusing on the goal of reporting the target more effectively than monolinguals, thereby decreasing AB. In other executive control tasks such as the flanker task, the same prioritization of goal-relevant stimuli is advantageous, allowing participants to report the direction of the target arrow without being distracted by the flanking arrows. Further research utilizing the RSVP paradigm will assist in clarifying the distinctions between executive control abilities of monolinguals and bilinguals of varying proficiency.

These few examples of studies examining bilinguals’ executive control abilities using the RSVP task show its potential for future increased use as a different measure of executive control using language as stimuli, as opposed to the shape stimuli used in the flanker task. Researchers interested in using this paradigm in this way can customize the sentence type, target word type, number of target words, modality of response, language blocking, and a number of other elements in order to fine-tune the task specifications to allow for desired comparisons.

**Limitations of RSVP**

In addition to those limitations created by high working memory demands, single word presentation does not allow readers to make regressions to reread words previously presented. A final note that compares RSVP to eye-tracking addresses whether RSVP’s lack of opportunity for regressions is problematic. In RSVP, presenting words one at a time prevents the reader from going back to reaffirm the identity or interpretation of any words. However, in natural reading, individuals often make regressions. Schotter et al. (2014) used a technique called the trailing mask paradigm to empirically test the importance of regressions to comprehension. In this task, participants try to read normally, but once they have moved their fixation past a word, that and all previous words are masked. For example, if the participant was reading the sentence *Bobby walked right past the block on the floor of his messy room*, they would read normally from left to right, and *Bobby* would be masked first. At the point at which they had read up to *block*, the sentence would look like this: *XXXX XXXXXX XXXX XXXX XXXX block on the floor of his messy room*. 
This technique ensures that, although the participant reads left to right in a natural way, they cannot make regressions (or at least they would be uninformative as the words have been replaced with masks) to earlier parts of the sentence. Some of the sentences were garden-path sentences with ambiguous meaning, such as the example above. Others were not misleading, such as when block is replaced with truck in the above example to create the unambiguous sentences *Bobby walked right past the truck on the floor of his messy room*. In this experiment, Schotter et al. (2014) manipulated the ambiguity of the sentence (misleading garden-path sentences or not misleading sentences) and the format of sentence presentation (traditional or trailing mask), and measured the participants’ accuracy for comprehension questions about the sentences.

Schotter et al. (2014) found that participants’ comprehension test answers were more accurate for unambiguous sentences (a main effect of sentence ambiguity), and less accurate in the trailing mask condition (a main effect of presentation format). The interaction of sentence ambiguity and presentation format approached significance ($p = .06$). The authors argued that the statistical null hypothesis for this effect should be retained and that an interaction between sentence ambiguity and presentation format does not exist. The absence of an interaction would support their claims that the ability to make regressions aids comprehension for all types of sentences (not just ambiguous sentences). However, given that the interaction very nearly reached significance, further replications would increase the persuasiveness of their claims. Schotter et al. also showed that in the traditional presentation format condition, the sentences in which regressions were made had equal comprehension performance to those that did not. The results of this study imply that regressions may compensate for poor understanding, and thus, the inability to make regressions in RSVP could make it challenging to read material any more difficult than short sentences.

**Summary and Conclusions**

Within this chapter, an overview of the RSVP methodology has been provided. It has included definitions and explanations of concepts related to this methodology, notes for use in research, and previous work with bilinguals that has employed this paradigm. Specifically, RSVP is most commonly used in bilingual research to study lexical processing, attentional processes including the AB and RB, and executive control. Future research might examine more closely differences in lexical processing and attentional processes as they vary with proficiency and age of acquisition. The initial work that has begun using RSVP paradigms with bilingual participants has often been limited to comparing bilinguals and monolinguals (e.g., Colzato et al., 2008; Wong et al., 2011), though some studies have done very well at teasing these characteristics apart (Khare et al., 2012) or have focused exclusively on bilinguals (e.g., Altarriba et al., 1992, 1996). Another focus of future research should include manipulations of word types and contexts for studies using bilingual
participants. While emotional words are one popular type of semantic manipulation, other characteristics such as animate/inanimate objects, word class (i.e., noun, verb, adjective, etc.), age of acquisition for specific words, or phonological or orthographic regularity would also be intriguing to investigate. This paradigm is a tightly-controlled, interesting way to investigate how bilinguals perceive, read, and attend to verbal stimuli, though it does have some limitations including the effects of memory on performance measures and the lack of regression capability. While to date it has only been used in a limited number of studies with bilinguals, investigators in the field should carefully consider whether RSVP may add to their options of laboratory techniques.

Keywords and Concepts

Attention, Attentional blink (AB), Backward-digit span tasks, Bilingual advantage, Bilingualism, Card sorting task, Cognate, Context effects, Item detection, Emotion, Executive control, Flanker task, Forward-digit span task, Goal-related focus, Homograph, Item identification, Inhibition, Lag, Lexical processing, Negative emotional words, Operational span task (O-Span), Perception, Rapid Serial Visual Presentation (RSVP), Reading, Repetition blindness (RB), Selection, Semantic features, Simon task, Sublexical elements, Target monitoring task, Translation, Valence, Visual attention, Word naming, Working memory

Review Questions

1. Brainstorm a list of advantages and disadvantages for using RSVP instead of a method like eye-tracking or self-paced reading. Include such factors as cost, generalizability, control, and naturalism among what you consider, along with any others that you think of yourself.

2. What other types of words may impact bilingual reading using RSVP? Specifically, given the minimal repetition blindness across languages for most words, might specific types of words induce an RB even across languages?

3. What can individual differences in executive control abilities such as those displayed by bilinguals on some tasks tell us about how these processes work in all populations?

4. Consider recent media attention on RSVP as an everyday reading method for "more efficient" reading. What are some possible advantages and disadvantages to using RSVP in this way? What impact could screen size and sentence difficulty have on reading performance?

5. What does bilinguals' good performance on high-constraint sentences vs. low-constraint sentences say about how they are accessing their two languages?
Suggested Student Research Projects

1. Use the RSVP applet (See Related Internet Sites below) to create an RSVP experiment. Enter words or letters into the applet. Have a friend or a classmate participate in the experiment, and then ask them to report back to you what they saw. Run the experiment once more, but this time, ask a different participant to locate just one or two specific words or letters. Repeat the experiment several times with different participants, using different items. How accurate are participants at perceiving the target items? Do you see differences based on whether participants are reporting the whole sequence or just one item? Ask them about their experience.

2. Translate some of the words from your lists from the first project into another language (or ask a proficient speaker to do this) for a new set of mixed-language lists. Find a bilingual participant who speaks both languages used in your stimuli and replicate the identification task described in the first project. How accurate are they at reporting targets written in the same or different language as the rest of the target words in the list? Are they better at reporting target words from their dominant language (ask your participant which language they feel more comfortable using)? If you can, repeat the experiment with another participant who speaks the same two languages, but has the opposite dominant language as your first participant.

3. Previous research has shown that taboo words (i.e., expletives) used as distractors create a larger attentional blink and that this effect is greater for the bilinguals’ more proficient language. This may be considered an emotional attentional blink for negatively valenced, high arousal words. Design a study that tests whether the emotional attentional blink generalizes to positively valenced emotional stimuli. Consider what type of target stimuli and what type of distractors to use. How would you test if the same pattern of results is found for more and less proficient bilinguals?

Related Internet Sites

Attentional Blink: http://www.scholarpedia.org/article/Attentional_blink
Attentional Blink Experiment: http://psych.hanover.edu/javatest/cle/cognition/cognition/attentionalblink2_instructions.html
Reading and RSVP: http://jhenderson.org/vclab/Blog/Entries/2014/3/7_Am_I_Reading_This_Right.html
RSVP applet: http://www.mscottreynolds.com/MyRSVP.html
Speed reading: http://www.huffingtonpost.com/2014/02/27/spritz-reading_n_4865756.html
Suggested Reading


References


