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Improving reading rates and comprehension? Benefits and limitations of the reading acceleration approach

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Abstract

The reading acceleration phenomenon refers to the effect that experimentally induced time constraints can generate instantaneous improvements of reading rate, accuracy and comprehension among typical and reading impaired readers of different age groups. An overview of studies applying the fading manipulation (i.e., letters are erased in reading direction), which induces the time constraints causing the acceleration phenomenon, is provided in the first part of this review. The second part summarises the outcomes of studies using a training approach called the reading acceleration program (RAP) that integrated core principles of the acceleration phenomenon to generate persistent reading performance improvements. Our review shows ample evidence for the validity of the acceleration phenomenon, since it has been replicated across various languages and populations. However, although there are several explanatory approaches for underlying mechanisms, none of them is well substantiated by empirical evidence so far. Similarly, although generally positive effects of RAP

training were reported for several languages and groups of readers, the exact mechanisms causing improved reading rates and comprehension are not well understood. Our critical discussion points out several limitations of RAP that call for further research. However, we also highlight several benefits regarding RAP's potential as an intervention approach for enhancements in reading performance. Video abstract link: https://youtu.be/wO6aEXavk8w

Given the particular importance of good reading skills in current academic and professional settings, the investigation of reading rate (i.e., number of words or letters read per time unit; Brysbaert, 2019; Meyer et al., 1999) and reading comprehension (i.e., accessing and constructing meaning from written text; Johnston et al., 2008) represents a research field of high social and economic significance. In particular, the relationship between reading rate and the complex process of comprehension, which requires the coordination of multiple levels of language and cognitive functions (Landi & Ryherd, 2017), has been in the centre of interest for empirical and theoretical research questions.

Theoretical frameworks, such as information processing models, define reading proficiency as 'effective reading speed', characterised by a correct understanding of semantic content (i.e., comprehension) and high reading rates (Perfetti, 1985). In this line of research, exposure to print and practice are expected to lead to more automatic processing, which enables the reader to identify and coordinate words into phrases without expending much attention to this process (LaBerge & Samuels, 1974). Attention can be reallocated, and cognitive capacity is released for higher-order processing. Automatic and efficient processing strengthens the path to long-term memory content, which in turn fosters the direct lexical retrieval of meaning from text, resulting in high reading comprehension performance (Woltz & Was, 2006, 2007). In other words, increasing reading rates are a contributing cause of improved reading comprehension (Kuhn & Stahl, 2003; O'Connor et al., 2007). In contrast, slow word recognition is associated with slow reading rates (O'Connor et al., 2010). However, the relationship between reading fluency and comprehension is not necessarily stable over time (Paris & Stahl, 2005); and the direction of the causal association between reading fluency and comprehension is still a matter of debate (Rasinski et al., 2006).

Independent from theoretical considerations, a growth of evidence supports the notion that slow reading rates are a major component of reading difficulties (Kuhn & Stahl, 2003; Ziegler et al., 2003). However, reading rate and comprehension are also influenced by linguistic features. For example, word length and frequency (i.e., occurrence counts in large text corpora) affect the speed at which single words are recognised (Gagl et al., 2015; Kliegl et al., 2004). Also, text length and difficulty affect not only reading times, but also—depending on an individual's reading rate—the level of comprehension accuracy (Carver, 1997). Furthermore, the transparency of a given orthography (i.e., consistency of grapheme-phoneme correspondence) affects the ease of developing automatisation. As word length and frequency are closely related (i.e., frequent words are often shorter) and orthographic characteristics comprise specific challenges (e.g., reading accuracy difficulties are more frequent in opaque than in transparent

orthographies) linguistic effects should be considered when aiming at observing or fostering reading performance. Across orthographies, reading rate has often been claimed to be an outcome variable depending on the effectiveness of word recognition skills and comprehension (Carver, 1990; Gough & Tunmer, 1986). However, the research line outlined in the following suggests that individual reading rates should be considered as an independent variable that can be manipulated experimentally (Breznitz & Berman, 2003).

1 | THE ACCELERATION PHENOMENON

More than three decades ago, Breznitz (1987a) demonstrated that participants who are artificially pushed to read faster improved their reading rate, accuracy and comprehension compared to their self-paced[1] reading performance. This perhaps counter-intuitive finding is referred to as the *acceleration phenomenon* and has been repeatedly replicated, see Table 1 for an overview.

The paradigm typically used to examine the effects of the experimentally manipulated reading rate on reading performance follows a three-condition within-subject design. In Condition 1 (self-paced 1), participants read items (e.g., sentences or paragraphs) presented on a computer screen at their individual reading rate; and the time required for reading is measured individually. Subsequently appearing multiple-choice questions query for comprehension. For reading aloud, decoding errors are registered as a reading accuracy measure. During Condition 2 (fading), parallel forms of reading items are read under fading conditions; text is erased from the computer screen in reading direction letter by letter at a fading rate[2] usually determined by the fastest measured reading rate in Condition 1. Letter-wise fading usually measured in units of milliseconds per letter is intentionally implemented, because word length effects are thus effectively controlled for. In Condition 3 (self-paced 2), participants read parallel forms of reading items again without fading. This single session experimental design typically yields an effect pattern in which participants enhance their reading performance in the fading condition, but revert to their initial reading rate during the second self-paced condition. The term acceleration phenomenon (i.e., enhanced reading performance) refers, thus, to a momentary phenomenon observable in the fading condition of the three-condition within-subject design (Nagler, Lindberg et al., 2016). However, repeated exposure to the fading condition may lead to long-term changes in reading behaviour. Results of studies, which integrated the fading procedure into a training approach, will be presented in the training section of this article.

2 | DIFFERENTIAL ACCELERATION PHENOMENON EFFECTS

Several studies investigated the acceleration phenomenon applying paradigm variants to different age groups, languages and reading proficiency levels, that is, typical readers (TRs) or readers with reading difficulties (RDs), which will be introduced in the following.

Age groups: The earliest reports on acceleration phenomenon effects come from studies investigating children's oral reading behaviour in single session experiments (Breznitz, 1987a, 1987b, 1988, 1997a, 1997b) as well as longitudinal research (Breznitz, 1997c), showing significant reading improvements in the fading condition. Studies investigating university students' silent reading performance reported similar effects of improved reading performance under fading compared to self-paced conditions (Breznitz et al., 1994; Breznitz & Leikin, 2001; Karni et al., 2005; Leikin & Breznitz, 2001). The acceleration phenomenon seems therefore valid for

TABLE 1 Overview of studies investigating the acceleration phenomenon

Reference	Study focus	Sample	Age	Language
Bar-Kochva and Hasselhorn (2015)	Silent reading acceleration phenomenon study introducing different orthographic fading units (lexical, sublexical or nonlexical)	$N = 63$ ($n = 29$ RD)	5th Grade	German
Breznitz (1987a)	Oral reading	$N = 161$ (all TR)	1st Grade	Hebrew, English
	Experiment 1: Assessment of fading effects on Israeli children	$N = 20$ (all HSES)		
	Experiment 2: Assessment of slow fading effects on HSES Israeli children	$N = 40$ ($n = 20$ LSES)		
	Experiment 3: Effects of deliberate errors on accuracy and compression in acceleration phenomenon paradigm	$N = 61$ (all TR)		
	Experiment 4: Cross cultural replication of fading effects on American children			
Breznitz (1987b)	Oral reading acceleration phenomenon study with children from lower versus middle-class background	$N = 100$ ($n = 50$ LSES)	1st Grade	Hebrew
Breznitz (1988)	Oral reading inclusion of pictorial distractors during self-paced and fading conditions	$N = 88$ (all TR)	1st Grade	Hebrew
Breznitz (1997a)	Oral reading acceleration phenomenon study introducing a series of STM-sensitive tasks during self-paced and fading condition	$N = 23$ (all RD)	3rd Grade[a]	Hebrew
Breznitz (1997b)	Oral reading acceleration phenomenon study introducing auditory masking comparing children with reading difficulties with reading-level matched typical readers	$N = 104$ ($n = 52$ RD)	RD: 3rd grade[a] TR: 1st grade[a]	Hebrew
Breznitz (1997b, 1997c)	Oral reading longitudinal acceleration phenomenon study to assess the relationship between reading rate, decoding and comprehension during consecutive stages of reading acquisition	$N = 81$ (unselected sample)	1st–5th Grade	Hebrew
Breznitz et al. (1994)	Silent reading ERP measures during self-paced and fading conditions	$N = 15$ (all TR)	University students	English

TABLE 1 (Continued)

Reference	Study focus	Sample	Age	Language
Breznitz and Leikin (2001)	Oral and silent reading ERP measures of processing sentence components with different grammatical functions during self-paced and fading conditions	$N = 40$ ($n = 20$ RD)	University students	Hebrew
Breznitz and Share (1992)	Oral reading acceleration phenomenon study introducing a series of STM-sensitive tasks during self-paced and fading condition	$N = 23$ (all TR)	2nd Grade	Hebrew
Karni et al. (2005)	Oral and silent reading fMRI study to compare brain activation patterns during slow (routine reading rate) and fast (accelerated) fading conditions	$N = 16$ ($n = 8$ RD)	University students	Hebrew
Leikin and Breznitz (2001)	Oral and silent reading ERP measures of processing sentence components with different grammatical functions during self-paced and fading conditions	$N = 20$ (all TR)	University students	Hebrew
Nagler, Linkersdörfer et al. (2016)	Oral reading acceleration phenomenon study introducing two different slow fading conditions	$N = 34$ (all RD)	3rd Grade	German
Nagler et al. (2014)	Oral reading acceleration phenomenon study introducing reading material with different levels of lexical accessibility (easy, intermediate, difficult)	$N = 39$ (all TR)	3rd Grade	German

Note: upper case N indicates complete sample size and lower case n denotes subsample sizes.

Abbreviations: ERP, event-related potentials; fMRI, functional magnetic resonance imaging; HSES, high socioeconomic status; LSES, low socioeconomic status; RD, reading difficulties; STM, short term memory; TR, typical readers.

[a]The grade level was approximated based on age information provided in the article.

different age groups, although more pronounced for younger readers (Breznitz & Berman, 2003).

Languages: Although the bulk of studies was conducted with Hebrew speaking participants (Breznitz, 1997a, 1997b, 1997c; Breznitz & Leikin, 2001; Breznitz & Share, 1992; Karni et al., 2005; Leikin & Breznitz, 2001), the reading acceleration was also observed for readers of English and German. For example, English-speaking university students showed significantly improved reading comprehension as well as faster reading rates under fading conditions (Breznitz et al., 1994). Also, studies applying fading manipulations to German school children generally supported the validity of acceleration phenomenon effects for the German language (Bar-Kochva & Hasselhorn, 2015; Nagler, Linkersdörfer et al., 2016; Nagler et al., 2014).

Reading proficiency levels and socioeconomic status. Several studies compared TR and RD populations (e.g., Breznitz, 1997a, 1997b; Breznitz & Leikin, 2001). In addition to the typically

observed decrease of decoding errors, and the increase of reading rate and comprehension under fading conditions, improvements were especially pronounced for reading impaired participants, indicating a greater gain for individuals with RD. Furthermore, Breznitz (1987b) investigated a sample of first graders with different socioeconomic background (low socioeconomic vs. middle-class background). Results showed that children from low socioeconomic background initially scored lower on reading comprehension and reading rate during self-paced reading compared to their middle-class peers. However, although reading rates and comprehension improved for all participants under fading conditions, compared to middle-class children, overall improvements were significantly higher for children from a lower socioeconomic background.

Fading variants. Exploring possible deceleration effects Breznitz (1987a) used a manipulation that encouraged first graders to read slower than their usual reading routine. This deceleration induced fewer decoding errors but impaired comprehension. In contrast, Nagler, Linkersdörfer et al. (2016) showed that third graders with RD can benefit from deceleration. When fading rates were set 40% slower than the self-paced reading rate, significantly higher reading rates and comprehension scores were observed. However, only slightly faster reading rates but no comprehension gains were found if fading rates were 70% slower than self-paced reading rates. The authors concluded that the fading manipulation itself might improve reading performance sufficiently even if not set to the upper limit of a participant's reading performance. Nonetheless, extremely slow rates that do not generate time constraints must be avoided as they were found to be ineffective. A variant of the fading manipulation, which selectively erased orthographic word units (e.g., prefix, suffix, stem) was introduced by Bar-Kochva and Hasselhorn (2015). The authors compared fading effects at the level of lexical, sublexical and nonlexical units in a sample of fifth graders with RD. Reading rate improvements due to fading were found to a similar extent across orthographic unit conditions without impairing comprehension. Hence, the authors emphasised that the fading induced time constraint affects reading performance positively irrespective of the fader's orthographic unit.

Reading material variations. Nagler et al. (2014) investigated the impact of reading material characteristics on fading effects. For this purpose, the reading material's *lexical accessibility* (i.e., the ease of access to the mental lexicon) was systematically varied in a study with third grade TRs. While reading rates increased significantly under fading conditions at all lexical accessibility levels, enhanced comprehension was only observed for easily accessible reading material and not for intermediate or difficult levels of lexical accessibility. The fading manipulation even produced lower comprehension performance for material that was difficult to retrieve from the mental lexicon. This result highlights the need to control for linguistic characteristics such as lexical accessibility, since they strongly influence comprehension performance (i.e., improvement, stagnation or decline) under fading conditions.

3 | PROPOSED UNDERLYING MECHANISMS OF ACCELERATION PHENOMENON EFFECTS

Although several explanatory approaches have been proposed to explain the underlying mechanisms leading to improved reading performance under fading conditions, their empirical validation is still pending. Nevertheless, three main proposals, considering attention orientation, working memory optimisation and lexical processing, will be outlined in the following.

Attention. Suggesting that the fading procedure might reduce distractibility and therefore direct attention to the reading task, Breznitz (1988) introduced pictorial distractors above presented text items. The participating first graders were asked to ignore distractors during reading in two conditions, that is, reading with fading versus self-paced reading. Participants in the fading group significantly improved their reading performance and recalled fewer distractors than control group participants. Hence, Breznitz (1988) concluded that fading group participants directed more attention to the reading material and less to distractors, which released cognitive capacities for text processing.

Working memory. Breznitz and Share (1992) tested the influence of the fading manipulation on three different working memory tasks. First, participants (second grade TRs) had to repeat the words of presented sentences in backward and forward order. Second, reading material with changes in semantics or wording was introduced. Target passages were followed by two test passages (i.e., the original and an altered version of the passage) between which the participants had to identify the original passage. Third, participants were confronted with single words (probes) which were part of a previously read passage. The task was to recall the words which had appeared immediately before and after the probe. The empirical results revealed significantly faster reading rates and better performance for all working memory tasks in the fading condition compared to the self-paced conditions. The authors assumed that the time constraint invoked an optimised usage of limited working memory capacity, which may have resulted in enhanced reading performance in the working memory tasks in the fading condition.

Lexical processing. Breznitz (1997b) suggested that the fading procedure might produce a shift from slow, phonological (sublexical) to a faster, orthographical (lexical) access route (Coltheart et al., 2001) and measured reading performance with and without fading while applying an auditory masking manipulation (i.e., a well-known children's song). First, participants (reading level matched first grade TRs and third grade RDs) read material without auditory masking in all three conditions (self-paced 1—fading—self-paced 2). Afterwards, participants were exposed to the auditory distractor while reading. As a result, all participants improved their reading rates under fading conditions compared to self-paced reading. The analysis of the self-paced condition under auditory masking, however, revealed a substantial difference between groups. While TRs did not significantly alter their reading rate compared to reading without auditory masking, RD children's reading rates significantly improved under auditory masking in the self-paced condition. Breznitz (1997b) concluded that for individuals with RD, auditory masking and the fading procedure created similar effects on reading rates, because the interference in the auditory channel might have encouraged children to rely on alternative information processing (i.e., lexical decoding) resulting in more efficient information processing. Similar assumptions motivated a study by Nagler et al. (2014), which found that reading rates and comprehension during fading improved only for reading material with easy levels of lexical accessibility. Embedding their results in a theoretical framework by Siegler (1991), Nagler, Linkersdörfer et al. (2016) argued that fading prompted a strategy called direct fact retrieval. An in-depth description of the various strategies proposed by Siegler (1991) is outside the scope of this article. However, as an attempt to briefly outline the concept of direct fact retrieval in the reading domain: it can be understood as an extension of direct lexical access that also assumes immediate retrieval of semantic representations. In other words, only if a child already developed stable lexical representations of words and understands their meaning, text fading can accelerate reading rates and improve comprehension.

The above list of proposed cognitive mechanisms might seem arbitrary, since the fading procedure may modify any or several cognitive subskills involved in reading. Based on our own

experience with the reading acceleration program (RAP) approach, we would speculate that text fading likely prompts a shift to faster reading strategies such as direct fact retrieval. We acknowledge that the notion of working memory representing a pivotal point seems plausible and promising. However, the broadly accepted view that limited working memory capacity is a core factor for comprehension difficulties has been challenged by work demonstrating that working memory capacities and several other reading related skills (e.g., IQ, vocabulary knowledge) are collinearly coupled (Van Dyke et al., 2014). Especially the finding that vocabulary knowledge is a core predictor for comprehension success highlights the necessity to ensure in future studies that reading materials equally allow direct fact retrieval before working memory manipulations are induced.

4 | READING ACCELERATION TRAINING

As already mentioned, the effect that text fading can improve reading rates, accuracy and comprehension at a single session level (i.e., acceleration phenomenon) has been described as momentary. The repeated application of the fading procedure, however, might still lead to persistent changes in reading behaviour. Therefore, the principles of the acceleration phenomenon were implemented into a training software called RAP (Breznitz & Bloch, 2010; Breznitz & Nevat, 2006). An overview of studies that employed RAP is provided in Table 2. A common outcome of most studies is that reading rates increased while comprehension improved or remained at high levels. However, Table 2 also discloses numerous differences between studies concerning target languages, research populations (i.e., age groups, TR and RD participants), reading materials (i.e., sentences, paragraphs) and several methodological aspects (i.e., control conditions, sample size). These aspects must be considered when reviewing the available evidence for and against the claim that RAP training can improve reading performance.

Most RAP studies share the same two-step procedure: In a first step, each participant's self-paced reading rate is measured, which provides for the second step an initial fading rate that is used to erase reading material from the computer screen. The fading rate is subsequently adjusted depending on comprehension performance: the fading rate increases if comprehension is sufficient, is left unchanged if comprehension is still acceptable, or decreases if comprehension suffers.

Considerable differences between RAP studies can be found regarding the applied research designs. As for all intervention studies, especially when targeting populations of young and beginning readers who continuously undergo reading instruction and maturation processes, the selection of a suitable control group is a major concern and methodological difficulty for the RAP approach. In the control condition applied by the developers of RAP (Breznitz et al., 2013) and others (Nagler et al., 2015; Snellings et al., 2009) participants continue to read in the same pretraining assessment of self-paced reading without any fading involvement over the training time course. The advantage of this design is that experimental and control group participants read the same items under comparable conditions, therefore higher training gains are ascribed to the fading manipulation. However, it remains unclear whether participants are aware of their allocation to the control group and how this might affect their effort and motivation. An attempt to create a situation in which both groups were equally convinced about their allocation to the experimental group was reported by Korinth et al., (2016); both groups accomplished 6 weeks of RAP training during which the fading rate was kept at a fixed rate for control group

TABLE 2 Overview of studies which applied reading acceleration training

Reference	Study focus	Sample	Age	Language	Training scope
Berninger et al. (2013)	RAP integrated in a large battery of several intervention approaches	N = 24 (all RD) n = 12	4th–9th Grade	English	No details provided
Breznitz et al. (2013)	Contrast 1: Accelerated versus unaccelerated reading Contrast 2: RAP effects on typical versus reading impaired readers	N = 110 (n = 55 RD) n = 40 RD accelerated n = 15 RD unaccelerated n = 40 TR accelerated n = 15 TR unaccelerated	University students	Hebrew	24 Sessions, 3 per week
Dai et al. (2016)	Contrast 1: Accelerated versus self-paced[a] reading Contrast 2: Word-wise versus character-wise acceleration	N = 45 (all RD) n = 15 self-paced n = 15 accelerated word n = 15 accelerated character	3rd–4th Grade	Chinese	9 Sessions, 3 per week
Franceschini et al. (2017)	RAP embedded in an investigation on hierarchical visual processing deficits (global vs. local)	N = 13 (all RD)	3rd–8th Grade	Italian	10 Sessions 2–3 per week
Horowitz-Kraus and Breznitz (2014)	EEG study: Comparison of a neuronal marker for error monitoring contrasting RD versus TR before and after RAP training	N = 60 (n = 29 RD)	7th Grade[b]	Hebrew	24 Sessions, 3 per week
Horowitz-Kraus (2016)	EEG study: Comparison of a neuronal marker for error monitoring contrasting RD versus TR before and after RAP training	N = 65 (n = 29 RD)	University students	Hebrew	24 Sessions, 3 per week
Horowitz-Kraus, Cicchino et al. (2014)	Comparison of RAP training effects in Hebrew versus English	N = 89 (all RD) n = 54 Hebrew n = 35 English	2nd–5th Grade	English and Hebrew	20 Sessions, 5 per week
Horowitz-Kraus, Vannest et al. (2014)	Contrast 1: RAP training versus waiting control group (only for RD) Contrast 2: RAP effects RD versus TR Contrast 3: fMRI study on brain circuitry in RD and TR	N = 51 (n = 33 RD) n = 18 RD accelerated n = 18 TR accelerated n = 15 RD waiting-control	3rd–6th Grade[b]	English	20 Sessions, 5 per week
Horowitz-Kraus and Holland (2015)	fMRI study: Functional connectivity in RD and TR before and after RAP	N = 51 (n = 33 RD) n = 18 RD accelerated n = 18 TR accelerated n = 15 RD waiting-control	3rd–6th Grade[b]	English	20 Sessions, 5 per week

(Continues)

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TABLE 2 (Continued)

Reference	Study focus	Sample	Age	Language	Training scope
Kasperski et al. (2019)	Investigation of RAP training effects on reading self-concept	$N = 130$ ($n = 51$ RD)	2nd–3rd Grade	Hebrew	28 Sessions, 1–2 per week
Korinth et al. (2016)	Contrast 1: Adaptively increasing fading rates versus reading at fixed rates Contrast 2: RAP effects on eye movements	$N = 36$ $n = 21$ accelerated reading $n = 15$ fixed fading rate	University students	German	24 Sessions, 4 per week
López-Escribano (2016)	Preliminary study on the applicability of RAP in Spanish contrasting groups of varying comprehension levels	$N = 12$ (all RD) $n = 4$ proficient comprehension $n = 8$ low comprehension	4th–5th Grade	Spanish	20 Sessions, 5 per week
Nagler et al. (2015)	Comparison of accelerated versus unaccelerated reading	$N = 22$ (unselected sample) $n = 10$ accelerated $n = 12$ unaccelerated	3rd Grade	German	9 Sessions, 3 per week
Nevo and Breznitz (2014)	Several contrasts testing for training effects of RAP alone versus RAP with succeeding or preceeding working memory training	$N = 97$ (all TR) $n = 27$ RAP + RAP $n = 23$ WM + RAP, $n = 27$ RAP + WM, $n = 20$ no training	3rd Grade	Hebrew	12 or 24 Sessions, 3 per week
Nevo et al. (2016)	Contrast 1: RAP training versus no training Contrast 2: RAP using single sentences versus paragraphs	$N = 79$ (all TR) $n = 25$ RAP sentences $n = 25$ RAP paragraphs $n = 29$ no training	2nd Grade	Hebrew	25 Sessions, 2 per week
Niedo et al. (2014)	Combination of RAP with instructions for self-regulating reading strategies	$N = 14$ (all RD) $n = 7$ RAP $n = 7$ waiting-control	4th Grade	English	9 Sessions
Paige (2011)	Contrasting repeated oral text reading with text fading to regular repeated oral reading	$N = 20$ ($n = 15$ RD) $n = 9$ accelerated $n = 11$ unaccelerated	6th Grade	English	60 Sessions, 5 per week
Snellings et al. (2009)	Contrast 1: Accelerated versus unaccelerated reading Contrast 2: RAP effects on typical versus reading impaired readers	$N = 59$ ($n = 24$ RD) $n = 15$ accelerated RD $n = 22$ accelerated TR $n = 9$ unaccelerated RD $n = 13$ unaccelerated TR	4th Grade	Dutch	9 Sessions, 3 per week

Note: EEG, electroencephalography; fMRI, functional magnetic resonance imaging; RAP, reading acceleration program; RD, reading difficulties; TR, typical readers; WM, working memory.

[a]The term self-paced refers in the study by Dai et al. (2016) to the procedure by which participants control the pace at which single words appear on the screen through button press.

[b]The grade level was approximated based on age information provided in the article.

participants. This design isolated the effect of the text fader itself from the impact of gradually adapting fading rates in the experimental condition. Comparable gains for both groups led to the conclusion that the fading manipulation itself creates significant improvements and not necessarily the enforced higher speed, which is in line with similar findings reported for single session experiments by Nagler, Linksersdörfer et al. (2016).

5 | TRAINING OUTCOMES

A direct approach to evaluate RAP's efficacy is the comparison of its target measures (i.e., reading rate and comprehension) before and after training. However, studies listed in Table 2 reported various outcome measures (e.g., silent reading rate, oral reading fluency, composite measures for reading rate and comprehension, tests for cognitive subskills). Nonetheless, we attempt to give an overview of training outcomes focussing on different aspects (i.e., effect sizes, language, transfer and subskill effects) in the following.

Effect sizes. Owing to a variety of methodological formats of reported studies (e.g., indices from inferential statistics, line graphs, standardised values), our review of effect sizes is limited to a subset of studies that reported descriptive statistics from RAP's self-paced reading performance (i.e., silent reading rate and comprehension) before and after training (see Table 3). Specifying magnitude and direction of training effects, Table 3 also provides Cohen's d values. Large effect sizes (i.e., Cohen's $d > 0.80$) indicating better comprehension after RAP training were reported for Chinese readers accomplishing RAP under word-wise fading conditions (Dai et al., 2016) as well as for English and Hebrew speaking children (Horowitz-Kraus, Cicchino et al., 2014). Small to medium were effect sizes (i.e., Cohen's d between 0.2 and 0.5) for comprehension improvements after RAP in a subgroup of Spanish children (López-Escribano, 2016), and for Chinese children accomplishing a character-wise fading training (Dai et al., 2016).

Importantly, in most studies comprehension improvements were accompanied by faster reading rates as is evident in Cohen's d ranging from –0.30 to –0.78. In a sample of young German adults, small and insignificant effects on comprehension were accompanied by largely improved reading rates, Cohen's $d = -1.13$ (Korinth et al., 2016). Nevertheless, faster reading rates (Cohen's d ranging from –0.73 to –1.24) and a concomitant decrease in comprehension in a sample of Dutch children (Snellings et al., 2009) demonstrate a potential risk when applying RAP unsupervised: a trade-off between reading comprehension and faster rates may lead to an undesired effect of superficial reading behaviour.

Language effects. RAP studies were conducted for readers of Chinese, Dutch, English, German, Hebrew, Italian and Spanish yielding in most cases positive training effects on reading rate and comprehension, which indicates that RAP is generally not restricted to a specific language. Languages listed above differ in terms of reading direction, orthographic transparency (Frost et al., 1986; Schmalz et al., 2015), or visual complexity of their graphemic representations (Pelli et al., 2006), which calls for comparative studies investigating orthography specific effects of RAP. To the best of our knowledge, only Horowitz-Kraus, Cicchino et al. (2014) made such an attempt by comparing RAP outcomes for 2nd–5th graders of the orthographically shallow version of Hebrew (i.e., with diacritics) and readers of the rather opaque English orthography. This comparison is especially interesting, as the shallow Hebrew orthography allows slow serial grapheme to phoneme processing, whereas readers of English have to rely on larger orthographic units. In line with the hypothesis that RAP reduces phonological decoding, readers of

TABLE 3 Descriptive statistics and Cohen's *d* for self-paced reading rate and accuracy before and after training

Reference	Training group	N	Comprehension accuracy (percent)			Pace (milliseconds per letter)		
			M (SD) pre	M (SD) post	Cohen's d	M (SD) pre	M (SD) post	Cohen's d
Dai et al. (2016)	Accelerated (character-wise)	15	63.20 (11.77)	77.41 (7.5)	1.44	7116.21 (2645.04)	6127.15 (3930.77)	−0.30
	Accelerated (word-wise)	15	72.92 (8.13)	75.76 (8.17)	0.35	6245.69 (2562.45)	4093.54 (1807.54)	−0.97
	Self-paced	15	63.67 (12.61)	65.52 (17.62)	0.12	7736.5 (1154.21)	7615.54 (2370.21)	−0.06
Snellings et al. (2009)	Accelerated RD	15	93 (9.02)	90 (11.0)	−0.30	210 (88.43)	151 (72.66)	−0.73
	Unaccelerated RD	9	95 (6.05)	86 (16.14)	−0.74	151 (42.7)	107 (35.38)	−1.12
	Accelerated TR	22	94 (5.97)	92 (10.12)	−0.24	120 (37.61)	77 (31.52)	−1.24
	Unaccelerated TR	13	97 (5.25)	97 (4.22)	0.00	106 (26)	84 (37.57)	−0.68
Korinth et al. (2016)	Accelerated	21	83.33 (8.74)	81.75 (13.34)	−0.14	59.48 (17.4)	40.6 (15.88)	−1.13
	Fixed fading rate	15	88.33 (6.14)	88.89 (6.8)	0.09	53.4 (14.47)	38.93 (8.39)	−1.22
Horowitz-Kraus, Cicchino et al. (2014)	Accelerated (Hebrew)	54	65.42 (12.58)	87.83 (6.12)	2.27	195.23 (94.52)	106.41 (51.83)	−1.17
	Accelerated (English)	35	64 (7.16)	88.37 (7.4)	3.35	166.88 (60.31)	125.91 (44.1)	−0.78
López-Escribano (2016)	Accelerated (good comprehension)	4	94 (7.65)	88 (4.61)	−0.95	163.53 (29.09)	138.27 (46.25)	−0.65
	Accelerated (poor comprehension)	8	79.38 (16.09)	84.13 (5.95)	0.39	156.86 (59.02)	159.59 (47.09)	0.05

Abbreviations: RD, reading difficulties; TR, typical readers.

Hebrew might therefore have gained more than readers of English. However, Horowitz-Kraus, Cicchino et al. (2014) found that both language groups improved reading rates and comprehension equally. Nevertheless, a unique feature of the Hebrew reading system is that the shallow, fully vowelised, script is primarily used for reading instruction, and vowel information is gradually reduced until fourth grade, which turns Hebrew into a deep orthography. It cannot be ruled out that readers of Hebrew already acquired fast recognition skills that made their word recognition routine comparable to the group of English children.

Taking advantage of the unique features of the Chinese orthography, Dai et al. (2016) assessed whether the fading manipulation is more efficient if conducted word by word or if character-wise fading is more suitable for the nonalphabetic Chinese language. Their finding that word-based fading was more efficient than the character-wise method seems to be in conflict with the preference for letter-wise fading applied in most other RAP studies. However, the letter-wise fading strategy is justified for alphabetic orthographies where it accounts for word length effects; a concept that only partially applies to Chinese where one or two morphemes (i.e., characters) create a semantic unit. Consequently, Dai et al. (2016) concluded that the word-wise fading manipulation enforced the processing of Chinese words as an entity instead of decoding constituent morphemes separately.

Transfer effects. An advantage of RAP is the independence of reading material used for training, pre- and posttests. Therefore, changes in reading behaviour are by default measured as transfer effects to previously not encountered reading material. An exception is a study by Paige (2011), who combined RAP with the currently most accepted intervention approach targeting reading fluency, that is, repeated reading (Lee & Yoon, 2017; Samuels, 1997). The sixth graders with RD in Paige's (2011) study accomplished an oral repeated reading task (i.e., reading one new text per week up to five times over 12 weeks). Text presentation for the experimental group was gradually faded out based on the achieved level of correct-words-per-minute. In addition to the repeated presentation of text material, this procedure differs considerably from all other studies in two other aspects: First, fading rates were not adjusted depending on comprehension, and second, the fading procedure was not implemented in a letter by letter but in a word-wise manner. Nevertheless, although this study is not comparable to other RAP training studies, it may provide insights into the impact of imposed time constraints when applied as an additional factor in an existing training approach. However, limited by a small and heterogeneous sample, Paige (2011) did not find evidence for an additional benefit from text fading on fluency, accuracy, comprehension and phonological decoding.

Subskill effects. In contrast to intervention approaches focussing on improving subskills (e.g., phonological processing, working memory, visual processing deficits) with the aim to improve reading performance, RAP is per se agnostic to possibly underlying subskill deficits. As discussed above, several hypotheses of why enforcing faster reading can improve reading rates and comprehension were proposed but they have not been sufficiently investigated so far. Nonetheless, several studies focused on the joint investigation of subskill influence and RAP training.

Motivated by the hypothesis that working memory usage moderates reading rate and comprehension, Nevo and Breznitz (2014) created a study design in which RAP was assessed either in isolation or combined with an additional working memory training in a sample of third grade Hebrew TRs. The combination of RAP and working memory training provided the best outcomes in terms of posttest reading skills. However, even participants who accomplished only RAP training exhibited gains in several working memory skills that were not explicitly trained. According to the cognitive training literature, working memory trainings can be considered effective. For instance, a meta-analysis focussing on children with learning

disabilities reported training gains of moderate effect sizes (Peijnenborgh et al., 2016). A general limitation of working memory trainings is, however, that training improvements are typically restricted to performance in rather artificial tasks (e.g., digit span) with small or no transfer effects to other working memory tasks (Sala et al., 2019). Nevo and Breznitz's (2014) results might therefore indicate that RAP training acts as a working memory training that does not require transfer effects, since it addresses the target task itself (i.e., reading) and even creates transfer effects to other working memory domains.

An Italian adaptation of RAP called The Library Tower (Franceschini et al., 2019) was used in a study by Franceschini et al. (2017). The authors postulated an effect mechanism in which low reading rates are caused by a preference for visual perception of local instead of global word features. Consequently, the authors assumed that RAP enforces rapid global visual processing, as their participants (3rd–8th graders with RD) improved word reading skills but also showed reduced local interference effects for global processing after training. Nevertheless, considering the small sample size ($N = 13$) and a large range of participants' age, these results should be interpreted cautiously.

Contrasting the perspective of Nevo and Breznitz (2014) with presumptions made by Franceschini et al. (2017) might raise the question whether the search for underlying effect mechanisms is relevant or whether a multiple factor perspective that emphasises the versatile character of RAP is more adequate. However, caution is advised as the latter perspective does not account for cases in which underlying deficits are resilient to RAP. A responsible application of RAP training must ensure that the program will not impact its users negatively (e.g., frustration due to ineffective training, enforcement of fast but superficial reading).

6 | TRAINING TIME COURSE: BALANCING FADING RATES AND COMPREHENSION

A valuable RAP feature is the option to track changes of fading rate and comprehension during the training's time course, which allows the evaluation of the process that led to a training outcome. Crucial here is the adaptation algorithm regulating the increase or decrease of fading rate depending on comprehension levels. The software used by the developers of RAP (Breznitz et al., 2013) increased fading rate by 2 ms/letter if more than 80% of the multiple-choice questions within a block of 10 items were answered correctly. For cases of exactly 80% correct answers, fading rate stayed unchanged and was decreased by 2 ms/letter if less than eight out of ten questions were answered correctly. Theoretically, this allows a trade-off between reading speed and comprehension as an increase in fading rates requires comprehension levels slightly above 80%. Breznitz et al. (2013), however, reported significant gains comparing the first and the last training session in which even RD participants reached almost 90% response accuracy during the last training session ($M = 89$, SD = 4%). In contrast, a study in a sample of German university students which used the same 80% threshold (Korinth et al., 2016) reported—similar to Breznitz et al. (2013) - a steep increase in fading rates that was, however, accompanied by a significant decrease in reading comprehension stabilising at around 80% comprehension accuracy. While an 80% threshold for comprehension accuracy may be considered appropriate, allowing comprehension to drop to a level of 60% seems risky. Nevertheless, this was the threshold in the RAP study with TR and RD children in Dutch (Snellings et al., 2009). The authors found that fading rates increased gradually during nine training sessions; comprehension of RD participants, however, dropped to approximately 60% after 5 days of training.

In contrast, two studies with populations of German third grade TRs (Nagler et al., 2015) and Spanish fourth and fifth graders with RD (López-Escribano, 2016) demanded 100% accuracy for comprehension questions before fading rates increased. Applying this threshold produced only mildly increasing fading rates for German children (Nagler et al., 2015) and led for the majority of Spanish children to a steady decrease in fading rates (López-Escribano, 2016). Hence, such conservative comprehension criteria may not provide enough space for an increase in fading rates. It is undisputed that the ultimate goal of reading is adequate text comprehension and a trade-off for speed is inacceptable since it would not comply with the core aim of RAP, which is enhanced comprehension because of higher reading rates. Nevertheless, posttraining reading performance is ultimately relevant without the artificial fading manipulation, which is why a temporary overstrain during the training might still yield positive transfer effects.

7 | CONCLUSIONS—LIMITATIONS AND BENEFITS

Studies reviewed so far support the claim that principles of the acceleration phenomenon used in RAP training represent a viable method to improve comprehension-based silent reading rates in various orthographies and reader groups. However, our review also stressed several research gaps. Unanswered remains, for instance, the question of what exactly causes the observed improvements and whether they are caused by one distinct effect mechanism. This issue is crucial as it may provide clear-cut indicators pointing to the circumstances under which RAP might be ineffective or even detrimental. Also, large variations between studies highlight the demand for systematic research on setting up efficient training regimes attuned to individual readers. Individual adjustments should concern the training frequency, the lengths of training sessions, the length of reading items, and thresholds at which comprehension can be considered sufficient. Also, only one study tested long-term training gains (Breznitz et al., 2013); although these results indicate persistent training effects, further research should investigate whether for instance occasional refresh sessions might yield additional benefits. Finally, with the exception of Nevo et al. (2016), most studies used single sentence training items, although longer passages represent ecologically more valid reading material.

The compilation of studies for this review made it evident that the bulk of research was conducted by one group, which included Breznitz herself, one of her students (i.e., Horowitz-Kraus, Nevo) and collaborators. This is—given their avant-garde position—not surprising. In light of the current replication crisis (Ioannidis, 2005), however, it would strengthen the status of the RAP approach, if independent groups would replicate its major findings (Makel & Plucker, 2014). To the best of our knowledge, there have been only three truly independent—without consultations with Breznitz group members—studies: Paige (2011), Dai et al. (2016) and Franceschini et al. (2017). None of these studies explicitly challenged the claim that the RAP approach can improve reading performance, but variations in study designs and language differences make direct comparisons difficult, which illustrates again that independent replications are imperative.

Also, we would like to point out that several program features would benefit from optimisation. For example, the fading rate at which a text disappears from the screen currently only accounts for word length effects since words are erased letter-wise (i.e., shorter words disappear faster than longer words). However, word frequency also influences the speed at which a word is recognised. Hence, an optimisation of the text fading algorithm that takes word frequency effects into account would comply with human reading behaviour more appropriately.

A disadvantage of the fading manipulation is that text, which disappeared from the screen, cannot be reinspected. This may seem like an intentional feature of RAP, since the prevention of regressions will inevitably lead to higher reading rates. However, regressions are often crucial to achieve sufficient levels of text comprehension and do not necessarily indicate low levels of reading proficiency (Inhoff et al., 2019). A technical solution for this problem might be a stop button, which pauses the fader and triggers the reappearance of the text, allowing the reinspection of a passage until the stop button is released.

Furthermore, research on how RAP may affect higher linguistic processes is an almost disregarded field. Obviously, good reading performance relies heavily on underlying perceptual and cognitive subskills, which explains the prominent focus on visual processing, phonological decoding, working memory or executive functions. Nevertheless, written texts are essentially human language encoded in a visual representation, which—like spoken language—follows rules specifying how sequences of words must be combined to create coherent semantic representations. An investigation of the extent to which a reader can rely on explicit and implicit knowledge about syntax may provide a fresh perspective for future research on the applicability of RAP. Finally, future RAP studies should also be complemented by data collection on socioemotional factors such as intrinsic reading motivation (Becker et al., 2010; Retelsdorf et al., 2011) or the reading self-concept (Kasperski et al., 2019) as they are closely associated with reading proficiency.

In conclusion, given the widespread availability of computers, RAP provides several benefits. The program can be used independent from locations (i.e., in schools, at home), it is highly adaptive (i.e., it monitors reading rate and comprehension by default), and it is reading material independent, which avoids overlearning of training material. Finally, since it demands only minimal supervision through educators, it is also very time- and cost-efficient. Further studies on how RAP can improve comprehension-based reading rates is therefore a promising research field.

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ENDNOTES

[1] The term self-paced reading is commonly used for an experimental procedure in which participants control the timing of single words appearance on a screen through button presses. In the context of the acceleration phenomenon, self-paced reading refers to a procedure in which a complete sentence or paragraph appears on a screen that can be read without any time constraints (i.e., at a reader's own pace).

[2] The terms *reading rate* and *fading rate* used throughout the manuscript need to be carefully distinguished. Reading rate refers to the time individuals need to read presented reading items; fading rate characterises the speed at which the reading material is erased from the computer screen.

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