Tracking the Transition from Sublexical to Lexical Processing in Reading Aloud:

On the Creation of Orthographic and Phonological Lexical Representations

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

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Abstract

Participants read aloud a set of *nonword* letter strings, one at a time that varied in the number of letters. The standard result was observed in two experiments; the time to begin reading aloud increased as letter length increases. This result is standardly understood as reflecting the operation of a serial, left to right translation of graphemes into phonemes. The novel result is that the effect of letter length is statistically eliminated for nonwords that have been repeated a small number of times. This elimination suggests that these nonwords are no longer *always* being read aloud via a serial left to right sublexical process. Instead, the data are taken as evidence that new orthographic and phonological lexical entries have been created for these nonwords, and that they are now read at least sometimes by recourse to the lexical route. Experiment 2 replicates the interaction between nonword letter length and repetition observed in Experiment 1 and also demonstrates that this interaction is not seen when subjects merely classify the string as appearing in upper or lower case. Implications for existing dual route models of reading aloud and Share's self-teaching hypothesis are discussed.

Acknowledgments

I extend a heartfelt thank you to Derek Besner and Evan Risko for their guidance, encouragement, and support throughout the development of this work. Their time and effort will not soon be forgotten.

Dedication

For E.F.R. For the countless hours, the immeasurable effort, and the oh-so-many “really?”s.

Table of Contents

List of Tables

List of Figures

Introduction

Treisman (1961) introduced the concept of a mental "dictionary" (the lexicon) with individual "dictionary units" (lexical entries) representing words. This lexicon was thought of as a mental store of all words known to the individual and has become a central component of various computational (and non-computational) models of visual word recognition and reading aloud (e.g., Coltheart, Rastle, Perry, Langdon & Zeigler, 2001; McClelland & Rumelhart, 1981; Morton, 1969; Perry, Ziegler & Zorzi, 2007). Despite the presence of multiple lexicons (orthographic and phonological) in such models, relatively little attention has been paid to the issue of *how* a letter string becomes part of a lexicon, in contrast to the amount of research devoted to other issues in the context of these models (but see Bowers & Michita, 1988; Share, 1995). The present experiments report a novel approach to determining how a letter string comes to be represented in both the orthographic input and phonological output lexicons.

Dual-Route Accounts of Reading Aloud

Coltheart and colleagues' (2001) Dual Route Cascaded (DRC) model of visual word recognition and reading accounts for a wide variety of reading related behaviours. The DRC model is dual-route in that it generates a phonological code from print by recourse to *lexical* and *non-lexical* routines.

The *lexical route* consists of an orthographic lexicon and a phonological lexicon. The orthographic lexicon contains a single node for each uniquely spelled word that the model knows. Similarly, the phonological lexicon contains a single node for each uniquely sounded word that the model knows. Letter units activate words in the orthographic lexicon. Activation in the orthographic lexicon feeds back to the letter level and forward to the phonological lexicon. Activation from the phonological lexicon feeds back to the orthographic lexicon and forward to the phoneme system. The lexical route can read aloud all the words it knows and is required to correctly read aloud words that do not follow the typical spelling-to-sound rules (exception words such as *pint*).

The non-lexical route translates print into sound sublexically via a set of grapheme–phoneme correspondence rules applied left to right, one letter at a time. This route produces a correct pronunciation for words that follow typical spelling-to-sound rules (regular words such as *mint*) and is required to read nonwords (e.g., *frane*) aloud. Coltheart and colleagues explicitly note that, in DRC letter strings that must be read via the serial, non-lexical routine (i.e., nonwords) are associated with a letter length effect in which longer strings take more time to read aloud. Coltheart and colleagues also note that, in DRC, the time to start reading monosyllabic *words* aloud is unaffected as letter length increases when the lexical route generates a pronunciation, given that letter identification occurs in parallel.[1]

A second model is the connectionist dual process model (CDP+; Perry, Ziegler & Zorzi, 2007) with a serial processing non-lexical route. Perry et al. also explicitly note that CDP+ produces an effect of letter length in the context of reading nonwords aloud, but not when reading aloud monosyllabic words (see also Ziegler, Perry, Jacobs & Braun, 2001). [2]

There is both broad and deep evidence for a serial non-lexical process in reading aloud (see Rastle & Coltheart's 2006 review). For example, Weekes (1997), using a set of monosyllabic items ranging from 3 to 6 letters, reported that the time it takes to begin pronouncing a monosyllabic nonword increases as letter length increases (Ziegler, Perry, Jacobs, & Braun, 2001; Perry, & Ziegler, 2002). Other well established phenomena consistent with this account include the position of the irregularity effect (Cortese, 1998; Roberts, Rastle, Coltheart, & Besner, 2003), the position of the bivalence effect (Havelka & Rastle, 2005), the position sensitive Stroop effect (Bibi, Tzeglov, & Henik, 2000), the exaggerated letter length effect in surface dyslexia (Gold, Balota, Kirchhoff, & Bickner, 2005), the whammy effect (Joubert & Lecours, 1998; Rastle & Coltheart, 1998), and the onset effect observed in masked form priming (Forster & Davis, 1991).

The Letter Length Effect

Although neither DRC nor CDP+ consider how lexical entries are acquired, in both cases it is not difficult to see how the formation of such entries can be indexed. Specifically, according to both of these accounts, if a letter string does not have entries in both the orthographic and phonological lexicons it must be read aloud via a sublexical procedure that will result in a letter length effect because this process is serial and left to right and must be completed before an articulation starts. If a letter string does have lexical entries in the orthographic and phonological lexicons it can be read aloud via the lexical route and hence need not yield a letter length effect. It is important to note that if a word does have lexical representations it can still be read sub-lexically and thus can still show a letter length effect. However, for a word to be read lexically it *must* have representations in the orthographic input lexicon and phonological output lexicon. Thus, the *absence* of a letter length effect when reading aloud provides a plausible index of the existence and use of lexical entries (at least in the case of short, (3 to 6 letters) monosyllabic strings).

The Self-Teaching Hypothesis

Share (1995) proposes that the application of sublexical spelling to sound correspondences when reading functions as a self-teaching mechanism that enables the reader to learn word-specific print-to-sound associations. *Repeated reading of a nonword* should thus quickly lead to the formation of item specific print to sound associations that bypass serial sublexical processing. Here I consider the joint effects of letter length and nonword repetition. A reduction in the effect of letter length as a function of nonword repetition would be consistent with Share's hypothesis.

Experiment 1

Participants read aloud a set of monosyllabic nonwords that were repeated four times. A set of nonwords was used that is known to produce a letter length effect on its first presentation in skilled readers (the item set from Weekes, 1997) and to also produce a letter length effect in both DRC and CDP+ (see Coltheart et al., 2000; Perry et al., 2007).

If repetition leads to the formation of lexical entries in both the orthographic and phonological lexicons then the effect of letter length should get smaller as the number of blocks (repetitions) increases because reading via the lexical route is independent of letter length (at least for monosyllabic items 3 to 6 letters long)[1]. If repetition does not lead to the formation of lexical entries then the effect of letter length should remain constant as the number of blocks (repetitions) increases because reading aloud such items will always be dependent on the serially based non-lexical route.

Method

Participants. Eighteen undergraduate students from the University of Waterloo were each granted experimental credit towards a psychology course. All were native English speakers and reported normal or corrected-to-normal vision.

Stimuli. The stimulus set consisted of the one hundred monosyllabic nonwords taken from Weekes (1997; except for the items “frosh” and “blog” which are words; these were replaced with “fitch” and “beld”). This set of items, among others (see Ziegler, et al., 2001; Perry, & Ziegler, 2002), is known to show a letter length effect. There were an equal number of three, four, five, and six letter strings.

Apparatus. The data were collected on a Pentium 4 computer running E-Prime 1.1 (Schneider, Eschman, & Zuccolotto, 2001). Stimuli were displayed on a 17” monitor and were displayed in white 16 point in Times New Roman font on a black background. Vocal responses were collected using a Plantronics LS1 microphone headset. Responses were recorded using DMDX software (Forster & Forster, 2003). Using this software in conjunction with CheckVocal (Protopapas, 2007), allows one to determine RTs using the waveform and hence serves to reduce measurement error associated with voice key timing (Rastle & Davis, 2002).

Procedure. Participants were tested individually and were seated approximately 50 cm from the screen. At this distance, 3-letter nonwords were approximately 1.5 cm in length and 6-letter nonwords were approximately 3 cm in length. All items were centered on the screen. Participants were instructed that when a letter string appeared, their task was to pronounce it as quickly and as accurately as possible. Responses were coded offline as correct, incorrect, or mistrial (e.g., no response) by the experimenter.

Each trial started with a fixation point. A letter string was then presented at fixation until a vocal response was detected. A set of eight practice trials served to familiarize the participant with the task and allowed the experimenter to adjust the microphone sensitivity to minimize spoiled trials. There were four blocks, each block containing the same one hundred nonwords. Each subject received a different random order of items within each block. Participants were given a self-timed break after each block.

Results

Trials on which there was a mistrial (the microphone did not trigger properly or the subject coughed or stuttered; .8%) or an incorrect response (3.3%) were removed prior to RT analysis. The remaining RTs were submitted to a recursive data trimming procedure using a 2.5

standard deviation cut-off in each cell resulting in an additional 2.1% of the RT data being removed. A 4 (Block: 1, 2, 3, 4) x 4 (letter length: 3, 4, 5, 6) ANOVA was conducted on both mean RT and percentage errors data. These data can be seen Table 1. One subject's data were discarded due to a large number of errors (21%).

RTs. There was a significant main effect of block, $F(3, 51) = 4.1$, $MSE = 2740$, $p = .01$, and a main effect of letter length, $F(3,51) = 6.1$, $MSE = 1000$, $p < .01$. Critically, there was a significant Block x Letter Length interaction, $F(9,153) = 2.3$, $MSE = 584$, $p < .05$, in which the letter length effect became smaller across blocks.

*Errors***.** There was no main effect of block *($F < 1$)*, and no main effect of letter length *($F = 1$)*. There was also no Block x Letter Length interaction *($F < 1$)*.

Table 1: Mean Response Times (ms) and Mean Percent Error in Reading Aloud as a Function of Number of Letters and Block in Experiment 1.

	Reading Aloud							
Letter Length	3		4		5		6	
Block	RT	%E	RT	%E	RT	%E	RT	%E
1	501	3.3	509	3.3	515	1.6	538	2.4
2	471	3.1	490	2.4	498	1.3	507	3.6
3	485	2.9	487	2.4	493	1.3	501	2.0
4	486	2.4	497	1.6	492	1.1	486	2.9

Discussion

The results of Experiment 1 are clear. Overall, longer letter strings took more time to read aloud than shorter ones. This replicates previous work by Weekes (1997) as well as others. The novel result is that the effect of letter length decreased as the number of repetitions increased. This reduction in the letter length effect across blocks suggests that these letter strings come to be read, at least sometimes, via the lexical route and thus must be represented in participants' orthographic and phonological lexicons**.**

Experiment 2

According to Share's (1995) self teaching hypothesis, the formation of lexical representations requires the *generation of a phonological code*. Thus, repetition of a letter string in a context in which a phonological code need not be generated (e.g., when subjects make a case decision, rather than read aloud) should not lead to the formation of a lexical entry. This prediction is tested in Experiment 2.

Two groups of participants underwent different training phases. Participants were presented with the same set of 50 nonwords 4 times (i.e., 50 nonwords appeared 4 times across 4 blocks – once per block). In the *case decision group* participants decided whether nonwords were presented in uppercase or lowercase. In the *reading aloud group* participants read the nonwords aloud. Following the training phase, both groups read aloud the 50 nonwords (block 5; see Figure 1 for a schematic of the experimental design).

A critical test of Share's (1995) hypothesis comes in the comparison between the effects of repetition in the reading aloud and case decision groups. If phonological recoding is a necessary condition for the formation of lexical entries in both orthographic and phonological lexicons then the letter length effect in Block 5 following four blocks of reading aloud should be smaller than the letter length effect in Block 5 following four blocks of case decision. In contrast, if mere exposure to the letter string is sufficient to form both orthographic and phonological lexical entries then the letter length effects in Block 5 should be equivalent across the case decision and reading aloud groups.

Method

Participants. Forty undergraduate students from the University of Waterloo were each granted experimental credit towards a psychology course. All were native English speakers and reported normal or corrected-to-normal vision.

Stimuli. The stimulus set consisted of the 50 monosyllabic 3 and 6 letter nonwords from Weekes (1997). Each subject received a different random order of items within each block. Half the nonwords appeared in uppercase (i.e., BEZ) and half appeared in lowercase (bez). Whether a nonword appeared in upper or lower case changed randomly across blocks. For the sake of simplicity, I removed the 4 and 5 letter nonwords from the previous experiment.

Apparatus. The apparatus was identical to that used in Experiment 1.

Procedure. Participants were tested individually. In the four blocks of the case decision task, participants were asked to verbally identify the case in which a letter string was presented by responding “upper” or “lower” aloud. In the 4 blocks of the reading aloud task, participants were asked to read the letter string aloud. In the fifth block (the test block) all participants were instructed to read aloud the letter string.

Each trial started with a fixation point. A letter string was then presented at fixation until a vocal response was detected. A set of six practice trials served to familiarize the participant with the task. Participants were given a self-timed break after each block. Responses were coded offline as correct, incorrect, or mistrial by the experimenter.

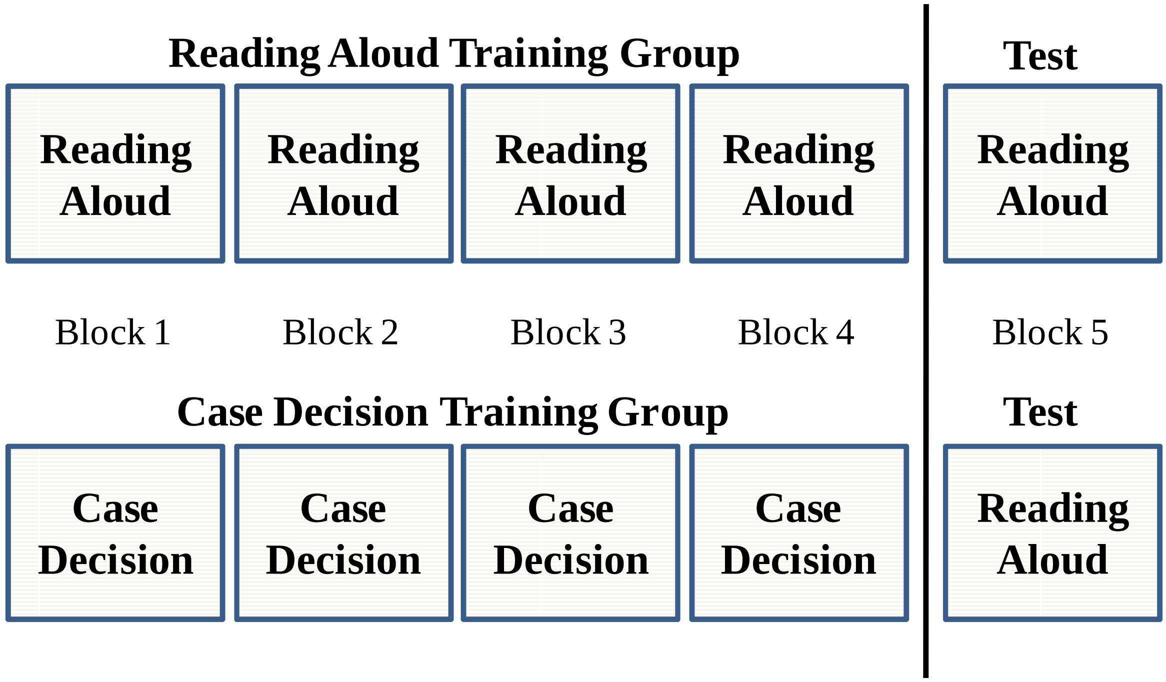

Figure 1. Sequence of events for the case decision training group and the reading aloud training group.

Results

Trials on which there was a mistrial (.5%) or an incorrect response (1.1 %) were removed prior to RT analysis. The remaining RTs were submitted to the same recursive data trimming procedure used in Experiment 1 resulting in 1.7% of the data being eliminated. Mean RTs and errors as a function of block, letter length, and group can be seen in Table 2.

RTs. A 5 (Block: 1- 5) x 2 (Letter Length: 3 vs. 6) ANOVA was conducted for the reading aloud group. As in Experiment 1, there was a significant Block x Letter Length interaction in which the magnitude of the letter length effect decreased across blocks, $F(4, 76) = 3.9$, $MSE = 474$, $p < .01$. A parallel analysis of the errors yielded a main effect of letter length, $F(1, 19) = 5.0$, $MSE = 20$, $p = .04$, such that more errors were made on 6 letter nonwords than on 3 letter nonwords. There was no Length by Block interaction ($F < 1$).

The significant interaction in the RT data, that replicated Experiment 1, allowed me to make an important comparison between the reading aloud group and the case decision group in block 5. Here, I conducted a 2 (Group: Reading Aloud vs. Case Decision) x 2 (Length: 3 vs. 6 Letters) ANOVA with group as a between subjects factor on the data from block 5. Most critically, there was a Group x Letter Length interaction, $F(1, 38) = 7.1$, $MSE = 790$, $p < .01$, such that the size of the letter length effect for the reading aloud group (13 ms) was smaller than the size of the length effect in the case decision group (45 ms). A parallel analysis of the errors yielded a main effect of length, $F(1,38) = 4.7$, $MSE = 20$, $p < .05$, such that more errors were made on the 6 letter stimuli than on the 3 letter stimuli, but no Group by Letter Length interaction ($F < 1$).

A 4 (Block: 1-4) x 2 (Length: 3 vs. 6 Letters) ANOVA conducted for the case decision group yielded a main effect of block, $F(3,57) = 2.9$, $MSE = 1534$, $p < .05$, such that case decisions were made more slowly in block 4 than in block 1. While at first glance this may seem counterintuitive (results from repetition priming studies suggest that I should see a benefit of repetitions across blocks), one possibility is that the slowing down is merely the result of participants becoming bored with such a tedious task.

An ANOVA comparing the letter length effect on RT in Block 1 of the reading aloud group with the length effect in Block 5 of the case decision group yielded no difference ($F > 1$).

Table 2: Mean Response Times (ms) and Mean Percent Error in Reading Aloud as a Function of Number of Letters, Block, and Group in Experiment 2.

	Reading Aloud				Case Decision			
Letter Length	3		6		3		6	
Block	RT	%E	RT	%E	RT	%E	RT	%E
1	595	2.1	641	3.3	586	0.9	602	0.5
2	564	0.6	604	1.7	599	0.5	602	0.2
3	580	0.8	602	2.3	604	1.4	607	0.6
4	576	1.0	611	2.2	613	0.6	625	0.4
5	**567**	**1.3**	**580**	**2.7**	**630**	**2.9**	**676**	**6.6**

* Note: both groups read aloud in block 5

General Discussion

The results of these two experiments are consistent with the argument that the generation of a phonological code leads to the formation of both orthographic and phonological lexical entries. This transition from reading via a non-lexical route to reading via the lexical route (i.e., via the creation of lexical entries) was indexed by a reduction in the magnitude of the letter length effect. When participants repeatedly read aloud nonwords the magnitude of the letter length effect was reduced. I hypothesize that this reduction arose because each response to a nonword allows for the establishment and strengthening of whole-item print to sound associations (creation of orthographic and phonological entries along with connection between them). This transition from reading via a non-lexical route to reading via the lexical route appears critically dependent on repeated reading aloud as opposed to mere repeated exposure to the letter string given that repeated case decisions in Experiment 2 did not reduce the letter length effect when subjects were asked to read these items aloud in block 5. These results thus provide strong support for Share's (1995) self-teaching hypothesis, and at the same time, provide a novel, conceptually grounded means through which to further assess issues surrounding the formation of lexical representations.

An Alternative Account

Several colleagues have suggested an alternative account for the nonword Letter Length by Repetition interaction in which there is improvement in the efficiency of sub-lexical processing with repetition. Repetition may simply strengthen the connections between particular graphemes and particular phonemes. I cannot rule this possibility out, but this account strikes me as strained, given the vast experience in translating graphemes to phonemes that university level readers bring to the present experiments.

Interpreting Interactions

A less theoretically driven alternative account is that the letter length effect gets smaller across blocks simply because overall RT is reduced. More specifically, it might be suggested that the effect of a manipulated factor is expected to be largest in the slowest condition (here, block 1). The counterargument is that, on this account, it should not be possible to find additive effects of two or more factors on RT, yet there are a large number of experiments in which two main effects are substantial but there is no evidence of an interaction. In particular, Scarborough et al. (1977) reported that the repetition and bias (proportion of words to nonwords) in the context of lexical decision produced large main effects of both factors but no interaction on RT. I therefore see no strong reason to conclude that the reduction in the letter length effect across blocks found here arises solely because of the reduction in overall RT.

Episodic versus abstractionist accounts

Lexical representations in the DRC and CDP+ models are abstract in the sense that a single canonical representation exists for each word in the lexicon. This view can be contrasted with representations that are *episodic* such that each word has a separate representation for each encounter. The present results are of course consistent with such an ‘episodic lexicon’ (e.g., see Goldinger, 1998).

Framed in terms of Logan’s (1988) instance theory, the present results reflect a gradual transition from *algorithmic* processing to *direct retrieval*. That is, the present results can be understood as reflecting a unique illustration of this transition because they not only demonstrate the characteristic speed up associated with repetition, but also demonstrate the shift from performance dominated by algorithmic processing (affected by letter length) to direct retrieval (not affected by letter length). If an account is to be developed in terms of episodic *retrieval*, a mechanism through which a letter length effect could emerge (for example, the first time a letter string is encountered) needs to be postulated. In Logan's theory, the *algorithm* would need to produce a letter length effect. The computational models of reading discussed here provide such a mechanism (serial sublexical spelling-sound conversion).

Conclusion

The present experiments demonstrate that *one* way a letter string can come to be represented in the orthographic and phonological lexicons is through repeated reading aloud. This demonstration, along with the novel use of the letter length effect as an index of the transition from sub-lexical to lexical processing, opens up numerous avenues for future research.

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Footnotes

1. I am of course aware of the reports by New, Ferrand, Pallier, and Brysbaert (2006) and Balota, et al. (2007) that RT to words increases as letter length increases. However, in the former case, the task is lexical decision and the increase in RT as letter length increases does not appear before the word is 7 letters long. Our experiment concentrates on letter strings that vary between 3 to 6 letters. It is true that Balota et al. report a letter length effect when reading words aloud, but many of their stimuli are multisyllabic (known to affect reading aloud times) and longer than 6 letters.
2. I do not discuss PDP models because no implemented PDP model produces a letter length effect when reading nonwords aloud.

APPENDIX

Appendix A

Individual subject RT (ms) means per condition in Experiment 1.

Response Time (ms)

Block	**1**				**2**				**3**				**4**			
# of Letters	3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
Subjects																
1	487	510	506	531	474	481	489	462	449	455	467	479	474	469	490	476
2	563	541	559	563	490	506	535	542	499	501	483	502	467	469	515	481
3	428	438	443	462	410	424	416	415	519	471	484	466	521	497	506	482
4	506	574	551	601	515	519	527	569	517	521	545	580	564	626	562	561
5	505	548	546	536	468	500	501	491	470	485	475	510	483	500	481	502
6	603	578	630	584	546	563	587	573	577	549	591	573	579	583	575	582
7	479	477	464	487	494	493	534	558	526	529	510	504	521	531	527	492
8	565	572	628	690	570	623	660	680	548	555	583	604	542	545	563	584
9	473	481	504	507	465	465	465	456	457	454	454	456	446	450	460	465
10	512	533	540	530	504	492	507	496	487	532	528	564	510	528	515	331
11	438	438	430	440	461	453	467	461	434	419	442	426	418	421	422	433
12	458	464	456	469	433	427	424	436	442	437	431	448	420	423	425	442
13	656	611	672	779	585	609	539	659	503	513	511	562	499	513	541	564
14	373	393	398	385	385	385	382	380	367	391	384	379	392	389	397	382
15	583	572	540	658	349	545	568	572	573	587	565	566	573	581	469	576
16	528	534	515	536	498	523	497	511	511	490	523	509	497	490	494	510
17	363	383	382	392	364	345	374	374	360	359	368	370	358	395	384	381
18	506	513	509	534	460	467	487	487	494	517	526	518	484	533	523	508
Mean	**501**	**509**	**515**	**538**	**471**	**490**	**498**	**507**	**485**	**487**	**493**	**501**	**486**	**497**	**492**	**486**

Appendix B

5 (Block: 1-5) x 4 (Length: 1-4) ANOVA table for subject RTs (ms) in Experiment 1.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
block	Sphericity Assumed	33582.399	3	11194.133	4.084	.011
	Greenhouse-Geisser	33582.399	1.888	17788.456	4.084	.028
	Huynh-Feldt	33582.399	2.116	15868.460	4.084	.023
	Lower-bound	33582.399	1.000	33582.399	4.084	.059
Error(block)	Sphericity Assumed	139776.163	51	2740.709		
	Greenhouse-Geisser	139776.163	32.094	4355.226		
	Huynh-Feldt	139776.163	35.977	3885.145		
	Lower-bound	139776.163	17.000	8222.127		
length	Sphericity Assumed	18195.622	3	6065.207	6.065	.001
	Greenhouse-Geisser	18195.622	1.760	10336.518	6.065	.008
	Huynh-Feldt	18195.622	1.948	9341.000	6.065	.006
	Lower-bound	18195.622	1.000	18195.622	6.065	.025
Error(length)	Sphericity Assumed	51003.441	51	1000.067		
	Greenhouse-Geisser	51003.441	29.926	1704.347		
	Huynh-Feldt	51003.441	33.115	1540.200		
	Lower-bound	51003.441	17.000	3000.202		
block * length	Sphericity Assumed	12182.531	9	1353.615	2.317	.018
	Greenhouse-Geisser	12182.531	3.440	3541.837	2.317	.077
	Huynh-Feldt	12182.531	4.418	2757.332	2.317	.059
	Lower-bound	12182.531	1.000	12182.531	2.317	.146
Error(block*length)	Sphericity Assumed	89374.156	153	584.145		
	Greenhouse-Geisser	89374.156	58.473	1528.460		
	Huynh-Feldt	89374.156	75.110	1189.911		
	Lower-bound	89374.156	17.000	5257.303		

Appendix C

Individual subject errors per condition in Experiment 1.

Proportion Error

Block	1				2				3				4			
# of Letters	3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
Subjects																
1	.00	.04	.08	.04	.00	.12	.00	.00	.12	.04	.00	.00	.12	.12	.00	.00
2	.00	.00	.00	.04	.00	.00	.00	.04	.04	.00	.04	.00	.00	.00	.00	.00
3	.04	.04	.00	.04	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.04	.00
4	.04	.12	.00	.04	.00	.00	.00	.04	.04	.00	.00	.00	.04	.04	.00	.04
5	.04	.00	.00	.00	.04	.00	.04	.04	.00	.00	.00	.00	.00	.00	.04	.08
6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.04	.00	.04	.00	.00	.00	.04	.04	.00	.00	.04	.04	.00	.00	.00	.04
8	.04	.00	.00	.00	.08	.08	.00	.00	.00	.00	.00	.04	.04	.04	.00	.00
9	.04	.00	.04	.00	.04	.00	.00	.00	.04	.00	.00	.00	.00	.00	.00	.00
10	.00	.08	.00	.00	.00	.00	.00	.08	.00	.08	.04	.00	.00	.00	.00	.20
11	.00	.00	.00	.04	.00	.00	.00	.04	.00	.00	.04	.04	.00	.00	.00	.04
12	.00	.00	.00	.00	.00	.04	.00	.08	.00	.04	.00	.12	.04	.04	.00	.00
13	.04	.08	.08	.12	.04	.00	.00	.04	.00	.08	.00	.04	.00	.00	.00	.04
14	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.04	.00	.00	.00
15	.16	.16	.04	.08	.24	.04	.12	.16	.12	.16	.04	.08	.08	.00	.04	.08
16	.00	.04	.00	.00	.00	.04	.00	.00	.00	.00	.00	.00	.00	.00	.04	.00
17	.04	.00	.00	.00	.04	.04	.00	.00	.08	.04	.00	.00	.04	.00	.04	.00
18	.12	.04	.00	.00	.08	.08	.04	.08	.08	.00	.04	.00	.04	.04	.00	.00
Mean	**.03**	**.03**	**.02**	**.02**	**.03**	**.02**	**.01**	**.04**	**.03**	**.02**	**.01**	**.02**	**.02**	**.02**	**.01**	**.03**

Appendix D

5 (Block: 1-5) x 4 (Length: 1-4) ANOVA table for subject errors in Experiment 1.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
block	Sphericity Assumed	.002	3	.001	.649	.588
	Greenhouse-Geisser	.002	2.480	.001	.649	.560
	Huynh-Feldt	.002	2.936	.001	.649	.584
	Lower-bound	.002	1.000	.002	.649	.432
Error(block)	Sphericity Assumed	.055	51	.001		
	Greenhouse-Geisser	.055	42.154	.001		
	Huynh-Feldt	.055	49.915	.001		
	Lower-bound	.055	17.000	.003		
length	Sphericity Assumed	.011	3	.004	2.356	.083
	Greenhouse-Geisser	.011	2.186	.005	2.356	.104
	Huynh-Feldt	.011	2.521	.004	2.356	.095
	Lower-bound	.011	1.000	.011	2.356	.143
Error(length)	Sphericity Assumed	.078	51	.002		
	Greenhouse-Geisser	.078	37.164	.002		
	Huynh-Feldt	.078	42.862	.002		
	Lower-bound	.078	17.000	.005		
block * length	Sphericity Assumed	.004	9	.000	.531	.850
	Greenhouse-Geisser	.004	3.456	.001	.531	.688
	Huynh-Feldt	.004	4.445	.001	.531	.732
	Lower-bound	.004	1.000	.004	.531	.476
Error(block*length)	Sphericity Assumed	.140	153	.001		
	Greenhouse-Geisser	.140	58.753	.002		
	Huynh-Feldt	.140	75.572	.002		
	Lower-bound	.140	17.000	.008		

Appendix E

Individual subject RT (ms) means per condition for the case decision training group in Experiment 2.

Response Time (ms)

Block	1		2		3		4		5	
# of Letters	3	6	3	6	3	6	3	6	3	6
Subjects										
1	539	548	585	611	607	642	555	581	590	664
3	636	735	673	722	688	697	747	685	815	845
5	508	554	544	559	531	518	525	546	512	542
7	513	518	496	496	509	547	492	531	577	558
9	574	579	587	593	574	636	577	590	648	683
11	589	597	632	612	608	596	635	588	523	539
13	493	468	447	490	578	541	552	567	620	656
15	534	544	527	539	528	516	530	525	601	707
17	584	652	656	668	650	725	744	791	930	990
19	624	636	621	593	602	569	621	657	593	688
21	588	584	597	572	664	604	653	670	632	632
23	720	739	648	641	687	635	707	819	593	648
25	551	597	574	576	587	576	583	618	748	916
27	653	656	602	603	622	677	645	670	718	722
29	525	524	544	575	562	534	559	547	475	509
31	685	677	724	696	673	671	709	619	545	604
33	612	621	638	641	609	620	611	599	578	623
35	640	677	686	698	645	691	691	699	746	729
37	568	591	637	633	643	648	577	658	601	673
39	579	545	556	515	522	505	537	544	546	585
Mean	**586**	**602**	**599**	**602**	**604**	**607**	**613**	**625**	**630**	**676**

Appendix F

Individual subject RT (ms) means per condition for the reading aloud training group in Experiment 2.

Response Time (ms)

Block	**1**		**2**		**3**		**4**		**5**	
# of Letters	3	6	3	6	3	6	3	6	3	6
Subjects										
2	532	583	514	566	571	552	595	652	602	528
4	541	671	537	612	558	608	552	602	523	593
6	637	617	504	513	528	527	506	531	501	541
8	541	671	537	612	558	608	552	602	523	593
10	539	519	511	541	529	500	509	522	509	528
12	548	619	553	601	567	602	552	591	539	580
14	778	827	763	761	725	797	773	808	751	748
16	584	681	599	648	577	639	638	583	586	619
18	557	571	502	526	504	497	499	526	526	537
20	676	738	567	629	642	680	564	598	535	554
22	555	615	538	602	539	577	513	540	522	564
24	584	606	578	611	613	649	606	654	616	599
26	581	539	541	569	560	536	541	540	562	554
28	547	612	554	557	545	563	498	577	515	555
30	561	574	561	588	557	594	578	555	556	553
32	520	555	506	529	519	571	527	545	516	511
34	647	690	600	623	645	614	626	700	644	623
36	537	570	535	567	536	553	531	597	525	558
38	636	638	565	643	632	611	587	636	590	569
40	806	916	707	783	694	752	784	852	704	687
Mean	**595**	**641**	**564**	**604**	**580**	**602**	**576**	**611**	**567**	**580**

Appendix G

5 (Block: 1-5) x 2 (Length: 3 vs. 6) ANOVA on RTs (ms) from reading aloud training group in Experiment 2.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
block	Sphericity Assumed	43547.780	4	10886.945	8.977	.000
	Greenhouse-Geisser	43547.780	2.589	16819.283	8.977	.000
	Huynh-Feldt	43547.780	3.034	14355.372	8.977	.000
	Lower-bound	43547.780	1.000	43547.780	8.977	.007
Error(block)	Sphericity Assumed	92172.220	76	1212.792		
	Greenhouse-Geisser	92172.220	49.194	1873.648		
	Huynh-Feldt	92172.220	57.638	1599.171		
	Lower-bound	92172.220	19.000	4851.169		
length	Sphericity Assumed	47247.380	1	47247.380	36.687	.000
	Greenhouse-Geisser	47247.380	1.000	47247.380	36.687	.000
	Huynh-Feldt	47247.380	1.000	47247.380	36.687	.000
	Lower-bound	47247.380	1.000	47247.380	36.687	.000
Error(length)	Sphericity Assumed	24469.020	19	1287.843		
	Greenhouse-Geisser	24469.020	19.000	1287.843		
	Huynh-Feldt	24469.020	19.000	1287.843		
	Lower-bound	24469.020	19.000	1287.843		
block * length	Sphericity Assumed	7344.320	4	1836.080	3.871	.006
	Greenhouse-Geisser	7344.320	3.323	2210.312	3.871	.011
	Huynh-Feldt	7344.320	4.000	1836.080	3.871	.006
	Lower-bound	7344.320	1.000	7344.320	3.871	.064
Error(block*length)	Sphericity Assumed	36051.280	76	474.359		
	Greenhouse-Geisser	36051.280	63.132	571.043		
	Huynh-Feldt	36051.280	76.000	474.359		
	Lower-bound	36051.280	19.000	1897.436		

Appendix H

2 (Group: Reading Aloud vs. Case Decision) x 2 (Length: 3 vs. 6) ANOVA on subject RTs (ms) in block 5 of Experiment 2

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
length	Sphericity Assumed	17140.513	1	17140.513	21.675	.000
	Greenhouse-Geisser	17140.513	1.000	17140.513	21.675	.000
	Huynh-Feldt	17140.513	1.000	17140.513	21.675	.000
	Lower-bound	17140.513	1.000	17140.513	21.675	.000
length * training_group	Sphericity Assumed	5661.612	1	5661.612	7.159	.011
	Greenhouse-Geisser	5661.612	1.000	5661.612	7.159	.011
	Huynh-Feldt	5661.612	1.000	5661.612	7.159	.011
	Lower-bound	5661.612	1.000	5661.612	7.159	.011
Error(length)	Sphericity Assumed	30050.375	38	790.799		
	Greenhouse-Geisser	30050.375	38.000	790.799		
	Huynh-Feldt	30050.375	38.000	790.799		
	Lower-bound	30050.375	38.000	790.799		

Appendix I

Individual subject errors per condition for the case decision group in Experiment 2.

Proportion Error

Block	**1**		**2**		**3**		**4**		**5**	
# of Letters	3	6	3	6	3	6	3	6	3	6
Subjects										
1	.00	.00	.00	.00	.04	.00	.04	.00	.00	.00
3	.04	.00	.00	.00	.00	.04	.00	.00	.12	.37
5	.04	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.04	.00	.00	.00	.00	.00	.00	.00	.00	.00
9	.00	.00	.04	.00	.04	.00	.00	.00	.08	.00
11	.00	.04	.04	.00	.00	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00	.00	.04	.00	.00	.04
15	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
17	.00	.00	.00	.00	.00	.00	.00	.08	.08	.37
19	.02	.02	.02	.00	.04	.00	.00	.00	.04	.02
21	.00	.00	.00	.00	.00	.00	.04	.00	.00	.08
23	.00	.00	.00	.00	.08	.00	.00	.00	.08	.04
25	.04	.00	.00	.04	.00	.08	.00	.00	.08	.17
27	.00	.04	.00	.00	.00	.00	.00	.00	.00	.08
29	.00	.00	.00	.00	.00	.00	.00	.00	.00	.08
31	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
37	.00	.00	.00	.00	.00	.00	.00	.00	.08	.00
39	.00	.00	.00	.00	.00	.00	.00	.00	.00	.04
Mean	**.01**	**.01**	**.01**	**.00**	**.01**	**.01**	**.01**	**.00**	**.03**	**.06**

Appendix J

Individual subject errors per condition for the reading aloud group in Experiment 2

Proportion Error

Block	1		2		3		4		5	
# of Letters	3	6	3	6	3	6	3	6	3	6
Subjects										
2	.12	.21	.04	.04	.08	.21	.17	.08	.00	.12
4	.00	.00	.00	.00	.00	.00	.00	.04	.00	.00
6	.00	.00	.00	.08	.00	.00	.00	.00	.00	.08
8	.00	.00	.00	.00	.00	.00	.00	.04	.00	.00
10	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
12	.00	.00	.00	.00	.00	.00	.00	.02	.00	.00
14	.00	.00	.00	.00	.04	.04	.00	.00	.00	.00
16	.00	.00	.00	.00	.00	.00	.00	.00	.04	.00
18	.00	.12	.00	.04	.00	.04	.00	.04	.00	.08
20	.00	.04	.00	.00	.00	.00	.00	.00	.00	.00
22	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
26	.00	.00	.00	.00	.00	.04	.00	.04	.00	.00
28	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
30	.00	.08	.04	.04	.00	.00	.00	.00	.00	.08
32	.00	.00	.00	.00	.00	.00	.00	.00	.04	.04
34	.17	.04	.00	.04	.00	.00	.00	.00	.04	.08
36	.00	.00	.00	.00	.00	.00	.00	.04	.00	.00
38	.00	.08	.00	.08	.00	.08	.00	.08	.04	.04
40	.12	.08	.04	.00	.04	.04	.04	.04	.08	.00
Mean	**.02**	**.03**	**.01**	**.02**	**.01**	**.02**	**.01**	**.02**	**.01**	**.03**

Appendix K

5 (Block: 1-5) x 2 (Length: 3 vs. 6) ANOVA on errors from reading aloud training group in Experiment 1.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
block	Sphericity Assumed	.005	4	.001	1.646	.172
	Greenhouse-Geisser	.005	2.286	.002	1.646	.202
	Huynh-Feldt	.005	2.615	.002	1.646	.196
	Lower-bound	.005	1.000	.005	1.646	.215
Error(block)	Sphericity Assumed	.062	76	.001		
	Greenhouse-Geisser	.062	43.430	.001		
	Huynh-Feldt	.062	49.694	.001		
	Lower-bound	.062	19.000	.003		
length	Sphericity Assumed	.007	1	.007	4.927	.039
	Greenhouse-Geisser	.007	1.000	.007	4.927	.039
	Huynh-Feldt	.007	1.000	.007	4.927	.039
	Lower-bound	.007	1.000	.007	4.927	.039
Error(length)	Sphericity Assumed	.029	19	.002		
	Greenhouse-Geisser	.029	19.000	.002		
	Huynh-Feldt	.029	19.000	.002		
	Lower-bound	.029	19.000	.002		
block * length	Sphericity Assumed	.000	4	.000	.067	.992
	Greenhouse-Geisser	.000	2.670	.000	.067	.968
	Huynh-Feldt	.000	3.148	.000	.067	.981
	Lower-bound	.000	1.000	.000	.067	.799
Error(block*length)	Sphericity Assumed	.046	76	.001		
	Greenhouse-Geisser	.046	50.732	.001		
	Huynh-Feldt	.046	59.806	.001		
	Lower-bound	.046	19.000	.002		

Appendix L

4 (Block: 1 - 4) x 2 (Length: 3 vs. 6) ANOVA on subject RTs for the case decision group in Experiment 2.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Block	Sphericity Assumed	13531.919	3	4510.640	2.940	.041
	Greenhouse-Geisser	13531.919	2.475	5466.456	2.940	.052
	Huynh-Feldt	13531.919	2.875	4706.672	2.940	.043
	Lower-bound	13531.919	1.000	13531.919	2.940	.103
Error(block)	Sphericity Assumed	87460.456	57	1534.394		
	Greenhouse-Geisser	87460.456	47.033	1859.536		
	Huynh-Feldt	87460.456	54.626	1601.079		
	Lower-bound	87460.456	19.000	4603.182		
Length	Sphericity Assumed	3053.756	1	3053.756	3.660	.071
	Greenhouse-Geisser	3053.756	1.000	3053.756	3.660	.071
	Huynh-Feldt	3053.756	1.000	3053.756	3.660	.071
	Lower-bound	3053.756	1.000	3053.756	3.660	.071
Error(length)	Sphericity Assumed	15852.369	19	834.335		
	Greenhouse-Geisser	15852.369	19.000	834.335		
	Huynh-Feldt	15852.369	19.000	834.335		
	Lower-bound	15852.369	19.000	834.335		
block * length	Sphericity Assumed	1406.419	3	468.806	.836	.479
	Greenhouse-Geisser	1406.419	2.218	634.009	.836	.451
	Huynh-Feldt	1406.419	2.525	557.101	.836	.463
	Lower-bound	1406.419	1.000	1406.419	.836	.372
Error(block*length)	Sphericity Assumed	31948.956	57	560.508		
	Greenhouse-Geisser	31948.956	42.148	758.025		
	Huynh-Feldt	31948.956	47.966	666.074		
	Lower-bound	31948.956	19.000	1681.524		

Appendix M

2 (Group: Reading Aloud vs. Case Decision) x 2 (length: 3 vs. 6) ANOVA on subject errors in block 5 of Experiment 2.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
length	Sphericity Assumed	.013	1	.013	4.738	.036
	Greenhouse-Geisser	.013	1.000	.013	4.738	.036
	Huynh-Feldt	.013	1.000	.013	4.738	.036
	Lower-bound	.013	1.000	.013	4.738	.036
length * training_group	Sphericity Assumed	.003	1	.003	.941	.338
	Greenhouse-Geisser	.003	1.000	.003	.941	.338
	Huynh-Feldt	.003	1.000	.003	.941	.338
	Lower-bound	.003	1.000	.003	.941	.338
Error(length)	Sphericity Assumed	.102	38	.003		
	Greenhouse-Geisser	.102	38.000	.003		
	Huynh-Feldt	.102	38.000	.003		
	Lower-bound	.102	38.000	.003		