Behavioural Science Institute
Master Science Thesis

Word Naming and the Effects of Repetition and Language on Noise Patterns

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Abstract

Previous research has found pink noise signals in word naming experiments and it has been hypothesized that such noise patterns are indicative of the healthy coordination between voluntary and involuntary control. Furthermore, in the domain of motor movement, pink noise has been shown to become clearer through training (i.e., learning). This study examined whether such learning effects are also present in a repeated word naming task and whether the amount of repetition within a task affects noise signals. Nonlinear analyses were used to calculate the fractal dimensions, which identify such noise signals. Although the data support the finding of pink noise in word naming data, no learning effects on the fractal dimensions were found. That is, the noise signals showed no changes as a result of learning (i.e., repetition). A possible explanation for this is that due to the level of reading proficiency already acquired by the age of the participants, they already possessed a healthy level of coordination between voluntary and involuntary control for this task. Future research should examine whether learning effects are present in the noise signals of speeded word naming in younger participants, such as children and/or teenagers.

Keywords: *word naming, fractals, noise patterns, 1/f, learning*

This study will examine the phenomenon that is usually discarded as background noise. Van Orden, Holden, and Turvey (2003) argued that it is in this so-called background noise that the dynamics that coordinate the mind and body are revealed. Now imagine walking home: Do you believe that the stride interval (i.e., the distance of your step) at the beginning of your journey affects the next one and the one thereafter, or even the final one? Or do you believe that each stride interval is random, and thus unrelated to any of the previous or subsequent ones? Or is each interval exactly the same? It is in the long-term correlations in the background noise, in this case in the stride intervals, that we can find plausible stories about how the mind and body coordinate and, more interestingly, whether we have any voluntary control over our behaviours (Van Orden, 2010).

Examining noise is the focus of the present study, and more specifically about its presence in a cognitive task, in this case a word-naming task. In order to have a full understanding of the topic at hand, I will start off by explaining two key concepts, namely fractals and noise patterns. Following this, previous research findings concerning these concepts in human behaviour will be discussed. Finally, the goal of the present study will be presented.

Fractals

Benoit Mandelbrot introduced the term fractal in 1975. A fractal is a mathematically self-similar pattern, which implies that large features of the pattern contain within themselves smaller features, which in turn contain even smaller features, and so on (Liebovitch & Shehadeh, 2005; Mandelbrot, 1982; Van Orden, Holden, & Turvey, 2003). Thus, when zooming in on fractal objects, smaller replicas of the larger object become visible. This is not to say that the smaller replicas are exact copies of the larger object; they can be, but they can also be similar looking copies. Apart from being self-similar, fractal objects are also dependent on the resolution

that is used to measure their dimension (Liebovitch & Shehadeh, 2005). For example, when measuring the length of the coastline of Britain, it matters for the outcome which measurement scale is used. This is due to the presence of bays and peninsulas that are present in the coastline: Small bays and peninsulas are only captured by smaller measurement scales. To explain fractals in more detail, two examples will be given next: One mathematical example and one example from natural fractals.

A fractal can be mathematically described with an iterative function. An iterative function is like a feedback mechanism: Each output serves as the input for the next equation, and so on. An iterative function can, for example, be written as a linear function as $x(t) = x_{t-1} + c$, or as a quadratic function as $x(t) = (x_{t-1})^2 + c$, where c is a constant (Peitgen, Jürgens, & Saupe, 1992). A classic example of an iteration that results in a fractal pattern is the Sierpinski triangle. Figure 1 shows that each subsequent step in the iteration takes away the middle quarter of each present black triangle, thus creating three times as many black triangles in each step. The Sierpinski triangle clearly shows the self-similarity of a fractal: Similar patterns are present at all scales.

Figure 1. The first five steps in the formation of the Sierpinski triangle.

Fractal patterns can also be found in the environment. Examples are trees and clouds, the leaves of flowers and trees, and the structure of the Romanesco broccoli (see Figure 2). When zooming in on the broccoli, smaller replicas of the larger image emerge. The shape of the entire

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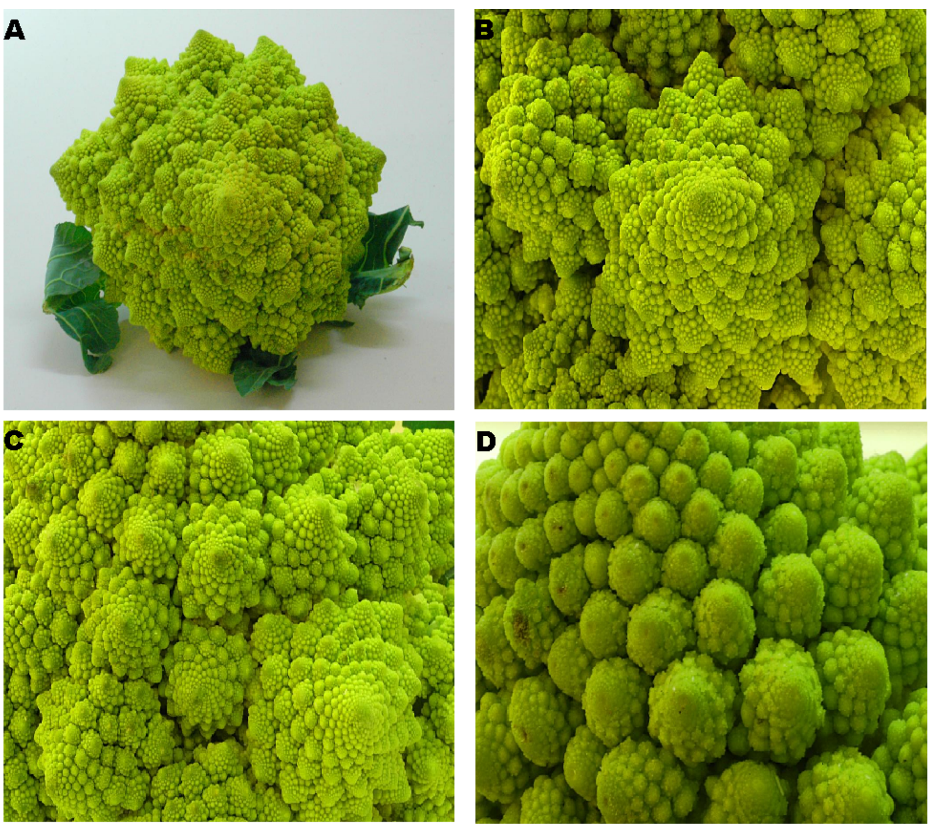

Figure 2□Fractal □atter□s i□t□e □o□a□esco □roccoli□□ac□su□se□ue□t i□age is a □oo□ed□i□ i□age of t□e □re□ious o□e□

Noise patterns

Where fractals are the spatial characterization of recurrent patterns (i.e. self-similarity), noise patterns are the temporal characterization. A sine wave is an example of a perfectly recurrent pattern. White noise (e.g. on the radio or television) on the other hand is the exact opposite: there is virtually no recurrence at all, it is completely random. But there is also a noise pattern that falls in between these two extremes. A classic example of such a pattern is the annual flooding of the Nile (Mandelbrot, 1982). What characterizes this annual flooding is that it does show a pattern, but the exact pattern is unclear and unpredictable because the pattern is fractal. Measurements over time of the tides of the Nile can be used to calculate the accompanying noise pattern. It appears that this pattern is pink, since in the long run (on larger time scales) periods of drought are followed by periods of flooding, but on smaller time scales there is still variability visible. Next, noise patterns will be discussed in more detail.

There are three types of noise patterns that dominate the literature, namely white, brown, and pink noise (e.g. Gilden, 2001; Holden, 2005; Van Orden, Kloos, & Wallot, 2009; Van Orden, 2010). White noise is 'over-random' noise, that is, there are no correlations between the consecutive data points (e.g. response times) in a time series. This in turn leads to the inability to predict any value based on any earlier observed value. Brown noise is the opposite of white noise, in that it is 'over-regular' noise. This means that based on the knowledge of a prior observed value one can predict the next value (due to the high correlations between consecutive data points). Pink noise falls in between white and brown noise, in that it is neither too predictable nor is it too random (Van Orden et al., 2009).

Figure 3 (adopted from Gilden, 2001) represents response time fluctuations as a time series for each of these types of noise, along with their power spectrum on double logarithmic

scales. As can be seen from Figure 3A, white noise is random and its power spectrum indicates that each frequency contributes equally to the shape of the overall signal (a flat line in the power spectrum): there is a lack of correlations in the time series (Holden, 2[illegible]). Figure 3B is an example of the fluctuations of brown noise. Its power spectrum reveals that the overall shape of this time series is dominated by low frequencies (slow waves) indicating that it is highly self-correlated. This is a so-called random walk correlation pattern (Brownian motion) where the next value is just a small random fluctuation from the previous value. As mentioned earlier, pink noise falls in between white and brown noise and is dominated by long-range correlations, which can been seen in Figure 3C. Its power spectrum shows that the lower frequencies dominate in power, but that higher frequencies nonetheless have some influence on the overall shape of the time series.

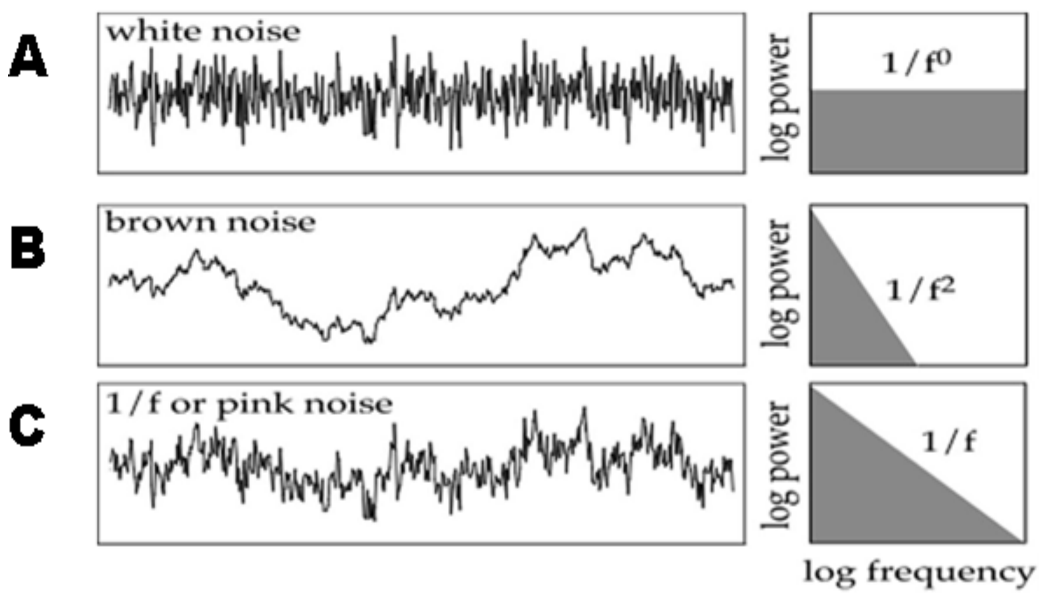

Figure 3. Patterns of (A) white, (B) brown, and (C) pink noise along with their power spectrum (Wilde[illegible], 2[illegible]1[illegible]).

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Pink noise in human behaviour

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reaction time and key contact duration (Kello, Beltz, Holden, & Van Orden, 2□□□) and locomotion (Kiefer, Riley, Shockley, Villard, & Van Orden, 2□□□). Kello and colleagues (2□□□) even hypothesised that pink noise may be a ubiquitous property of repeated measures of human performance, but what meaning can be given to the finding of pink noise in human behaviour?

For one, previous research has shown linkages between pink noise and health. An example of this comes from research that has shown that a healthy heartbeat is accompanied by a pink noise signal (Goldberger, Bhargava, West, & Mandell, 1□□□; Goldberger et al., 2□□2; Peng et al., 1□□□). Deviations from this pattern have been shown to be associated with an unhealthy heart rate. For example, congestive heart failure shows patterns of brown noise in heart beat intervals. Patients with a cardiac arrhythmia, atrial fibrillation, produced a white noise heart rate pattern (Goldberger et al., 2□□2).

Other examples concerned with pink noise and health come from research on Parkinson's and Huntington's disease. For Parkinson's, it has been found that the scaling exponents for gait, arm movement and speech all move in the direction of brown noise, and that the degree of departure is associated with the severity of other symptoms related to Parkinson's (□a□□□, □as□i□□a□a□oto, & Kwa□, 2□□□). Concerning Huntington's, Hausdorff and colleagues (1□□□) showed that stride interval fluctuations of people with Huntington's disease and elderly people while walking were more random, that is towards white, compared to healthy or younger people whose stride interval fluctuations were pink. The finding that health is associated with the finding of pink noise patterns suggests the possibility that pink noise is a marker for healthy human behaviour. The previous findings of pink noise in cognitive and motor performance tasks could indicate that it is not only a marker for health per se, but for good or healthy performance in these domains as well.

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Pink noise and word naming

To get back to the topic of the present study, namely pink noise and its relation to speeded word naming, it has been shown that speeded word naming shows signs of being fractal, because of the presence of pink noise in the data (Holden, Van Orden, & Turvey, 2009; Van Orden, Holden, & Turvey, 2003). In these studies participants had to name 1,200 visually presented words as fast as possible. The resulting time series of the response times appeared to be pink, suggesting in light of Van Orden's (2010) hypothesis that the participants showed a healthy coordination between voluntary and involuntary control during the task. Originally, however, this cognitive task is believed to elicit automatic cognitive processes (Van Orden, Holden, & Turvey, 2003), but the finding of pink noise brings this assumption in doubt. Thus, if pink noise indicates the coordination between voluntary and involuntary control, as suggested by Van Orden (2010), then this would imply that there are also voluntary controlled processes active during speeded word naming, rather than just automatic cognitive processes.

To examine the possibility that voluntary controlled processes are active during speeded word naming, the current study will try to answer the question of how pink noise manifests itself in word naming, and more specifically, if and how repetition affects the noise signal. The first hypothesis is that repeating a word naming task will lead to clearer patterns of pink noise in the data and that this effect is even stronger when there are more learning opportunities (i.e. more repetition of words within the task). If a shift from white(r) noise towards pink(er) noise is found, then this could indicate that voluntary controlled processes are active during word naming and thus more coordination, which would support the claim made by Van Orden (2010) that pink noise could signal the healthy coordination between voluntary and involuntary processes.

The second hypothesis is that this potential shift towards pink noise will be clearer for a

foreign language (English) compared to a native language (Dutch), since for a foreign language there might be more need for coordination when reading words. Kroll, Michael, Tokowicz, and Dufour (2002) found that second language naming times were slower than those of the first language and this could indicate that there is more need for coordination when reading a foreign language and thus more potential for changes in the noise pattern. In sum: Does the amount of repetition within a task and/or language matter to the observed noise pattern?

Method

Participants

Thirty-four students (32 women, two men; M_{age} = 1[illegible] years, age range: 1[illegible]–2[illegible] years) from the Radboud University Nijmegen received course credits in exchange for participation. The only two criteria for participation were that participants had no language impairments, such as dyslexia, and that Dutch was their first language. Participants were randomly assigned to one of three experimental conditions. The data of one female participant was excluded from the analyses because of technical problems with the data recording.

Before both experiments the participants had to complete a short task to determine their reading fluency. For the Dutch words this was done by presenting the participants with the One-Minute-Test (Brus & Voeten, 1[illegible]3), in which the participants had to read out loud as many words as possible within one minute (M = 1[illegible]1 words, SD = [illegible]3, range: [illegible]–11[illegible] words). In the case of the English words this was a list consisting of [illegible] words adopted from the study by Koele and Visser (2[illegible]1[illegible]; see Appendix [illegible]), which they had to read out loud as quickly as possible without a time limit (M = 2[illegible]3[illegible] seconds, SD = 3[illegible], range: 2[illegible]–3[illegible] seconds).

Stimuli

The words used in the present study (both the Dutch and English) were collected from the

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Materials

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Procedure

□□e ex□eri□e□t too□ □lace o□ two se□arate days□ wit□ exactly o□e wee□ i□ □etwee□□ □□e first day t□e □artici□a□ts were □rese□ted wit□ Dutc□ words□ t□e wee□ after wit□ □□glis□ words□

At the start of each experiment, both for the Dutch and English conditions, a message on the computer screen explained the procedure to the participants. Next, a practice list consisting of twenty words was presented to familiarize the participants with the experiment. These twenty practice trials were only presented to the participants before the first experimental list, for the Dutch as well as the English words. After the practice trials another screen with some additional information appeared, after which the first list of 1□1□□ experimental trials began.

Each trial began with a fixation signal (□□□□□) that remained visible for □□□ ms. This signal was followed by the word to respond to. The participants had to pronounce the word presented in the center of the screen as quickly and accurately as possible into the microphone. If no response was recorded after 1□ seconds, the trial timed out and the next trial began. The inter-trial interval (the time between pronunciation and the fixation signal) was set at 2□□□ ms. During the experiment the experimenter sat quietly behind the participant and recorded any errors made in pronunciation or failures in the data recording (e.g., when the microphone did not record a pronunciation). After each session of 1□1□□ experimental trials the participants had a 1□-minute break. During these breaks the participant and experimenter left the room for a recreational walk or a cup of coffee. It took participants approximately 1 hour and □□ minutes to complete the entire experiment, including the two times 1□-minute breaks. This was the case for both the Dutch and the English condition.

Analyses

Before the data were analyzed, the errors that were recorded by the experimenter during the experiments were deleted from the response time data. The upper and lower limits for extreme removal were set at 1□□ ms and 1□□□ ms to ensure that errors (which the experimenter failed to record) were also removed from the data. Next, the reaction times that were larger or

smaller than three times the SD from the mean were also removed. This was done to ensure that inherent biases in the applied time series analyses were eliminated (see Holden, 2□□□), while still respecting the intraindividual differences in reaction times in all three experimental groups (Wijnants et al., 2□1□). To time series that did not meet the required length of 1□2□ data points after the removal of errors and extremes, zeros were added. For those time series that consisted of more than 1□2□ data points after removal of errors and extremes, the first data points in the time series were removed until the length matched the required 1□2□ trials. Next, the time series were detrended. Detrending the time series removes linear and quadratic trends from the data, which avoids potential biases in the estimated spectral slopes and fractal dimensions (Holden, 2□□□). Finally, the data was normalized, which resulted in the time series having a mean of zero and a variance of one (Holden, 2□□□). Next, the two types of nonlinear analyses used to determine the fractal dimensions in these time series will be discussed.

Spectral analysis

Through a Fast-Fourier Transformation, spectral analysis transforms the time series from the time domain (milliseconds) into a frequency domain (□□□□, Wijnants et al., 2□□□). What this procedure does is finding the best-fitting sum of sine and cosine waves that are present in the time series and puts their frequencies and amplitudes on a log-log scale. The slope of the spectral plots is of interest here, since it signals the relation that is present between the frequencies and amplitudes in the data. The fractal dimension resulting from the spectral analysis can be obtained with the use of the equation 1 □ □! □ 1□2, where ! is the absolute value of the spectral slope.

While spectral analysis requires extensive preprocessing of the data, and extreme values can contaminate the outcome measures, it is very robust in many other aspects (Holden, 2□□□). It

provides a clear measure of the scaling relation in the lower frequency region of the spectral plot.

Detrended fluctuation analysis (DFA)

Detrended fluctuation analysis represents the relation between preset window sizes of data, which in the present study ranged from [illegible] to 1[illegible]2[illegible], and the mean standard deviations of this windowed data. As a first step the time series is divided into bins of equal sizes, which are non-overlapping. Next, in each bin the locally best-fit line is subtracted. Finally, the root mean square of these binned and locally detrended time series is computed for windows of the same size. This process is repeated across increasing window sizes beyond the limits of the actual data set. A scaling exponent is obtained by plotting the average fluctuation across the increasing window sizes on a log-log scale. The fractal dimension resulting from the detrended fluctuation analysis can be obtained with the use of the equation 2 − α, where α is the scaling exponent of the analysis. In contrast to spectral analysis, detrended fluctuation analysis (DFA) does not require the arbitrary setting of parameters, while still being reliable and robust ([illegible]e[illegible]er, [illegible]; Kocsis & Ko[illegible]a[illegible], 2[illegible]2[illegible]).

Results

Repeated measures analyses were conducted on all of the measured variables (see Table 1). This resulted in a 2 x 3 (Language (Dutch, English) x Session (1, 2, 3)) within-subjects design. The between-subjects variable was condition (no repetition, three times 1[illegible]1[illegible] words, three times [illegible]x2[illegible] words). In the following, for each separate variable the results of these

Table 1.

Descriptive Statistics of the Measured Variables

	Condition								
	No repetition (n = 12)			3 x 1,100 words (n = 9)			3 x 4x275 words (n = 12)		
Session	1	2	3	1	2	3	1	2	3
Dutch									
Mean Response Time (*ms*)	493	484	471	546	519	493	500	468	460
Mean SD (*ms*)	81	82	84	103	83	72	72	61	64
Mean Number of Errors	45	45	56	56	45	41	26	18	20
Mean Task Duration (*min*)	23.39	23.05	22.75	24.82	23.90	23.20	23.27	22.57	22.44
English									
Mean Response Time (*ms*)	559	554	545	603	555	542	534	494	475
Mean SD (*ms*)	116	113	111	115	91	82	97	69	70
Mean Number of Errors	51	49	45	50	31	34	40	18	14
Mean Task Duration (*min*)	24.57	24.46	24.20	25.45	24.24	24.14	24.04	22.99	22.66

analyses are presented. First, the descriptive statistics of the variables used are discussed followed by the fractal dimensions.

Descriptive statistics

Mean response time. The three-way interaction effect was non-significant for mean response time, $F(4, 60) = 1.89$, $p = .11$. The Language x Condition interaction was significant, $F(2, 30) = 5.53$, $p = .009$, as well as the interaction effect of Session x Condition, $F(4, 60) = 7.91$, $p < .001$. The main effect of Language was also significant, $F(1, 30) = 65.52$, $p < .001$, indicating that Dutch words were read faster than English words. To further examine these interaction effects, one-way ANOVA's were conducted. The results of these analyses can be found in Table 2. For mean response time, all changes across sessions were significant, indicating that across sessions the mean response times reduced: Participants responded faster to the stimuli. Furthermore, the Dutch response times were significantly faster than the English response times.

Post hoc analyses revealed that, in the Dutch condition, both the group that received no repetition ($p = .02$), as well as the group that received the stimuli three times 4x275 words ($p = .006$), had significantly faster response times than the group that received three times 1,100 words. In the English condition, the group that received three times 4x275 words had significantly faster response times than both the group that received no repetition ($p = .02$) and the group that received three times 1,100 words ($p = .006$).

Mean standard deviation. For the mean standard deviation, there was no significant three-way interaction effect, $F(4, 60) = .42$, $p = .76$. There were no significant Language x Condition, $F(2, 30) = 2.40$, $p = .11$, or Language x Session interaction effects, $F(2, 60) = 1.48$, $p = .24$. The Session x Condition interaction effect was significant, $F(4, 60) = 7.67$, $p < .001$. The

Table 2.

F-Statistics of the Measured Variables

		Mean RT			Mean SD			Mean Number of Errors			Mean Task Duration		
Session		*F*	*η*	*p*	*F*	*η*	*p*	*F*	*η*	*p*	*F*	*η*	*p*
1													
	Dutch	8.40[1]	.43	.002	.08[1]	.01	.91	1.12[3]	.11	.35	4.81[1]	.30	.04
	English	3.53[1]	.24	.047	.23[1]	.02	.79	.77[1]	.07	.47	3.29[1]	.23	.06
2													
	Dutch	35.04[2]	.81	.001	7.19[2]	.47	.006	2.60[2]	.25	.13	20.10[2]	.72	.001
	English	35.04[2]	.81	.001	17.42[2]	.69	.001	5.88[2]	.42	.01	23.22[2]	.74	.001
3													
	Dutch	15.79[1]	.59	.002	9.79[1]	.47	.006	3.32[1]	.23	.06	13.90[1]	.56	.002
	English	19.73[1]	.64	.001	7.28[1]	.40	.01	5.59[1]	.34	.04	22.73[1]	.67	.001

[1] Degrees of freedom (2,22)
[2] Degrees of freedom (2,16)
[3] Degrees of freedom (2,18)

main effect of Language was also significant, $F(1, 30) = 17.21$, $p < .001$, indicating that the Dutch response times were less variable than the English. To further examine these effects, one-way ANOVA's were conducted. The results of these analyses can be found in Table 2. The groups that received repetition both showed a significant decrease in variability across sessions, both in the Dutch and English conditions, indicating that their response times became less variable. This was however not the case for the group that received no repetition.

Post hoc analyses revealed that there were no significant differences between groups in the Dutch condition, only a marginally significant difference between the group that received three times 1,100 words and the group that received three times 4x275 words ($p = .07$). In the English condition, there was only a significant difference between the group that received no repetition and the group that received three times 4x275 words ($p = .003$), indicating that the latter group is less variable in their response times in the English condition than the first. There was no difference between both repetition groups in the English condition.

Mean number of errors. There was no significant three-way interaction effect, $F(4, 56) = .82$, $p = .49$. There was neither a significant Language x Condition interaction effect, $F(2, 28) = 1.63$, $p = .22$, nor was there a significant Language x Session interaction effect, $F(2, 56) = 2.11$, $p = .14$. The Session x Condition interaction effect was significant, $F(4, 56)$, $p = .03$. However, the main effect of Language was non-significant, $F(1, 28) = .17$, $p = .69$. Thus, the mean number of errors was the same for both Dutch and English. To further examine these effects, one-way ANOVA's were conducted (see Table 2). The group that received three times 1,100 words only showed a significant decrease in the mean number of errors across the English sessions, whereas the group that got three times 4x275 words, showed a marginally significant change in the Dutch condition, as well as a significant change in the English condition. The group that received no

repetition showed no significant changes in either the Dutch or the English condition.

Post hoc analyses revealed that, in the Dutch condition, the group that received three times 4x275 words made significantly fewer errors than the group that received no repetition ($p = .02$) and the group that received three times 1,100 words ($p = .04$). In the English condition, there was no significant difference between both groups that received repetition, but there was a significant difference between the group that received no repetition and the group that received three times 4x275 word ($p = .01$), indicating that the group that received the most repetition made significantly fewer errors than the group that received no repetition.

Mean task duration. The three-way interaction effect was non-significant, $F(4, 60) = 2.17$, $p = .09$. The Language x Condition interaction effect was significant, $F(2, 30) = 3.42$, $p < .05$, as was the Session x Condition interaction effect, $F(4, 60) = 7.05$, $p < .001$. The interaction effect of Language x Session was non-significant, $F(2, 60) = .53$, $p = .57$. However, there was a significant main effect of Language, $F(1, 30) = 28.86$, $p < .001$, indicating that participants completed the three Dutch sessions faster than the English sessions. To further examine these effects, one-way ANOVA's were conducted (see Table 2). The group that received no repetition showed a marginally significant change across sessions in the English condition, whereas the task duration in the Dutch condition reduced significantly across the sessions. Both groups that received repetition showed a significant decrease in task duration across sessions in both the Dutch and the English conditions.

Post hoc analyses revealed that there was only a significant difference in the Dutch condition between the groups that received repetition ($p = .01$), indicating that the group that received three times 4x275 words took significantly less time than the group that received three times 1,100 words to complete the task. In the English condition, the group that received three

times 4x275 words took significantly less time than both the group that received no repetition (*p* = .02) and the group that received three times 1,100 words (*p* = .01) to complete the task.

Fractal dimensions

Fractal dimensions (*FD*s) were calculated by averaging the resulting fractal dimensions of the spectral analyses and detrended fluctuation analyses. Table 3 summarizes the descriptive statistics of these averaged fractal dimensions. The three-way interaction was non-significant, $F(4, 60) = .62$, $p = .64$. The Language x Condition interaction effect was also non-significant, $F(2, 30) = 1.58$, $p = .22$, nor were the Session x Condition, $F(4, 60) = .93$, $p = .45$, or the Language x Session, $F(2, 60) = 1.84$, $p = .17$, interaction effects. The results showed that there was also no significant main effect of Language, $F(1, 30) = 1.04$, $p = .32$, or Session, $F(2, 60) = 2.10$, $p = .14$. The between-subjects effect of Condition was also non-significant, $F(2, 30) = 1.37$, $p = .27$.

Table 3.

Descriptive Statistics of the Fractal Dimensions

	Condition								
	No repetition (*n* = 12)			3 x 1,100 words (*n* = 9)			3 x 4x275 words (*n* = 12)		
Session	1	2	3	1	2	3	1	2	3
Dutch									
Mean *FD*	1.40	1.42	1.40	1.41	1.42	1.42	1.38	1.42	1.44
Standard Deviation of *FD*	0.05	0.06	0.06	0.08	0.07	0.04	0.07	0.08	0.10
English									
Mean *FD*	1.43	1.41	1.44	1.46	1.43	1.45	1.39	1.39	1.41
Standard Deviation of *FD*	0.06	0.04	0.06	0.04	0.03	0.07	0.05	0.04	0.06

Further investigation of the separate conditions and languages showed that there was a marginally significant change in the fractal dimension of the three times 4x275 words repetition group, $F(2, 22) = 3.06$, $p = .07$. Both the no repetition, $F(2, 22) = .38$, $p = .69$, and three times 1,100 words repetition, $F(2, 16) = .25$, $p = .78$, conditions showed no significant changes in the fractal dimensions across sessions. Post hoc analyses revealed that there was a significant difference in the English condition between the groups that received repetition ($p = .01$), such that the group that received three times 4x275 words had significantly lower fractal dimensions than the group that received three times 1,100 words.

Next, it was examined whether the fractal dimensions correlated with the scores on the fluency tests. As can be seen in Table 4, there were no significant correlations between the fractal dimensions and the scores on the fluency tests for any of the groups. The two fluency test scores, on the other hand, were strongly correlated, $r(31) = -.64$, $p < .001$.

As a final test, all fractal dimensions (*FD*s) were subject to a one-sample t-test in order to compare them with the fractal dimensions of perfect white ($FD = 1.5$) and pink noise ($FD = 1.2$), to find out whether they differed significantly from either or both of these values. The resulting statistics of these analyses can be found in Tables 5 and 6. Table 5 reveals that all fractal dimensions differed significantly from perfect white noise, except for the third Dutch session of the group that received three times 4x275 words, which was only marginally significant ($p = .07$). Thus, all fractal dimensions were significantly lower than that of perfect white noise. All fractal dimensions were also significantly different from perfect pink noise, shown in Table 6. Thus, all fractal dimensions were significantly higher than that of perfect pink noise. In sum, all fractal dimensions were neither white nor pink.

Table 4.

Correlations Between Fluency Tests and Fractal Dimensions

	EMT		English Fluency Test	
*FD*s	Dutch	English	Dutch	English
No repetition				
1	.14	-.17	-.11	.31
2	.25	.52	.01	.12
3	.33	-.17	-.83*	.25
Three times 1,100 words				
1	-.11	-.34	.15	.11
2	.27	-.34	-.39	.34
3	-.35	.29	-.16	-.40
Three times 4x275 words				
1	-.08	.01	.13	-.30
2	-.55	.01	.28	.28
3	.06	.16	-.36	-.06

* Correlation is significant at the 0.01 level (2-tailed)

Table 5.

T-Statistics of the Comparison Between the Fractal Dimensions and Perfect White Noise

		Test Value = 1.5								
		No repetition (n = 12)			Three times 1,100 words (n = 9)			Three times 4x275 words (n = 12)		
Session		*t*	*df*	*p*	*t*	*df*	*p*	*t*	*df*	*p*
1										
	Dutch	-6.61	11	.001	-3.59	8	.007	-6.41	11	.001
	English	-3.98	11	.002	-2.97	8	.018	-7.42	11	.001
2										
	Dutch	-5.07	11	.001	-3.34	8	.010	-3.58	11	.004
	English	-7.54	11	.001	-7.05	8	.001	-8.28	11	.001
3										
	Dutch	-5.94	11	.001	-6.28	8	.001	-2.04	11	.07
	English	-3.58	11	.004	-2.37	8	.045	-5.48	11	.001

Table 6.

T-Statistics of the Comparison Between the Fractal Dimensions and Perfect Pink Noise

		Test Value = 1.5							
		No repetition (n = 12)			Three times 1,100 words (n = 9)			Three times 4x275 words (n = 12)		
Session		*t*	*df*	*p*	*t*	*df*	*p*	*t*	*df*	*p*
1										
	Dutch	14.08	11	.001	7.88	8	.001	9.23	11	.001
	English	12.22	11	.001	17.05	8	.001	13.21	11	.001
2										
	Dutch	13.55	11	.001	8.75	8	.001	9.43	11	.001
	English	17.84	11	.001	21.15	8	.001	15.00	11	.001
3										
	Dutch	12.58	11	.001	18.46	8	.001	8.02	11	.001
	English	14.98	11	.001	11.09	8	.001	12.06	11	.001

Discussion

The present study set out to examine noise patterns in word-naming data, and more specifically, whether the amount of repetition and language matter. The first hypothesis was that more repetition would lead to clearer patterns of pink noise, and the second hypothesis was that the change in the noise pattern would be stronger for the second compared to the first language.

The changes in the descriptive measures show that the more repetition there was within the task, the faster participants responded, the less variable they were in their responses, and the fewer errors they made, as well as that Dutch words were read faster than English words, despite the fact that English is their second language. This provides evidence for the suitability of the experimental set-up for examining learning effects across the sessions, as previous studies of word naming found, for example, similar results concerning response times, accuracy (i.e., error rate), and second language naming (Kroll, Michael, Tokowicz, & Dufour, 2002). Thus, the reliability of the results of this study are in no doubt.

The results provide some evidence for the finding of pink noise in word-naming

experiments. Fractal dimensions were lower than that of perfect white noise, but also higher than that of perfect pink noise. Due to the properties of word-naming data, such as the variability of words, word length, etcetera, pink noise signals are observed less prominently in word-naming experiments, that is, the signals tend to be somewhat whitened. This is because these random word properties decorrelate the pink noise signal (Van Orden, Holden, & Turvey, 2003). Thus, the results do provide evidence for the presence of partly decorrelated pink noise in the data, as the values of the fractal dimensions in the present study are comparable to those found by Van Orden, Holden, and Turvey.

However, none of the three experimental groups showed clearer patterns of pink noise across the subsequent sessions. Rather, their fractal dimensions remained similar across sessions. Thus, the hypothesis that the pink-noise signals would become clearer across sessions could not be confirmed. This is not in line with the findings of Wijnants and colleagues (2009), who did find clearer patterns of pink noise across trials. However, in their task the participants actually had some sort of voluntary control over the reaction times, in that they were the ones that made the actual movements. In the present study however, the participants were exposed to uncontrollable intertrial intervals, and thus the inability to self-pace the naming (i.e., involuntary control), which could have led to the absence of pink noise changes across sessions.

Indeed, it has been found in stride intervals that these become more random when the movement is not self-paced, due to the instruction to walk to the beat of metronome (Kiefer, Riley, Shockley, Villard, & Van Orden, 2009). As an explanation for this, Hausdorf and colleagues (1996) proposed that this entrainment to the metronome provides a constraint to the normal timing of the strides. Van Orden, Holden, and Turvey (2003) provide a more general explanation: External factors can change the task demands, which in turn affect the measurement

of pink noise. As for the present study, it is possible that the variability of the intertrial intervals, and thus the inability to self-pace the responses, constrained the participants' normal timing of the responses, which in turn affected the measurement of the pink noise signal. And, as Holden, Choi, Amazeen, and Van Orden (2011) stated, "Unsystematic inter-stimulus or inter-trial intervals ... will whiten a fractal pattern that would otherwise be apparent" (p. 941). Future research should therefore look for possibilities to use fixed intertrial intervals after a pronunciation has ended, that is, that the intertrial interval sets in *after* the word has fully been pronounced.

Another possible explanation for observing no changes in the fractal dimensions could be that the level of reading proficiency of the participants, just like the earlier mentioned elite ballet dancers, was at such a level that there was no need for (more) coordination across the sessions, as they could have started at a level which was suitable for fulfilling the task requirements. As Spieler and Balota (2000) stated, the majority of language learning can be expected to be completed by the age of young adulthood. In light of this, it is plausible that the fractal dimensions do not change across conditions, since there is nothing left to be learned. Compare this to riding a bicycle: When you know how to ride a bicycle, and you are told to ride the same route multiple times, it can be expected that you take less time to ride the route, since you might take shorter turns, etcetera. However, the way you ride your bike probably stays the same. The same may be true for word naming: You get faster, make fewer errors, etcetera, but the word-naming process itself, as shown in the fractal dimension, stays the same. Following from this, it could also be the case that such tasks are unaffected by learning *from* a certain age. Therefore, future research should examine different age groups, in order to answer this question.

The second hypothesis was that the noise patterns in the English condition would tend to

become more pink across sessions than those of the Dutch condition, but the results do not support this hypothesis. This hypothesis was based on the idea that, since English is a second language, it provides more opportunities for learning, and thus more opportunities for noise patterns to change. Again, the absence of any changes in the fractal dimensions, and no differences between Dutch and English, can be attributed to a level of language learning that, as stated earlier, is to some extent completed (Spieler & Balota, 2000). Thus, it is possible that the words used in the present study, for both Dutch and English, are too simple to produce changes in the fractal dimensions (i.e., the task coordination). The finding that the mean number of errors for both Dutch and English did not differ supports this additional hypothesis. Future research should therefore examine whether or not such changes are present when using more difficult words, such that there is a difference in task difficulty between Dutch and English.

Although the results of the present study did not support the hypotheses, it has provided useful insights for follow-up studies. The process of word naming is not random, since partially decorrelated pink noise signals were observed in the data. Thus, there appears to be more to it than just automaticity of reading. Furthermore, the absence of changes in the fractal dimensions across sessions does not take away the possibility of such changes. Maybe such changes are only present up until a certain age, and finding out whether this is the case, could provide useful information with respect to reading instruction. Furthermore, if the amount of repetition (also) affects these changes, then this would provide a framework for enhancing the coordinated reading behaviour of students, such that they are provided with reading instruction that provides them the most opportunities for effective coordination while reading. Also, this issue may be relevant for remediation of students with reading problems (e.g., dyslexia) as well.

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Appendix

English Fluency Test

climb	absent
doubt	job
thumb	pub
black	public
rock	fact
scissors	scream
odd	mad
grandson	gladly
traffic	left
sign	spring
egg	dog
daughter	danger
light	leg
stomach	hungry
ghost	habit
knife	keep
knee	kidnap
knock	milk
tall	salt
walk	garden
autumn	stamp
receipt	task
dress	sister
island	victim
listen	king