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The representation of plural inflectional affixes in English: Evidence from priming in an auditory lexical decision task

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Abstract

The representation of inflection is controversial: theories of morphological processing range from those that treat all inflectional morphemes as independently represented in memory to those that deny independent representation for any inflectional morphemes. Whereas identity priming for stems and derivational affixes is regularly reported, priming of inflectional affixes is understudied and has produced no clear consensus. This paper reports results from a continuous auditory lexical decision task investigating priming of plural inflectional affixes in English, in plural prime-target pairs such as *crimes*→*trees*. Our results show statistically significant priming facilitation for plural primes relative to phonological (*cleanse*→*trees*) and singular (*crime*→*trees*) controls. This finding indicates that inflectional affixes, like lexical stems, exhibit identity priming effects. We discuss implications for morphological theory and point to questions for further work addressing which representation(s) produce the priming effect.

Keywords

morphology; inflection; identity priming; lexical decision

Introduction

An active controversy in the study of the mental lexicon concerns the representation of inflectional morphology. Even in the wake of a vast literature comparing different approaches to the representation of regular versus irregular inflection in the “past tense debate”, there is little consensus concerning how inflectional morphology is represented. Approaches that admit independent morphological representation range from those that posit activation of morphemes as objects in memory, without whole-word representations (“decompositional accounts” e.g., Taft & Forster 1975 and much subsequent work) to those that posit morphological representations in addition to or following activation of whole-word representations (“supra-lexical accounts” e.g., Giraudo & Grainger 2001). At another extreme are approaches denying independent morphological representation across the board. For Plaut & Gonnerman 2000, for example, all putatively morphological effects are

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derivative of phonological and semantic representations and their interactions (cf. Baayen et al. 2011).

Here, we investigate the representation of the English plural inflectional suffix. A direct way of examining how inflectional morphology is represented is to see whether inflectional affixes show priming effects in the way that stems and derivational affixes do. The main contribution paper of this paper is a demonstration of inflectional affix priming: In a continuous auditory lexical decision task, we find evidence that processing of a plural word is facilitated by a plural prime, relative to phonological and singular controls. The implications are examined in the discussion, where we outline how this project can be developed in ways that disentangle the relative contribution of syntactic, semantic, and phonological similarities.²

Background

Identity priming effects, i.e., facilitation of the target when primes and targets are identical in some way, are well-established in the lexical processing literature. Examples include whole word repetition (e.g., Scarborough et al. 1977; Forster & Davis 1984), syllable rhyme repetition (e.g., Slowiaczek et al. 2000; Norris et al. 2002), or lexical stem repetition (see below). Under abstractionist accounts (Bowers 2000; Morton 1969), these priming effects are attributed to shared representations (though see the exchange between Amenta & Crepaldi 2012 and Giraudo & Dal Maso 2016). Residual activation of the shared representation from processing the prime facilitates subsequent access in the target. The idea that priming effects diagnose shared representations has been used extensively. Most relevant here are (i) previous positive findings with stems and derivational morphemes and (ii) the **absence** of such results for inflection. There is much evidence that lexical stems exhibit identity priming in both simplex and complex words, in visual, cross-modal, and auditory presentation (see Amenta & Crepaldi 2012; Marslen-Wilson 2007). Derivational affixes have also been shown to display identity priming in a range of modalities (e.g., Marslen-Wilson et al. 1996; VanWagenen 2005; Duñabeitia et al. 2008). However, similar findings have not been established for inflectional affixes (reviewed in Table 1).

There are several reasons why inflectional affix priming effects, if they exist, might be small relative to lexical stem priming effects (and thus difficult to detect). Here we review four.³

First, inflectional affixes can be high frequency. Identity priming effects have been shown to be smaller for high-frequency items than lower-frequency items (see Kinoshita 2006). This is also consistent with inverse-frequency and surprisal effects found in structural priming studies (e.g., Bernolet & Hartsuiker 2010; Bock 1986; Ferreira 2003; Jaeger & Snider 2013).

Second, inflectional affixes are *functional* rather than *lexical* items. As such, they are neutral in valence, low in arousal, and low in concreteness. Valence and arousal (e.g., Kuperman et al. 2014) and concreteness (e.g., Yap et al. 2012) contribute to word recognition speed. Work investigating priming effects for functional items is limited (cf. Schmauder et al. 2000), and

²This study is also discussed in Goodwin Davies 2018.

³Some of these reasons are specific to inflectional affixes; others also apply to derivational affixes in comparison to lexical stems.

it is possible that functional items have a different profile with regards to identity priming due their grammatical rather than lexical nature. Correspondingly, theories of syntax and morphology often treat functional and lexical morphemes as different in kind (e.g., Embick 2015).

Third, inflectional affixes, especially suffixes, are often prosodically weak (not bearing stress; shorter in duration than full words). Phonological weakness leads to a general lack of salience; furthermore, as the items are short in duration, potential speed-up from priming facilitation is limited.

Fourth, there can be extensive homophony among inflectional affixes. This is the case for plural affixes in English, which are homophonous with third person agreement, the possessive clitic, and contractions of the copula.⁴ It is conceivable that even temporary uncertainty about which morpheme is present in a word can attenuate activation, particularly in tasks with single word presentation.

Perhaps due to these methodological challenges, there are few attempts to investigate inflectional affix priming in the literature. One contributing factor to this apparent gap may be the “file-drawer problem” (Rosenthal 1979); previous work on inflectional affix priming was not published because it yielded null results. The available studies, briefly overviewed in Table 1, are varied in methodology (e.g., modality, affix properties) and taken together, the results are difficult to interpret.

The current study

In this study, we examine inflectional affix priming effects for English plural inflectional suffixes (restricted to the voiced allomorph, /z/) in an immediate auditory continuous lexical decision task (see Bacovcin et al. 2017 and Wilder et al. 2019 for similar methodology). Although we do not have specific predictions concerning modality, it is important to consider that suffixes, in particular, may be processed differently in auditory versus visual presentation. Suffixes are encountered late in auditory presentation, as the signal unfolds incrementally. Even if sub-phonemic co-articulatory cues are present in the stem prior to the actual suffix, it is necessary for the speech signal to unfold before these become apparent to the listener, unlike in visual presentation where suffixes are perceptible from the beginning of a word being displayed (see Wilder et al. 2019 for discussion).

Care was taken to ensure that the study was appropriately powered. A power curve analysis was conducted in R with the package *simr* (Green & MacLeod 2016).⁷ Using data from a separate pilot, new data was simulated with increasing numbers of participants. With an effect size of 15ms,⁸ the study was determined to reach power of >80% with approximately 200 participants.

⁴For example, /woks/ in “these walks are...”, “she walks...”, “this walk’s highlight is...”, and “this walk’s fun...”.

⁷See Supplementary Materials here: github.com/amygood/infl-prime

⁸We specified a 15ms average speed-up for targets in the plural condition compared to the singular control condition. This was selected as a lower bound because in the means per condition of the pilot data, the plural condition was 17.4ms faster than the phonological control condition and 15.9ms faster than the singular control condition.

Experiment

The procedure and the analyses were preregistered.⁹ Three changes were made to the preregistered plan: Firstly, following Milin et al. (2017), prime was added as a random effect. This is more conservative as it reduces the extent to which random variation among the prime words is attributed to the experimental conditions. Secondly, due to a technical issue, there was unwanted variation in the inter-stimulus interval (ISI). To address this, trials where the ISI was longer than 900ms were removed. Thirdly, rather than z-scoring trial number in our analyses, we center it.

Stimuli

3 prime conditions were constructed to compare facilitation due to shared morphological structure to phonological and singular controls (Table 2). Targets are plural nouns ending with /z/. There are several reasons motivating this choice. /z/ is productive, applying to novel nouns (e.g., Berko 1958). It has syntactic reflexes, i.e., triggering agreement on verbs, which demonstrates it has processing consequences in sentence production. By using only the voiced allomorph, we keep phonological realization consistent, which removes any effects that might arise from morpho-phonological alternations.

The plural primes share this morphological and phonological structure. Per target, the singular control prime is the singular version of the plural prime, thus controlling for semantic relatedness among prime and target stems and providing an unrelated baseline condition. The phonological control primes share the phonological structure of the target but not the morphological structure, i.e., non-plural words which end with /z/ which are not homophonous with a plural word, and for which the phonological string prior to /z/ is not a reduced syllable.

The presentation of stimuli was counterbalanced such that every participant encountered each of the 36 targets once and encountered 12 primes in each condition. To achieve this, there were 3 lists. Plural primes and singular control primes were varied per list to avoid stem repetition, whereas the phonological control primes remained constant. As such, across all lists there were 36 plural primes, 36 singular control primes and 12 phonological control primes. Words of English that meet our criteria for phonological control primes are limited, so we opted for a design in which 12 rather than 36 were required. Per experimental list, no prime or target was repeated.

Latent Semantic Analysis (LSA; Dennis 2007) was used in stimuli selection to restrict semantic relatedness below a threshold of .3 between critical primes and targets to minimise semantic priming (where a value of 1 indicates maximum relatedness). To avoid phonological inhibition, no critical primes and targets shared an onset. Across the 3 conditions, primes were matched for frequency using the Lg10CD¹⁰ frequency from SUBTLEX-US (Brysbaert & New 2009).

⁹<http://aspredicted.org/blind.php?x=hf4a5p>

¹⁰This is the base 10 log of the number of films in which a word appears in a database of 8388 films + 1.

The critical stimuli made up 16.1% of the experiment. 152 filler words and 224 phonotactically licit nonwords were included, resulting in an equal number of words and nonwords. All stimuli were monosyllabic. Each participant encountered 448 stimuli arranged into pairs which were balanced for all four lexicality combinations.¹¹ Pairings were not made explicit to participants.

Due to the high proportion of /z/ final and plural words in the critical stimuli, plurality and whether a stimulus ended with /s/ or /z/ was carefully controlled within the fillers. No word filler ended with /z/. 28 word fillers ended with /s/, 50% of which were plural. Aside from these plural words, all other fillers were monomorphemic. Of the nonword fillers, 28 ended with /z/ and 28 ended with /s/. 54 nonword fillers were constructed to be “foils” which encouraged participants to attend to the final segments of stimuli prior to making a lexical decision: 28 phonologically embedded a real word (e.g., /kIs/ of *kiss* embedded in the nonword *kisp*/kIsp/) and 28 shared an initial (C)VC sequence with a real word (e.g., /tr2s/ in nonword *trusk* shared with the word *trust*). Composition of the stimuli is summarised in Table 4 below. See Appendices for complete stimuli lists.

Stimuli were recorded in a soundproof booth using a Blue Snowball microphone by a male speaker of General American English and segmented in Praat.

Procedure

228 native speakers of North American English took part in the study in the fall semester of 2017. Informed consent was obtained from each participant, and the experimental protocol was approved by the IRB. Participants were financially compensated for their participation, managed through the research crowdsourcing platform “Prolific” (Damer & colleagues 2018).

The experiment was run online using the experimental presentation software “Ibex” (Drummond 2017). The task was continuous lexical decision: participants responded to both primes and targets.

Participants were instructed to indicate (as quickly and as accurately as possible) whether each sound they heard was a word of English. Participants first responded to 16 practice trials (50% nonwords) before being randomly assigned to one of the three experimental lists. This resulted in the following distribution: 89 in List 1, 73 in List 2, and 68 in List 3. The order of stimulus presentation was randomised within a template to ensure that critical pairs were never adjacent, a block never began with a critical pair, and that, aside from the critical pairs, no stimuli ending with /z/ were adjacent. The ISI was 600–800ms, randomised to discourage participants from responding at regular intervals. The ISI was measured from the end of the soundfile or participant response, whichever was later. The experimental procedure had 4 blocks with a break between blocks. Response time was measured from the onset of stimulus presentation.

¹¹Word-word, word-nonword, nonword-nonword, and nonword-word.

Results

Participants with overall accuracy below 70% were excluded from the study ($n=28$). After subsetting the data to include only critical trials, inaccurate trials (inaccurate responses to prime or target) were removed. Response time outliers were removed following procedures in Baayen & Milin 2010 which involve examining RTs for each participant and by target separately and removing outliers which fall outside a normal distribution (see Table 5 for a summary). As mentioned, trials with ISIs greater than 900ms between prime and target were also removed.

A linear mixed effects model was fitted to log-transformed (binary logarithm) response time to targets in R, using the package lmerTest (Kuznetsova et al. 2018). Residuals greater than 2.5 standard deviations from the mean were trimmed following Baayen & Milin 2010. Prime condition was coded with plural as the reference level so that separate comparisons were made between (i) the plural prime and the singular prime and (ii) the plural prime and the phonological control prime. The following z-scored control fixed effects were included: LSA value corresponding to semantic relatedness between prime and target; ISI between prime and target; duration of target soundfile; and target frequency. Trial number (centered), was also included. The fixed effects which were predicted to co-vary with prime condition were z-scored and centered by prime condition: Mel-frequency Cepstral Coefficient (MFCC) value corresponding to phonetic relatedness between prime and target; phonological Levenshtein distance value corresponding to phonological relatedness between prime and target; prime frequency; and prime response-time. Random effects for participants and targets were optimised following Bates et al. 2015 which resulted in random intercepts for participants, primes, and targets. The model's fixed effect estimates are summarised in Table 7. The Satterthwaite (1946) method for denominator degrees of freedom was used for computing the p-values. Marginal and Conditional R^2 was calculated using the Nakagawa & Schielzeth (2013) method implemented in the package MuMIn (Barto 2018).

Responses to targets following plural primes were significantly faster than responses following phonological control primes ($\beta=.037$, $p=.015$). Responses to targets following plural primes were significantly faster than responses following singular control primes ($\beta=.027$, $p=.02$).¹² The model indicates that, for an average target word, the speed-up for a plural prime compared to a phonological control prime was 24.9ms, whereas the speed-up compared to a singular control prime was 18.3ms.

As anticipated for lexical decision tasks, the control variables of trial number, target duration, target frequency, and prime response time were significant predictors of response time. LSA was a significant predictor of response time, indicating that, despite restricting relatedness between primes and targets to be below a threshold (.3), semantic relatedness influenced response time.

¹²The reference level was the plural prime. For this reason, the β values are positive, indicating that the controls are slower.

Discussion

In this paper, we find priming effects for plural primes and targets relative to both singular and phonological controls. This result should be replicated for English plural suffixes and examined for additional affixes and additional languages in both visual and auditory modalities.

As anticipated, the size of the effect is small relative to identity priming for stems, which were in the 150–200ms RT speedup range in a similar study (Wilder et al. 2019).¹³ It is possible that stem versus affix priming facilitation magnitude differences are due to representational differences between stems and affixes; most morphological theories treat these as distinct types of objects. It is also possible that differences in other factors, such as frequency, semantic contribution, prosodic strength, and extent of homophony among stems versus affixes contribute to these magnitude differences, as discussed in the Background section.¹⁴

The importance of an affix priming facilitation result is that it provides a foundation for a further set of questions that are central to morphological processing and representation. A first point of interest involves identifying the loci of inflectional priming effects. The second involves questions about whether morphology merely involves features that are associated with plural words in some way, or whether there are *discrete* inflectional affix morphemes, represented as pieces in memory.

Concerning the loci of priming, critical primes and targets shared (i) semantic interpretation (i.e., a notion of multiple units), (ii) morpho-syntactic feature [+PL] (plurality, as diagnosed through agreement), (iii) phonological realisation (/z/), and (iv) syntactic structure (noun-affix). Future research can elucidate which of shared representations (i)-(iv) (or some combination) are responsible for the effect. In our view, sensible first steps would address the following questions:

1. *Is shared semantic interpretation required?* (a) Do plural words without the semantic interpretation of plurality (such as *scissors/pants*) produce the same facilitation as typical plurals? (For an analogous question concerning the effects of transparency/opacity on the processing of stems see e.g., Smolka et al. 2015; Creemers et al. 2020). (b) If semantic overlap is required for the effect, a next step would investigate whether non-plural words associated with a similar

¹³These studies, although similar, have some important differences. For example, in the current study, the critical prime→target structure is [stem₁][affix₁]→[stem₂][affix₁] (e.g., *crimes*→*trees*) with the repeated unit occurring with different non-repeated units in both prime and target. In contrast, in the relevant stimuli from Wilder et al. (2019), the structure is [stem₁][affix₁]→[stem₁] (e.g., *frogs*→*frog*) with the repeated unit occurring in isolation in the target. A more directly comparable stem priming prime→target structure would be [stem₁][affix₁]→[stem₁][affix₂] (e.g., *walks*→*walked*). Still greater comparability would be achieved if the linear order of repeated versus non-repeated unit was controlled across stem priming and affix priming stimuli, e.g., [affix₁][stem₁]→[affix₂][stem₁] and [stem₁][affix₁]→[stem₂][affix₁].

¹⁴For example, focusing on duration (one aspect of prosodic strength): If we were to consider a priming effect as percentage speed-up across the duration of a stem/affix, we find similar effect sizes for affix priming in the current study and stem priming in Wilder et al. 2019. For the 36 plural targets in this study, the mean duration of the affix was approximately 200ms. As such, a 29ms increase indicates an approximately 15% facilitation across the duration of the affix. This is similar to the percentage speed-up observed across the duration of the stem for plural→singular (e.g., *frogs*→*frog*) priming at an immediate distance in Wilder et al. 2018, where speed-up was 11% and 15% in Experiments 1 and 2 respectively.

semantic interpretation (e.g., countable mass nouns such as *furniture*) produce equivalent facilitation to plural words.

2. *Is shared phonological realisation required?* Do words with different inflectional allomorphs produce the same amount of facilitation as plural words with the same allomorph? Stimuli in which allomorphs are typically analysed as derived from a single underlying form (e.g., voicing allomorphy in voiceless *cats* versus voiced *trees*) could be compared with suppletive allomorphy, where there is no hypothesised underlying phonological form (such as *oxen/geese*). Again, there is an analogous literature which examines the role of stem allomorphy in morphological processing (see e.g., Morris & Stockall 2012; Pastizzo & Feldman 2002).

It is important to point out that questions about the loci of priming arise for derivational affixes as well. Prior reports of facilitation for derivational affixes (e.g., *darkness*→*happiness*), have been taken as evidence for their independent representation (e.g., Duñabeitia et al. 2008). However, the locus of the effect could be probed further. For example, for the *darkness*→*happiness* example, it could be investigated whether representations associated with the semantic interpretation of abstract nominals or a morpho-syntactic feature are responsible for the effect.

Another question concerns whether the representation shared in inflectional priming is an isolable unit or a feature of an indivisible whole. Linguistic theories are sharply divided on this question. The “word and paradigm” (Matthews 1972) and related approaches (such as Anderson 1992) deny discrete morpheme status for inflection but have features like [+PL] bundled with plural nouns. Opposed to this, approaches like Distributed Morphology (Halle & Marantz 1993; Embick 2015) hypothesise that inflectional morphology involves discrete morphemes. A theory without discrete morphemes would represent a plural noun like *crimes* as [CRIME +PL], i.e., as a single word with a plural feature. In morpheme-based theories, on the other hand, the [+PL] is a piece on a par with the stem: [CRIME]-[+PL]. Since both of these theories employ a [+PL] feature, both are in principle able to account for the type of inflectional priming that we report here.

In our view, identifying the loci of affix priming effects is a good next step towards a fuller understanding of the fine-grained details of morphological representation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Continuous lexical decision task

Figure 2. Density plot of trimmed response time data for targets preceded by primes in the three experimental conditions

Figure 3. Box plot of trimmed response time data for targets preceded by primes in the three experimental conditions

Figure 4.
Plot of model fixed effect estimates and 95% confidence intervals

Table 1

Overview of previous inflectional affix priming studies

	Emmorey 1989, Experiment 2	Reid & Marslen-Wilson 2000, Experiment 1	Smolik 2010	VanWagenen & Pertsova 2014
<i>Language</i>	English	Polish	Czech	Russian
<i>Affixes</i>	Verbal: <i>-ing</i> , <i>-ed</i> , Nominal: <i>-es</i>	Verbal: <i>s-</i> , <i>na-</i> (perfective), Nominal: <i>-ek</i> (diminutive), <i>-arz</i> (agentive) ⁵	Nominal: <i>-a</i> (feminine nominative), Verbal: <i>-ete</i> (2p. pl.)	22 affixes ⁶
<i>Task</i>	Paired lexical decision	Paired lexical decision	Paired lexical decision at 50ms and 150ms inter-stimulus intervals (ISIs)	Paired lexical decision
<i>N Subjects</i>	20	40	39	36
<i>N Targets per Subject</i>	18 (12 <i>-ing</i> , 5 <i>-ed</i> , 1 <i>-es</i>)	88 (24 <i>s-</i> , 22 <i>na-</i> , 18 <i>-ek</i> 24 <i>-arz</i>)	52 (26 <i>-a</i> , 26 <i>-ete</i>)	16 (affix breakdown unavailable)
<i>Modality</i>	Auditory	Cross-modal (auditory prime, visual target)	Visual	Visual
<i>Effect</i>	Not sig. vs. unrelated control prime	18ms (sig.) for all affixes treated as a group vs. unrelated control prime	Nominal: Not sig. Verbal: 14ms (marginal, $p=.08$) at 150ms ISI vs. phonological control prime	Nominal: Not sig., Verbal: 59ms (sig.) vs. phonological control prime

⁵These affixes are mixed: *s-* (perfective) appears to be inflectional. Reid & Marslen-Wilson (2000) label *na-* (perfective) as “aspectual-derivational” indicating it has some derivational and inflectional properties. *-ek* (diminutive) and *-arz* (agentive) would typically be analysed as derivational.

⁶See full list in Appendices.

Table 2

Prime and target design

	Prime	Target
<i>Plural prime</i>	crimes	
<i>Phonological control prime</i>	cleanse	trees
<i>Singular control prime</i>	crime	

Table 3

Mean LSA and frequencies in each prime condition

	Mean LSA (SD)	Mean frequency (SD)
<i>Inflectional plural prime</i>	.065 (.067)	2.04 (.48)
<i>Phonological control prime</i>	.070 (.059)	2.05 (.50)
<i>Singular control prime</i>	.062 (.076)	2.62 (.53)

Table 4

Composition of the stimuli across the experiment, per participant (columns do not sum to 448 because a single stimulus can be a member of multiple categories)

	Count	Percentage
<i>Critical stimuli</i>	72	16.1
<i>Word</i>	224	50
<i>/z/ final word</i>	100	22.3
<i>/s/ final word</i>	56	12.5
<i>Plural word</i>	76	17.0
<i>/z/ final nonword</i>	28	6.25
<i>/s/ final nonword</i>	28	6.25
<i>Embedded word nonword</i>	28	6.25
<i>Shared (C)VC nonword</i>	28	6.25

Table 5

Data removal

	Datapoints	Percentage
<i>Experimental trials</i>	7200	100
<i>Inaccurate trials</i>	1200	16.67
<i>Initial trimming (300>RT<3000)</i>	89	1.24
<i>ISI trimming (ISI<900)</i>	165	2.29
<i>Participant trimming</i>	79	1.1
<i>Item trimming</i>	45	.62
<i>Residual trimming</i>	126	1.75
<i>Total removed</i>	1704	23.67
<i>Total remaining</i>	5496	76.33

Table 6

Mean RT (trimmed data) and percent accuracy across conditions

	Mean (SD) accurate RT	Percent accuracy
<i>Plural prime</i>	989.5 (243.3)	91
<i>Phonological control prime</i>	1013.4 (251.4)	89
<i>Singular control prime</i>	1018.1 (266.4)	90

Table 7

Response time model summary

Log-transformed RT			
Fixed Effects	<i>Estimates</i>	<i>95% CI</i>	<i>p-values</i>
Intercept	9.911	9.868, 9.954	<.001
Prime condition			
Phon. cntrl vs. Plural	.037	.010, .063	.015
Sing. cntrl vs. Plural	.027	.006, .048	.020
Trial number	.000	.000, .000	<.001
Prime-target LSA	-.014	-.026, -.002	.024
ISI	.006	.000, .013	.050
Target duration	.064	.025, .104	.004
Target frequency	-.069	-.109, -.030	.002
Prime-target MFCC	.011	-.001, .022	.078
Prime-target Levenshtein distance	-.012	-.025, .010	.085
Prime frequency	.001	-.012, .014	.906
Prime response time	.074	.066, .081	<.001
Random Effects	<i>N</i>	<i>Variance</i>	<i>Standard deviation</i>
Participants	200	.0149	.122
Primes	84	.0013	.036
Targets	36	.0129	.113
Residual		.0480	.219
N Datapoints	5496		
Marginal R²	.144		
Conditional R²	.467		