Masking auditory feedback does not eliminate repetition reduction

Cassandra L. Jacobs¹, Torrey M. Loucks², Duane G. Watson³, & Gary S. Dell[§]

1: University of Wisconsin, Madison
2: University of Alberta
3: Vanderbilt University
4: University of Illinois at Urbana-Champaign

Corresponding address:

Cassandra L. Jacobs
University of Wisconsin, Madison
Department of Psychology
1202 W Johnson St.
Madison, WI 53706
jacobs.cassandra.l@gmail.com

Abstract

Repetition reduces word duration. Explanations of this process have appealed to audience design, internal production mechanisms, and combinations thereof (e.g. Kahn & Arnold, 2015). Jacobs, Yiu, Watson, and Dell (2015) proposed the auditory feedback hypothesis, which states that speakers must hear a word, produced either by themselves or another speaker, in order for duration reduction on a subsequent production. We conducted a strong test of the auditory feedback hypothesis in two experiments, in which we masked auditory feedback and whispering to prevent speakers from hearing themselves fully. Both experiments showed that despite limiting the sources of normal feedback, repetition reduction was observed to equal extents in masked and unmasked conditions, suggesting that repetition reduction may be supported by multiple sources, such as somatosensory feedback and feedforward signals, depending on their availability.

Keywords: repetition reduction; auditory feedback; language production; feedforward processes

Introduction

The production of fluent speech requires a speaker to plan multiple linguistic units at multiple linguistic levels. Such planning involves the ordering of units, a topic that has received much attention ever since Lashley (1951). Fluency also concerns timing—*when* a word is produced and *for how long* that word unfolds. In this paper we focus on the sensory mechanisms that particularly influence word onset and word duration, as a function of whether that word is being said for the first time or whether it has recently been produced. For example, if one says, “Cats are majestic creatures, but cats are also little goblins.”, how does the prior production of “cat” affect the temporal properties of the subsequent production? One potentially influential factor on a repeated word’s duration is auditory feedback, the subject of the present study.

Several studies have demonstrated that repetition of the target word leads to a reduced duration (Fowler, 1988; Fowler & Housum, 1987, Lam & Watson, 2010, 2014; Arnold, Kahn, & Pancani, 2012; Bard et al., 2000). This reduction has been attributed to many factors, but chief among them is the possibility that the prior production of the word has strengthened the production process so that the subsequent production proceeds more quickly. Earlier work (Jacobs et al., 2015) refined this hypothesis by suggesting that the second utterance of a word is shortened because duration is controlled in part by auditory feedback and the processing of that feedback has been facilitated by the prior utterance of the word. We refer to this as the *auditory feedback hypothesis*.

Evidence for the auditory feedback hypothesis comes from a number of experiments testing the effect of the speaker having recently heard the word on whether that word was subsequently reduced when it was repeated. Specifically, Jacobs et al. (2015) contrasted repetition reduction for words that were first produced in inner speech (a form of auditory and

articulatory imagery; Reisberg, 2014) to words that were first produced with overt speech. While words that were first produced in overt speech showed the classic repetition reduction effect, words that were first produced in inner speech were not reduced when they were overtly produced. The absence of reduction with inner speech could not be attributed to weak phonological planning in inner speech (e.g. Oppenheim & Dell, 2008) because silently mouthing a word prior to producing it overtly also did not lead to repetition reduction. The importance of an auditory record from the first production was also supported in a third experiment that found that producing a word's homophone (e.g. "pie" before "pi") can lead to reduced durations, though this reduction was not as great as when that word had actually been repeated. Thus, it seems clear that the second utterance of a word by a speaker is reduced if the speaker heard herself say the word the first time. The third piece of evidence showing the importance of hearing the word comes from the finding that if the speaker is repeating a word that they recently heard someone else say, their production of it is reduced (Kahn & Arnold, 2015).

In light of their results, Jacobs et al. (2015) proposed the auditory feedback hypothesis. They argued that repetition reduction arises after *hearing* the phonological form of the prime from either their own or another's production. When a prime is heard, a speaker-independent auditory memory is retained. This memory consists of recently produced (available) phonological sequences that remain active; it subsequently interacts with the processing of auditory feedback to affect duration. The assumed process goes something like this: Assume that "cat" is the target, represented by a series of segments (i.e. /kæt/). To produce the target word quickly, the articulators must make rapid transitions between these segments. If that sequence has recently been produced aloud or heard, these transitions may be facilitated because this auditory memory can provide feedback that provides additional cues as to the identity of the next

segment. That is, feedback (or *reaffERENCE*) from producing the sound /æ/ can facilitate retrieval of the sound /t/. Thus, the memory of the prior /kæt/ facilitates the use of feedback to move rapidly through the segments of /kæt/ the second time. An example of a model that would behave this way is a version of the simple recurrent network of Dell, Juliano, and Govindjee (1993). In that model each phoneme is cued by two sources of information, the lexical plan (e.g. a unit representing /kæt/ as a whole), and a representation derived from auditory feedback of what sounds of the word if any have already been produced (e.g. context units that are copied from recent output). Each time the model processes or produces a word, it strengthens the connections that do this cuing, crucially, how each phoneme is cued from the auditory feedback of previous phonemes. This strengthened cuing through auditory feedback can speed the transitions through the phonemes, leading to repetition reduction.

However, auditory feedback or reaffERENCE need not be the only route to repetition reduction. Production in both inner speech and overt speech, for example, relies predominantly on *feedforward*, *predictive* processes (Perkell, 2012; Oppenheim, 2013; Guenther, 1995). That is, before feedback is available, the speaker predicts the forms of what they are going to produce, which allows successful speech production to take place. Internal estimations of the expected feedback (such as through internal models) operate faster than feedback processes, which always have inherent delays of being processed through peripheral sensory mechanisms and pathways (Shadmehr, Smith, & Krakauer, 2010). Internal estimations built up through learning do not have peripheral processing delays and can be used to update feedforward processes more rapidly than waiting for external feedback (Shadmehr, Smith, & Krakauer, 2010). Evidence that feedforward mechanisms in speech production are faster than feedback processes also comes from the observation that speakers can typically correct their speech prior to having produced a

full-blown speech error (Dell, 1986; Hickok, 2012; Levelt, 1983). With respect to prosodic phenomena, feedforward mechanisms are thought to be involved in online pitch correction as well (Jones & Munhall, 2000; Purcell & Munhall, 2006). There is also considerable evidence that feedforward and feedback processes serve different purposes in speech production.

Feedforward signals convey articulatory plans while feedback is now known to provide rapid articulatory corrections, monitor suprasegmental features and update internal representations (Guenther, 1995; Hickok, 2012; Guenther & Hickok, 2015; Tian & Poeppel, 2014; Dell, 1986).

Auditory feedback has received renewed attention in speech production research for its profound effects on ongoing speech production. In particular, studies that vary the auditory feedback a speaker experiences (e.g. the frequency of a vowel formant or the pitch of a syllable) show that speakers compensate for these perturbations at rapid latencies (~150 ms). The presentation of delayed auditory feedback during speech production, in which speakers hear their own productions at a lag, can induce disfluencies and phonetic speech errors (Fairbanks & Guttman, 1958; Yates, 1963; Howell & Archer, 1984; Stuart, Kalinowski, Rastatter, & Lynch, 2002). The most disruptive results for speech production arrive at a delay of approximately one syllable (200-250 ms). So, even though speech planning depends on *feedforward* processes, auditory feedback can be used to determine the state of the system and maintain fluent production.

Most computational models of speech production implement both feedforward and feedback mechanisms that are used for monitoring or message modification (Levelt, Roelofs, & Meyer, 1999; Dell, 1986; for an overview of these models, see Postma, 2000). The DIVA model (Guenther, 1995; Tourville & Guenther, 2011), for example, uses a forward model to produce speech, and an overt feedback mechanism to adjust productions. The Hierarchical State

Feedback Control (HSFC) model instead uses internal feedback to prevent potential speech errors (Hickok, 2012; Guenther & Hickok, 2015). Feedback is also implicated in many models of speech motor control (e.g. Tian & Poeppel, 2010; Tian & Poeppel, 2014). Despite the clear role of feedback in speech production, existing accounts of typical speech production largely rely on feedforward mechanisms for explaining utterance duration or speech rate (e.g. Sevald & Dell, 1994; Watson, Buxó-Lugo, & Simmons, 2015; Gahl, 2008). For example, feedforward mechanisms allow for lexical factors to influence word durations. In this respect, the auditory feedback hypothesis's explanation for duration effects is unusual, though consistent with the broader literature on repetition reduction (e.g. Bard et al., 2000; Kahn & Arnold, 2015). The present research sought to directly test it by examining repetition reduction when auditory feedback is greatly reduced.

The auditory feedback hypothesis of Jacobs et al. (2015) predicts that repetition reduction should not occur if formation of an auditory memory of a prior word production is minimized. To test the effect of auditory perturbations on repetitions effects, we conducted two experiments using the paradigm of Jacobs et al. (2015). In Experiment 1, we tested whether 90 dB pink noise would dampen or eliminate repetition reduction, as noise at this level masks speakers' ability to hear themselves as well as others. Experiment 2 further reduced the potential for auditory feedback influences on repetition through a combination of whispering and masking to prevent bone conduction.

Experiment 1

The present experiment uses an event description task that has been shown to elicit repetition reduction (Lam & Watson, 2010; Lam & Watson, 2014; Jacobs, Yiu, Watson, & Dell, 2015), in which participants produce two utterances (e.g. "The cat/pizza shrinks" and "The cat flashes").

In these utterances, a target word is either repeated (i.e. *given*). In others, it is produced after an unrelated word (i.e. *new*). The present experiment extends this paradigm by incorporating auditory feedback manipulations.

We first sought to reduce the availability of auditory feedback by eliminating speakers' ability to hear their air-conducted feedback. At 90 dB, speakers cannot hear others speaking in a normal voice from a short distance. While this manipulation does not fully eliminate auditory input from bone conduction (Dean, 1930; Tonndorf, 1976; Watson, 1938), feedback from a forward model (Guenther, 1995), or somatosensory feedback (Tremblay, Shiller, & Ostry, 2003), it eliminates air-conducted feedback, providing a rigorous test of Jacobs et al. (2015)'s auditory feedback hypothesis.

Methods

Participants

We recruited 50 participants from the University of Illinois undergraduate course credit subject pool who were enrolled in either a Psychology course or a Speech and Hearing Science course. Each participant received one hour of credit for their participation. All participants were native speakers of English who acquired no language other than English before age 5 and passed a hearing screening at the beginning of the experiment (20 dB HL at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz).

Materials

We constructed 40 critical displays in addition to 40 filler displays. Each display contained 4 images of easily nameable objects presented in a fixed quadrant of the screen. All images were taken from the colorized Snodgrass and Vanderwart (1980) images of Rossion and Pourtois (2004). On "new" trials, one image was designated the prime image (e.g. a pie), and a different

image (e.g. a cat) was the target. On repeat trials, the same image (i.e. cat) was used for both the prime and the target.

All target image names had phonetic constraints to facilitate word boundary identification. They started with a consonant; all but one critical item was monosyllabic (*lettuce*), and only one item resulted in difficult segmentations between the target noun and the target verb “flashes” (*leaf*). Filler trials were constructed from an additional set of images with no phonetic constraints. On the critical displays, the two or three images that were not named came from the set of filler images.

Counterbalance

Critical trials (for analysis) constituted half of the total trials in this experiment. Each participant did 40 critical trials, each with a different target. 10 of these were in the *masking-given* (repeated) condition, 10 were in the *unmasked-given* condition, 10 were in the *masking-new* (not repeated) condition, and 10 were in the *unmasked new* condition. The assignment of targets to these four conditions was determined by a Latin-square counterbalance ensuring that each target was equally tested in all four conditions across the experiment. This counterbalance identified four different assignments of targets to conditions.

The 40 critical trials that each participant experienced were arranged into blocks: A then B then C and then D. Each block had 10 critical trials in it. Blocks A /C and B/D were constrained to be in the same noise condition (e.g. A and C had noise, while B and D did not). Four lists of critical trials were then created in the following manner: Each of the four assignments of targets to conditions was fitted into this block structure, with targets randomly assigned to blocks and randomly ordered except for the constraint that trials in each block had the same noise condition and that each subsequent block's trials had the opposite noise condition.

The order of the all critical trials for these four lists was then reversed to make four additional lists. The resulting eight lists defined the structure of the critical trials. Each participant received one of these lists. The lists were augmented with 40 filler trials containing a random set of 4 images, 20 in noise (masked) blocks and 20 in no-noise (unmasked) blocks. These had the same structure as the critical trials except that no filler trial involved the repetition of a target. The images/words used for fillers were not used for critical trials. The purpose of the fillers was to make the given condition (when the target repeats the prime item) relatively uncommon (25% of all trials). The critical and filler stimuli for one of the four counterbalanced lists are available in the Appendix.

Equipment

We used a Stadler GSI 16 Audiometer for the hearing screening and the noise masking. The masking was presented to participants using Sennheiser HD 280 Pro Circumaural headphones that were calibrated to 90 dB SPL with a 6cc coupler and Bruel Kjaer (model 2245) sound level meter. Both testing procedures are described below.

Procedure

Setup. Two research assistants assisted with the study. One research assistant was assigned to the audiometer to monitor and present noise over the headphones to the participant, while the other was assigned to the keyboard and computer to ensure that the experiment script ran correctly, to signal to the research assistant at the audiometer as to whether to start or end the presentation of noise, and to provide potential corrections to the participant in case they had misunderstood the instructions. In speech masking blocks, participants were presented incrementally louder pink noise, moving from 40 dB to 75, 80, 85, and 90 dB every 2 seconds. Earphones were adjusted to be flush against the participant's skin to prevent incomplete

masking. Before the experiment began, the experimenters confirmed with the participant that they could not hear the experimenters and that the noise level was not painful by soliciting a “thumbs up” at the final testing level of noise (90 dB), which was presented continuously.

Participants then read the following instructions presented on the computer screen: “In this phase of the experiment you will be describing the events you see on the screen. When you see an object that shrinks, for example, a porcupine, you should say out loud ‘The porcupine shrinks.’ When you see an object that flashes, for example, a lemur, you should say out loud ‘The lemur flashes.’ When the computer has started recording, you will see the text “GO” appear. When done talking, click the mouse. Ready? The experiment is about to begin.”

Blocks. The experiment was broken up into 4 blocks of 20 trials each, which we counterbalanced into four lists using a Latin square design. A block could either take place under 90 dB noise masking or without. Blocks alternated between the noise and non-noise conditions (hereafter, “unmasked”), as determined by counterbalance. Participants with even ID numbers were assigned to the noise-first condition, and participants with odd ID numbers were assigned to the masking-first condition. At the end of the block, participants were permitted to take a short break before beginning the next one. Each block lasted approximately 7 minutes.

Trials. Each trial consisted of a unique set of 4 pictures, one in each quadrant of the computer display. Participants saw the 4 pictures for 100 milliseconds prior to the beginning of the first animation. Trials were broken up into two phases: a prime phase, and a target phase. On prime trials, participants would see one of four images, for example, a cat, shrink. This animation unfolded for 1 second, after which the screen cued “GO!” at the center of the screen and participants began to provide a description of the event, e.g., “The cat shrinks.” Participants then clicked to end the recording, which would trigger the next animation, which took place 500

milliseconds later. The target animation period was identical to the prime phase except the referent on the screen blinked. Participants were again cued to speak using the “GO!” cue, providing a description such as, “The cat flashes.” When they were done speaking, they clicked the mouse to end the recording. A fixation cross then appeared at the center of the screen for 1.5 seconds, at which point the experiment continued on to the next trial.

Coding

Critical trials were coded at the word level in Praat version 6.0.19 (Boersma & Weenink, 2018) by the first author; both the waveform and spectrogram were displayed. Sound files were anonymized as to condition information prior to transcription and then re-referenced post transcription in order to ensure cross-condition consistency in the annotation process. Utterances were segmented into several regions: speech onset latency, the determiner “the”, the target noun, the verb “flashes”, and a final pause. In addition to the regions of interest, segments such as disfluencies (“um”, “uh”), pauses, and disfluency-linked determiners (i.e. “thee”) were coded as such. Speech onset latencies are defined as the period of silence prior to the production of the word “the”, including any initial pre-voicing.

Target word durations are defined as the period between the offset of the word “the” and the onset of the word “flashes.” The verb has clear high-frequency boundary cues, which enables easy segmentation of the offsets of target words for analysis. To identify the offset of the article “the” (the onset of the target word), the coder made use of several acoustic cues, including termination of voicing (if available) and clear demarcations of closure for stop onsets.

Additionally, the transcriber used the additional constraint that the beginnings of words should subjectively sound only like the target word (i.e. no clear word-initial vowels).

Data exclusion. We excluded trials from analysis that did not conform to the expected form (i.e. silence, “the”, noun, “flashes”, silence). We excluded trials containing a non-standard label for an image (e.g. “fruit” or “avocado” instead of “peach”) to facilitate comparison of the same target across speakers. Trials containing deviant verb forms (e.g. “is flashing”) were excluded because these forms can negatively impact word segmentation. Similarly, we excluded trials containing pauses, disfluencies (“um”, “uh”) or disfluency-linked determiners (“thee”), as these are not representative of fluent production. With these exclusion criteria, a total of 1612 out of the original 2000 trials remained.

In general, data loss appears to be higher in noise conditions (834 total observations in the no-noise condition vs. 786 total observations in noise), and approximately the same in the repeat (805) and no-repeat conditions (815). A total of 397 trials in the masked-given condition, 426 in the unmasked-new condition, 389 in the masked-new condition, and 408 in the unmasked-given condition remained. A Fisher’s exact test for count data showed that data loss across the four cells of the design was comparable (odds ratio = 1.07, $p = .55$).

Results

We opt for Bayesian hypothesis testing, which allows us to construct models that quantify the degree of “support” for the influence of repetition and noise factors on speech prosody. Importantly, Bayesian statistics have an intuitive interpretation in which likely statistical effects are those whose credible intervals do not include 0. Multilevel models were fit using the Bayesian regression package *brms* (version 2.3.1; Bürkner, 2017) in *R* version 3.4.3. We fit random intercepts and slopes for the main effects and interactions at the participant and item levels assessing the effect of masking and repetition on reaction times and durations. Both speech onset latencies and durations were log transformed to make the distribution more

symmetric. All predictors (repetition, masking) were sum (-1/1) coded to permit testing of the main effects and interactions.

Speech onset latencies. As speech onset latencies have been shown to be reliably sensitive to repetition (Jacobs et al., 2015), we analyze them here as a replication and to provide evidence that utterance initiation is facilitated even in the absence of clear auditory feedback. We present the condition means and standard deviations for speech onset latencies in log milliseconds below in Table 1. We visualize the group averages for speech onset latencies in log milliseconds below in Figure 1. The statistical model found that target latencies produced under masking are later than unmasked targets. Repetition reduces latencies for both masked and unmasked targets. There was no interaction between the two factors. We present these results below in Table 2 and the random effects and convergence information in the Supplemental Materials.

Table 1. Mean and standard deviations (in parentheses) in milliseconds, speech onset latencies, Experiment 1.

	New (no repeat)	Given (repeat)	
Unmasked	375 (191)	357 (182)	366 (187)
Masked	416 (211)	398 (323)	407 (273)
	394 (202)	377 (262)	
Grand mean	386 (234)

Figure 1. Speech onset latencies (reaction times) as a function of repetition and masking.

Targets produced under masking are produced later than unmasked targets. Repetition reduces reaction times, with no interaction.

Table 2. *brms* model population-level estimates for the effect of repetition and masking on speech onset latencies (reaction times). Note: Sufficient evidence for group mean differences is obtained when both l-95% and u-95% CIs do not include 0.

	Estimate	Error	l-95% CI	u-95% CI	Significance
Intercept	5.79	0.05	5.70	5.88	*
Repetition	-0.04	0.02	-0.07	-0.01	*
Masking	0.04	0.02	0.01	0.08	*

Repetition x Masking	-0.01	0.02	-0.04	0.03
----------------------	-------	------	-------	------

Durations. We present the condition means, standard deviations, and number of observations for speech onset latencies in log milliseconds below in Table 3. We visualize the group averages in log milliseconds below in Figure 2.

Table 3. Mean and standard deviations (in parentheses) in milliseconds, target word durations, Experiment 1.

	New (no repeat)	Given (repeat)	
Unmasked	358 (97)	338 (99)	348 (99)
Masked	396 (113)	380 (109)	388 (111)
	376 (107)	359 (106)	
Grand mean	367 (107)

Figure 2. Target word durations as a function of repetition and masking. Targets produced under masking are longer than unmasked targets. Repetition reduces durations for both masked and unmasked targets, with no interaction.

The statistical model found that targets produced under masking were longer than unmasked targets. Repetition reduced whole-word durations for both masked and unmasked targets. There was no interaction between the two factors. We present these results below in Table 4 and the random effects and convergence information in the Supplemental Materials.

Table 4. brms model population-level estimates for the effect of repetition and masking on target word durations. Note: Sufficient evidence for group mean differences is obtained when both l-95% and u-95% CIs do not include 0.

	Estimate	Error	l-95% CI	u-95% CI	Significance
Intercept	5.87	0.04	5.79	5.95	*
Repetition	-0.03	0.00	-0.04	-0.02	*
Masking	0.05	0.01	0.04	0.06	*
Repetition x Masking	-0.00	0.00	-0.01	0.01	

Discussion

The auditory feedback hypothesis makes the prediction that noise masking should greatly reduce repetition reduction. We see a clear effect of masking on speakers' productions, as they consistently lengthened every aspect of their productions under noise masking. The slowdowns could be the product of strategic hyper-articulation to maintain speech contrasts (e.g. Lombard, 1911; Agnello, 1970; Dean, 1930). However, we found that repetition reduction still occurred despite the presence of this masking.

The effect of repetition on speech onset latencies clearly replicates the results of Jacobs et al. (2015), who found that targets that were repeated in inner speech and mouthed inner speech were nevertheless initiated earlier than targets that were not named in inner speech. The general pattern of facilitation on onsets can be attributed to strengthened lexical access as outlined in their proposed model. On the other hand, the results of Experiment 1 show that whole-word durations are also sensitive to repetition reduction, contrasting with the inner speech results of Jacobs et al. (2015). A number of other research groups have noted occasional symmetry

between reaction times and whole-word durations (Kahn & Arnold, 2015; Balota, Boland, & Shields, 1989) while others have claimed that there is a mediating relationship between onsets and durations (Buz & Jaeger, 2016). Therefore, there remains some controversy as to whether, when, and why these two measures seem differentially sensitive to psycholinguistic variables.

The repetition reduction effects we observed could be due to the fact that speakers can still hear their air-conducted feedback, albeit not very clearly. The experimenters noted during data collection and transcription that speakers increased their volume under noise masking, presumably as a compensatory mechanism in the presence of degraded auditory feedback (Lane & Tranel, 1971; Lombard, 1911; Summers et al., 1988). One plausible account of the repetition reduction effect we see is that by speaking more loudly, participants were potentially able to generate a sufficient auditory signal for feedback. To test whether speakers were in fact significantly louder during the masking condition, we conducted a post-hoc analysis of the amplitude of participants' productions.

We extracted amplitudes of target words using Python, taking the absolute value of the amplitude at each time point. We then averaged the amplitudes over the target word region, providing a mean intensity value for each target word. Using a Bayesian mixed effects analysis with maximal random intercepts and slopes by participants and items, we found that targets produced under masking were significantly louder than targets produced without. Repetition significantly reduced amplitudes, with no significant interaction between repetition and speech masking. We summarize this analysis in Table 3. We plot this data in Figure 3.

Figure 3. Target word intensities as a function of repetition and masking. Targets produced under masking are louder than unmasked targets. Repetition reduces intensities for both masked and unmasked targets, with no interaction.

Table 5. *brms* model population-level estimates for the effect of repetition and masking on mean target word intensity (loudness). Targets produced under masking have greater intensity (are louder) than unmasked targets. Repetition reduces intensity for both masked and unmasked targets, with no interaction. Note: Significance obtained when both l-95% and u-95% CIs do not include 0.

	Estimate	Error	l-95% CI	u-95% CI	Significance
Intercept	6.23	0.10	6.03	6.44	*

Repetition	-0.02	0.01	-0.05	-0.00	*
Masking	0.60	0.05	0.50	0.70	*
Repetition x Masking	0.01	0.01	-0.02	0.03	

Overall, there is substantial evidence that speakers were responding to the changes in feedback that altered some aspects of their productions. Speakers lengthened word durations and were substantially louder under 90 dB masking noise (Lombard, 1911; Lane & Tranel, 1971). Despite the main prediction of the auditory feedback hypothesis, however, repetition reduction still occurred on whole-word target durations, suggesting a possible limitation of the original proposal in Jacobs et al. (2015). However, the increase in intensity and duration of the productions suggests that speakers may be relying on the degraded auditory feedback that is obtainable through bone conduction, the presence of which may be sufficient to trigger repetition reduction. Another alternative is that alternate sources of feedback and *feedforward* processes, might be involved in the repetition reduction process as well, rather than auditory feedback alone. We explore this possibility in Experiment 2.

Experiment 2

Experiment 1 demonstrated that there was no differential effect of noise masking on either reaction times or target noun durations; repetition reduction occurred in all noise conditions. One possible explanation of these results is that speakers were still able to hear their masked productions to some extent, perhaps by speaking more loudly and producing a signal that could be conveyed via bone conduction. In Experiment 2, we sought to reduce auditory feedback even further through masking and by instructing participants to whisper during the productions of all primes. Whispering under masking limits bone conduction and any potential air conduction cues.

Methods

Participants

50 participants from the University of Illinois course credit (n=25) and paid (n=25) subject pools were recruited. Participants for course credit received 1 hour of credit; paid participants received \$8. As in Experiment 1, participants were native speakers of English who acquired no other language before age 5. Eligible participants in Experiment 2 passed a simple hearing screening prior to the beginning of the experiment; the screen was conducted in the same manner as Experiment 1.

Materials and Equipment

Materials and equipment were the same as in Experiment 1.

Procedure

The procedure of Experiment 2 followed Experiment 1 closely but differed in two important ways. First, we employed a whisper training task that suppressed phonation during the prime production of the task only; target trials were fully voiced. Consequently, the second change to the procedure changed the prompt text from “GO!” to “WHISPER!” on prime trials, and to “SPEAK!” on target trials, to remind participants of the speaking mode task.

Whisper training. Anecdotal evidence suggests that participants have difficulty maintaining a whisper under 90 dB noise masking, posing a potential problem for our manipulation. To prevent data loss, we trained participants to whisper both in unmasked speech by pointing out to them the properties of phonation (vocal fold vibration) and how to sense it with their fingers. To train them, we had them continue to read the first sentence from the story *Alice in Wonderland* until they were capable of whispering the entire sentence under noise masking. Additionally, participants were asked to keep one hand on their throat to monitor and

maintain whispering. If participants demonstrated shifted from whisper to voicing during prime trials in the experiment, the experimenters gestured to the participant to switch back to whispering of their prime productions.

Coding

Critical target trials were coded in the same manner as Experiment 1. We excluded 298 of the trials following the same criteria as in Experiment 1, leaving 1702 of the original 2000 trials for analysis. A Fisher's exact test for count data showed that there were no significant differences in data loss across the four conditions in the experiment (odds ratio = 1.04, $p = .70$).

Results

The analysis proceeded as in Experiment 1.

Speech onset latencies. We present the condition means and standard deviations for speech onset latencies in log milliseconds below in Table 6. We visualize the group averages for these results below in log milliseconds below in Figure 4. The statistical model found a significant effect of repetition on speech onset latencies. Unlike Experiment 1, there was no significant effect of masking. As in Experiment 1, there was no interaction between these two factors. These results broadly replicate the effects of Jacobs et al. (2015), who found repetition facilitated speech onset latencies in the absence of an auditory memory. We present these results below in Table 7 and the random effects and convergence information in the Supplemental Materials.

Table 6. Mean and standard deviations (in parentheses) in milliseconds, speech onset latencies, Experiment 2.

	No repeat	Repeat	
--	------------------	---------------	--

No noise	446 (246)	368 (205)	408 (230)
Noise	482 (538)	376 (237)	430 (422)
	464 (418)	372 (222)	
Grand mean	419 (341)

Figure 4. Speech onset latencies (reaction times) as a function of repetition and masking.

Targets produced under masking are as long as unmasked targets. Repetition reduces durations for both masked and unmasked targets, with no interaction.

Table 7. *brms* model population-level estimates for the effect of repetition and masking on speech onset latencies (reaction times). Targets produced under masking are longer than

unmasked targets. Repetition reduces durations for both masked and unmasked targets, with no interaction. Note: Significance obtained when both l-95% and u-95% CIs do not include 0.

	Estimate	Error	l-95% CI	u-95% CI	Significance
Intercept	5.85	0.05	5.75	5.95	*
Repetition	-0.10	0.02	-0.13	-0.06	*
Masking	-0.00	0.02	-0.05	0.04	
Repetition x Masking	-0.00	0.01	-0.03	0.02	

Durations. We present the condition means, standard deviations, and number of observations for speech onset latencies in log milliseconds below in Table 8. We visualize the group averages in log milliseconds below in Figure 5.

Table 8. Mean and standard deviations (in parentheses) in milliseconds, target word durations, Experiment 2.

	No repeat	Repeat	
No noise	365 (124)	345 (115)	355 (120)
Noise	365 (128)	346 (116)	356 (122)
	365 (101)	345 (92)	
Grand mean	355 (97)

Figure 5. Target word durations as a function of repetition and masking. Targets produced under masking are as long as unmasked targets. Repetition reduces durations for both masked and unmasked targets, with no interaction.

The statistical model found a significant effect of repetition on speech onset latencies. Unlike Experiment 1, there was no significant effect of masking. As in Experiment 1, there was no interaction between these two factors. We present these results below in Table 9 and the random effects and convergence information in the Supplemental Materials.

Table 9. *brms* model population-level estimates for the effect of repetition and masking on target word durations. Targets produced under masking are not longer than unmasked targets.

Repetition reduces durations for both masked and unmasked targets, with no interaction. Note: Significance obtained when both l-95% and u-95% CIs do not include 0.

	Estimate	Error	l-95% CI	u-95% CI	Significance
Intercept	5.85	0.04	5.78	5.92	*
Repetition	-0.03	0.00	-0.04	-0.02	*
Masking	0.00	0.01	-0.02	0.02	
Repetition x Masking	0.00	0.00	-0.01	0.01	

Discussion

Experiment 2 was conducted with the goal of significantly reducing participants' ability to hear themselves through bone conduction, ideally eliminating any auditory component involved in repetition reduction. We had anticipated that participants would have less repetition reduction or not reduce entirely in the masked condition. Instead, participants appear to reduce repeated words to the *same extent* in the masked condition as the unmasked condition, in both Experiment 1, where auditory feedback was impaired, and Experiment 2, where the only feedback the speakers received would have been sensorimotor or internal feedback mechanisms. We did notice an elimination of the Lombard effect from Experiment 1, suggesting that whisper may provide different feedback to the production system, a topic which requires further study.

The clear ability for whispered productions under masking to cause repetition reduction therefore necessitates revision of the auditory feedback hypothesis. In the next section, we outline how auditory feedback may only be one among several routes to repetition reduction.

General Discussion

In two experiments, we tested whether production of a repeated target word was shortened under conditions designed to suppress auditory feedback. We expected attenuation or elimination of the repetition reduction effect when speakers produced the first instance of a target in noise. We saw general effects of noise on production; specifically, speakers became significantly louder and spoke more slowly, demonstrating that a noise-free auditory environment is a critical factor impacting word duration. However, the effect of repetition on word durations in both Experiment 1 and Experiment 2 showed that repeating a word reduced word durations to the same extent in noise and in a noise-free environment, even when speakers had severely limited auditory input during the first production of a word. These results are contrary to the auditory feedback hypothesis.

Recall that the auditory feedback hypothesis was designed to account for repetition reduction in three special cases: (1) Speakers reduce words that their interlocutors have recently produced (Bard et al., 2000; Kahn & Arnold, 2015). (2) They reduce “repeated” homophones (e.g. *pie* and *pi*), even though they are new to the discourse (Jacobs et al., 2015). (3) Speakers do not reduce repeated words if the first mention of a word was made in inner speech or mouthed inner speech (Jacobs et al., 2015). The latter result is especially critical for the auditory feedback hypothesis: Because mouthing a word and retrieving its phonological sequence are not sufficient for repetition reduction, but listening is, the authors concluded that the availability of an *auditory* memory is critical.

Aside from our data, the auditory feedback hypothesis has limitations. First, the hypothesis does not specify what amount of auditory feedback a speaker must receive for reduction to occur. The strongest version of the hypothesis presumably would predict that if a speaker can hear themselves at all, a repeated word will be shortened, but the lack of specifics in

the hypothesis makes precise prediction difficult. Second, the auditory feedback hypothesis does not consider the possible influences of somatosensory feedback in controlling duration. Such feedback is present when the first utterance of a repeated word is by the speaker, rather than someone else. Finally, it is well-established that a feedforward process is involved in phonological sequencing mechanisms prior to articulation (e.g. Levelt et al., 1999; Oppenheim & Dell, 2008) and such a process could also influence duration.

The present study showed that auditory feedback is not necessary for repetition reduction. We therefore propose a modification to the auditory feedback hypothesis, which we term the *multiple routes* account. The multiple routes proposal is not in direct conflict with the auditory feedback hypothesis, but rather specifies that speakers may differentially weight auditory and other sources of feedback during the production process, depending on what sources of information are available.

The multiple routes account begins with the perhaps uncontroversial assumption that fluent speech production is achieved by consulting multiple sources of information. In a relatively noise-free environment, fluent speech integrates the different modalities of sensory information. In addition to auditory feedback, there is information about the articulators, that is, somatosensory feedback (Tian & Poeppel, 2014) and internal feedforward mechanisms that evaluate the potential effectiveness of sequences of intended articulations (e.g. Postma, 2000; Levelt et al., 1999; Houde & Nagarajan, 2011). The multiple routes proposal is consistent with prior research showing that speakers typically make use of multiple information sources such that they exceed a certain threshold of “evidence” in articulatory production (Houde & Jordan, 1998; Lane et al., 1997; Schuerman, Nagarajan, McQueen, & Houde, 2017; Shiller, Sato, Gracco, & Baum, 2009).

Furthermore, we know that when auditory information is present, the extent to which it is used varies depending on whether one is speaking or listening. Hearing oneself speak and playing back one's voice to someone who is not currently speaking manifest themselves differently in the brain (Kell et al., 2017; Chu et al., 2013; Turner et al., 2009; Fridriksson et al., 2009; Okada, Matchin, & Hickok, 2018). For example, when speakers engage in speech production, the amplitude of the N2 evoked potential in auditory cortex is dampened (Houde, Nagarajan, Sekihara, & Merzenich, 2002), even though identical recorded productions of the speaker's voice do not change the ERP. Such a result suggests that reafferent feedback may update the production system, thereby providing a pathway to prime or facilitate the speech production system for repetition reduction. In the absence of reafference (i.e. inner speech and mouthed inner speech), the conditions that allow for repetition reduction may not arise.

Given this perspective, it is reasonable that the weightings of information sources will change when other sources are absent. When the input of their productions to the auditory system is degraded (e.g. very loud or noisy environments, or when one is speaking softly, say at the library), speakers may engage in compensatory behavior. We see evidence for this in Experiment 1, in which speakers' utterances were both longer and louder, perhaps because speakers aim for a specific level of evidence that they are on track to produce the right message.

Our most important claim, though, is that the multiple routes account explains why repetition reduction was not eliminated in both Experiment 1 and Experiment 2, while it was eliminated in the inner speech findings of Jacobs et al. (2015). Specifically, we assume that fluent speech involves rapid updating of the internal state of the production system and that the effectiveness of this process affects word durations. Prior experience that primes the updating of this state (e.g. from prior experience with the current target word) can shorten durations. How

does this priming work? We know that masking a prior production with noise still leads to reduction, but an inner prior production does not, even if the inner speech involves some articulatory movements. This leads to the question of what the crucial differences between masked and inner production of the prime are. The most obvious difference is that somatosensory cues for updating the internal state are intact in masked speech, but nonexistent or distorted in inner speech. Thus, these cues are good candidates for extra reliance when auditory cues are missing.

We cannot rule out, however, that some kind of cues unrelated to feedback, i.e. feedforward cues such as the knowledge that one has just initiated some particular gesture, are updating the internal state. Perhaps the full articulation of the masked prime more effectively strengthens these feedforward cues, as well, compared to the absent or distorted articulation of the inner speech prime. In short, our work suggests that repetition reduction is caused by priming the use of cues that update the internal state of the production system (Dell, Juliano, & Govindjee, 1993). The cues that can be effectively strengthened and speed the updating of the production state are primarily auditory, but in the absence of auditory cues, other cues that are experienced during full articulation of the prime can be strengthened and thus lead to reduction.

In sum, the present results question the proposal of Jacobs et al. (2015) that auditory feedback is the sole route to repetition reduction. Instead, we suggest that in the absence of typical sources of feedback, the production system can rely on other sources of information, specifically those sources of information that are persistently available to be leveraged, such as somatosensory information and the internal state of the production system.

References

- Arnold, J. E., Kahn, J. M., & Pancani, G. C. (2012). Audience design affects acoustic reduction via production facilitation. *Psychonomic Bulletin & Review*, 19, 505-512.
- Balota, D. A., Boland, J. E., & Shields, L. W. (1989). Priming in pronunciation: Beyond pattern recognition and onset latency. *Journal of Memory and Language*, 28, 14-36.
- Bard, E. G., Anderson, A. H., Sotillo, C., Aylett, M., Doherty-Sneddon, G., & Newlands, A. (2000). Controlling the intelligibility of referring expressions in dialogue. *Journal of Memory and Language*, 42, 1-22.
- Boersma, P. & Weenink, D. (2018). Praat: doing phonetics by computer [Computer program]. Version 6.0.19, retrieved 13 June 2016 from <http://www.praat.org/>
- Bürkner, P-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, 80, 1-28. doi:10.18637/jss.v080.i01
- Chu, Y. H., Lin, F. H., Chou, Y. J., Tsai, K. W. K., Kuo, W. J., & Jääskeläinen, I. P. (2013). Effective cerebral connectivity during silent speech reading revealed by functional magnetic resonance imaging. *PLoS One*, 8, e80265.
- Dean, C. E. (1930). Audition by bone conduction. *The Journal of the Acoustical Society of America*, 2, 281-296.
- Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93, 283.
- Dell, G.S., Juliano, C., & Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. *Cognitive Science*, 17, 149-195.
- Fairbanks, G., & Guttman, N. (1958). Effects of delayed auditory feedback upon articulation. *Journal of Speech & Hearing Research*, 1, 12-22.

- Fowler, C. A. (1988). Differential shortening of repeated content words produced in various communicative contexts. *Language and Speech*, 31, 307-319.
- Fowler, C. A., & Housum, J. (1987). Talkers' signaling of "new" and "old" words in speech and listeners' perception and use of the distinction. *Journal of Memory and Language*, 26, 489-504.
- Fridriksson, J., Moser, D., Ryalls, J., Bonilha, L., Rorden, C., & Baylis, G. (2009). Modulation of frontal lobe speech areas associated with the production and perception of speech movements. *Journal of Speech, Language, and Hearing Research*, 52, 812-819.
- Gahl, S. (2008). Time and thyme are not homophones: The effect of lemma frequency on word durations in spontaneous speech. *Language*, 84, 474-496.
- Guenther, F. H. (1995). Speech sound acquisition, coarticulation, and rate effects in a neural network model of speech production. *Psychological Review*, 102, 594-621.
- Guenther, F. H., & Hickok, G. (2015). Role of the auditory system in speech production. In *Handbook of clinical neurology* (Vol. 129, pp. 161-175). Elsevier.
- Hickok, G. (2012). Computational neuroanatomy of speech production. *Nature Reviews Neuroscience*, 13, 135-145.
- Houde, J. F., & Jordan, M. I. (1998). Sensorimotor adaptation in speech production. *Science*, 279(5354), 1213-1216.
- Houde, J. F., Nagarajan, S. S., Sekihara, K., & Merzenich, M. M. (2002). Modulation of the auditory cortex during speech: an MEG study. *Journal of Cognitive Neuroscience*, 14, 1125-1138.
- Houde, J. F., & Nagarajan, S. S. (2011). Speech production as state feedback control. *Frontiers in Human Neuroscience*, 5, 82.

Howell, P., & Archer, A. (1984). Susceptibility to the effects of delayed auditory feedback.

Perception & Psychophysics, 36, 296-302.

Jacobs, C. L., Yiu, L. K., Watson, D. G., & Dell, G. S. (2015). Why are repeated words produced with reduced durations? Evidence from inner speech and homophone production. *Journal of Memory and Language*, 84, 37-48.

Jones, J. A., & Munhall, K. G. (2000). Perceptual calibration of F0 production: Evidence from feedback perturbation. *The Journal of the Acoustical Society of America*, 108, 1246-1251.

Kahn, J. M., & Arnold, J. E. (2015). Articulatory and lexical repetition effects on durational reduction: Speaker experience vs. common ground. *Language, Cognition and Neuroscience*, 30, 103-119.

Kell, C. A., Darquea, M., Behrens, M., Cordani, L., Keller, C., & Fuchs, S. (2017). Phonetic detail and lateralization of reading-related inner speech and of auditory and somatosensory feedback processing during overt reading. *Human Brain Mapping*, 38, 493-508.

Lam, T. Q., & Watson, D. G. (2010). Repetition is easy: Why repeated referents have reduced prominence. *Memory & Cognition*, 38, 1137-1146.

Lam, T. Q., & Watson, D. G. (2014). Repetition reduction: Lexical repetition in the absence of referent repetition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40, 829.

Lane, H., & Tranel, B. (1971). The Lombard sign and the role of hearing in speech. *Journal of Speech and Hearing Research*, 14, 677-709.

Lane, H., Wozniak, J., Matthies, M., Svirsky, M., Perkell, J., O'Connell, M., & Manzella, J. (1997). Changes in sound pressure and fundamental frequency contours following

- changes in hearing status. *The Journal of the Acoustical Society of America*, 101, 2244-2252.
- Lashley, K. S. (1951). The problem of serial order in behavior (Vol. 21). Bobbs-Merrill.
- Levelt, W. J. (1983). Monitoring and self-repair in speech. *Cognition*, 14, 41-104.
- Levelt, W. J. (1993). Speaking: From intention to articulation (Vol. 1). MIT press.
- Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22, 1-38.
- Lombard, E. (1911). Le signe de l'elevation de la voix. *Ann. Mal. de L'Oreille et du Larynx*, 101-119.
- Okada, K., Matchin, W., & Hickok, G. (2018). Neural evidence for predictive coding in auditory cortex during speech production. *Psychonomic Bulletin & Review*, 25, 423-430.
- Oppenheim, G. M. (2013). Inner speech as a forward model? *Behavioral and Brain Sciences*, 36, 369-370.
- Oppenheim, G. M., & Dell, G. S. (2008). Inner speech slips exhibit lexical bias, but not the phonemic similarity effect. *Cognition*, 106, 528-537.
- Perkell, J. S. (2012). Movement goals and feedback and feedforward control mechanisms in speech production. *Journal of Neurolinguistics*, 25, 382-407.
- Postma, A. (2000). Detection of errors during speech production: A review of speech monitoring models. *Cognition*, 77, 97-132.
- Purcell, D. W., & Munhall, K. G. (2006). Adaptive control of vowel formant frequency: Evidence from real-time formant manipulation. *The Journal of the Acoustical Society of America*, 120, 966-977.
- Reisberg, D. (Ed.). (2014). *Auditory imagery*. Psychology Press.

- Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, 33*, 217-236.
- Schuerman, W. L., Nagarajan, S., McQueen, J. M., & Houde, J. (2017). Sensorimotor adaptation affects perceptual compensation for coarticulation. *The Journal of the Acoustical Society of America, 141*, 2693-2704.
- Sevald, C. A., & Dell, G. S. (1994). The sequential cuing effect in speech production. *Cognition, 53*, 91-127.
- Shadmehr, R., Smith, M. A., & Krakauer, J. W. (2010). Error correction, sensory prediction, and adaptation in motor control. *Annual Review of Neuroscience, 33*, 89-108.
- Shiller, D. M., Sato, M., Gracco, V. L., & Baum, S. R. (2009). Perceptual recalibration of speech sounds following speech motor learning. *The Journal of the Acoustical Society of America, 125*, 1103-1113.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 174-215.
- Stuart, A., Kalinowski, J., Rastatter, M. P., & Lynch, K. (2002). Effect of delayed auditory feedback on normal speakers at two speech rates. *The Journal of the Acoustical Society of America, 111*, 2237-2241.
- Summers, W. V., Pisoni, D. B., Bernacki, R. H., Pedlow, R. I., & Stokes, M. A. (1988). Effects of noise on speech production: Acoustic and perceptual analyses. *The Journal of the Acoustical Society of America, 84*, 917-928.
- Tian, X., & Poeppel, D. (2010). Mental imagery of speech and movement implicates the dynamics of internal forward models. *Frontiers in Psychology, 1*, 166.

- Tian, X., & Poeppel, D. (2014). Dynamics of self-monitoring and error detection in speech production: evidence from mental imagery and MEG. *Journal of Cognitive Neuroscience*, 27, 352-364.
- Tonndorf, J. (1976). Bone conduction. In *Auditory System* (pp. 37-84). Springer, Berlin, Heidelberg.
- Tourville, J. A., & Guenther, F. H. (2011). The DIVA model: A neural theory of speech acquisition and production. *Language and Cognitive Processes*, 26, 952-981.
- Tremblay, S., Shiller, D. M., & Ostry, D. J. (2003). Somatosensory basis of speech production. *Nature*, 423(6942), 866.
- Turner, T. H., Fridriksson, J., Baker, J., Eoute Jr, D., Bonilha, L., & Rorden, C. (2009). Obligatory Broca's area modulation associated with passive speech perception. *Neuroreport*, 20, 492-496.
- Watson, D. G., Buxó-Lugo, A., & Simmons, D. C. (2015). The effect of phonological encoding on word duration: Selection takes time. In *Explicit and implicit prosody in sentence processing* (pp. 85-98). Springer, Cham.
- Watson, N. A. (1938). Limits of audition for bone conduction. *The Journal of the Acoustical Society of America*, 9, 294-300.
- Yates, A. J. (1963). Delayed auditory feedback. *Psychological Bulletin*, 60, 213-232.

Appendix

Counterbalance List	Control Prime	Target	Image 3	Image 4
1 - Critical	frog	barn	swan	ring
	swan	screw	rabbit	monkey
	seal	bed	giraffe	candle
	tiger	cow	axe	deer
	lightbulb	bat	apple	ring
	monkey	glove	seal	whistle
	nail	nose	grasshopper	television
	kangaroo	clock	frog	strawberry
	ring	thread	house	wrench
	grasshopper	brush	wrench	axe
1 - Filler	harp	zebra	lightbulb	knife
	whistle	helicopter	hammer	rabbit
	piano	pencil	pot	watch
	football	knife	drum	giraffe
	helicopter	refrigerator	rabbit	zebra
	alligator	drum	corn	house
	doll	corn	door	harp
	frog	fence	artichoke	ruler
	kangaroo	door	doll	axe
	sandwich	axe	seal	eagle
2 - Critical	refrigerator	train	candle	alligator
	watermelon	lettuce	door	lightbulb
	orange	fly	rooster	owl
	pipe	plug	ruler	button
	watch	skunk	knife	drum
	whistle	vest	chicken	rooster
	ruler	bread	fence	seal
	sandwich	church	doll	frog
	knife	car	motorcycle	watermelon
	artichoke	tie	hammer	doll
2 - Filler	eagle	nail	fence	swan
	axe	ring	elephant	door
	refrigerator	whistle	apple	chicken
	tomato	pot	snake	sandwich
	rooster	house	ruler	deer
	orange	drum	whistle	kangaroo
	deer	monkey	motorcycle	corn
	button	kangaroo	nail	frog
	tiger	ruler	piano	turtle
	pipe	orange	axe	wrench

Appendix, cont'd.

3 - Critical	harp	fox	lightbulb	grasshopper
	pot	bell	pipe	eagle
	pencil	leaf	helicopter	elephant
	button	book	tiger	house
	chicken	ball	eagle	orange
	fence	swing	watermelon	hammer
	rooster	peach	sandwich	corn
	rabbit	chain	spider	pot
	giraffe	truck	corn	helicopter
	axe	mouse	ring	chicken
3 - Filler	hammer	watermelon	owl	refrigerator
	grasshopper	harp	ring	monkey
	door	apple	television	motorcycle
	nail	seal	candle	apple
	fence	piano	sandwich	pencil
	turtle	spider	watch	doll
	chicken	grasshopper	eagle	artichoke
	pencil	frog	monkey	piano
	corn	doll	zebra	seal
	motorcycle	rooster	strawberry	grasshopper
4 - Critical	deer	clown	alligator	zebra
	helicopter	bird	pot	harp
	elephant	star	refrigerator	watermelon
	zebra	flag	monkey	fence
	doll	cat	watch	tomato
	hammer	shoe	button	football
	television	bow	deer	giraffe
	tomato	gun	drum	watch
	candle	key	artichoke	rabbit
	spider	pear	kangaroo	artichoke
4 - Filler	zebra	watch	rooster	pipe
	rabbit	swan	button	orange
	seal	giraffe	swan	elephant
	spider	candle	giraffe	tiger
	apple	television	wrench	candle
	monkey	deer	tiger	alligator
	elephant	hammer	tomato	snake
	snake	motorcycle	pencil	ring
	swan	chicken	kangaroo	apple
	house	eagle	deer	spider