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„The influence of sound symbolism in an oral iterated learning experiment“

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Abstract

We transmit cultural information via language through speaking, writing and listening. Language, however, does not only influence cultural transmission, but it has been argued that next to biological evolution, culture has an impact on the development of linguistic properties. Through transmission chain experiments, the effects of cultural pressures on the development of these linguistic properties have been simulated. In the present study, language was transmitted orally in this type of experiment. In order to study the effect *sound symbolism* has on the development of words during cultural language evolution, sound symbolic words have been implemented in the initial input of the experiment. In this transmission chain experiment, we were able to show that also orally transmitted language became more learnable and structured, while the *expressivity* decreased. In the holistic, idiosyncratic language of the first generation, sound symbolism was, however, not recognized and therefore not transmitted by the participants. Due to the decrease of expressivity and the increase in structure in the course of the transmission chain experiment, systematicity seemed to emerge. In some of the artificial languages even sound symbolic features could be identified. This contradicts the hypothesis, however, that sound symbolism only emerges through communication. Possibly oral transmission could also have an effect on the emergence of sound symbolism.

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1. Introduction

Human society without language is unimaginable – yet language is the most unique feature humans share. Many components of language, such as signal learning, vocal production and vocal imitation, are not uniquely human (Fitch, 2010, 2017). Nevertheless, no other species has been found to engage in a similar complex communication system. According to Kirby (2017), not only biological evolution caused the emergence of language in humans but also culture and individual learning influenced this process. Arguably, both biological components, such as genetics and neural mechanisms, and culture interacted in the course of the origins of language and thus lead to the advancement of both culture and language (Tamariz & Kirby, 2016). Laboratory experiments contributed to this research area by simulating the impact of cultural pressures on the development of linguistic properties. This thesis provides further insight in cultural language evolution by showing how cultural pressures influence the transmission of orally produced language and how *sound symbolism* affects this process.

1.1. Cultural language evolution

The instinct to learn from others seems to be particularly strong in humans (Henrich & McElreath, 2008). A crucial element of this ability is a process called *iterated learning*, which is the "process during which an individual learns a behavior from another individual who had acquired it in the same way (Kirby, 2014)." Arguably, genetically evolved physiological adaptions lead to its dominance in humans and caused the emergence of *cultural transmission* (Henrich & McElreath, 2008; Kirby, 2017). In fact, language seems to enhance cultural learning and the transmission of culture. Morgan et al. (2015), for instance, showed in a cultural transmission experiment how the use of language and teaching increased the quality of Oldowan stone tools significantly more than processes like imitation and emulation. Therefore, they suggest that the use of language lead to an immediate benefit when acquiring and also when passing on the skill (Morgan et al., 2015).

While this indicates how language influenced cultural transmission, also culture impacts linguistic properties, including expressivity and arbitrariness (Tamariz & Kirby, 2016; Tamariz, 2017) (box 1). Apart from language surveys and computational models, laboratory experiments have provided major evidence of how linguistic properties develop under cultural pressures (Tamariz & Kirby, 2016; Kirby, 2017; Tamariz, 2017). In fact, transmission chain experiments, which were first introduced by Kirby et al. (2008), enabled the analysis of the impact of cultural pressures on the linguistic properties of a holistic, idiosyncratic language in a laboratory setting. This experiment has been a template for a number of experiments (see Kirby, 2017; Tamariz, 2017 for review). These experiments have led to important conclusions about how cultural evolution influences the development of linguistic properties.

Kirby et al.'s (2008) transmission chain paradigm worked similarly to the children's game broken telephone as artificial words were passed on from participant to participant. The individuals were told to learn an alien language as well as they could, but were oblivious to the fact that they were exposed to the written output of the previous participant. Each individual embodied a so-called generation. The participants in Kirby et al.'s paradigm learned the language in three phases. Each phase consisted of a training phase and a testing phase. In the training phases, the participants were asked to memorize word-meaning pairs. These were followed by testing phases in which participants had to label the visual stimuli. The labels given in the last testing phase were then the input for the following generation.

One essential feature of this paradigm is that the participants are not exposed to the whole set of stimuli. In Kirby et al.'s (2008) experiment, the participants were, in fact, only subjected to 14 of the 27 stimuli. This so-called *informational bottleneck* mirrors the fact that the number of possible words, phrases and sentences is too large that a single person can be exposed to all of these in their lifetime and especially not in their first years of life (Kirby, 2017). Kirby et al. (2008) and Kirby (2017) argue that this informational bottleneck leads to the *systematicity* and underspecification of language because participants, like humans in real life, attempt to find structure within language (Box 1). Through accumulation of similar sounding features, participants assume a non-existent structure and create systematicity and arguably *compositionality* in progress (Kirby, 2017). Simultaneously, however, the language becomes less expressive, which results in the underspecification of less relevant features (Winters et al., 2015).

While Kirby et al.'s (2008) experiment has been carried out through written communication, most language acquisition is performed orally. Moreover, educated individuals, memorize vocabulary in a second language better when reading as opposed to listening (Vidal, 2011). This may have lead to a distortion of the results and interpretations of the effects of cultural pressures on language evolution. In order to study if also orally transmitted language adapts to the cultural pressures of a transmission chain experiment as it has been shown for written language, an oral version of Kirby et al. (2008) was designed and conducted. Our hypothesis was that a holistic artificial language would become more learnable and structured, while the expressivity would decrease in the course of this oral transmission chain experiment, as it was the case in Kirby et al.'s (2008) paradigm. Different to Kirby et al. (2008), the words were not presented via written labels underneath the visual stimuli but through headphones. Furthermore, the participants had to label the visual stimuli in the testing phases by speaking into a microphone instead of typing. Due to our second research question, however, this experiment was not a strict replication of Kirby et al. (2008) and also differed in some other features.

Box 1: Some effects of the informational bottleneck

Arbitrariness
Arbitrariness is defined as the “unpredictable mapping of form and meaning (Dingemanse et al., 2015).”

Systematicity
Systematicty is “a statistical relationship between the patterns of sounds for a group of words and their usage (Dingemanse et al., 2015).” It develops through the accumulation of sounds, which are then associated to certain meanings (Monaghan et al., 2012; Monaghan *et al.*, 2014).

Expressivity and Underspecification
Through adapting to the informational bottleneck, languages become less expressive and features that are less relevant to the learners are not specified in language (Kirby, 2017).

1.2. Sound Symbolism

The question whether language consists of an arbitrary accumulation of sounds or if there are form-meaning correspondences has been a long dispute. Traditionally, it had been argued that language is arbitrary (de Saussure, 1983). This idea is, however, contrasted by the concept of *iconicity*, which is an umbrella-term that covers all types of communicative signs that manifest a resemblance between form and meaning (Perniss & Vigliocco, 2014; Lockwood & Dingemanse, 2015; Dingemanse et al., 2015). Despite the fact that these notions are complete opposites, both concepts seem to influence the human communication system (Dingemanse et al., 2015; Tamariz et al., 2018). Due to the discrepancy between the scarce evidence of iconicity found in Indo-European languages compared to the less studied non Indo-European languages, iconicity might have been underestimated (Imai et al., 2008). In fact, this phenomenon has been identified in numerous languages, such as in the languages of Australia (Haynie et al., 2014), Africa and Asia (Bodomo, 2006). By comparing 100 basic vocabulary items in over 6000 languages, Blasi et al. (2016) demonstrated that form-meaning associations also persists across this large variety of languages. This evidence of the universal distribution of iconicity within and across languages leads to the assumption that this phenomenon might be critical in language acquisition and thus cultural language evolution (Imai & Kita, 2014).

Iconicity is, however, a heterogeneous concept and various forms, such as absolute iconicity and relative iconicity, exist (Gasser et al., 2011) (Box 2). The relative iconicity of shape was first studied by Köhler (1949), who introduced a forced-choice task experiment during which participants had to match the non-words *maluma* and *takete* to either a round or a spiky drawing (Fig. 1). He observed that participants would associate *maluma* with the round object and *takete* with the spiky object. Ramachandran & Hubbard (2001) came to the same results though naming the objects *bouba* and *kiki* and thus introducing the more widely known *bouba-kiki* paradigm. When this experiment was carried with participants from different language backgrounds, the same form-meaning bias as for English speakers was discovered (Davis, 1961; Bremner et al., 2013; but see Styles &

Gawne, 2017). In an experiment, which was designed to explain which sounds triggered this effect, Nielsen & Rendall (2013) were able to show that spiky shapes were associated with plosive consonants and unrounded vowels, while round shapes were linked to sonorant consonants and rounded vowels. The participants seemed to choose both consonants and vowels equally to create sound symbolic words (Nielsen & Rendall, 2013).

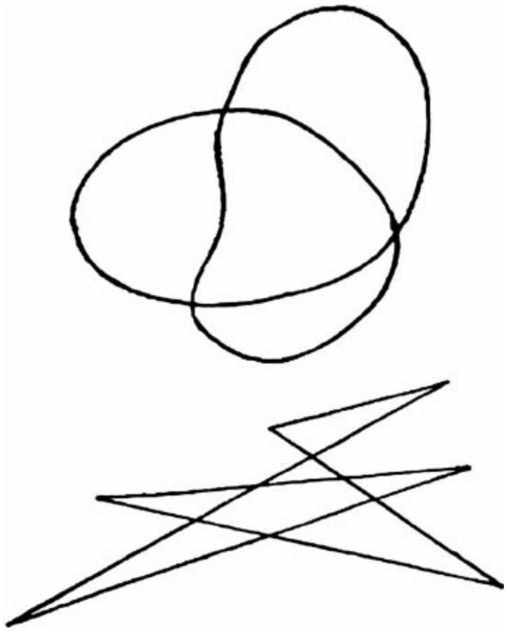


Figure 1: stimuli created by Köhler (1949). The item above was mostly associated with the non-word *maluma* and the image below with the non-word *takete.*

While most research on relative iconicity has been focused on shape, this phenomenon has also been investigated for size (see Thompson, 2013; Lockwood & Dingemanse, 2015 for review). Already in 1929, Sapir described that participants were more likely to choose the non-word *mil* for a small table and *mal* for a large table. In a similar experiment, Newman (1933) observed that large objects were often signified by lower back vowels, such as [a;o] and small objects by high front vowels, like [i].

Box 2: Forms of iconicity

Iconicity

- *Absolute iconicity*

Absolute iconicity occurs when there is a direct relationship between form and meaning (Dingemense et al., 2015). An example of absolute iconicity would be the mimicking of animal sounds.

- *Relative iconicity*

Relative iconicity is an analogical resemblance of relations between forms to relations between meanings (Dingemanse et al., 2015). One example would be, for instance, the analogical resemblance of the relations between certain vowels to the relations between certain shapes of objects.

In fact, Berlin (2006) also found this to be true in multiple different indigenous languages. He noted, that smaller birds and fish carried names formed with the high-front vowel [i] while larger birds and fish had received names that included the vowels [u] and [a] significantly above chance level (Berlin, 2006).

The reason why these associations persists across numerous languages, cultures and experiments might be due to the reason that iconicity is caused through perceptuomotor analogies and neural mechanisms (Dingemanse et al., 2015; Kanero et al., 2014; Monaghan et al., 2014). This is also supported by the growing evidence that already toddlers and non-verbal infants are able to detect sound symbolism (Maurer et al., 2006; Asano et al., 2015; Imai *et al.*, 2015; Ozturk et al., 2013; Peña et al., 2011). The term sound symbolism is used when there are associations between sound and meaning. In other words, it signifies iconicity in spoken language (Lockwood & Dingemanse, 2015). Since the first words acquired in life tend to be iconic, it had been argued that sound symbolism might be relevant for the acquisition of language (Imai & Kita, 2014; Monaghan et al., 2012). In fact, sound symbolism might fulfill a bootstrapping function during first language acquisition in children (Imai & Kita, 2014). If sound symbolism and iconicity are relevant in language learning, the assumption arises that these concepts might have been crucial in the evolution of language (Imai, 2008; Kita et al., 2010; Perniss & Vigliocco, 2014).

Cultural language evolution experiments contribute to this research by showing how cultural pressures influence the spread of sound symbolic features and systematicity. Experiments that focus on the development of sound symbolism in the course of cultural cumulative evolution have mostly been carried out using the replication method and by utilizing the shapes from the *bouba-kiki* paradigm. This aforementioned method was first introduced by Kirby *et al.* (2015) and is a combination of Garrod *et al.'s* (2007) dyad learning experiment and Kirby et al. 's (2008) transmission chain experiment. The focus of this method is, however, on communication rather than on the informational bottleneck.

(Tamariz et al., 2018) concluded from this type of experiment that compositionality and iconicity only evolve when communication is involved in the experiment. While Tamariz et al. (2018) argue that iconicity is caused through communication, Jones *et al.* (2014) argue that iconicity also emerged in their transmission chain experiment.

Due to the fact that (Imai & Kita, 2014) argue that sound symbolism bootstraps language learning, we assumed that this effect might be strong enough to boost the development of sound symbolic items and that those would become more learnable and structured than their non sound symbolic counterparts. In order to investigate this hypothesis, we divided the stimuli into four categories according to their shape and size. One of these categories was sound symbolic, while the other items received neutral names in the first generation. The learnability, structure and expressivity of the sound symbolic categories and non sound symbolic categories were compared in order to draw conclusions whether sound symbolism implemented in the beginning of an experiment had an impact on the developing language.

2. Methods

The conducted oral experiment was similar to the written transmission chain experiment by Kirby et al. (2008) and consisted of four chains, which each contained ten generations. The participants were told that they would have to learn an alien language. This language consisted of 24 word-meaning pairs. The visual stimuli varied in their shape, size, motion and color. The shape of the stimuli was in accordance with the *bouba-kiki* paradigm. These were paired with auditory stimuli, which were played to the participants via headphones. In order to test whether sound symbolic words become more learnable and structured, some words contained sound symbolic features, while the remaining words were neutral in the first generation. The participants were exposed to the alien language in training phases and were tested on the language in testing phases. In the training phases, the participants were only exposed to half of the stimuli, the so-called SEEN items. The UNSEEN remained hidden. In the last testing phase, they were, however, tested on all of the stimuli. This output was then the input for the following generation.

2.1. Participants

Fifty University students (N=50, mean age=23.8 years, female:male ratio 30:20, minimum age: 18 years, maximum age: 56 years) from the University of Vienna participated in the study and received 5 Euro in return. The ethics committee of the University of Vienna approved this study on 20. April 2017 (reference number 00259). All participants were fluent in German, had no background in linguistics and did not have any visual or auditory impairment. The participants were told that it was their task to learn an alien language as well as they possibly could.

2.2. Experiment Design

This experiment is an adapted version of the original transmission chain paradigm from Kirby et al. (2008) and was carried out on a computer program, which was designed with Python 2.7 especially for this project (Python Software Foundation). Like Kirby et al. (2008), this experiment consisted of four chains with ten generations each (Fig. 2). Each generation consisted of one participant, who learned the language from the participant before him or her. In Kirby et al.'s (2008) experiment, this transmission took place through written communication. However in the present study, the transmission of the artificial language was conducted orally. The output of the participants was recorded with an H4next microphone (ZOOM cooperation), which was played to the next participant through headphones. This information was, however, not communicated to the participants.

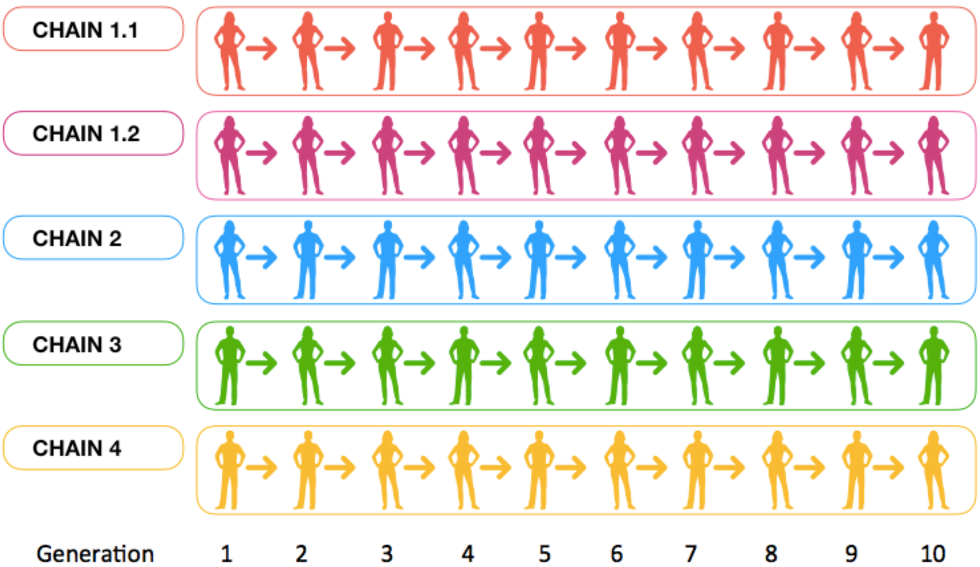


Figure 2: This transmission chain experiment consisted of four plus one (Chain 1.2) chains. Each chain was composed of ten generations and each generation equaled one participant, who learned the language of his or her predecessor.

2.3. Visual stimuli

The visual stimuli differed in four aspects: shape (round, spiky), size (big, small), color (color 1, color 2) and movement (fast, slow, none) (Fig. 3.). The shapes were adapted from Ramachandran and Hubbard (2001) and Maurer et al. (2006). The aspects of the stimuli were designed in a way that they would not be nameable in German or other available languages. Therefore, the differences in movement and size were relative and not categorical; the colors were chosen in a way that they would not interfere with German color terms; and the participants were unfamiliar with the *bouba-kiki* paradigm. Unlike Kirby et al. (2008), the stimuli were animated and actually moved.

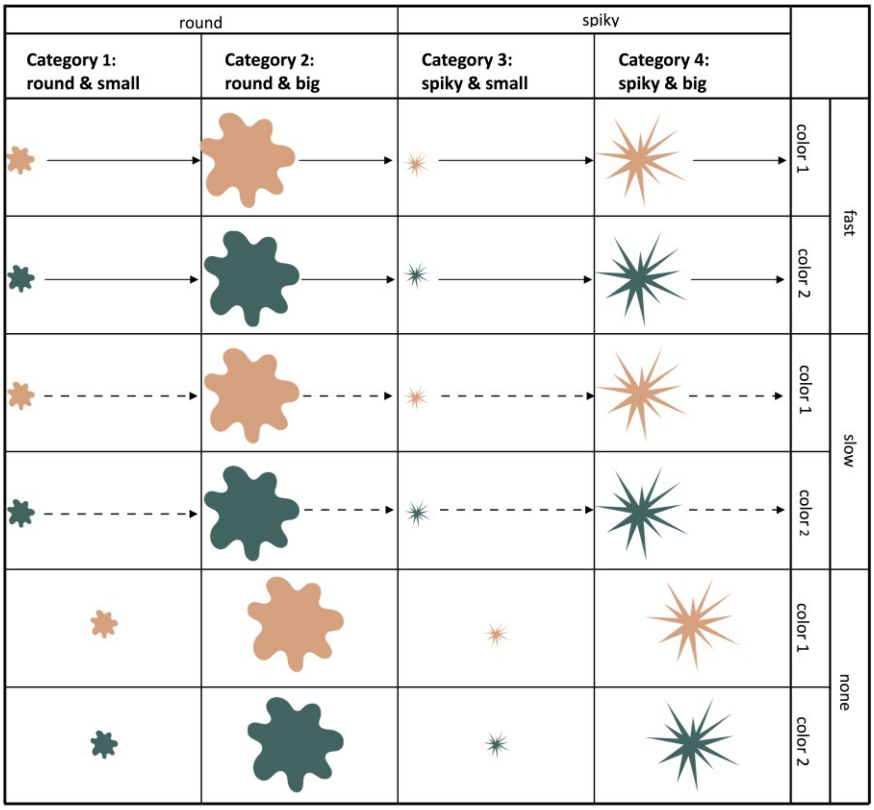


Figure 3: The 24 visual stimuli differed in their shape (round/spiky), size(big/small), color (color1/color2), movement (fast/slow/none). Since sound symbolism was tested for shape and size, four categories were designed, which differed in these two features. Note that the arrows indicate actual movement.

2.4. Auditory input

During the exposure of the visual stimuli, the participants heard the paired artificial words through headphones. Due to the oral transmission of the artificial word throughout the experiment, the labels to the moving images changed with each generation. In order to test our hypothesis that iconic word-meaning pairs would become more learnable and structured than non sound symbolic word-meaning pairs, the initial labels were designed accordingly. In order to examine all shape-size combinations, each chain started with different word-meaning pairs in the beginning. Chain 1.2 was a replicate of Chain 1.1 and started with the same word-meaning pairs in generation 1.

All of the 24 visual stimuli were divided into four categories according to their shape and size, namely Category 1 (round-small), Category 2 (round-big), Category 3 (spiky-small) and Category 4 (spiky-big) (Fig. 3). In each chain, one of these categories received sound symbolic labels, while the others were given general non sound symbolic names. The categories were matched to the chains according to their numbers. In Chain 1, for instance, Category 1 was sound symbolic and Categories 2, 3 and 4 were given non sound symbolic labels.

In order to create the auditory input for the first generation, consonants and vowels, commonly used in German or English, were combined into all possible consonant-vowel combinations. Sixty-six syllables were randomly chosen from these combinations. Each consonant and each vowel were represented at least three times. These pairs were recorded by a female native German speaker with an H4next microphone (ZOOM company). The amplitude was equalized with PRAAT (Boersma & Weenink, 2010). In the course of an online survey, participants (N=11, mean age= 34.7, female: male ratio= 13:11, minimum age= 18, maximum age= 59) were exposed to these recorded syllables and had to rate each syllable on two scales, which ranged from 1-10. On one scale they had to rate whether the syllable sounded either spiky (1) or round (10), and on the other one whether it sounded small (1) or big (10) to them. The mean of the rating of each syllable was then calculated. Syllables were considered to be spiky or small if their mean was lower than four and they were considered to be round or big if their mean was above six. Syllables that had a mean between four and six were considered to be neutral for the respective feature.

Afterwards, it was assessed which consonants and vowels were present in each rated combinations. If, for example, a specific vowel was only present in syllables that were rated as big or in syllables that were either rated as big or neutral, it was considered to be symbolic for big. If it only appeared in syllables that were rated as small or as small or neutral, it was regarded as sound symbolic for small. When this specific vowel was only present in syllables that were rated as neutral or appeared in all of the categories, it was considered neutral for size.

Subsequently, four pools were constructed, one pool for each feature (big/small/round/spiky). Each pool consisted of the consonants and vowels that were considered as sound symbolic for the specific feature. These pools were then assigned to their matching category. The pool with the spiky sounding vowels and consonants, for instance, was assigned to the categories 3 and 4, since these two categories contained spiky objects (see categories in graph 3). Therefore, each category was assigned two pools, one for its size and one for its shape. For the chain where the specific category was sound symbolic, the vowels and consonants were drawn from these pools. In the other chains, where this category was not sound symbolic, the consonants and vowels were drawn out of a third pool. This pool consisted of all the consonants and vowels that were not present in any of the other two pools each category was assigned to.

Due to the fact that the participants were only exposed to half of the stimuli, only twelve of the twenty-four stimuli were labeled. Therefore in each chain, three stimuli per category were randomly chosen. For each category in each chain, two three-syllabic words (CVCVCV) and one two-syllabic word (CVCV) were created. For the sound symbolic three-syllabic words, one syllable was randomly chosen from the sound symbolic size pool and one from the sound symbolic shape pool.

The syllable in the middle was randomly chosen from the neutral pool. Due to the fact that there were two three-syllabic words, the sequence of the syllable for size and for the syllable for shape were alternated. For the two-syllabic sound symbolic words, the central syllable was omitted. The words from the non sound symbolic categories were created using the neutral pool. If possible the combinations, which were considered as sound symbolic in their respective categories, were excluded. In chain 1, for instance, category 1 (round/small) was sound symbolic. The sound symbolic words, for instance, were kitɛbo, xebo and dohaxi. In this case, ki, xi and xe represented the small size, bo and do indicated the shape. Neutral labels like juzɛha and zahøvu were created with the neutral pool and were not paired to their respective stimuli (for the full set the created words see Generation 0 in Appendix E). The syllables were recorded by the same female native German speaker. The amplitude was equalized and the syllables were concatenated to form words with PRAAT (Boersma & Weenink, 2010).

2.5. The learning process

The participants were told in an introductory video that they had to learn an alien language and that they had to memorize the stimuli as well as they could (Appendix B). The learning process was divided into three rounds. After each round, the participants were free to take a five-minute break, which participants rarely used. Each round consisted of a training phase and a testing phase.

In order to create the informational bottleneck, the participants were only exposed to half of the 24 word-meaning pairs in the training phase. Thus, the stimuli were randomly divided into a SEEN group, which the participants were exposed to, and an UNSEEN group, which they did not see in the training phases. For the input of the first generation, three word-meaning pairs were randomly chosen to be SEEN from each category. In the remaining generations, however, the SEEN word-meaning pairs were randomly chosen from the complete set of the 24-stimuli of the output of the previous participant. Each distinct word was only allowed once in the input for the next generation and doubles were excluded like it was the case in experiment 2 in Kirby et al. (2008). If the number of distinct words sank below twelve in the course of the experiment, doubles were allowed after all of the distinct words were selected.

During the training phases, the participants were exposed to the SEEN stimuli twice in a random order and they heard the matching auditory stimuli over headphones. Each training phase was followed by a testing phase. For the testing phase, the participants saw the moving images on a computer screen. At the lower half of the screen, there appeared a record button, which the participants had to press in order to record themselves. When they finished recording their output, the next item came onto the computer screen. In the first two testing phases, the participants were only tested on half of the twenty-four items, namely half of the SEEN items and half of the UNSEEN items. In the last testing phase, the participants had to label all of the items. These items were then used for the analysis. As mentioned before, half of these items were then randomly chosen to be the input for the next generation.

2.6. Analysis

The output of the third testing phase was transcribed by two people separately. These transcriptions were then compared and combined in order to create a final version, which was then used for further analysis. The learnability, systematicity and expressivity of the language were measured in order to draw conclusions about our hypothesis that these factors behave similar as in written experiments. The measurements were conducted, using the software R (R Development Core Team, 2008). Furthermore, the measurements were conducted similarly to Kirby et al. (2008).

Learnability

In order to measure learnability, the transmission error was calculated. This measure was calculated with the normalized Levenshtein distance between the words with the same meaning in the two approximate generations of same chain. In order to examine if there is a change in learnability in the course of the transmission chain, a generalized linear mixed model (GLMM) was performed with the assumption that the Levensthein distance would be lower in later generations. Chain was taken as a random factor.

Expressivity

The expressivity of the developing language was measured by counting the number of distinct words in a generation. Furthermore, the ratio of the unique syllables to all syllables was calculated. Through calculating this ratio, the performance of a GLMM with chain as a random factor was enabled.

Structure

In order to calculate the structure of the language for each generation, the difference between all the meanings had to be calculated with the Hamming distance, which ranged from 1 to 4. 1 signified that only one feature differed between the images and 4 meant that all variables of the image were different. Furthermore, the distances between all the strings in each generation were calculated with the normalized Levenshtein distance. A Pearson correlation coefficient was calculated for every generation separately with the assumption that more similar meanings would have more similar strings. Furthermore, it was assumed that this correlation would become stronger with each generation. In order to test this assumption a GLMM was performed with the values from the Pearson correlation coefficient calculation and chain as a random factor.

Sound Symbolism

In order to measure if these effects are stronger in the selected sound symbolic category as opposed to non sound symbolic categories, the measurements for learnability, structure and expressivity were conducted for both of these groups separately. A GLMM model for each of these measurements was built. For each of these measurements another model that included sound symbolism as a fixed factor was created. Via an ANOVA it was tested whether sound symbolism significantly influenced the development of the language.

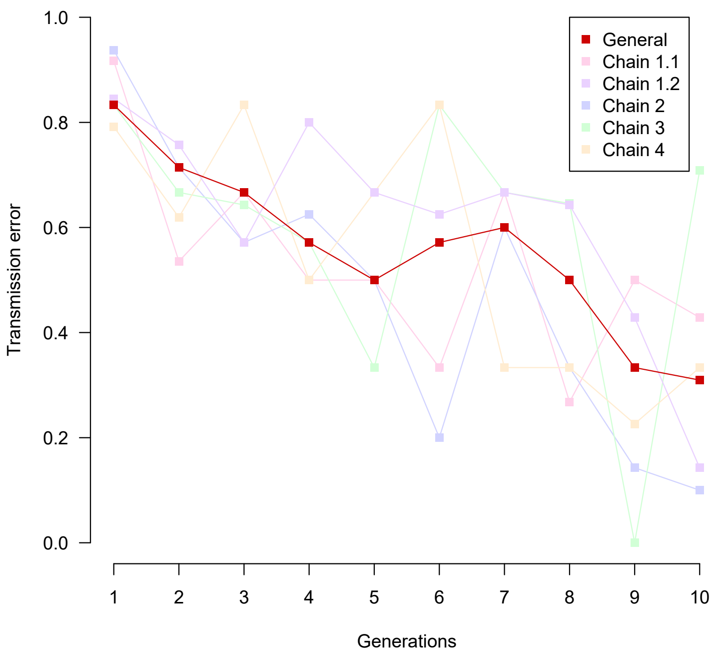
3. Results & Discussion

3. 1. Oral transmission chain experiment

3. 1. 1. Result

Learnability

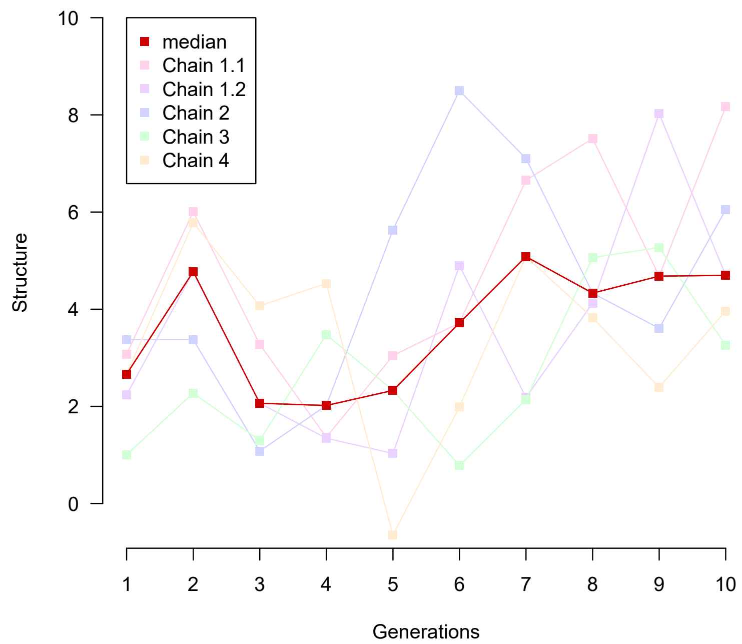
The development of learnability was measured with the transmission error, which is the normalized Levenshtein distance of the words with the same meaning in the two adjacent generations (Kirby et al., 2008). In the course of the experiment, the transmission error decreased significantly (correlation coefficient= -0.035, SE= 0. 004, t = -9.9, P< 0.001) (Graph 1). In generation 1, there was a transmission error of 81.8%. The transmission error declined continuously over the first five generations (Graph 1). At generation 5, 49.6% of the language was replicated. In generation 6 and 7, the transmission error rose again. After generation 7, the error rate decreased strongly and leveled out from generation 9 to 10 at a transmission error of 38%.



Graph 1: This graph shows the development of the transmission error in the course of the transmission chain experiment. Here the median of the transmission error of each generation of each chain is plotted. Furthermore, the median of all the data combined is marked in red.

Structure

The structure is defined by the correlation of the difference in meaning (measured with the Hamming distance) to the string distance (measured with the Levenshtein distance) (Kirby et al., 2008). This correlation was measured with the Pearson correlation coefficient for each generation. Like in Kirby et al. (2008), a significant increase in structure was determined in this experiment (correlation coefficient= 0.293, SE= 0.092, t = 3.198, $P< 0.05$) (Graph 2). There was a strong increase in structure in generation 2, which was followed by a stark decrease in generation 3 (Graph 2). This was the case for all of the individual chains. The greatest increase in structure occurred from generation 5 to 7. After generation 7, the structure of the language leveled out at a t-value of around 5.



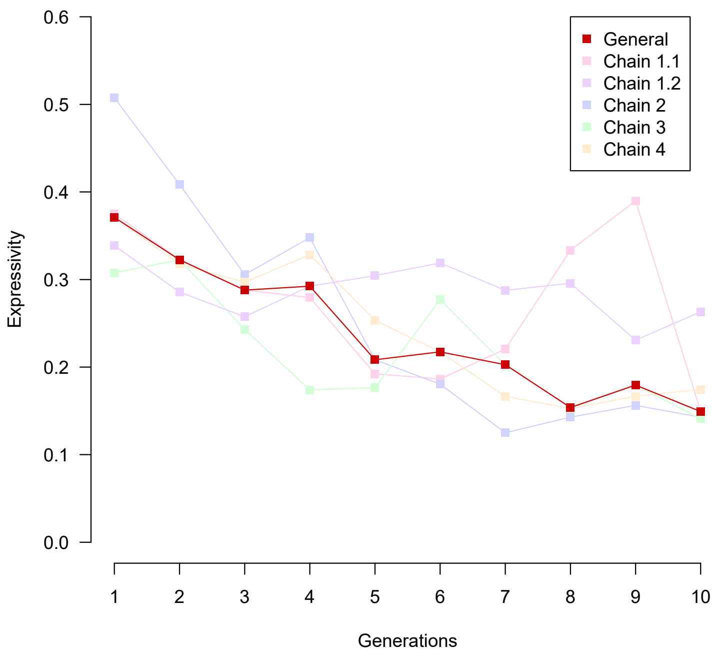
Graph 2: In this graph, the development of the structure in the course of the transmission chain experiment can be observed. The values shown are the t-values of the Pearson correlation coefficient of each generation. The red line signifies the median of the individuals chains.

Expressivity

Expressivity is usually measured with the number of distinct words (Table 1) (Kirby et al., 2008). In order to calculate the expressivity of the individual categories and to examine expressivity in more detail, in this experiment the ratio of the unique syllables and the overall number of syllables had been calculated as well (graph 3). For both methods, a significant decrease of expressivity was documented (correlation coefficient= -0.019 SE= 0.003, t =-6.17, P < 0.002).

Table 1: This table shows the decrease of expressivity on the word-level. It can be observed that the number of distinct words decreases in the course of the experiment.

Generations	0	1	2	3	4	5	6	7	8	9	10
Chain 1.1	24	24	14	16	21	14	9	14	15	19	6
Chain 1.2	24	20	20	15	15	23	15	18	14	9	10
Chain 2	24	23	18	14	17	12	11	8	9	7	6
Chain 3	24	19	15	16	14	12	14	11	8	10	8
Chain 4	24	19	15	15	15	18	9	10	10	8	7
Mean	24	21	16.4	15.2	16.4	15.8	11.6	12.2	11.2	10.6	7.4



Graph 3: This graph shows the decrease of the ratio of unique syllables to all syllable in the course of the transmission chain experiment.

3. 1.2. Discussion

For all of these three measurements, significant changes were reported in the course of this oral transmission chain experiment. It can therefore be concluded that also orally produced language adapts to be successfully transmitted in this type of experiment. While the transmission error (81.8%) was exceptionally high in the first generation, it sank continuously in the course of the experiment. Only in generation 6 and 7, the transmission error increased slightly. During these two generations, also the greatest development of structure occurred. In fact due to the steady decrease of expressivity, underspecification and systematicity arose, which eventually influenced the structure and learnability of the languages.

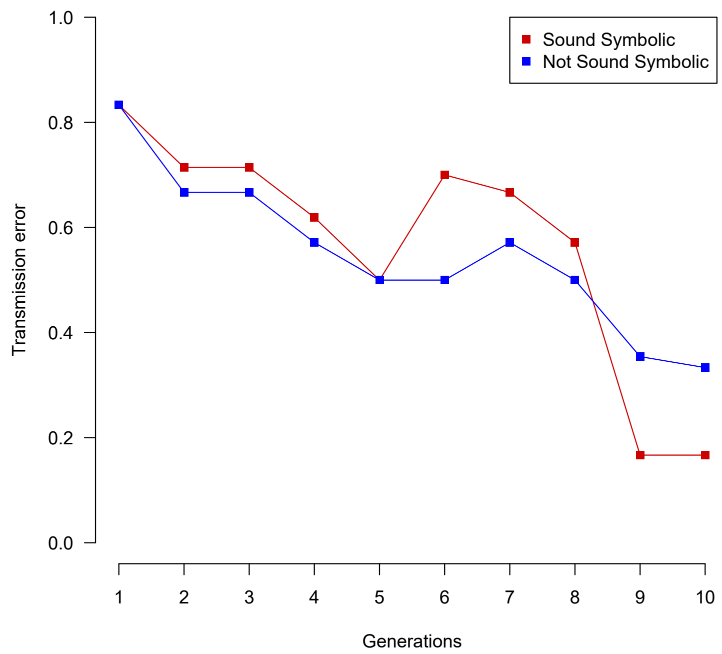
When drawing conclusions about this oral transmission chain experiments in comparison to its written counterpart, it has to be noted that this study is not a strict replication of Kirby et al. (2008). In fact, the experiments differ in their stimuli, the number of stimuli, the size of their bottleneck and the construction of the initial auditory stimuli. Despite the significant results for learnability, expressivity and structure, some dissimilarity to the written transmission chain experiment can be observed. Even though there is a significant decline of the transmission error, for instance, the error rates are generally higher for each generation and are descending later than in the written experiment. In the first generation, the transmission error was 81.8% in this experiment, while in Kirby et al. (2008) it was around 70%. In fact, the initial stimuli might be slightly more difficult to learn in this experiment. However, the transmission error continues to be higher than in Kirby et al. (2008) throughout the experiment. This could be due to the reason that educated individuals, who have a low proficiency level in a second language, remember vocabulary better through reading than listening because they can observe the items in more detail (Vidal, 2011). Therefore, written stimuli might have even slightly distorted conclusions about cultural language evolution since it is likely that University students have a higher proficiency level in reading and thus can observe patterns of language more closely.

Furthermore, structure developed later in this experiment and there appear to be phases when the development of structure is stronger than in the rest of the experiment. The first major increase occurred from generation 1 to 2. This increase was, however, followed by an immediate decrease. This pattern, which was observed in all of the individual chains, could be due to oral transmission. The reason why this early increase in structure was not viable is unknown and might have to be examined in further studies. With the exception of the spike of structure in generation 2, the greatest growth in structure occurred during generation 6 and 7 (Graph 2). Structure or the lack of structure appears to be stable before and after this stark increase. A reason for this development of structure could be that the mean number of unique words has dropped below 12 at this point. Therefore, only half of the words were unique and some words appeared twice in the input of the following participant (Table 1). In fact through this underspecification, regularities emerge, which help the learners to generalize the words appropriately (Silvey et al., 2015). This development might also be linked to the accumulation of systematic sound patterns, which will be discussed in the general discussion.

3. 2. Sound symbolism

3.2.1. Results

For this analysis, an average of the data was analyzed and the sound symbolic category was compared to the combined non sound symbolic categories. A GLMM model with sound symbolism as a fixed factor did not explain this data significantly better than the same model without sound symbolism as a fixed factor (AIC_null=553.05, AIC_symbolism=554.83, p= n.s.)(Graph 4). As can be seen in graph 4, the transmission errors in both categories developed similar to each other. In the first generation, the learnability of both categories was equal (81.1%). After generation 1, the sound symbolic categories continuously showed a higher transmission error as the non sound symbolic categories. Only in generation 5, the transmission rates are equal and for generations 9 and 10, the sound symbolic categories became more learnable as the non sound symbolic categories. As mentioned before, however, this difference is not significant.



Graph 4: This graph shows a comparision of the mean of the sound symbolic categories to the mean of the non sound symbolic categories. It can be observed that there was no significant difference between the learnability of the sound symbolic items to the non sound symbolic items.

3.2.2. Discussion

Due to the fact that it was argued that sound symbolism is connected to neural processes and bootstraps language during acquisition (Imai & Kita, 2014; Kanero et al., 2014), it was assumed that sound symbolic word-meaning mappings would become more learnable and structured than the non-symbolic items in the course of an iterated learning experiment. The results of this study, however, do not support this claim. As mentioned before, the transmission error (81.8%) of the first generation was exceptionally high. The transmission error was, in fact, identical for the sound symbolic category. Due to this high error rate, the features of the sound symbolic categories were not transmitted. The absence of transmission leads to the conclusion that the individuals in the first generation did not recognize sound symbolism. Eventually, conclusions about why sound symbolism was not transmitted as expected can only be drawn for the holistic, idiosyncratic language of the first generation.

A cause for the loss of the sound symbolic categories might be that memorizing word-meaning mappings is only possible until a certain vocabulary size is reached (Brand et al., 2017). If the vocabulary is small, sound symbolism assists the learning of single word-meaning associations (Brand et al., 2017). In large vocabulary, however, word-meaning learning of single items is not viable anymore and the role of sound symbolism changes to assisting category learning (Brand et al., 2017; Monaghan et al., 2012). Apparently, the vocabulary in this experiment was too large and complex to allow single word-meaning associations. At this stage, however, also category learning was not fostered through the sound symbolic items. This could be due to vast complexity of this holistic and idiosyncratic language since in the course of the experiment the role of sound symbolism and the related systematicity seemed to change.

3. 3. General Discussion

In general, this experiment showed how also oral transmission enabled the emergence of linguistic properties and possibly sound symbolism. During the first generation, sound symbolic categories were not transmitted due to a large and complex vocabulary (Brand et al., 2017). As mentioned before, the role of sound symbolism shifts to assisting category learning rather than word-meaning mapping when the vocabulary is large (Brand et al., 2017). This might also be the case in the present study. In fact through the cultural pressure the informational bottleneck imposes on the language, the communication system became increasingly underspecified. Simultaneously, sound patterns, which were paired to certain meanings, developed in the course of the experiment. In generation 10 of chain 2, for instance, it can be observed that nearly all of the spiky words ended with [-i] and all of the round objects with [-gly] (Figure 5). These patterns seem to have developed in the course of generations 4-6 and resulted in systematicity (Appendix C).

Arguably, some of these emerged patterns contain sound symbolism. On the final position of the round word-meaning pairs, for instance, the syllable [-gly], which contains the sonorant [-l] and the rounded vowel [–y], is located. The spiky objects, however, have [-i| at their final position. All of these features seem to be sound symbolic for their paired object (Berlin, 2006; Newman, 1933; Köhler, 1929) (Figure 5). Similar features also occurred in the final generation of other chains. In Chain 1.1, 1.2 and 4, there was, for instance, an increased presence of the rounded vowels [-o], [-u] and [-y] for the round shape. Furthermore, in Chain 1.2, the consonants [-k] and [-t] and vowels [-i] and [-e] were more dominant for spiky objects (Appendix D). These observations might be relevant since this would contradict the idea that sound symbolism only occurs when there is communication (Perniss & Vigliocco, 2014; Tamariz et al., 2018; Boer, 2018). A possible cause for this development could be that oral transmission significantly influences the spread of sound symbolism.

round		spiky			
Category 1: round & small	**Category 2: round & big**	**Category 3: spiky & small**	**Category 4: spiky & big**		
para-gly	para-gly	silo-li	pa-li	color 1	fast
para-gly	para-gly	silo-li	pa-li	color 2	
para-gly	para-gly	pa-li	tera-gly	color 1	slow
para-gly	para-gly	pa-li	pa-li	color 2	
tsyntra-gly	tsyntra-gly	pa-si	pa-si	color 1	none
tsyntra-gly	tsyntra-gly	pa-si	pa-si	color 2	

Figure 5: This figure shows the output of generation 10 of Chain 2. It can be observed that the round words end with the ending [-gly] and with one exception, the final syllable of spiky objects are either [-li] or [-si]. In Figure 3, the visual stimuli matching these words can be viewed.

The observed systematicity, however, almost exclusively developed for shape instead of other features. Also Kirby et al. (2008) noted that the structure of the artificial languages in their experiment adapted to shape, which lead to the underspecification of the other factors such as size, motion and color. Shape bias is a wide spread phenomenon and may be caused due to a better memory for shape information (Landau et al., 1988; Vlach, 2016). In fact, languages adapt to information, which is relevant to achieve communicative success (Winters et al., 2015). Since shape seems to be best-memorized feature, it is the most relevant to the individuals and therefore the artificial language adapted to shape information. This shows that not only cultural pressures influenced the development of the articficial languages but also the biologically evolved neural capacities, such as memory and perceptuomotor analogies.

In order to fully understand, however, whether iconicity arose in this experiment and to compare this data to other studies, it might be crucial to measure iconicity and systematicity, like it was conducted in Jones et al. (2014) and Tamariz et al. (2018). In fact, Tamariz et al. (2018) had argued that sound symbolism did not develop when there was no communication. It is very likely that if the same measurements were conducted with the present data, conclusions could be drawn that sound symbolism also occurs during oral transmission without communication. Therefore, it might also be important to continue studying sound symbolism in further oral transmission chain experiments and to investigate how these relate to the communicative approaches like the replication method.

While sound symbolic features were not transmitted in the first generation, transmission patterns might change with different forms of iconicity. As mentioned before, iconicity is a heterogeneous concept and various forms of iconicity have been described. In various non-Indo European languages, absolute iconicity, like *onomatopoeia* and *mimetics*, have their own grammatical categories (Kita et al., 2010). Therefore, these forms of iconicity might have a stronger impact on cultural language evolution than relative iconicity. In further studies, it might therefore be interesting to study whether other types of iconicity, like absolute iconicity, might have a greater impact on a holistic, idiosyncratic language. Furthermore, it might be relevant to investigate how sound symbolism might influence a smaller holistic and idiosyncratic language and how it would develop as the vocabulary grows.

Due to the fact that this oral transmission chain experiment provided significant results, it could now be possible to study how an artificial language develops when it is transmitted by different groups of participants, such as children and people who use different scripts. Henrich et al. (2010) point out that when drawing conclusions about cultural processes, it is essential to gather information from non-western communities because in many aspects western societies are statistical outliers. Until now exclusively western University students participated in transmission chain experiments. In order to create a more realistic perspective on the process of cultural language evolution, transmission chain experiments with participants from various cultural and linguistic backgrounds and different ages would be necessary. This oral transmission chain experiment might be the first step leading into this direction.

For participants, transmission chain experiments are, however, cognitive highly demanding tasks. As could be shown through the higher transmission error, oral transmission chain experiments seem to be even more challenging. In fact, multiple University students who have participated in the study have reported feeling frustrated and felt like the task was too difficult for them. University students have, however, been exposed to education and cognitively challenging tasks for a long period of time. Therefore, it can be assumed that these feelings might be even stronger for children, who have not been exposed to this extent of education. This could lead to a distortion of the results, since the task might simply be too difficult. In a cultural transmission chain experiment with dot patterns, Kempe et al. (2015), however, showed that structure emerged even faster when children carried out the experiment. This shows that studies with children might lead to interesting and important results. Therefore, in order to carry out this experiment with younger participants, it might have to be adapted in a way to limit the extensive cognitive demands.

4. Conclusion

In conclusion, this experiment demonstrates that also orally produced language follows the cultural pressures simulated in the transmission chain paradigm. Even though it had been argued that sound symbolism is bootstrapping language and thus fosters language acquisition (Imai & Kita, 2014; Monaghan et al., 2012), sound symbolism did not have an impact on the development of sound symbolic words in a holistic, idiosyncratic language. However, through the pressure of the informational bottleneck, systematicity and underspecification seem to have developed in the course of the experiment. In fact, in some chains of the experiment, some sound symbolic features that relate to the shape of the object seem to develop. These sound symbolic features are closely linked to the systematicity of the language, which fosters category learning (Dingemanse et al., 2015). The lack of influence of sound symbolism in the first generation and the possible appearance of the phenomenon in the course of the experiment, relates to Brand et al.'s (2017) conclusion that vocabulary size influences the role of sound symbolism. Due to the fact that vocabulary size in this experiment was large and complex, sound symbolism seemed to foster category learning rather than word-meaning associations in this experiment. Furthermore, shape seemed to influence the developing linguistic features the most. This could be due to the reason that the shape of objects is better memorized than other features and therefore language is influenced by this advantage in order to permit successful transmission (Vlach, 2016; Winters et al., 2015). The possible appearance of sound symbolism in this experiment, however, contradicts the assumption that sound symbolism only develops through communication (Tamariz et al., 2018; Boer, 2018). Therefore, it is important to continue to study the impact of orally produced language in transmission chain experiments and compare the results to other types of cultural language experiments. Furthermore, these experiments would allow the examination of how cultural pressures would influence the transmission of an artificial language produced by other groups of people, such as children and people who use different scripts.

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Appendix

Appendix A – German translation of the abstract

Kulturelle Informationen werden über Sprache übertragen, indem wir sprechen, schreiben und zuhören. Sprache beeinflusst jedoch nicht nur die Übertragung von kulturellen Informationen, sondern wird selbst von dem Prozess beeinflusst. Mittels sogenannter *transmission-chain*-Experimente kann dieser Einfluss simuliert werden. In dieser Studie wurde in dieser Art von Experiment eine künstliche Sprache mündlich übertragen. Außerdem wurde untersucht, welchen Effekt *Sound-Symbolismus* auf die Entwicklung von Wörtern im Laufe von kultureller Sprachevolution hat. Dies wurde gemessen, indem *sound-symbolische* Elemente in den Input am Anfang des Experiments eingebracht wurden. In diesem Experiment konnte gezeigt werden, dass auch mündlich übertragene Sprache lernbarer und strukturierter wird, während die Ausdrucksstärke der Sprache sinkt. In der holistischen und idiosynkratrischen Sprache am Anfang des Experiments wurde *Sound-Symbolismus* nicht erkannt und deshalb nicht weiter übertragen. Durch die Abnahme der Ausdrucksstärke und die Zunahme von Struktur im Laufe des *transmission-chain*-Experiments entwickelten sich Lautmuster, welche auch *systemticity* genannt werden. In manchen Ketten konnten auch *sound-symbolische* Elemente identifiziert werden. Diese Beobachtung widerspricht jedoch der Hypothese, dass *Sound-Symbolismus* ausschließlich durch Kommunikation entsteht. Eine mögliche Ursache für die Entwicklung von *Sound-Symbolismus* in diesem Experiment könnte mündliche Übertragung sein.

Appendix B – Information given to the participants

The original German text:

Willkommen auf dem Planeten Beta 457!

Wir befinden uns in einer Galaxie weit, weit entfernt. Seit wir auf diesem Planeten gelandet sind, haben wir Kontakt zu Aliens hergestellt, die eine Sprache sprechen, die uns fremd ist. Ihre Aufgabe ist es nun, diese Sprache so gut Sie können zu lernen.

Machen Sie sich keine Sorgen, falls es Ihnen schwer fällt die Sprache zu lernen. Die Aliens wissen, dass es eine schwere Aufgabe ist und sie werden ihr Bestes geben alles zu verstehen was Sie sagen.

Sie werden nun eine Reihe von sich bewegenden Objekten sehen und hören wie die Aliens sie beschreiben würden. Von Zeit zu Zeit wird ein Alien Sie testen und Ihnen die Objekte ohne Beschreibung zeigen. In diesem Fall werden Sie am Bildschirm eine Record Taste finden. Klicken sie diese an, warten sie kurz und sprechen dann deutlich in das Mikrophon. Wenn Sie fertig gesprochen haben, drücken Sie nochmals die Taste und Sie werden das nächste Objekt sehen.

Geben Sie den Aliens immer eine Antwort! Dann wissen sie, dass Sie sich Mühe geben und werden geduldig sein, alles zu verstehen was Sie sagen. Nach jedem Test haben Sie die Option eine kurze Pause von 5 Minuten einzulegen. Falls Sie irgendwelche Fragen haben, fragen Sie die verantwortliche Person jetzt.

Viel Glück!

The English translation:

Welcome on the planet Beta 457!

We are located in galaxy far, far away. Since we have landed on this planet, we have made contact to aliens, who speak a language that is foreign to us.It will be your task to learn this language as well as you can.

Do not worry if it is difficult for you to learn this language. The aliens know that it is a challenging task and they will do their best to understand you.

You will now see a number of moving objects. Simultaneously, you will hear how the aliens would label them. From time to time, an alien will test you by showing you the objects without telling you how they are called. In this case you will find a record button on the screen. Press this button and wait for a short time. Then speak into the microphone in a clear manner. When you have finished speaking, press the record button again and you will see the next item.

Always answer the aliens, please! Then they will know that you strive to learn their language and they will be patient to understand everything you say. After every test, you will have the option to take a short break of 5 minutes. In case you have any question, ask the responsible person now.

Good luck!

Appendix C - Development of Systematicity in the final syllable of Chain 2

Chain 2

Item Name	Generation 0	Generation 1	Generation 2	Generation 3	Generation 4	Generation 5	Generation 6	Generation 7	Generation 8	Generation 9	Generation 10
bouba-big-color1-fast	ganeʃo	ʃamøgy	bifula	tøʃøky	parakla	sedula	tsentrogly	silogly	paragly	paragli	paragly
bouba-big-color1-none		baʃøla	bafø kla	situla	øntyky	sentogly	tsentrogly	tsentrogly	tsentrogly	tsyntrogly	tsyntragly
bouba-big-color1-slow	bova	tuluk	baføkla	barekla	fidula	sedula	tsentrogly	paragly	paragly	paragli	paragly
bouba-big-color2-fast		døʃøga	baføkla	bitula	sedula	sentrogly	sidogly	silogly	paragly	paragli	paragly
bouba-big-color2-none	doløgɛ	lyfo	døʃøga	tyʃyky	sidoly	sedula	tsentrogly	paragly	tsentrogly	tsyntrogly	tsyntragly
bouba-big-color2-slow		baføkla	doguʃla	teguʃla	sentogly	sytogly	sidogly	paragly	paragly	paragly	paragly
bouba-small-color1-fast	zuta	tulusa	situla	fitula	parakla	sidoly	sidogly	silogly	silogly	paragli	paragly
bouba-small-color1-none		tuga	gøgøʃka	tøʃøky	sedula	paragly	paragly	tsentrogly	tsentrogly	tsyntrogly	tsyntragly
bouba-small-color1-slow	tɛluza	pirøga	fugula	situky	sidugly	sidoly	ilogly	paragly	silogli	paragli	paragly
bouba-small-color2-fast		fitula	fitula	fitula	fedula	sidoly	sidogly	silugly	paragly	paragly	paragly
bouba-small-color2-none	ʃanɛpø	gøʃøla	tuluza	sytyky	situla	paragly	paragly	tsentrogly	tsentrogly	paragli	tsyntragly
bouba-small-color2-slow		fugula	fogula	fogula	siduly	sidola	silogly	paragly	paragly	teragly	paragly
kiki-big-color1-fast	nufapy	ʃømøga	bitula	fitula	terakla	sidokla	tsentrokla	siluly	silogly	teragly	pali
kiki-big-color1-none	lyʃø	tʃepfyla	tʃepfyla	tøpfyla	tepfokla	tetrokla	tetrokla	tsentroly	pasi	pasi	pasi
kiki-big-color1-slow		borega	tarykla	tarykla	terakla	sytokla	tsentrokla	paraly	paragli	pali	teragly
kiki-big-color2-fast		parygø	fitula	fitula	fitukla	sentokla	tsentrokla	siluly	teragly	teragly	pali
kiki-big-color2-none		ʃømøga	taryka	birogla	NA	sentokla	tetrokla	parasi	pasi	pasi	pasi
kiki-big-color2-slow	sakøʃe	taryga	døʃøky	terokla	fitukla	sentokla	tsentrokla	paraly	teragly	pali	pali
kiki-small-color1-fast	xufɛna	suta	situla	fitula	mikrokla	sidokla	sidokla	siluly	siloli	siloli	siloli
kiki-small-color1-none		gatysa	tʃepfyla	situla	tserakla	parakla	parakla	tsentroly	siloli	pasi	pasi
kiki-small-color1-slow		sutula	pirokla	tøʃøky	firula	sytokla	sidoly	paraly	parali	pali	pali
kiki-small-color2-fast		fity	fity	bitula	fidukla	sidokla	sidokla	siluly	siloli	siloli	siloli
kiki-small-color2-none	lafu	teʃela	sityla	terokla	parakla	parakla	parakla	tsentroly	siloli	pasi	pasi
kiki-small-color2-slow	katusø	dorega	taryka	barekla	mikrokla	sidokla	sidola	paraly	siloli	pali	pali

- ending with -gly/-gli
- ending with -i
- ending with -ly
- ending with -kla
- ending with -la
- other ending with -y
- other ending with -a
- other ending

*the sound symbolic category is highlighted with dark grey labels

Appendix D – all chains

Chain 1.1

Item Name	Generation 0		Generation 1		Generation 2		Generation 3		Generation 4		Generation 5		Generation 6		Generation 7		Generation 8		Generation 9		Generation 10
bouba-big-color1-fast		U	sataho	U	kiʃefa	S	tomaha	U	kaʃøla	S	kaʃøla	U	kivepu	U	fatu	U	topto	U	faʃela	U	dotroʃ
bouba-big-color1-none	tazuvɛ	S	hota	U	kiʃe	U	kiʃi	S	taʃøla	U	kavɛpu	U	kiʃepu	S	faʃapu	S	tomatou	U	totroʃ	S	dotroʃ
bouba-big-color1-slow		U	keʃefa	S	kiʃefa	U	tomaha	U	taʃala	U	kiʃipu	S	tomaha	U	toto	S	topto	S	tropo	U	dotroʃ
bouba-big-color2-fast	hutøʃa	S	dikasu	U	tamaha	S	tikøpu	U	kiʃala	U	kavɛpu	S	kivepu	U	tomahu	U	kapo	S	praʃe	U	dipau
bouba-big-color2-none		U	haʃøvu	U	kiha	S	kiha	S	kiʃi	S	kiʃi	S	kiʃepu	S	homapu	S	faʃapo	U	trøpa	S	dipahu
bouba-big-color2-slow	jɛʃɛ	S	tamaha	S	tamaha	U	tomaha	S	tomaha	S	tomaha	S	tomaha	U	kapu	S	kapo	U	tropto	U	dipahu
bouba-small-color1-fast	kitɛbo	S	tikøpo	S	tikøpo	U	tafala	S	tafala	S	tafala	U	faʃyla	S	tomahu	U	dipahu	S	diphau	U	dipahu
bouba-small-color1-none	xebo	S	keta	U	kiʃe	U	tika	S	tiku	U	kipu	U	kipu	U	tomahu	S	faʃapo	S	dibau	S	dotroʃ
bouba-small-color1-slow		U	titøbo	U	tikøpu	S	tikøpu	S	tikepu	S	kiʃipu	U	kaʃela	U	tomahu	U	dipau	S	tribau	U	dipahu
bouba-small-color2-fast		U	tekapo	S	tikapu	U	fasala	S	fazala	U	tafala	U	kivepu	U	tipahu	S	vipaho	U	dipahu	U	dipahu
bouba-small-color2-none		U	keha	S	kiha	U	kipu	S	kipu	S	kipu	S	kipu	U	kiʃapu	S	giʃapu	S	dipra	S	dipahu
bouba-small-color2-slow	dohaxi	S	ʃaha	S	tikapu	S	tikøpu	U	fazala	U	kavɛpu	U	tomaha	S	tomahu	U	vipaho	U	dipahu	S	dipahu
kiki-big-color1-fast	zɛta	S	sataha	U	keseva	S	tøʃøva	U	tiʃøpu	S	kiʃøla	U	kaʃøla	S	faʃøla	U	faʃela	U	treʃela	S	faʃela
kiki-big-color1-none	juzɛha	S	keʃe	S	kiʃe	U	faʃøla	U	kiʃøpu	S	kiʃøpu	U	kiʃepu	U	faʃala	S	braʃala	S	kroʃepo	S	fraʃela
kiki-big-color1-slow		U	sutaʃa	S	tøsøva	S	faʃøla	U	kiʃøpu	U	kaʃøla	S	kaʃøla	S	faʃøla	S	faʃela	U	tropto	S	fraʃela
kiki-big-color2-fast		U	ʃavøha	S	ʃiha	S	ʃøvøha	S	ʃøvøha	U	kiʃøla	S	kivepu	S	kaʃøla	S	kaʃea	S	faʃela	U	fraʃela
kiki-big-color2-none		U	ʃahø	U	kiha	U	taføla	S	kaʃala	U	kiʃøpu	S	kiʃepu	U	kaʃala	U	kaʃara	S	fraʃela	U	fraʃela
kiki-big-color2-slow	vøtuʃɛ	S	tʃahøfa	S	ʃiha	U	ʃøvøla	U	faʃøla	S	faʃøla	U	kaʃela	S	kaʃela	S	kaʃela	U	tropto	U	faʃela
kiki-small-color1-fast	hɛtazø	S	sataʃa	U	tisava	S	faʃøla	U	taʃøla	S	kafala	S	faʃela	S	faʃela	U	baʃela	U	faʃera	S	faʃela
kiki-small-color1-none		U	kesa	U	kiʃe	S	kiʃe	U	taʃala	U	kaʃøpu	U	kipu	U	faʃela	U	baʃela	S	traʃepa	S	fraʃela
kiki-small-color1-slow		U	kesafa	S	kisava	U	faʃøla	S	taføla	U	faʃyla	S	faʃøla	S	faʃela	S	faʃela	S	faʃela	S	faʃepa
kiki-small-color2-fast		U	tahaʃa	S	tisafa	S	tifasa	U	ʃøvøla	U	faʃala	S	kaʃela	S	kaʃela	U	kaʃela	U	faʃra	U	fraʃela
kiki-small-color2-none	ʃahɛ	S	keʃa	U	kiha	U	kiʃe	S	kiʃe	S	kiʃøpu	U	kipu	S	fatu	U	kaʃela	S	fala	U	fraʃela
kiki-small-color2-slow	zahøvu	S	ʃajufa	U	ʃavøha	S	ʃifala	U	kivøpu	S	faʃøla	S	kaʃela	U	kaʃøla	U	kaʃela	U	fraʃela	S	fraʃela

The sound symbolic categories are highlighted with dark grey labels. Whether a specific item had been viewed in the training phases of a certain generation is indicated with S(=SEEN) or U(=UNSEEN) on the left side of the resulting label.

Chain 1.2

Item Name	Generation 0		Generation 1		Generation 2		Generation 3		Generation 4		Generation 5		Generation 6		Generation 7		Generation 8		Generation 9		Generation 10
bouba-big-color1-fast		U	hate	U	tohase	S	tohaze	U	sedadu	S	sasete	S	rasate	U	bohulje	S	poxolje	U	poxeija	U	poxeija
bouba-big-color1-none	tazuvɛ	S	tahevu	U	toha	U	setʃahu	U	doa	U	toua	U	bohuje	U	bohulja	S	poxolje	U	poxela	U	poxulja
bouba-big-color1-slow		U	tahe	S	deo	U	tohaze	U	setʃevu	S	setase	U	bohuje	U	bohilja	U	poxolje	S	poxela	S	poxela
bouba-big-color2-fast	hutøʃa	S	tʃatevu	S	setʃahu	S	tʃahazu	U	doavu	S	ohua	S	bohuja	U	bohilja	S	paeja	U	poxeija	S	poxeija
bouba-big-color2-none		U	hatʃa	S	setʃa	U	seta	U	doa	U	bohua	S	bohulje	S	bohulje	U	poxolje	S	poxulja	S	poxulja
bouba-big-color2-slow	jɛʃɛ	S	sarutʃa	U	deasu	S	setʃase	S	sedase	S	satadu	U	bohuje	U	deteja	S	sasdela	U	poxela	S	poxela
bouba-small-color1-fast	kitɛbo	S	tsuhebo	U	tohase	U	setʃase	U	isuxa	S	dedase	U	asate	U	frasade	S	kasaxse	S	kasaxste	S	kasaxste
bouba-small-color1-none	xebo	S	beho	S	doa	U	itaze	U	saevu	U	tuhua	S	bohuje	U	sesdrelge	S	poxelo	S	poxejo	S	poxeijo
bouba-small-color1-slow		U	batebu	U	doavu	S	toavu	S	josuxa	U	rasate	S	rasate	S	bohilja	U	poxeja	S	poxejo	U	poxeijo
bouba-small-color2-fast		U	tuhetʃa	S	deau	U	ease	S	sedahu	U	saʃese	U	rasate	S	kasaste	S	pasate	S	kasaxste	U	kasaxste
bouba-small-color2-none		U	satetʃa	S	dea	U	toha	S	doa	S	sabexe	S	bohuje	U	sesdeja	S	poxolje	U	poxela	U	poxaijo
bouba-small-color2-slow	dohaxi	S	tuhetʃa	S	ejau	S	tøsuha	S	sedase	U	eleija	U	bohuja	S	kateja	S	poxeija	U	poxejo	S	poxeijo
kiki-big-color1-fast	zɛta	S	dase	U	itase	U	iteza	S	saevu	S	atesa	U	testeija	S	teteja	U	stateija	U	stateija	S	pstetaija
kiki-big-color1-none	juzɛha	S	hase	U	ija	S	ija	U	eja	S	eja	U	tedeija	S	sesdrelge	U	faeja	S	efeija	S	kefaija
kiki-big-color1-slow		U	satebu	U	itesa	S	iteza	U	tohavu	U	sedeʃe	U	testeija	U	basate	S	statulja	S	stateija	U	kefaija
kiki-big-color2-fast		U	satebu	U	itese	S	setahu	S	sedahu	U	satetu	U	setelkja	S	kateija	U	stateja	S	stateija	U	pstetaija
kiki-big-color2-none		U	tatʃa	U	seta	S	seta	S	seda	U	seja	S	stedeija	U	sesdrelge	U	statate	U	efaija	U	kefaija
kiki-big-color2-slow	vøtuʃɛ	S	tʃehavu	S	setʃase	U	tehasu	S	sedahu	S	satade	S	statade	S	sdadeja	S	pasate	U	efaija	S	kefaija
kiki-small-color1-fast	hɛtazø	S	satebu	S	itasu	S	iteza	U	edese	S	sedase	S	setelke	S	basade	U	statate	S	instatate	U	instatate
kiki-small-color1-none		U	sase	U	eja	S	eja	S	eja	U	eja	U	stadeija	U	sdadade	S	state	U	instatate	S	instatate
kiki-small-color1-slow		U	satebu	U	setʃase	S	iteza	U	sedaxu	S	setese	U	NA	U	sesdrelge	U	stateija	U	instatate	U	instatate
kiki-small-color2-fast		U	sahu	S	itase	U	itaze	S	edesa	S	setade	S	tadaije	S	prasade	U	stateija	S	instatate	U	kefulja
kiki-small-color2-none	ʃahɛ	S	santʃe	S	ija	U	eja	U	seda	U	sedeja	S	steteija	S	teteija	U	statate	S	instatate	S	instatate
kiki-small-color2-slow	zahøvu	S	saheva	S	itesu	U	setʃahu	S	edesa	U	tadesa	S	tedelje	S	sesdelge	U	stateija	U	instatate	U	kefulja

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Chain 2

Item Name	Generation 0		Generation 1		Generation 2		Generation 3		Generation 4		Generation 5		Generation 6		Generation 7		Generation 8		Generation 9		Generation 10
bouba-big-color1-fast	ganeʃo	S	ʃamøgy	S	bifula	S	tøʃøky	S	parakla	U	sedula	S	tsentrogly	U	silogly	S	paragly	U	paragli	U	paragly
bouba-big-color1-none		U	baʃøla	U	baføkla	S	situla	S	øntyky	U	sentogly	S	tsentrogly	S	tsentrogly	S	tsentrogly	U	tsyntrogly	U	tsyntragly
bouba-big-color1-slow	bova	S	tuluk	U	baføkla	U	barekla	S	fidula	U	sedula	U	tsentrogly	U	paragly	U	paragly	S	paragli	U	paragly
bouba-big-color2-fast		U	døʃøga	S	baføkla	U	bitula	U	sedula	S	sentrogly	U	sidogly	U	silogly	U	paragly	U	paragli	U	paragly
bouba-big-color2-none	doløgɛ	S	lyfo	U	døʃøga	U	tyʃyky	S	sidoly	S	sedula	U	tsentrogly	U	paragly	U	tsentrogly	S	tsyntrogly	S	tsyntragly
bouba-big-color2-slow		U	baføkla	S	doguʃla	S	teguʃla	S	sentogly	S	sytogly	S	sidogly	U	paragly	S	paragly	U	paragly	S	paragly
bouba-small-color1-fast	zuta	S	tulusa	S	situla	S	fitula	U	parakla	U	sidoly	S	sidogly	U	silogly	U	silogly	U	paragli	S	paragly
bouba-small-color1-none		U	tuga	U	gøgøʃka	U	tøʃøky	U	sedula	U	paragly	S	paragly	S	tsentrogly	S	tsentrogly	S	tsyntrogly	S	tsyntragly
bouba-small-color1-slow	tɛluza	S	pirøga	S	fugula	U	situky	S	sidugly	S	sidoly	U	ilogly	S	paragly	S	silogli	S	paragli	U	paragly
bouba-small-color2-fast		U	fitula	S	fitula	S	fitula	U	fedula	S	sidoly	U	sidogly	S	silugly	S	paragly	S	paragly	S	paragly
bouba-small-color2-none	ʃanɛpø	S	gøʃøla	S	tuluza	U	sytyky	S	situla	S	paragly	U	paragly	S	tsentrogly	U	tsentrogly	U	paragli	U	tsyntragly
bouba-small-color2-slow		U	fugula	S	fogula	S	fogula	U	siduly	U	sidola	S	silogly	S	paragly	U	paragly	U	teragly	U	paragly
kiki-big-color1-fast	nufapy	S	ʃømøga	U	bitula	S	fitula	U	terakla	S	sidokla	S	tsentrokla	U	siluly	S	silogly	U	teragly	S	pali
kiki-big-color1-none	lyʃø	S	tʃepfyla	S	tʃepfyla	S	tøpfyla	S	tepfokla	S	tetrokla	S	tetrokla	U	tsentroly	U	pasi	S	pasi	U	pasi
kiki-big-color1-slow		U	borega	U	tarykla	S	tarykla	S	terakla	U	sytokla	U	tsentrokla	S	paraly	S	paragli	S	pali	S	teragly
kiki-big-color2-fast		U	parygø	U	fitula	U	fitula	S	fitukla	S	sentokla	U	tsentrokla	U	siluly	U	teragly	U	teragly	U	pali
kiki-big-color2-none		U	ʃømøga	U	taryka	U	birogla	S	NA	U	sentokla	U	tetrokla	S	parasi	S	pasi	S	pasi	S	pasi
kiki-big-color2-slow	sakøʃe	S	taryga	S	døʃøky	S	terokla	U	fitukla	U	sentokla	S	tsentrokla	U	paraly	U	teragly	S	pali	S	pali
kiki-small-color1-fast	xufɛna	S	suta	S	situla	U	fitula	U	mikrokla	U	sidokla	U	sidokla	S	siluly	S	siloli	S	siloli	S	siloli
kiki-small-color1-none		U	gatysa	U	tʃepfyla	U	situla	U	tserakla	U	parakla	S	parakla	U	tsentroly	U	siloli	U	pasi	U	pasi
kiki-small-color1-slow		U	sutula	U	pirokla	S	tøʃøky	U	firula	S	sytokla	S	sidoly	S	paraly	U	parali	S	pali	U	pali
kiki-small-color2-fast		U	fity	S	fity	U	bitula	U	fidukla	S	sidokla	S	sidokla	U	siluly	U	siloli	S	siloli	S	siloli
kiki-small-color2-none	lafu	S	teʃela	U	sityla	S	terokla	S	parakla	S	parakla	U	parakla	S	tsentroly	S	siloli	U	pasi	S	pasi
kiki-small-color2-slow	katusø	S	dorega	U	taryka	U	barekla	U	mikrokla	U	sidokla	U	sidola	S	paraly	S	siloli	U	pali	U	pali

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Chain 3

Item Name	Generation 0		Generation 1		Generation 2		Generation 3		Generation 4		Generation 5		Generation 6		Generation 7		Generation 8		Generation 9		Generation 10
bouba-big-color1-fast		U	ʃawi	S	rikawa	S	rikamu	S	mirakwi	U	haʃukwa	U	ekuwa	S	hekaka	S	pekaka	U	pekaka	S	emtʃulia
bouba-big-color1-none	habuwa	S	haʃiwa	U	høʃaly	S	øʃavy	U	eʃaku	S	eʃaku	S	ʃawi	U	ekwasi	U	pekaka	S	pekaka	U	petʃulia
bouba-big-color1-slow		U	røkaʃa	S	piraku	S	øʃakwa	S	eʃakwa	U	haʃuku	S	eʃakwa	S	pekaka	S	pekaka	U	pekaka	U	emtʃulia
bouba-big-color2-fast	wøba	S	haʃiwa	S	haʃiwa	S	øʃaku	S	eʃawi	S	haʃukwa	S	ekaka	S	nekaka	S	enkaka	S	emkaka	S	emkaka
bouba-big-color2-none		U	øʃavy	S	haʃiwu	U	haʃikwa	S	eʃakwa	S	eʃakwa	S	mikwa	S	elasa	S	enkaka	U	edʒulia	U	petʃulia
bouba-big-color2-slow	røʃagu	S	bikøha	S	lirakwa	U	rikaku	S	haʃuwi	U	haʃuku	U	nekaka	S	pekaka	U	enpeka	S	emkaka	S	emkaka
bouba-small-color1-fast		U	raʃiwa	U	ʃavy	S	ʃawi	S	ʃawi	U	ʃawi	U	pekaka	S	ekaka	U	pekaka	S	pekaka	U	emkaka
bouba-small-color1-none	hogaʃa	S	raky	U	ʃavy	U	haʃikwa	U	mirakwa	S	ʃawi	U	ʃawi	S	etʃulia	U	pekaka	U	pekaka	S	petʃulia
bouba-small-color1-slow	baʃo	S	øraku	U	lirakwa	U	haʃiwu	S	ʃawi	S	ʃawi	S	pekaka	U	nekaka	U	pekaka	U	pekaka	U	emtʃulia
bouba-small-color2-fast	rahøwu	S	øʃiwa	U	hatʃikwa	S	ʃɛwi	U	ʃawi	U	haʃuwi	U	ekwia	U	ekaka	S	enteka	S	tekaka	S	emkaka
bouba-small-color2-none		U	rikaʃu	S	rikatʃu	U	rikakwa	S	haʃuwi	S	ʃawi	U	hekaka	U	etʃila	S	endʒulia	S	etʃulia	S	pekaka
bouba-small-color2-slow		U	liwaka	S	haʃiwa	U	øʃavy	S	haʃuwi	U	haʃuwi	S	ʃawi	U	nekaka	U	enkaka	S	emteka	S	emkaka
kiki-big-color1-fast	ruboʒa	S	ʃiwa	U	pirakwa	S	lirakwa	U	haʃukwa	S	haʃukwa	U	eʃakwi	U	ekwasi	U	tekela	S	tekela	U	aijuasim
kiki-big-color1-none	ʒugø	S	ʃiwa	U	rikatʃu	U	haʃikwa	U	mirakwa	U	haʃuwi	U	etʃuja	S	etʃulia	S	edʒulia	S	endʒulia	S	petʃulia
kiki-big-color1-slow		U	birakwa	S	pirakwa	U	pikakwa	U	mirakwi	S	haʃukwi	S	pekaka	U	etʃila	S	tekela	U	tekela	U	aijuase
kiki-big-color2-fast		U	kiraky	U	piraku	U	pikakwa	S	pikaka	S	miraka	U	etʃila	S	entʃila	S	tekela	U	tekela	U	aijuase
kiki-big-color2-none		U	ʃiwaky	S	rikatʃu	S	pikaku	U	mirakwi	U	pirakwa	S	etʃilua	S	elasa	U	edʒulia	S	endʒulia	U	emteka
kiki-big-color2-slow	børahu	S	ʃikavy	U	liraku	S	liraku	U	pikakwa	U	haʃakwa	S	eʃakwa	U	ekwasi	U	eluase	U	tekela	S	aijuase
kiki-small-color1-fast		U	ʃiwa	U	raky	U	haʃikwa	U	miraka	S	miraka	S	ʃawi	U	ekwasi	S	tekela	U	tekela	U	emteka
kiki-small-color1-none	kiwave	S	ʃawy	S	ʃavy	U	haʃikwa	U	mirakwa	U	pikaka	S	eʃakwi	S	entʃila	U	edʒulia	U	eluasim	S	emteka
kiki-small-color1-slow		U	ʃikavy	U	haʃira	S	niraku	S	pirakwa	S	pikaka	U	ʃawi	U	ekwasi	U	tekela	S	tekela	U	emteka
kiki-small-color2-fast	vɛky	S	ʃawy	U	myrawy	S	haʃikwa	U	pikaka	U	pikaka	U	pekaka	U	ekvisa	S	tekela	U	tekela	U	aijasim
kiki-small-color2-none		U	øraku	S	ʃawy	U	pikakwa	U	mirawi	U	haʃuku	U	ʃawi	U	elasi	S	eluase	S	emdʒulia	S	petʃulia
kiki-small-color2-slow	xɛʒɑfi	S	ʃirakwa	S	lirakwa	S	pirakwa	S	pirakwi	S	mirakwi	S	etʃia	S	ekwasi	U	tekela	U	tekela	S	aijuasim

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Chain 4

Item Name	Generation 0		Generation 1		Generation 2		Generation 3		Generation 4		Generation 5		Generation 6		Generation 7		Generation 8		Generation 9		Generation 10
bouba-big-color1-fast	nølyʃa	S	køla	S	kølama	U	karenu	U	tarelnu	S	katehi	S	katehi	S	kateki	U	takeki	U	takehy	U	tsakehy
bouba-big-color1-none		U	haʃoki	U	kølawa	S	døgeny	U	granuan	S	sakøki	U	katehy	U	katehy	U	delegan	U	delegan	S	telegan
bouba-big-color1-slow		U	kølawoa	S	kølava	S	karelnu	U	talenu	S	talakø	S	katehy	S	katehy	U	takeky	S	katehy	S	telegan
bouba-big-color2-fast		U	dønuroa	S	karenu	S	savakø	S	sakøde	U	deleguan	U	katehy	U	katehy	S	sakeki	U	katehy	U	patehy
bouba-big-color2-none	ʃuky	S	ʃoki	U	karenu	U	sakødø	S	sakøde	S	taki	U	katehy	S	katehy	S	delegan	S	delegan	U	patehy
bouba-big-color2-slow	rybapu	S	karenu	S	karenu	U	karelny	S	savaki	S	deleguan	U	sakeki	U	kakehy	S	takehy	S	tsakeky	S	tekety
bouba-small-color1-fast	makø	S	køla	U	kølama	U	karelnu	S	tarany	U	taleke	U	sakeke	U	sakeki	S	sateki	U	takehy	S	tekety
bouba-small-color1-none	tymøla	S	seki	U	kamu	U	gwady	S	geleguan	U	deleguan	S	delegan	S	delegan	S	delegan	S	delegan	U	tekety
bouba-small-color1-slow		U	kamugu	U	kølamua	S	karelnu	U	tarelnu	S	tahaki	U	sakeki	S	delagan	U	katehy	U	takehy	U	telegan
bouba-small-color2-fast		U	kamu	S	dølamua	S	degeny	S	karelny	S	sakekø	S	sakeke	U	kateki	S	takeki	U	katehy	U	patehy
bouba-small-color2-none		U	kanu	U	kølamu	S	delaguan	S	deleguan	S	deleguan	U	sakeki	U	delegan	S	delegan	U	delegan	S	telegan
bouba-small-color2-slow	pøʃanu	S	kaʃemu	S	kamu	U	savaki	S	karelny	U	sakeki	S	sakeke	U	delagan	S	katehy	U	takehy	S	telegan
kiki-big-color1-fast	tiʃøgo	S	tiʃego	S	hakø	S	dølavan	S	dølaman	S	tavaki	S	delaman	S	takehy	U	takeki	S	takeki	S	takeki
kiki-big-color1-none		U	jøʃaki	U	hakø	U	køvala	S	sakødø	U	døleaman	U	sakeky	S	sakeky	U	sakeky	S	katehy	S	patehy
kiki-big-color1-slow	jɛxi	S	tiʃego	U	haʃeke	S	karenu	U	sakødø	U	sakøke	S	delaman	U	sakeky	U	satehy	S	sakeky	U	takehy
kiki-big-color2-fast		U	loamu	S	delakø	S	saki	S	saki	U	talaki	U	NA	U	sakeky	U	sateki	S	takeki	S	sakeki
kiki-big-color2-none	hopyvɛ	S	saki	S	saki	U	saki	U	svakedø	S	sakeky	S	sakeky	U	sakeky	S	sakeki	U	sakeky	U	takehy
kiki-big-color2-slow		U	jøʃaki	U	saki	S	saki	U	saki	S	saki	S	delaman	U	takehy	S	sakehy	S	sakeky	S	sakeki
kiki-small-color1-fast		U	køla	U	hakø	U	karelnu	U	dølaman	U	talahi	U	sakeke	S	takeki	S	sakeki	U	sakeki	U	takeki
kiki-small-color1-none	buʃarø	S	kiʃerø	U	hakø	U	kiʃ	S	kiʃ	U	talaky	S	delaman	U	takeki	U	katehy	S	katehy	U	takeki
kiki-small-color1-slow		U	hakø	S	hakø	U	køsava	U	dølaman	U	dølaman	S	sakeke	S	delagan	U	katehy	U	sakehy	U	takeki
kiki-small-color2-fast	bølu	S	segomu	S	denuran	S	saki	U	sake	S	sakeki	U	takeky	S	takeki	U	sakeki	S	sakeki	S	takeki
kiki-small-color2-none		U	kiʃerø	S	kiʃelø	S	saki	U	saki	U	talaki	S	telekan	S	takeky	S	satehy	S	sakehy	U	takeki
kiki-small-color2-slow	kaʃymu	S	kalømu	U	deluran	U	saki	U	sake	U	sakekø	U	delaman	S	delagan	U	takehy	U	sakehy	S	takeki

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