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Contents

Zusammenfassung

Nach einem Infarkt in der linken Hirnhälfte erleiden die Betroffenen häufig einen tiefgreifenden Verlust der Spontansprache — eine sogenannte nicht-flüssige Aphasie. Doch oft können sie noch ganze Texte fehlerfrei *singen*. Aus dieser erstaunlichen Beobachtung haben sich insbesondere *zwei* wissenschaftliche Fragen herausgebildet. Liegt das methodische Augenmerk auf einem Messzeitpunkt (*Querschnitt*), stellt sich die Frage, inwiefern Gesang die Sprachproduktion für Patienten mit nicht-flüssigen Aphasien erleichtert. Werden mehrere Messzeitpunkte verglichen (*Längsschnitt*), liegt die Frage nahe, ob sich Gesang auch zur Therapie nicht-flüssiger Aphasien eignet. Die vorliegende Arbeit widmet sich diesen beiden Fragen mit zwei Experimenten.

Ein experimenteller *Querschnitt* untersuchte den jeweiligen Einfluss von Melodie, Rhythmus und Liedtextart auf die Sprachproduktion an siebzehn Patienten mit nicht-flüssigen Aphasien. Kontrolliert wurden der stimmliche Grundfrequenzverlauf, die Tonhöhengenauigkeit beim Singen sowie eine Reihe weiterer Einflüsse, wie Rhythmizität, Silbendauer, phonetischer Schwierigkeitsgrad, Lerneffekte und das akustische Umfeld. Entgegen früheren Berichten erwies sich das Singen im Experiment als *nicht* über den Rhythmus hinaus entscheidend für die Sprachproduktion der untersuchten Patienten. Anderslautende Befunde in der Vergangenheit sind womöglich die Folge akustischer Gegebenheiten, einer erhöhten Silbendauer im Singen oder sprachmetrischer Eigenschaften. Die vorliegenden Ergebnisse lassen

vielmehr *rhythmischen Taktgebern* eine wesentliche Bedeutung zukommen, insbesondere für Patienten mit Läsionen einschließlich der Basalganglien. Das Schädigungsausmaß der Basalganglien erklärte zu über fünfzig Prozent rhythmusbedingte Varianz in den Daten. So könnten Befunde, die in früheren Arbeiten dem Singen zugeschrieben wurden, tatsächlich auf Rhythmus beruhen. Die Ergebnisse unterstreichen darüberhinaus den hohen Stellenwert der Liedtextart. Die *Vertrautheit* und *Formelhaftigkeit* der Texte hatte weitreichende Auswirkungen auf die Sprachproduktion der untersuchten Patienten — unabhängig davon, ob diese sangen oder rhythmisch sprachen. So mag für Patienten mit nicht-flüssigen Aphasien nicht das Singen selbst maßgebend sein, sondern das Erinnern vertrauter Liedtexte („Hänschen klein ging allein...“) und der Abruf überlernter, formelhafter Ausdrücke („Guten Tag, alles klar?“).

Ein experimenteller *Längsschnitt* untersuchte, wie Gesang und rhythmisches Sprechen die Produktion formelhafter und nicht-formelhafter Sprache über einen therapeutischen Zeitraum hinweg beeinflussten. Fünfzehn Patienten mit chronischen nicht-flüssigen Aphasien erhielten entweder Singtherapie, Rhythmustherapie oder herkömmliche Sprachtherapie. Kontrolliert wurden der stimmliche Grundfrequenzverlauf, die Tonhöhengenauigkeit beim Singen, phonatorische Merkmale des Stimmklangs sowie die Silbendauer, der phonetische Schwierigkeitsgrad, das akustische Umfeld und durch Messungen hervorgerufene Lerneffekte. Singen und rhythmisches Sprechen erwiesen sich im Experiment als *ähnlich wirksam* in der Behandlung nicht-flüssiger Aphasien. Sowohl mit Sing- als auch mit Rhythmustherapie erzielten die Patienten beachtliche Fortschritte in der Produktion *formelhafter Ausdrücke*, die nach derzeitigem Wissen von Teilen der rechten Hirnhälfte unterstützt werden. Die Fortschritte zeichneten sich in beiden Therapien zu einem frühen Zeitpunkt ab und waren auch über die Behandlung hinaus messbar. Berichten von Angehörigen zufolge waren die Patienten zudem imstande, eine begrenzte Zahl formelhafter Ausdrücke situationsgerecht im Alltag einzubringen. Die Fähigkeit der Patienten, sich singend oder rhythmisch sprechend zu artikulieren, war zu keinem Zeitpunkt abhängig von der jeweiligen Therapieform. Patienten mit Sprachtherapie zeigten insgesamt weniger Fortschritte in der Produktion formelhafter Ausdrücke. Sie allein verbesserten sich jedoch bei der Produktion ungeübter, *nicht-formelhafter Äußerungen* — im Gegensatz zu Patienten mit Sing- und Rhythmustherapie. Aus den vorliegenden Ergebnissen lässt sich daher die vorsichtige Empfehlung ableiten, das Üben formelhafter Ausdrücke stärker als bisher in die gängige Sprachtherapie einzubinden. Nachrangig ist dabei, ob formelhafte Ausdrücke gesungen oder rhythmisch gesprochen werden. Eine um formelhafte Ausdrücke erweiterte Sprachtherapie könnte jeder der obigen Therapieformen in ihrer ausschließlichen Anwendung überlegen sein. Die Varianz der Daten im Hinblick auf zeitliche Veränderungen ließ sich zu über neunzig Prozent durch Therapieform und Formelhaftigkeit der Texte erklären.

Die vorliegende Arbeit liefert *drei* Hauptergebnisse. *Erstens*, nicht das Singen selbst scheint für die Sprachproduktion und die Therapie nicht-flüssiger Aphasien entscheidend zu sein, sondern Rhythmus und Liedtextart. *Zweitens*, die Befunde widersprechen der Annahme, Gesang rege rechte frontotemporale Hirnareale dazu an, Aufgaben geschädigter linker Sprachnetzwerke zu übernehmen. Vielmehr rücken die Daten den Einfluss rhythmischer Taktgeber in den Mittelpunkt, die womöglich Störungen im Austausch zwischen Basalganglien und Großhirnrinde teilweise überbrücken können. *Drittens*, die Ergebnisse bekräftigen die Auffassung, derzufolge die Produktion formelhafter und nicht-formelhafter Sprache auf unterschiedlichen neuronalen Verarbeitungswegen beruht. Sprachtherapie mit Schwerpunkt auf nicht-formelhafter, propositionaler Sprache könnte demnach insbesondere linke periläsionale Hirnregionen beanspruchen, während die Therapie formelhafter Sprache auf Ressourcen der unversehrten rechten Hirnhälfte zurückgreift — auch ohne Gesang.

Abstract

Left-hemisphere stroke patients often suffer a profound loss of spontaneous speech — known as non-fluent aphasia. Yet, many patients are still able to *sing* entire pieces of text fluently. This striking finding has inspired mainly *two* research questions. If the experimental design focuses on one point in time (*cross section*), one may ask whether or not singing facilitates speech production in aphasic patients. If the design focuses on changes over several points in time (*longitudinal section*), one may ask whether or not singing qualifies as a therapy to aid recovery from aphasia. The present work addresses both of these questions based on two separate experiments.

A *cross-sectional* experiment investigated the relative effects of melody, rhythm, and lyric type on speech production in seventeen patients with non-fluent aphasia. The experiment controlled for vocal frequency variability, pitch accuracy, rhythmicity, syllable duration, phonetic complexity and other influences, such as learning effects and the acoustic setting. Contrary to earlier reports, the cross-sectional results suggest that singing may *not* benefit speech production in non-fluent aphasic patients over and above rhythmic speech. Previous divergent findings could be due to affects from the acoustic setting, insufficient control for syllable duration, and language-specific stress patterns. However, the data reported here indicate that *rhythmic pacing* may be crucial, particularly for patients with lesions including the basal ganglia. Overall, basal ganglia lesions accounted for more than fifty percent of the variance related to rhythmicity. The findings suggest that benefits typically attributed to singing in the past may actually have their roots in rhythm. Moreover, the results demonstrate that lyric type may have a profound impact on speech production in non-fluent aphasic patients. Among the studied patients, *lyric familiarity* and *formulaic language* appeared to strongly mediate speech production, regardless of whether patients were singing or speaking rhythmically. Lyric familiarity and formulaic language may therefore help to explain effects that have, up until now, been presumed to result from singing.

A *longitudinal* experiment investigated the relative long-term effects of melody and rhythm on the recovery of formulaic and non-formulaic speech. Fifteen patients with chronic non-fluent aphasia underwent either singing therapy, rhythmic therapy, or standard speech therapy. The experiment controlled for vocal frequency variability, phonatory quality, pitch accuracy, syllable duration, phonetic complexity and other influences, such as the acoustic setting and learning effects induced by the testing itself. The longitudinal results suggest that singing and rhythmic speech may be *similarly effective* in the treatment of non-fluent aphasia. Both singing and rhythmic therapy patients made good progress in the production of common, *formulaic phrases* — known to be supported by right corticostriatal brain areas. This progress occurred at an early stage of both therapies and was stable over time. Moreover, relatives of the patients reported that they were using a fixed number of formulaic phrases successfully in communicative contexts. Independent of whether patients had received singing or rhythmic therapy, they were able to easily switch between singing and rhythmic speech at any time. Conversely, patients receiving standard speech therapy made less progress in the production of formulaic phrases. They did, however, improve their production of unrehearsed, *non-formulaic utterances*, in contrast to singing and rhythmic therapy patients, who did not. In light of these results, it may be worth considering the combined use of standard speech therapy and the training of formulaic phrases, whether sung or rhythmically spoken. This combination may yield better results for speech recovery than either therapy alone. Overall, treatment and lyric type accounted for about ninety percent of the variance related to speech recovery in the data reported here.

The present work delivers *three* main results. *First*, it may not be singing itself that aids speech production and speech recovery in non-fluent aphasic patients, but rhythm and lyric type. *Second*, the findings may challenge the view that singing causes a transfer of language function from the left to the right hemisphere. Moving beyond this left-right hemisphere dichotomy, the current results are consistent with the idea that rhythmic pacing may partly bypass corticostriatal damage. *Third*, the data support the claim that non-formulaic utterances and formulaic phrases rely on different neural mechanisms, suggesting a two-path model of speech recovery. Standard speech therapy focusing on non-formulaic, propositional utterances may engage, in particular, left perilesional brain regions, while training of formulaic phrases may open new ways of tapping into right-hemisphere language resources — even without singing.

Preface

It may be one of the mysteries in clinical practice that many stroke patients with severe speech production disorders are nonetheless able to *sing* — with some patients even being able to sing entire pieces of text fluently. This finding has inspired a number of singing therapies worldwide and a growing scientific debate that focuses mainly on *two* questions. *First*, what exactly enables patients to produce text when they sing? *Second*, does singing qualify as a speech therapy? The present work aims to contribute to this debate.

The *first* part of this thesis introduces various speech production disorders in left-hemisphere stroke patients, based on a neurocognitive model of word and phrase production (Chapter 1. Non-fluent aphasia: an introduction). Moreover, the first part highlights a number of skills that are typically preserved in left-hemisphere stroke patients (Chapter 2. Preserved skills in patients with non-fluent aphasia). The first part concludes with several research questions that are then translated into testable hypotheses (Chapter 3. Open questions).

The following parts familiarize the reader with the experimental work carried out. Part *two* details the methods of a cross-sectional experiment (Chapter 4. Methods). The cross-sectional results relate to the question of what exactly enables patients to produce text when they sing (Chapter 5. Results). Part *three* then describes the methods of a longitudinal experiment (Chapter 6. Methods). The longitudinal results address the question of whether singing qualifies as a speech therapy (Chapter 7. Results).

The *fourth* part of this thesis provides a summary of both experiments, followed by a critical discussion of the results (Chapter 8. Cross-sectional experiment; Chapter 9. Longitudinal experiment). Finally, the fourth part broadens the scope in order to integrate the current results within a more comprehensive analytical framework (Chapter 10. Concluding remarks and future perspectives).

Part I

Theoretical and empirical background

Chapter 1

Non-fluent aphasia: an introduction

Left-hemisphere stroke patients often suffer a profound loss of spontaneous speech — known as non-fluent aphasia. Such a loss usually results in a sudden disruption of the patients' social and professional life, leading to isolation, despair, and sometimes severe depression. Many patients never recover completely, despite intensive therapy. Looking closer at the term 'non-fluent aphasia', one may think of a homogeneous group of patients, who share more or less the same inability in the spontaneous expression of speech. In theory and clinical practice, however, the heading of 'non-fluent aphasia' actually covers *a number of* disorders that vary in type and aetiology. Moreover, most left-hemisphere stroke patients suffer from *several* speech production disorders at the same time. Consequently, different concurrent disorders are sometimes difficult to distinguish, even for experienced aphasiologists.

The following sections introduce the most common speech production disorders based on a neurocognitive model of word production.

1.1 A neurocognitive model of word production

The perception and production of language, both spoken and written, are closely intertwined in everyday life. In linguistic theory, this view is reflected in a range of models, the logogen model being a distinct example (Morton, 1969; Forster, 1976; Patterson, 1988). For the purpose of the current work, the introduction focuses on *spoken word production*. An influential model of word production has been proposed by Levelt and colleagues (1999). Although not originally conceived to account for clinical disorders, the model has proven to be useful in describing critical, error-prone stages of word production (Ziegler, 2009, 2010). The model proceeds in six stages that will be presented in an extended form to address some communicative-pragmatic aspects of speech production. An outline of the model is shown in Figure 1.

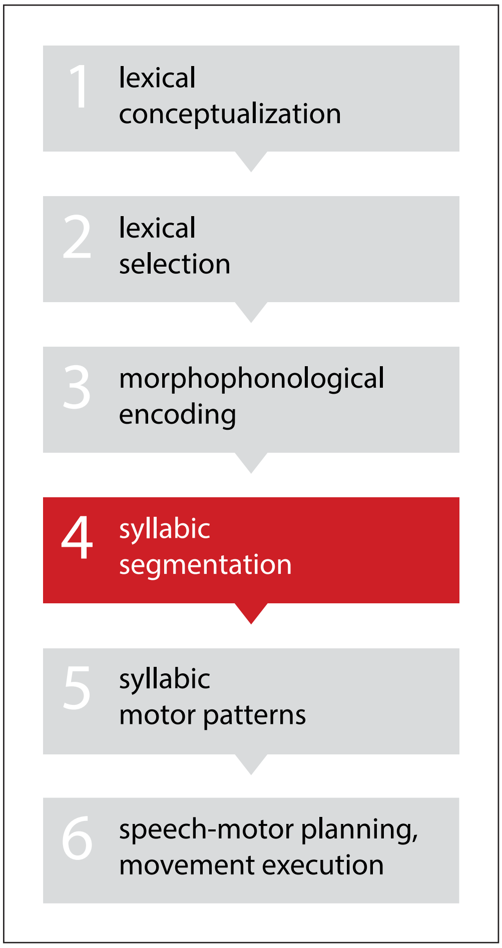

Figure 1: A neurocognitive model of word production (Levelt et al., 1999). Speech production proceeds in six stages. Rhythmic features — marked in red throughout the entire work — may play a critical role in word production, as metrical stress was suggested to facilitate syllabic segmentation (Cutler & Norris, 1988).

At level *one* of Levelt's model, notions about things are mapped to lexical concepts — mainly to verify whether or not a corresponding lexical concept is available. For example, one may want to convey the desire for water to another person. In order to do so, the notion 'desire for water' needs to match an available *lexical concept*. In case of 'desire for water', the speaker may find that an appropriate lexical concept exists: 'thirst'. This would not equally apply to the notion of being *satisfied* with water. Although the related concepts 'hydrated' and 'quenched' may help out, no simple one-word expression would precisely capture this notion in English. In other words, notions about things are not necessarily linked to available lexical concepts in a given language. Moreover, lexical concepts are often embedded in a *communicative context*, as in the current example, with two people interacting. A typical communicative phrase verbalizing desire for water could start with 'I'm...', followed by a critical word to be specified at the subsequent stages.

At level *two*, a meaningful word in accordance with the lexical concept is chosen from a set of words. This may be the word 'thirst' in the present example, as successfully chosen from the competitive words 'drink' and 'water'. At this stage, the word is represented as a *semantic* and a *syntactic* entity, sometimes referred to as 'lemma'. Word lemmas contain a number of semantic and syntactic features. English verb lemmas, for instance, include information about number, person and tense.

Level *three* of Levelt's model describes the morphophonological encoding of the chosen word. The speaker retrieves the phonological shape and the prosodic pattern of the word — [θɜːst] —, while adding morphemes to make the word form fit. In the current example, the phrase 'I'm...' requires an adjective, thus the word 'thirst' needs to be extended by the morpheme 'y' — resulting in [θɜːsti]. At this stage, the word is represented as *phonological* entity, sometimes referred to as 'lexeme'. The inability to access the lemma, but not the lexeme of a word, is a commonly known as tip-of-the-tongue phenomenon (Levelt, 1989). In this case, the speaker is able to retrieve semantic and syntactic features of a word, but not its phonological form.

At level *four*, the chosen word is segmented into syllables. The word 'thirsty', for instance, consists of two spoken syllables, [θɜː] and [sti]. Levelt and colleagues argue that syllable boundaries in English strongly depend on the entire phrase, in which the word is embedded. Therefore, syllable boundaries need to be computed *anew* each time a speaker produces a word (Levelt et al., 1999; Cholin, Dell, & Levelt, 2011). As far as stress-timed languages such as English and German are concerned, one further task at level four is to define the *metrical stress pattern*. The syllables [θɜː] and [sti] require a trochaic stress pattern, meaning that the first syllable is emphasized, while the second syllable is not — hence ['θɜː.sti]. Some evidence indicates that metrical stress within a word concurs with increased vocal loudness and increased vowel duration (Kochanski, Grabe, Coleman, & Rosner, 2005; Kochanski & Orphanidou, 2008). Moreover, metrical stress was suggested to facilitate syllabic segmentation (Cutler & Norris, 1988). At this point, it may become evident that syllables and rhythmic features play a crucial role in word production.

At level *five*, the articulatory task is specified. It is assumed that speakers rely on overlearned *motor patterns*, especially for frequent syllables (Levelt et al., 1999; Aichert & Ziegler, 2004a; Ziegler, 2009, 2010). The speaker needs to retrieve these motor patterns to form a sequence of syllables in a given word. In case of the bisyllabic word 'thirsty', motor patterns of the syllables [θɜː] and [sti] are matched to the sequence [ˈθɜː.sti]. Note that levels four and five in this outline of Levelt's model are *not* necessarily subsequent steps. Rather, syllabic segmentation and motor mapping have to be viewed as one processing unit.

At level *six*, articulatory movements are *planned* by the cognitive speech-motor system. Finally, the planned movements are *executed* by the muscular system, including lungs, larynx and vocal tract. That is, level six proceeds in two stages: speech-motor planning and execution of articulatory movements. In the current example, the speaker plans and executes the movements necessary to produce the word 'thirsty' — embedded in the phrase 'I'm thirsty'.

1.2 Errors in word and phrase production

The phrase 'I'm thirsty' was introduced as consisting of two separate units: a *fixed string* ('I'm...'), followed by a *slot* to be filled with the critical word ('thirsty'). From a pragmatic-communicative point of view, this procedure may apply to a large number of propositional utterances produced in everyday life (Bannard, Lieven, & Tomasello, 2009). The phrase 'I'm thirsty', however, is highly overlearned and may be more properly considered as a *single string on its own*. In other words, things may be different in case of common, formulaic expressions. Overlearned phrases have been proposed to constitute *fixed, cohesive units* — in contrast to newly created, propositional expressions (Van Lancker Sidtis, 2004). One may argue that one-word utterances and overlearned phrases — such as ‘I’m thirsty’ — share a couple of features in how they pass through the different stages of speech production. For introductory purposes, Levelt’s model will therefore be extended to account for both words *and* formulaic phrases (see also 2.5 Formulaic phrase production).

Taking a closer look at the different stages of Levelt’s model, it seems clear that numerous errors may occur at *each* level of word and phrase production. Furthermore, errors tend to occur at *several* levels at the same time. This illustrates how difficult it can be to relate an individual pattern of concomitant errors to a universal, clinically meaningful label. Nonetheless, Levelt’s model allows for broadly defining two major groups of disorders: errors occurring at *higher* levels and at *lower* levels of word and phrase production. High-level disorders refer to the levels one, two and three of Levelt’s model (lexical conceptualization; lexical selection; and morphophonological encoding). Low-level disorders refer to the levels four, five and six (syllabic segmentation; retrieval and composition of syllabic motor patterns; speech-motor planning and execution of articulatory movements).

High-level disorders are often denoted as *language disorders* (*Sprachstörungen*), as they depend on higher cognitive functions in language processing. Typical examples of high-level disorders in speech production involve global aphasia and Broca’s aphasia. Low-level disorders are often denoted as *speech disorders* (*Sprechstörungen*), as they occur at the lower levels of speech production. Typical examples of low-level disorders in speech production include apraxia of speech and dysarthria. The following sections aim to further specify these two major groups of disorders.

1.3 High-level disorders of word and phrase production

Patients with high-level disorders — commonly following an extended left-hemisphere stroke — often fail to map notions to lexical concepts (level *one* of Levelt's model). That is, patients have an idea of what they want to convey, but they are unable to verify whether or not their lexical inventory provides the matching concept. As a consequence, patients show word-finding difficulties, using pointing, gestures, and prosody to transmit their thoughts. Meanwhile, some patients produce automatized, recurring utterances — words, pseudowords or syllables that are usually unrelated to what the patients have in mind. The origin of these utterances is widely unknown, with some authors suggesting that inhibitory deficits due to subcortical lesions may be the cause (Wallesch & Blanken, 2000). Although recurring utterances may derive from a later point in word production, they are introduced at this stage as they typically occur in severely affected patients (Poeck, De Bleser, Keyserlingk, & Graf, 1984; Takizawa et al., 2010). Coming back to the above example, patients may point to a bottle of water to express thirst, while they repetitively produce the syllable [tã]. It is noteworthy that patients with high-level disorders tend to be *unaware* of how challenging it is to guess their thoughts.

Accessing the lexical inventory, patients may show extreme difficulties in choosing a word from a set of competitive words (level *two* of Levelt's model). As a result, patients often produce the wrong word. This could be: a semantically related word ('water' instead of 'thirst'; *semantic* paraphasia); a phonemically related word ('third' instead of 'thirst'; *phonemic* paraphasia); various combinations of both ('dribble' instead of 'thirst'; phonemic paraphasia of the semantically related 'drink'); or a semantically *and* phonetically unrelated word (*remote* or *neologistic* paraphasia).

A number of errors occur if patients are not able to correctly retrieve the phonological shape and the prosodic pattern of a word (level *three* of Levelt's model). For instance, the phonological shape and the prosodic pattern of a word may be severely distorted. Moreover, adding morphemes may pose insurmountable problems. Patients may typically produce [θɜːst] instead of ['θɜːsti], omitting the morpheme 'y'.

Moving beyond the production of words and phrases, the inability to adjust for syntactic rules in sentences may likewise result in grammatical errors, denoted as *agrammatism*. The underlying mechanisms of agrammatic errors are barely understood, mainly because agrammatic symptoms vary considerably within and between patients (Springer, 2006). An influential model suggests intact lexical access, but impaired use of function words in agrammatic patients (Garrett, 1984). This idea is in accordance with the finding that agrammatic patients tend to omit function words, such as prepositions (Friederici, 1982; Grodzinsky, 1984). Utterances in agrammatic patients have therefore been described as resembling telegraphic messages.

As a remnant of history, some of the high-level symptoms outlined in this section are often grouped together as typological syndromes, known as *global aphasia* and *Broca's aphasia*. It should be noted that further syndromes such as Wernicke's aphasia are omitted in this introduction, as they are not tested or reflected in the current work.

1.3.1 Global aphasia

Patients with non-fluent, global aphasia show profound deficits in both speech production *and* comprehension, whether spoken or written. Speech production in global aphasia typically includes: automatized, recurring utterances without any communicative context; a small number of formulaic phrases according to communicative contexts; and remote or neologistic paraphasias (e.g., Huber, Poeck, & Willmes, 1984; Ellis & Young, 1996). Mapping global aphasia to Levelt's model, patients are mainly affected at the *first* level of word and phrase production. Yet, speech production in persons with global aphasia can be so heavily distorted that it is impossible to trace the origin of the different underlying symptoms.

Global aphasia usually follows an extended left-hemisphere stroke (Kang et al., 2010). In many cases, global aphasia gradually evolves into Broca's aphasia or other aphasic syndromes after several months (Mohr et al., 1978; Pedersen, Vinter, & Olsen, 2004). This explains why, historically, global aphasia was considered an aggravated form of Broca's aphasia (Marie, 1906).

1.3.2 Broca's aphasia

The French surgeon and anthropologist Paul Broca (1824–1880) described symptoms in two patients with left-sided frontal lesions, including Broca's area (Brodmann areas 44 and 45; see Broca, 1861a, 1861b, 1861c). Notably, these lesions involved a number of additional subcortical areas in both cases (Dronkers, Plaisant, Iba-Zizen, & Cabanis, 2007). The main symptoms observed were: arduous speech production and widely preserved comprehension. Further symptoms were: phonemic paraphasias; impaired morphology; agrammatism; and limited prosody (e.g., Huber et al., 1984; Ellis & Young, 1996). Mapping Broca's aphasia to Levelt's model, patients are mainly affected at the *second* and *third* level of word and phrase production.

Global and Broca's aphasia mainly differ in how severely the patients' *comprehension* is constrained: persons with Broca's aphasia show better comprehension skills than persons with global aphasia. Paul Broca documented a range of symptoms, which later became famous as the syndrome 'Broca's aphasia'. In today's clinical practice, Broca's aphasia covers a nonexhaustive list of possible, but not necessarily concurrent deficits. Given the disorders originally described by Broca, it may well be the case that patients with Broca's aphasia display further symptoms, such as semantic paraphasias or remote paraphasias. Moreover, patients with Broca's aphasia are often able to produce a small number of formulaic phrases in communicative contexts. Conversely, Broca reported on automatized, recurring utterances in one of his historical patients (the syllable [tã]). Today, recurring utterances are more typically ascribed to patients with global aphasia.

The use of typological syndromes — such as global or Broca's aphasia — has been controversially discussed among practitioners and scientists. On the one hand, the syndromes are useful for clinicians to communicate within and especially between the different disciplines. On the other hand, patients who are diagnosed with one typological syndrome may nonetheless vary *considerably* in terms of individual symptoms. Hence, even if typological syndromes may be clinically useful, individual, symptom-based diagnostics remains indispensable (for a detailed critique of the syndrome-based approach, see De Bleser, Cholewa, & Tabatabaie, 1997; De Bleser, Cholewa, Stadie, & Tabatabaie, 2004).

1.4 Low-level disorders of word and phrase production

High-level disorders in word and phrase production often occur in combination with low-level disorders. In fact, only a small number of patients with high-level disorders do *not* suffer from concomitant low-level disorders. However, patients tend to be more *aware* of low-level errors. This is one of the reasons why low-level errors play a critical role in speech therapy.

Patients with low-level disorders typically show difficulties in segmenting words and phrases into syllables (level *four* of Levelt's model). For instance, many patients tend to underestimate the actual number of syllables within an utterance. Accordingly, syllabic counting has been proposed as a therapy to address this problem (Simmons, 1978). Another problem at this stage is that some patients are unable to produce metrical stress (Aichert & Ziegler, 2004b). In case of the phrase 'I'm thirsty', patients may put stress on the first rather than on the second syllable: [ˈaɪm.θɜː.sti]. Such rhythm-related deficits may be viewed as a specific form of amusia, a diagnosis referring to a number of musical inabilities (Peretz, Champod, & Hyde, 2003). Unsurprisingly, aphasia and amusia were found to frequently co-occur (Brust, 2001). Nonetheless, little is known so far about rhythm-related speech production deficits in aphasic patients (see 2.2 Rhythmic speech).

Retrieving syllabic motor patterns, patients may be unable to form correct sequences of syllabic motor patterns within a given word or phrase (level *five* of Levelt's model). As a consequence, motor patterns often appear in the wrong order. Given the motor patterns [aɪm], [θɜː] and [sti], the third motor pattern may appear too early in the sequence: [aɪm.ˈsti.sti]. Yet, many patients are able to *correct* these errors online. In such a case, patients recombine the sequence of motor patterns as soon as they become aware of the misplaced syllable [sti]. This self-correction can be very fast. For example, the final utterance may be [aɪm.'stɜː.sti], with only the onset of the second syllable relating to the wrong motor pattern ([st]), while the vowel is correct ([ɜː]). In other words, patients are able to *monitor* their utterances at this and at later stages of word and phrase production. Monitoring often slows down articulatory tempo considerably, resulting in frequent pauses, extended vowels, continuous self-corrections and visible groping (Brendel & Ziegler, 2008; Ziegler, 2009, 2010).

Finally, many patients fail to plan and to execute speech-motor movements (level *six* of Levelt's model). Consonants are particularly difficult, especially if they appear at the onset of a syllable. For instance, patients may produce [aɪm.'ɜː.sti], omitting the initial sound [θ] of the second syllable. *Two* error types are commonly distinguished at this stage: errors occurring during *speech-motor planning*; and errors occurring during *execution of articulatory movements*. Patients with impaired speech-motor planning often show *inconsistent*, unpredictable patterns of articulatory errors (sometimes ['θɜː.sti], sometimes ['ɜː.sti]). In contrast, patients with impaired execution of articulatory movements show *consistent*, predictable patterns of articulatory errors (always ['ɜː.sti]; for experimental evidence, see Ziegler & Hoole, 1989). Errors occurring during speech-motor planning and at earlier stages of Levelt's model — including the levels three, four and five — are usually referred to as *phonemic* errors. Conversely, errors occurring during execution of articulatory movements are classified as *phonetic* errors. Phonetic errors are sometimes misconstrued as phonemic errors, as we tend to perceive lower executive errors as deriving from higher planning units.

The low-level symptoms presented above are commonly grouped together under the labels of *apraxia of speech* and *dysarthria*. Further syndromes such as dysphagia are omitted in this introduction, as they are not decisive in the current work.

1.4.1 Apraxia of speech

Apraxia of speech is a frequent concomitant disorder in aphasic patients and mainly refers to *impaired speech-motor planning*. That is, patients with apraxia of speech show difficulties in *planning* articulatory movements. Moreover, apractic patients are often unable to segment words into syllables and to retrieve and compose syllabic motor patterns. The symptoms include: arduous speech, with pauses and extended vowels; numerous self-corrections; visible groping; phonemic and phonetic errors (e.g., Ziegler, 2009). Apractic patients typically produce *inconsistent* error patterns. Furthermore, articulatory quality in apractic patients is strongly determined by word length, syllable complexity, and syllable frequency (Aichert & Ziegler, 2004a; Ziegler, 2010). Mapping apraxia of speech to Levelt's model, patients are mainly affected at the levels *four*, *five*, and at the planning stage of level *six*.

1.4.2 Dysarthria

Whereas apraxia of speech refers to deficits in speech-motor planning, dysarthria occurs at the *executive* level, involving the *muscular system*. That is, patients show difficulties in *executing* articulatory movements, resulting in phonetic errors (e.g., Dykstra, Hakel, & Adams, 2007). Dysarthric patients typically produce *consistent* error patterns. Hence, error consistency is an important criterion to distinguish between apraxia of speech and dysarthria in clinical practice. Mapping dysarthria to Levelt's model, patients are affected at the executive stage of level *six*.

1.5 Lesion-symptom mapping of speech production disorders

This section briefly outlines as to whether speech production disorders may be related to specific lesion sites in the brain.

So far, individual lesion locations in stroke patients have failed to predict subsequent aphasic *syndromes* even in larger samples (for syndrome type, see De Bleser et al., 1997; for syndrome recovery, see Lazar, Speizer, Festa, Krakauer, & Marshall, 2008). This finding may not be surprising given the variability of different *symptoms* at numerous stages of word and phrase production, as illustrated above. Moreover, indirect evidence from language *perception* in aphasic patients suggests that speech production may not engage specific brain areas, but extended networks (Wilson & Saygın, 2004; Tyler et al., 2011; for language network modelling, see Pulvermüller & Preißl, 1994). Indeed, some work points to an elaborated network of cortical, subcortical and cerebellar brain areas during *production* of phonemes, syllables and words (Peeva et al., 2010). The role of individual brain areas in this network depends on various factors, such as the experimental task and the type of semantic information to be retrieved (Price, 2010). Hence, lesion-based approaches relating speech production disorders to discrete brain areas may need to be viewed with caution.

Clinicoanatomical evidence of speech production disorders is sparse and often inconsistent. Based on a few lesion studies, Taubner and colleagues (1999) have proposed *three* lesion sites that may concur with specific non-fluent aphasic symptoms. *First*, patients with inferior frontal lesions including the left pars opercularis tend to show syntactic disorders, such as agrammatism and omissions of function words. This may be particularly true if the right frontal operculum is not able to take over functions for the damaged left speech areas (Ohyama et al., 1996). In other words, bilateral pars opercularis lesions may account for some symptoms typically found in patients with chronic Broca's aphasia. *Second*, patients with lesions including the left pars triangularis or the adjacent prefrontal cortex tend to show impaired lexical access. For instance, patients may be unable to produce semantically correct words in naming tasks. *Third*, lesions including the left primary motor cortex and efferent subcortical projections from this area may cause disorders in speech-motor planning, as commonly observed in patients with apraxia of speech. In contrast, different authors argue that primary motor cortex lesions would rather result in some form of dysarthria, whereas apraxia of speech may be due to damage in the left insula (Ackermann & Riecker, 2004).

Obviously, this cannot be the complete story. More research will be necessary to meaningfully relate individual speech production disorders to specific lesion sites and language networks in the brain. It has been argued that lesion site fails to predict aphasic *syndromes*. This may similarly apply to aphasic *symptoms*, as even symptoms consist of various subprocesses in speech production. Impaired syllabic segmentation, for example, may depend on a couple of factors, such as the question of how *rhythm* affects speech production (Cutler & Norris, 1988; Kotz, 2006; Kotz, Schwartze, & Schmidt-Kassow, 2009). Investigating the role of rhythm in speech production may therefore provide an important prerequisite to learn more about the underlying causes of impaired syllabic segmentation, both at the behavioral and at the neurophysiological level.

Chapter 2

Preserved skills in patients with non-fluent aphasia

The previous sections focused on the *loss* of function after a left-hemisphere stroke. Conversely, the following sections introduce a number of abilities that are usually *preserved* in left-hemisphere stroke patients.

For nearly two centuries clinicians have reported that patients with severe and chronic non-fluent aphasia are nevertheless able to sing *melodies* (Jacome, 1984; Warren, Warren, Fox, & Warrington, 2003; Peretz, Gagnon, Hébert, & Macoir, 2004). About half of these patients are still able to sing *words* (Yamadori, Osumi, Masuhara, & Okubo, 1977). More specifically, the patients are able to sing *familiar lyrics* (Ustvedt, 1937; Benton & Joynt, 1960; Smith, 1966; Baur, Uttner, Ilmberger, Fesl, & Mai, 2000; Tomaino, 2010) and common, *formulaic phrases* (Mills, 1904; Gerstmann, 1964; Keith & Aronson, 1975). This astonishing finding has inspired a number of singing therapies (Keith & Aronson, 1975; Marshall & Holtzapple, 1976; Van Eeckhout et al., 1997; Jungblut, 2009; for review, see Bradt, Magee, Dileo, Wheeler, & McGilloway, 2010), among them a rehabilitation program known as melodic intonation therapy (Albert, Sparks, & Helm, 1973; Sparks, Helm, & Albert, 1974; Sparks & Holland, 1976; Albert, 1998).

Melodic intonation therapy consists of *three* main components: singing, rhythmic speech, and common phrases. Yet, the treatment manual includes a number of further elements destined for different stages of the therapy (Helm-Estabrooks, Nicholas, & Morgan, 1989; Helm-Estabrooks & Albert, 2004). Patients are trained to produce formulaic phrases ('I'm thirsty') in each of the following conditions: singing in thirds or rhythmic speech with exaggerated prosody; with or without vocal accompaniment provided by the therapist; with or without rhythmic tapping of the patients' left hand; and with or without role-play based on common phrases. Further elements were proposed, such as covert phrase production ('inner rehearsal') and acoustic monitoring of articulatory errors ('auditory motor-feedback training'; see Norton, Zipse, Marchina, & Schlaug, 2009).

The overall composition of melodic intonation therapy and other singing therapies may appear meaningful from a therapeutic point of view. However, when focusing on the different therapeutic elements and their *individual* contributions to clinical efficacy, some questions arise. To what extent is melody, rhythm, or their combination decisive for speech production in aphasic patients? Does this depend on individual lesion locations or damaged neural networks in the brain? What role does memory play if one employs familiar song lyrics? And to what degree may the benefits of singing therapies be due to the use of overlearned, formulaic phrases?

Recent work on these questions has led to a number of ambiguous, sometimes contradictory results. The following sections summarize the state of the art on preserved singing and related abilities in patients with non-fluent aphasia.

2.1 Singing

According to the inventors of melodic intonation therapy, singing is the crucial element of the treatment (Albert et al., 1973; Sparks et al., 1974). After a left-hemisphere stroke, singing is thought to stimulate *right* cortical brain regions with homotopic location relative to *left* language areas. As a result, the intact right hemisphere is supposed to assume the function of damaged left-hemisphere speech areas. This, in turn, was suggested to aid speech recovery in aphasic patients. Indeed, this series of assumptions seems consistent with right-hemispheric processing of features related to music and prosody (Perry et al., 1999; Riecker, Ackermann, Wildgruber, Dogil, & Grodd, 2000; Jeffries, Fritz, & Braun, 2003; Callan et al., 2006; Özdemir, Norton, & Schlaug, 2006; Hyde, Peretz, & Zatorre, 2008; Poeppel, Idsardi, & van Wassenhove, 2008; Merrill et al., 2012). Moreover, some evidence indicates that the right hemisphere may have a compensatory function in speech recovery (Basso, Gardelli, Grassi, & Mariotti, 1989; Cappa & Vallar, 1992; Weiller et al., 1995; Ohyama et al., 1996; Musso et al., 1999; Blasi et al., 2002; Saur et al., 2006).

Several *cross-sectional* studies with non-fluent aphasic patients, however, failed to support the more effective role of singing as compared to rhythmic speech (Cohen & Ford, 1995; Boucher, Garcia, Fleurant, & Paradis, 2001) or natural speech (Hébert, Racette, Gagnon, & Peretz, 2003). Notably, one study revealed an advantage of singing over natural speech when patients were singing along to vocal playback delivered by headphones (Racette, Bard, & Peretz, 2006). Until now, *longitudinal* evidence for the efficacy of singing in speech recovery is sparse, and a closer look at the studies that do exist reveals some experimental problems. Only two case reports made use of a control condition, with one study controlling for singing in an experienced singer (Wilson, Parsons, & Reutens, 2006) and another study controlling for singing, but not for rhythmic left-hand tapping, in two patients (Schlaug, Marchina, & Norton, 2008). Consequently, the results from these reports may be confounded by musical training and influences related to rhythm.

Neuroimaging research on the role of singing in speech recovery has given rise to some ambiguous results. In multiple-case reports, aphasic patients were singing formulaic phrases over a period of several weeks (Schlaug et al., 2008; Schlaug, Marchina, & Norton, 2009). At the end of this training, the patients' speech had improved. Functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI) suggested functional changes in the right hemisphere (Schlaug et al., 2008) and structural changes in the right arcuate fasciculus (Schlaug et al., 2009). One could conclude that singing has a causal, curative effect on speech production in these patients. However, there are different ways to interpret these data.

Structural changes in the right arcuate fasciculus, if indeed such findings are validated, may well be the result of *intensive singing*, whereas the benefits in speech production could be due to *massive repetition of phrases*. In other words, singing and massive repetition of phrases may be thought of as *two independent mechanisms* that are not causally linked to each other. Conclusions regarding benefits from singing for speech production are therefore questionable in light of these data. Hence, there is little support from neuroimaging studies for the idea that singing causes a transfer of language function from the left to the right hemisphere (see also 2.5 Formulaic phrase production).

2.2 Rhythmic speech

Rhythmic pacing has proven to be helpful in the treatment of motor disorders, such as in hemiparetic stroke patients (Thaut, McIntosh, & Rice, 1997) and in patients with Parkinson's disease (McIntosh, Brown, Rice, & Thaut, 1997; for review, see Thaut, Kenyon, Schauer, & McIntosh, 1999). However, the role of rhythm in recovery from aphasia appears to have been neglected for some time. One reason for this may be the experimental problem of how to *control* for rhythm. Only a few studies addressed this problem. In one of these studies, natural speech was chosen as a control for rhythmic speech (Cohen & Ford, 1995). Although not mentioned by the authors, the use of natural speech may have resulted in *different syllable durations* in each condition (for evidence, see Kilgour, Jakobson, & Cuddy, 2000; Racette et al., 2006). Slowing down of syllable duration, however, was found to improve speech production, at least to some degree (Beukelman & Yorkston, 1977; Laughlin, Naeser, & Gordon, 1979; Pilon, McIntosh, & Thaut, 1998; Hustad, Jones, & Dailey, 2003). Furthermore, natural speech in *stress-timed languages* — in this case English — implies a distinct meter and may still be considered as rhythmic. Finally, a metronome accompaniment was chosen for the *rhythmic condition only*. This may have advantaged the production of natural speech, since no additional sound source interfered. Accordingly, the results of this study indicate better performance in the natural speech condition, and may have to be viewed with caution.

Nonetheless, three longitudinal studies provide evidence for the efficacy of rhythmic pacing in speech recovery (Rubow, Rosenbek, Collins, & Longstreth, 1982; Pilon et al., 1998; Brendel & Ziegler, 2008; for review, see Ziegler, Aichert, & Staiger, 2010). The results of these studies suggest that speech recovery may be modulated by auditory, visual, or tactile rhythmic cues. It may therefore be critical that melodic intonation therapy includes rhythmic hand tapping. Tactile stimulation, such as tapping of the left hand, may affect speech production by engaging sensorimotor networks in the right hemisphere (Gentilucci and Dalla Volta, 2008). In other words, rhythmic pacing may have a strong impact on speech recovery in aphasic patients.

2.3 Rhythm and the basal ganglia

So far, neuroimaging research on singing therapies has been mainly focused on the dichotomy of left and right cortical functions in speech recovery. Conversely, the contribution from *subcortical areas* has not drawn much attention. This is all the more surprising as syllabic segmentation and rhythmic features may be crucial in speech production, as illustrated above (see 1.1 A neurocognitive model of word production). Indeed, rhythm perception and production were found to involve cortical and subcortical areas, including the *basal ganglia* (Jantzen, Steinberg, & Kelso, 2005; Grahn & Brett, 2007; Grahn & Rowe, 2009; Karabanov, Blom, Forsman, & Ullén, 2009; Jungblut, Huber, Pustelniak, & Schnitker, 2012). The basal ganglia may be critical in this context, as they seem to support *rhythmic* features in particular (Schmitz-Hübsch, Eckert, Schlegel, Klockgether, & Skodda, 2012), whereas the cerebellum, for example, is more involved in *motor timing* (Nichelli, Alway, & Grafman, 1996; Penhune, Zatorre, & Evans, 1998; Knolle, Schröger, Baess, & Kotz, 2012). Moreover, the decisive role of the basal ganglia may extend to rhythmic features in speech perception and production (Kotz, 2006; Kotz et al., 2009; Schmitz-Hübsch et al., 2012).

Given the functional relationship between the basal ganglia and rhythmic speech, one may argue that patients with *larger* basal ganglia lesions could benefit *more* from external rhythmic sources such as a percussive accompaniment. In contrast, patients with *smaller* basal ganglia lesions may be *less* dependent of such rhythmic aid. Indeed, there is indirect evidence for this view. A multiple-case report indicates that patients with larger subcortical lesions tend to respond better to melodic intonation therapy than patients with smaller subcortical lesions (Naeser & Helm-Estabrooks, 1985). The rhythmic component of the therapy as well as the extent of basal ganglia lesions may be responsible for this result.

2.4 Familiar lyric production

Research on the production of familiar lyrics in aphasic patients is based on the observation of a few cases. Two non-fluent aphasic patients showed improved performance for familiar song lyrics as compared to spontaneous speech (Hébert et al., 2003) or unknown lyrics (Straube, Schulz, Geipel, Mentzel, & Miltner, 2008). Interestingly, lyric production in these patients was *not* affected by the circumstance of whether the original melody was used or not. This finding is unexpected, as a number of studies with healthy participants suggested perceptual connectedness of melody and lyrics in memory (Serafine, Crowder, & Repp, 1984; Serafine, Davidson, Crowder, & Repp, 1986; Crowder, Serafine, & Repp, 1990; Hébert & Peretz, 2001; Peretz, Radeau, & Arguin, 2004; Gordon, Schön, Magne, Astésano, & Besson, 2010). Yet, some work points to an independent, dual encoding of lyrics and melody (Samson & Zatorre, 1991, 1992).

The case reports presented here (Hébert et al., 2003; Straube et al., 2008) indicate that lyric production in aphasic patients may be mediated by verbal long-term memory. However, it remains unclear whether this finding holds true for a *larger* sample of patients. In addition, a larger sample may help to determine whether the contribution of memory to lyric production depends on individual factors — such as age. Furthermore, it may be useful to disentangle effects of long-term memory from motor automaticity in formulaic expressions, as lyric memory and motor automaticity may affect speech production in different ways. For example, a positron emission tomography (PET) study with healthy participants revealed diverging patterns of brain activity during recitation of well-known song lyrics as opposed to automatized counting (Blank et al., 2002).

2.5 Formulaic phrase production

The use of common, formulaic phrases is a substantial component of singing therapies (for melodic intonation therapy, see Albert et al., 1973; Sparks et al., 1974; Helm-Estabrooks et al., 1989; Albert, 1998; Helm-Estabrooks & Albert, 2004; Norton et al., 2009). Surprisingly, the contribution of formulaic language to clinical efficacy of singing therapies has not been investigated up until now. The role of formulaic phrases in singing therapies is critical, as the right hemisphere supports more than just features related to singing. Several studies with aphasic patients suggest that the production of formulaic speech engages *right* corticostriatal brain areas (Speedie, Wertman, Ta'ir, & Heilman, 1993; Van Lancker Sidtis, McIntosh, & Grafton, 2003; Van Lancker Sidtis & Postman, 2006; Sidtis, Canterucci, & Katsnelson, 2009; for review, see Van Lancker Sidtis, 2009, 2010). Thus, the ability to produce formulaic expressions is often preserved in left-hemisphere stroke patients (Lum & Ellis, 1994). Conversely, the recovery of non-formulaic, propositional speech may involve, in particular, *left* perilesional regions (Cao, Vikingstad, George, Johnson, & Welch, 1999; Heiss, Kessler, Thiel, Ghaemi, & Karbe, 1999; Warburton, Price, Swinburn, & Wise, 1999; Kessler, Thiel, Karbe, & Heiss, 2000; Rosen et al., 2000; Zahn et al., 2004; Meinzer, Flaisch, Breitenstein, Wienbruch, Elbert, & Rockstroh, 2008; for review, see Heiss, Thiel, Kessler, & Herholz, 2003). In other words, formulaic and propositional speech may be lateralized differently in the brain (Van Lancker Sidtis, 2004).

Let us assume that formulaic and non-formulaic language are functionally independent. In this simplified case, one may consider that training of formulaic speech *specifically* facilitates the recovery of formulaic, but not of non-formulaic speech — and vice versa. A number of clinical implications may be derived from this hypothetical finding. For instance, speech therapy would need to focus on the *combined* training of formulaic and non-formulaic speech. Moreover, specific training effects would provide evidence for the idea that the recovery of formulaic and non-formulaic language relies on two separate neural mechanisms.

If formulaic language is indeed supported by right corticostriatal brain areas, this finding may shed new light on imaging studies that have reported right-hemispheric changes in aphasic patients after singing therapy (Schlaug et al., 2008, 2009). In fact, these changes may not necessarily relate to singing, as they could just as well arise from the use of formulaic language. Furthermore, right corticostriatal processing of formulaic language may help to better understand the results of a frequently discussed study with seven aphasic patients (Belin et al., 1996). All of these patients had previously undergone singing therapy. Unexpectedly, PET revealed increased *left* prefrontal activation in the patients when they were singing simple, concrete words. Several methodological reasons may account for this finding — such as lyric type. It should be noted that the patients in this study were producing *non-formulaic* utterances, engaging primarily *left* perilesional brain regions. Hence, neurophysiological correlates in the context of singing may be strongly influenced by whether or not formulaic language is used.

Chapter 3

Open questions

Preserved singing in patients with non-fluent aphasia has drawn much scientific attention in the last few decades. Attention has been mainly focused on *two* research questions: from a *cross-sectional* view, one may ask whether it is singing itself that enables aphasic patients to produce text; from a *longitudinal* view, one may ask whether one could use singing to aid speech recovery. The present work addresses both of these questions based on two separate experiments.

At first glance, cross-sectional and longitudinal designs may not seem fundamentally different. However, there is good reason to distinguish between both temporal perspectives. The present chapter briefly highlights these differences and their respective impact on experimental designs, results and range of validity.

3.1 Cross-sectional view

Cross-sectional designs focus on *one* point in time. In a cross-sectional experiment, aphasic patients may produce text under different conditions. The results of such an experiment may provide knowledge on how different conditions have affected speech production in the studied patients. However, the results do *not* provide any knowledge about the possible long-term effects that may be associated with the observed conditions. In other words, the range of validity does not extend to possible changes over time. For example, a cross-sectional experiment may indicate that singing facilitates speech production in aphasic patients. Yet, this finding would not warrant singing as a speech therapy.

The current cross-sectional experiment aims to assess the relative effect of melody, rhythm, lyric familiarity, and formulaic language on speech production in aphasic patients. Moreover, the cross-sectional experiment explores the degree to which lesions including the basal ganglia affect speech production in aphasic patients. Based on the research outlined in the previous sections, rhythm, lyric familiarity, and formulaic language are expected to *benefit* speech production in aphasic patients, whereas melodic intoning may not improve speech production over and above rhythmic speech. Finally, patients with larger basal ganglia lesions are expected to depend *more* on external sources of rhythmicity than patients with smaller basal ganglia lesions.

3.2 Longitudinal view

Longitudinal designs focus on temporal changes based on observations at *several* time points. In a longitudinal experiment, aphasic patients may undergo different treatments over several weeks. The results of this type of experiment may provide knowledge on how the different treatments have affected speech recovery in the studied patients. That is, longitudinal sections provide knowledge about the *efficacy of a treatment*. So far, only a few longitudinal studies have addressed the role of singing in recovery from aphasia (Wilson et al., 2006; Schlaug et al., 2008, 2009), with a number of methodological issues discussed above (see 2.1 Singing; 2.5 Formulaic phrase production). For this reason, the current knowledge on the clinical efficacy of singing is mainly based on assumptions, with some of them being derived from cross-sectional work.

The current longitudinal experiment aims to assess the relative effects of melody and rhythm on the recovery of formulaic and non-formulaic speech in patients with non-fluent aphasia. Until now, it remains unclear whether or not singing conveys any therapeutic advantage over rhythmic speech. Moreover, there is no evidence as to how well patients can switch between singing and rhythmic speech if their training is focused on either singing or rhythmic speech. Are there any modality-specific training effects? Finally, it is unclear whether intense training of formulaic phrases benefits the recovery of non-formulaic, propositional speech. Based on the research outlined in the previous sections, singing therapy and rhythmic therapy are expected to be *equally effective* in recovery of formulaic language. In other words, singing may not add value to the recovery of formulaic language over and above rhythmic speech. Furthermore, the longitudinal section explores whether possible progress in the production of formulaic speech extends to the production of non-formulaic speech.

Part II

A cross-sectional experiment

Chapter 4

Methods

This chapter describes the methods of a cross-sectional experiment. Based on the theoretical and empirical body of work elaborated above, the cross-sectional experiment investigates the effect of *four* key factors on speech production in non-fluent aphasic patients: melody, rhythm, lyric familiarity, and formulaic language. Moreover, the cross-sectional experiment explores whether patients with larger basal ganglia lesions depend more on external sources of rhythmicity than patients with smaller basal ganglia lesions.

4.1 Participants

The present multicenter experiment was conducted at five rehabilitation centers located in Berlin, Germany. Seventeen stroke patients were included in the study. Table 1 provides an overview of the patients' individual case histories.

Table 1: Patient histories (cross section)

Patient	**Gender**	**Age (years)**	**Months since last infarction**	**Number of infarcts**	**Handed-ness**	**Aetiology**	**Left-sided BG lesions**	**Right-sided lesions**
AS	F	65	8	1	R	left MCA ischemia	none	none
BN	F	76	84	1	R	left MCA ischemia	putamen, caudate*, pallidum	none
CM	M	46	23	1	R	left MCA ischemia	putamen, caudate*, pallidum*	none
DO	M	46	5	1	R	left MCA ischemia	putamen*, caudate*, pallidum*	none
FF	F	27	12	1	R	left MCA ischemia, left BG hemor-rhage	putamen	none
HK	F	52	10	1	R	left MCA ischemia	putamen	none
HP	F	68	6	1	R	left BG hemor-rhage	putamen, caudate, pallidum	none
HS	F	80	1	1	R	left MCA ischemia	none	none
IK	M	61	9	1	R	left MCA ischemia	putamen, caudate, pallidum	none
JD	M	52	4	1	R	left MCA ischemia	putamen, caudate*	none
KH	M	39	36	1	R	left MCA ischemia	none	right cerebellum
LS	F	53	36	2	R	left MCA ischemia	putamen, caudate, pallidum	none
LT	M	76	5	1	R	left MCA ischemia	putamen*	right parietal cortex
PL	M	49	6	1	R	left MCA ischemia	putamen, caudate, pallidum	none
PR	F	58	156	1	R	left MCA ischemia	putamen, caudate, pallidum	none
RK	M	62	12	2	R	hemor-rhage in left BG, left pons, and left medulla	putamen, pallidum	right BG, right pons
TJ	F	45	7	1	R	left MCA ischemia	putamen, caudate, pallidum	none

* Localization with limited certainty; data are therefore excluded from further analysis.

M = male; F = female; R = right; MCA = middle cerebral artery; BG = basal ganglia

Patients were German native-speakers, right-handed, and aged 27 to 80 years (mean age: 56 years; standard deviation: 14 years). Except for two patients with previous infarctions (patients LS and RK), none of the patients had a pre-morbid history of neurological or psychiatric impairments, nor did any of the patients suffer from dementia. None of the patients had hearing problems or complained of impaired hearing. At the time of testing, all patients were at least three months post infarction, except in one case (patient HS). Eight independent speech-language pathologists tested the patients within one month prior to the study, using a German standard aphasia test battery (*Aachen Aphasia Test*, Huber et al., 1984). Specified test scores are given in Table 2.

Table 2: Language assessment (cross section)

Patient	**Token Test**	**Comprehension**	**Naming**	**Repetition**	**Diagnosis**
AS	2/50	120/120	99/120	122/150	Broca's aphasia; mild-moderate AOS
BN	16/50	104/120	0/120	91/150	Broca's aphasia; moderate AOS
CM	21/50	93/120	0/120	43/150	Broca's aphasia; moderate-severe AOS
DO	37/50	39/120	0/120	32/150	global aphasia; moderate AOS
FF	0/50	120/120	88/120	124/150	Broca's aphasia; mild AOS
HK	26/50	72/120	0/120	58/150	global aphasia; mild-moderate AOS
HP	24/50	76/120	5/120	85/150	global aphasia; mild dysarthria
HS	34/50	77/120	0/120	47/150	global aphasia
IK	16/50	90/120	57/120	100/150	Broca's aphasia; moderate AOS
JD	14/50	110/120	57/120	83/150	Broca's aphasia; moderate AOS
KH	0/50	120/120	98/120	144/150	Broca's aphasia; mild AOS
LS	31/50	57/120	0/120	24/150	global aphasia; moderate-severe AOS
LT	12/50	89/120	82/120	140/150	Broca's aphasia; mild AOS
PL	14/50	99/120	60/120	77/150	Broca's aphasia; severe AOS; mild dysarthria
PR	9/50	112/120	75/120	102/150	Broca's aphasia; moderate AOS
RK	27/50	75/120	21/120	34/150	global aphasia; mild-moderate AOS
TJ	19/50	72/120	5/120	11/150	global aphasia; severe AOS

Scores of the *Aachen Aphasia Test*. Token Test: no/mild disorder (0–6); light (7–21); middle (22–40); severe (>40). Comprehension (including words and sentences in both the visual and auditory modality): no/mild disorder (104–120); light (87–103); middle (58–86); severe (1–57). Naming: no/mild disorder (109–120); light (92–108); middle (41–91); severe (1–40). Repetition: no/mild disorder (144–150); light (123–143); middle (75–122); severe (1–74). Severity levels of apraxia of speech and dysarthria are based on the ratings in the patients' clinical files.

AOS = apraxia of speech

Patients were diagnosed with Broca's aphasia (n = 10) or global aphasia with prevailing expressive deficits (n = 7). Patients with non-fluent aphasia usually show numerous disorders at several levels of word and phrase production (see 1.2 Errors in word and phrase production). To increase diagnostic reliability, concomitant speech disorders in the studied patients had to be diagnosed by at least two experienced speech-language pathologists. Patients were diagnosed with *apraxia of speech* on the basis of direct observations, which involved inconsistently occurring phonemic or phonetic errors, word initiation difficulties, and visible groping (Brendel & Ziegler, 2008). Correspondingly, *dysarthria* was diagnosed in case of consistently occurring phonetic errors. As a result, the diagnosed concomitant speech disorders in the current patient sample involved apraxia of speech (n = 15), and dysarthria (n = 2).

Patients were eligible for inclusion in the study when the aphasia test results indicated preserved simple comprehension, with comparably limited verbal expression. It should be noted that the patients were considered 'non-fluent' based on the typological classifications indicated by the aphasia test (global or Broca's aphasia). Moreover, the speech-language pathologists diagnosed non-fluent aphasia as a prevailing disorder in all of the patients. All patients had undergone speech therapy, which did not comprise singing or explicit rhythmic speech. None of the patients displayed any specific musical training or experience in singing. The sample may therefore be considered as exemplary in a clinical context.

CT and MRI scans, as well as relevant medical reports, were obtained for all patients. A neurologist with special expertise in neuroradiology re-analyzed all CT and MRI scans blinded to the speech profile of the patients. All patients showed a left middle cerebral artery infarction, except for three patients with (supplementary) left basal ganglia hemorrhages (patients FF, HP, RK). To increase the variability in pitch accuracy for subsequent co-variation analyses, three aphasic patients (patients KH, LT, RK) with additional lesions in the right hemisphere were included. All CT or MRI scans were thoroughly analyzed for lesions within the left basal ganglia, including the caudate nucleus, the putamen, and the pallidum. First, separate scales for each basal ganglia substructure were computed (0 = no lesion; 1 = lesion). When a lesion could not be identified with satisfying certainty, it was discarded from further analysis (0.5 = lesion identification impossible). Finally, a composite score was computed, indicating the number of sub-structure lesions within the basal ganglia (0–3 = zero to three substructure lesions including the caudate nucleus, the putamen, and the pallidum). Figure 2 shows the brain scans of two participants with lesions either including the basal ganglia (A) or not (B).

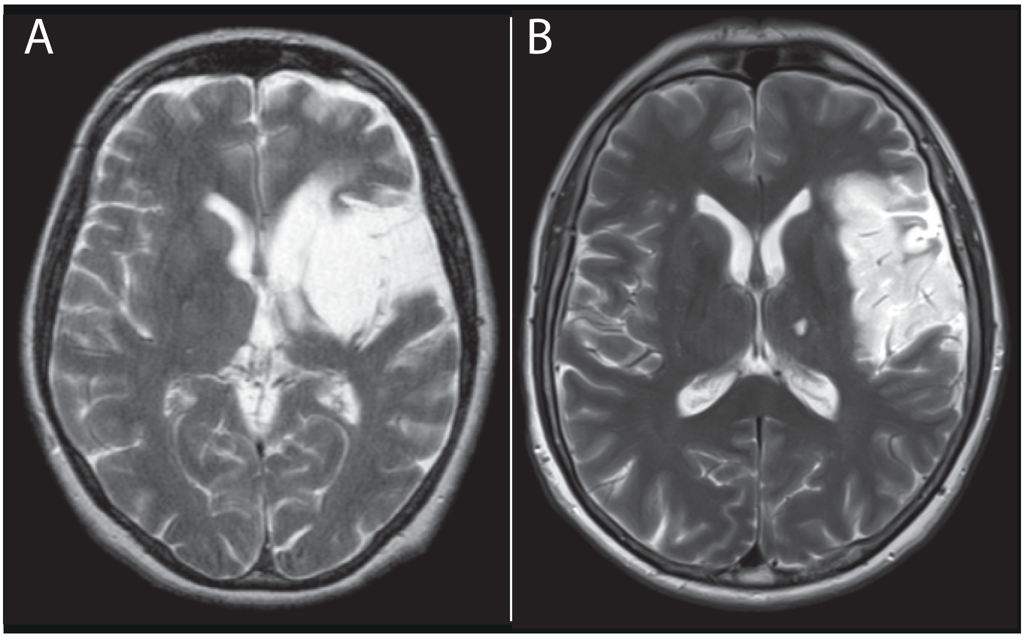

Figure 2: T_2-weighted MRI scans (axial view) of patients PR **(A)** and AS **(B)**. Both scans show left middle cerebral artery infarctions, with only patient PR's lesion including the left basal ganglia.

The study was approved by the Ethical Committee at University of Leipzig and by the participating clinics in Berlin, and informed consent was obtained from all patients.

4.2 Stimuli

The experimental design focused on melody, rhythm, and lyric type. A schematic overview of the experimental design is provided in Figure 3.

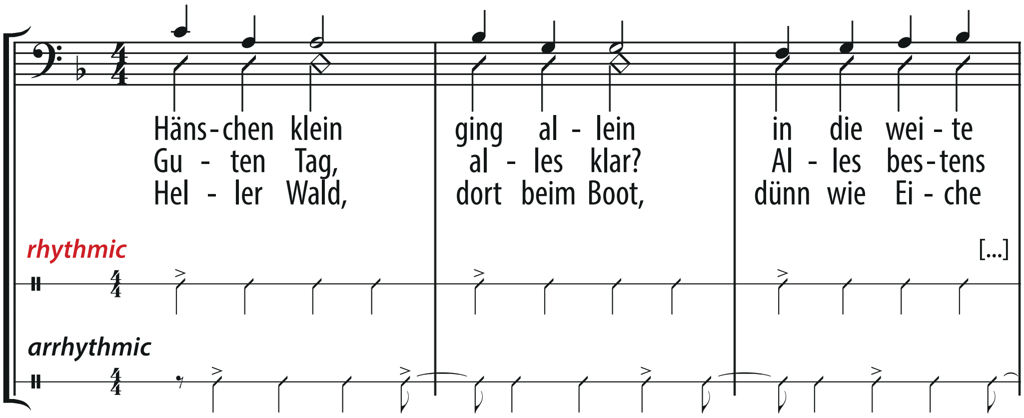

Figure 3: Schematic overview of the cross-sectional design. Three lyric types were employed: original, formulaic and non-formulaic lyrics (from *top* to *bottom*). Each lyric type was produced in three experimental modalities: melodic intoning, rhythmic speech, and a spoken arrhythmic control. In the conditions melodic intoning and rhythmic speech, patients were singing or rhythmically speaking along with a playback composed of a voice to mimic and a rhythmic percussion beat, which is shown here (rhythmic). The first beat in every 4/4 measure was stressed by lowering the percussion frequency and by accentuating its intensity. In the spoken arrhythmic control, the percussion beat turned into a 3/4 stress pattern, and was shifted by an eighth note (arrhythmic).

Three experimental modalities were applied: melodic intoning, rhythmic speech, and a spoken arrhythmic control. In the conditions melodic intoning and rhythmic speech, patients were singing or speaking along to a playback composed of a pre-recorded voice to mimic and a 4/4 percussion beat according to a chosen song (see below). The pre-recorded voice and the percussion beat were consistently used in every sung and spoken condition, including the spoken arrhythmic control. In the spoken arrhythmic control, however, the percussion beat turned into a 3/4 measure, and was shifted by an eighth note. This arrhythmic interference paradigm was chosen to manipulate the degree of rhythmicity, while not confounding the results by different syllable durations. It should be noted that the percussive manipulations did *not* affect the duration of each syllable throughout the experiment. Rhythmic speech served as the control condition for melodic intoning, whereas the arrhythmic condition provided the control for rhythmic speech. To assess the degree of rhythmicity in each condition, five healthy pilot participants were asked to perform the different conditions while rating the perceived rhythmicity. All raters independently classified the spoken arrhythmic control as 'highly arrhythmic'.

Playback voice and percussion beat were mixed in the recording, with both tracks being separately normalized. The sound intensity level of the percussion beat was decreased by 10 dB to make both tracks clearly audible. A male singer performed both the sung and spoken vocal playback parts. The sung playback parts were recorded in two tonal keys (B and F major) to represent the patients' individual vocal range, with a piano sound indicating the initial note. Natural prosody was employed for the spoken playback parts. The playback voice was digitally edited to ensure that each syllable was precisely placed on the beat. For the percussion beat, a wooden metronome sound was used. The first percussion beat in every 4/4 and 3/4 measure was stressed by lowering the percussion frequency and by accentuating its intensity (first beat in every measure: fundamental frequency of 280 Hz, sound intensity level of 80 dB; all remaining beats in every 4/4 or 3/4 measure: fundamental frequency of 420 Hz, sound intensity level of 70 dB). Based on pilot data, a tempo of 100 beats per minute was chosen, with a mean duration of 780 ± 25 ms per syllable. With this tempo, patients produced about half of the syllables correctly, thus indicating a medium difficulty level. Every condition was primed by two measures of 4/4 percussion beats.

Rhythmic percussive accompaniments are usually not part of spoken utterances in everyday life. To test whether the rhythmic percussion beats in the spoken conditions may have interfered with speech production in the current sample, the experiment was repeated with four control patients (patients JD, KH, LS, LT). The control patients were rhythmically speaking with the vocal playback used in the rhythmic speech condition, the only difference being that half of the playbacks did *not* include rhythmic percussion. In other words, the control patients were rhythmically speaking with and without percussive accompaniment.

Three types of lyrics were employed in each of the modalities described above: original, formulaic, and non-formulaic lyrics. To select a song with highly *familiar lyrics*, the familiarity of common German nursery rhymes and folk songs was explored in an age-matched control group of thirty-five healthy participants. First, the control participants were presented with four initial song bars and instructed to complete the melody by humming the remaining notes. Correspondingly, participants were asked in a second step to complete the song lyrics by free recitation. Based on this procedure, a well-known German nursery rhyme was chosen (*Hänschen klein*), with 100% of correctly produced notes, and 87% of correctly produced lyric syllables. It is noteworthy that a correlation between correctly produced syllables and the control participants' age did *not* reach significance. The melody of the chosen song mainly consists of seconds and thirds, while not exceeding the range of a fifth, and may therefore be considered as very simple.

In a next step, *formulaic lyrics* were developed while using the same melody. Formulaic lyrics were composed of stereotyped phrases ('Hello, everything alright? Everything's fine…'). Eight clinical linguists were asked to judge over 100 common phrases, and classified half of them as being 'formulaic'. Fifteen of these phrases were chosen and combined to form a sequence that could be found in typical 'small talk'. The phrases are highly relevant for communication in everyday life, ranging from salutations and farewells to well-being and food. The sequence of phrases showed high word transition frequencies, indicating high co-occurrences between adjacent words. Notably, the sequence of formulaic phrases was based both on the linguists' judgments, and on word transition frequencies that may be viewed as a psycholinguistic marker for overlearnedness.

Finally, *non-formulaic lyrics* were developed to assess the production of non-formulaic, propositional speech. However, formulaic phrases and non-formulaic speech are often difficult to distinguish because even remote expressions may be or may become formulaic in a given communicative context. Hence, non-formulaic lyrics had to be largely devoid of stereotyped expressions and common word transitions to meet the requirements of the present study. Non-formulaic lyrics therefore included very unlikely, but syntactically correct phrases, such as might occur in modern poetry ('Bright forest, there at the boat, thin like oak…'). Low word transition frequencies were used as a psycholinguistic marker to avoid high co-occurrences of words. As a result, non-formulaic lyrics showed significantly lower word transition frequencies than formulaic lyrics [$t(66) = 2.23$, $p = 0.029$]. To make formulaic and non-formulaic lyrics equally singable, they were conceived so as not to differ in: word frequency [$t(68) < 0.01$, not significant (n.s.)]; word frequency variance [$F(34, 34) = 1.09$, n.s.]; syllable frequency [$t(68) = 0.45$, n.s.]; number of consonants; and syntactic phrase structure. Both lyric types were consistent with the rhythmically required meter in German. The meter is trochaic, meaning that stressed syllables are always followed by unstressed syllables or a short pause. Table 3 provides some characteristics of the lyrics.

Table 3: Characteristics of the lyrics

Feature	**Original lyrics**	**Formulaic lyrics**	**Non-formulaic lyrics**
Mean word frequency (CI)	574,980 (± 400,874)*	110,900 (± 58,289)	110,921 (± 67,376)
Mean word transition frequency (right neighbor)	4,128	4,609	0
Mean syllable frequency (CI)	9,510 (± 7,893)	10,881 (± 8,096)	13,615 (± 11,459)
Number of words	38	35	35
Number of syllables	49	49	49
Number of consonants	93	82	82
Number of syllable onsets with: two consonants; one consonant; vowel only	4; 40; 5	2; 40; 7	4; 39; 6
Number of ellipsoidal phrases	7	15	14

Syllable frequencies have been computed based on the CELEX database (Baayen et al., 1993). Further values were taken from the online database *Wortschatz Leipzig* (University of Leipzig, www.wortschatz.uni-leipzig.de).

* Here, the average is biased by the use of three articles, which display very high frequencies in German. Formulaic and non-formulaic lyrics, however, do not include articles, since articles are generally not part of formulaic expressions in German.

CI = confidence interval

4.3 Procedure

Testing took place in two sessions during one hour. Every session was divided in two parts with pauses in between according to the patients' individual needs. To avoid carryover effects, modalities (sung, spoken, spoken arrhythmic control) were presented in separate blocks, with each block including three lyric types (original, formulaic, non-formulaic). Patients produced each lyric type once per block. Overall, patients were presented with twelve blocks that appeared in counterbalanced order for each participant: sung, spoken, arrhythmic, pause, arrhythmic, spoken, sung, in the first session and with the reversed order in the second session. A correlation between articulatory quality in each condition and the corresponding trial number suggested learning effects in three patients [patients JD, FF, AS; $r(34) = 0.67, 0.57, 0.33$, $p < 0.001$, < 0.001, and $p = 0.049$]. However, none of these patients exhibited a deviant result pattern of overall means in any of the test conditions.

Participants were seated in front of two loudspeakers at a distance of 75 cm. Patients listened to the vocal playback to sing or speak along with, while being provided with separate sheets of text for each lyric type. It should be noted that lip-reading was not possible. Moreover, rhythmic hand tapping was not allowed as it may facilitate speech production by engaging the sensorimotor system. The acoustic setting was conceived to resemble choral singing, with auditory feedback originating from the singer's own voice, as well as from surrounding sound sources. In pilot work with five healthy participants, the playback intensity was chosen to be approximately balanced with the singer's perceived own vocal loudness. Auditory feedback was not given via headphones to preserve natural vocal self-monitoring. Utterances were recorded using a head microphone (C520 Vocal Condenser Microphone, AKG Acoustics, Vienna, Austria) and a digital recording device (M-Audio Microtrack II, Avid Technology, Burlington, Massachusetts).

4.4 Data analysis

Two speech-language pathology students independently rated the articulatory quality of the produced utterances based on the digital sound files, with two raters for each patient. Articulatory quality was denoted as the percentage of correct syllables in each condition. Syllables were chosen over words as the critical unit to account for the fact that, in apractic patients, errors often occur at the syllable level (Aichert & Ziegler, 2004a; Ziegler, 2009, 2010).

A total number of 28,764 syllables were rated. The analyses focused on the segmental sound structure at both the phonemic and the phonetic level. The first two syllables in each condition were discarded from the analyses to control for onset difficulties. Correct syllables were scored with one point (41% of all rated syllables). Half points were given for two conditions: phonemic or phonetic errors occurring in one or more consonants per syllable, but not in the vowel — and vice versa (27% of syllables). No points were allocated when errors occurred in both the vowel and in one or more of the consonants within a syllable (24%). Further errors were classified as syllable substitutions as part of a different word (1%) or omissions

(7%). The scoring procedure is based on a previous study (Racette et al., 2006), with a more precise definition of the half-point category being applied in the present work.

Pitch accuracy was assessed for each sung syllable, separately for each lyric type. It is noteworthy that pitch accuracy did *not* significantly differ between any of the lyric types employed [mean pitch accuracy of original lyrics: 71%; formulaic lyrics: 67%; non-formulaic lyrics: 63%; for each comparison: $t(16) \leq 1.40$, n.s.]. This result was independent of whether the patients with additional right hemisphere lesions were included or not. As expected, patients with left-hemisphere lesions produced more correctly intoned notes (mean pitch accuracy: 75%; range: 22 to 96%) than patients with additional right hemisphere lesions (mean pitch accuracy: 25%; range: 0 to 47%). Inter-rater reliabilities for articulatory quality and pitch accuracy in each patient resulted in correlations ranging from 0.93 to 1.00, $p(16) < 0.001$, with an overall inter-rater reliability across patients of 0.98, $p(304) < 0.001$.

Average scores, composed of two raters' judgments for each condition and patient, were computed separately for articulatory quality and pitch accuracy. Based on the average scores for articulatory quality in each condition, a repeated measures analysis of covariance (ANCOVA) was performed, including the factors modality (sung, spoken, spoken arrhythmic control) and lyrics (original, formulaic, non-formulaic), with patients' age and composite basal ganglia lesion scale as covariates. The pitch accuracy scores were used for subsequent post-hoc analyses, as no apriori predictions were made as to whether pitch accuracy affects speech production. For additional post-hoc frequency analyses the software *Praat* was used (Boersma & Weenink, 2011). The requirements for the repeated measures ANCOVA with small samples were met: according to Shapiro-Wilk tests, the data were normally distributed, and the standard deviations in each condition did not differ much in size, ranging from 24 to 29. An alpha level of 0.05 and the Bonferroni correction for multiple comparisons were applied.

Chapter 5

Results

5.1 Singing

Results in this section focus on the question of whether melodic intoning may have facilitated speech production in the current patient sample.

A repeated measures ANCOVA based on articulatory quality did not indicate an effect of melodic intoning as contrasted with the spoken conditions [$F(1, 14) = 0.55$, not significant (n.s.)], nor did a pairwise comparison of the means reveal a difference between melodic intoning (mean articulatory quality [M] and confidence interval [CI]: $M = 53.47$, 95% CI [41.76, 65.18]) and rhythmic speech ($M = 56.32$, 95% CI [43.43, 69.21], n.s.). These results did not change when three patients with additional right hemisphere lesions were excluded. Moreover, it was assessed whether the absence of an effect from melodic intoning applied to each lyric type separately. No interaction of modality and lyrics was found [$F(4, 56) = 0.51$, n.s.]. In other words, there was no effect of singing on articulatory quality as compared with rhythmic speech, whichever lyric type was used. Means of the results for the conditions melodic intoning and rhythmic speech, separately for each lyric type, are shown in Figure 4.

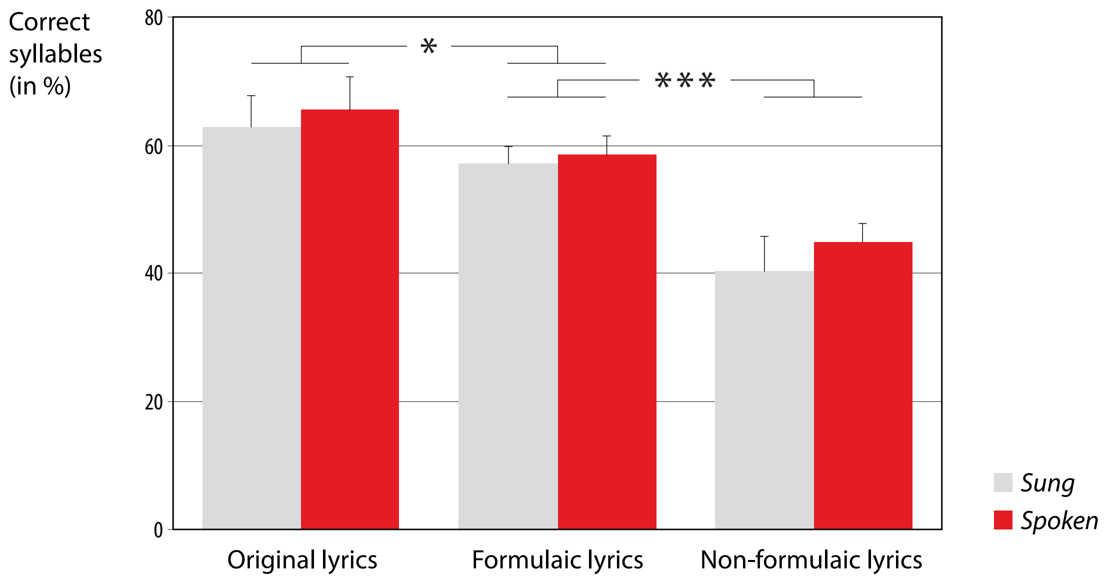

Figure 4: Correctly produced syllables in the conditions melodic intoning (sung) and rhythmic speech (spoken) for three lyric types (original, formulaic, non-formulaic). Articulatory quality significantly differed for each lyric type, irrespective of whether lyrics were sung or spoken (* $p < 0.05$; *** $p < 0.001$). Error bars represent confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

To further explore these findings, several post-hoc analyses were performed. It was investigated whether articulatory quality depended on *prosody* or, more technically, the variance of fundamental frequency in the patients' utterances. *Praat* was used to quantify the fundamental frequency variances in the conditions melodic intoning and rhythmic speech separately for each lyric type. In a next step, relative values for fundamental frequency variance and articulatory quality were computed. Each of these variables was expressed as a difference between the conditions melodic intoning and rhythmic speech. Relative values were chosen instead of absolute values to control for inter-individual differences. Based on these values, a correlation between fundamental frequency variance and articulatory quality did not yield significant results [$r(16) = -0.19$, n.s.]. This finding was independent of whether all or specific lyric types were considered.

Further post-hoc analyses focused on the question of whether *pitch accuracy* in the sung conditions had any impact on articulatory quality. Notably, pitch accuracy is conceptually *unrelated* to frequency variability. Frequency variability reflects the amount of fundamental frequency changes over time, irrespective of whether these frequency changes are consistent with the melody or not. In contrast, pitch accuracy indicates the degree to which changes in perceived fundamental frequency are in accordance with the melody. A correlation analysis of pitch accuracy with relative articulatory quality did not yield significant results [$r(16) = 0.29$, n.s.]. This finding was independent of whether all or only left-hemisphere lesion patients were included.

5.2 Rhythmic speech

Results in this section address the question of whether rhythmicity may have affected speech production in the current patient sample.

Based on articulatory quality, a pairwise comparison of the means revealed a superiority of rhythmic speech (mean articulatory quality [*M*] and confidence interval [CI]: $M = 56.32$, 95% CI [43.43, 69.21]) as contrasted with the spoken arrhythmic control ($M = 54.60$, 95% CI [42.08, 67.12], $p = 0.010$). To further explore the relationship between basal ganglia lesions and rhythmicity, the composite basal ganglia lesion scale was included as a covariate. A contrast analysis indicated an interaction of basal ganglia lesions with rhythmic speech and the spoken arrhythmic control [$F(1, 14) = 16.90$, $p = 0.001$, partial $\eta^2 = 0.55$]. Such an interaction with basal ganglia lesions was not found for the conditions melodic intoning and rhythmic speech. As indicated in Table 4 and Figure 5, patients with larger basal ganglia lesions tended to perform worse in the spoken arrhythmic control compared to rhythmic speech. This pattern was not found in patients with smaller basal ganglia lesions. Moreover, patients with larger basal ganglia lesions showed lower means throughout the experiment. As inter-individual differences in lesion size may be responsible for this finding, it should be noted that the design was only sensitive to intra-individual differences.

Table 4: Rhythm and basal ganglia lesions

Patient subgroup	Melodic intoning	Rhythmic speech	Spoken arrhythmic control
Composite basal ganglia lesion score > 1.5 ($n = 9$)	42 (± 6.6)	47 (± 3.6)	43 (± 5.5)
Composite basal ganglia lesion score ≤ 1.5 ($n = 8$)	67 (± 6.3)	67 (± 4.5)	68 (± 5.0)

Values represent correct syllables (in %), here averaged over lyric types. Values in brackets display confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

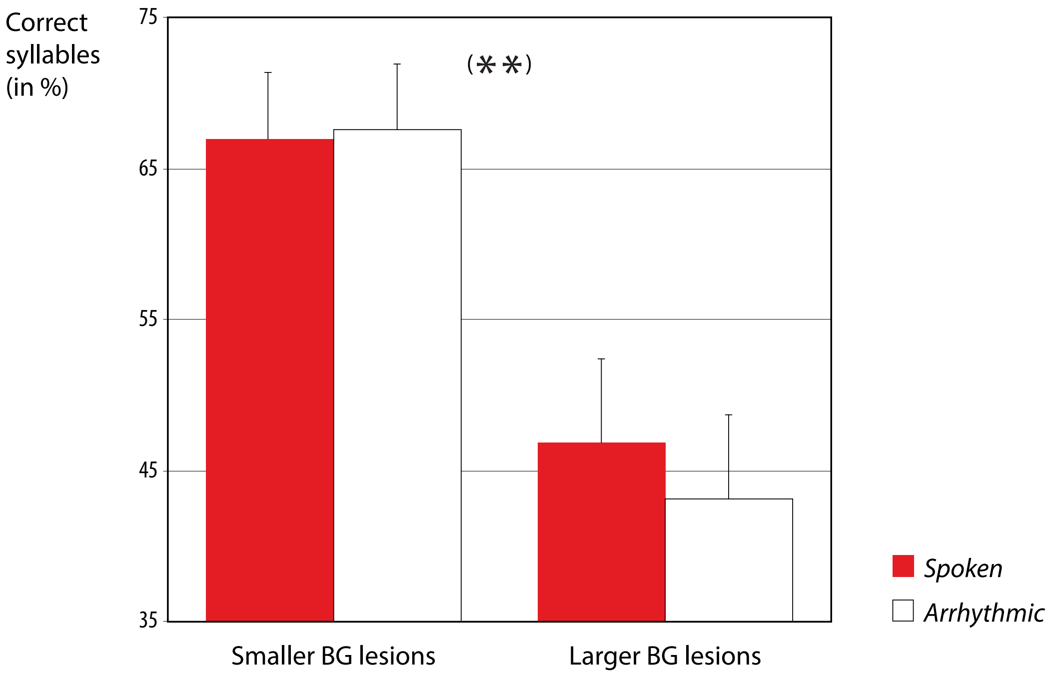

Figure 5: Correctly produced syllables in the conditions rhythmic speech (spoken) and the spoken arrhythmic control (arrhythmic) averaged across lyric types. The results show a significant interaction of basal ganglia (BG) lesions and rhythmicity (** $p < 0.01$). Nine patients with larger basal ganglia lesions (composite basal ganglia lesion score > 1.5) tended to perform worse in the spoken arrhythmic control compared with rhythmic speech. This pattern was not found in eight patients with smaller basal ganglia lesions (composite basal ganglia lesion score ≤ 1.5). Error bars represent confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

To control whether rhythmic percussion beats in the spoken conditions may have interfered with speech production in the patients, the experiment was repeated with four control patients (see 4.2 Stimuli). Control patients were presented with the spoken playbacks of the main experiment, either with or without rhythmic percussive accompaniment. The result did not yield significant differences between the spoken conditions with and without rhythmic percussion beats. Means of the control experiment are given in Table 5.

Table 5: Rhythmic interference effects

Patient subgroup	Rhythmic speech with rhythmic percussion beat	Rhythmic speech without percussion beat
JD, KH, LS, LT	71 (± 5.1)	72 (± 4.3)

Values represent correct syllables (in %), here averaged over lyric types. Values in brackets display confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

5.3 Lyric familiarity and formulaic language

Results in this section relate to the question of whether lyric familiarity and formulaic language may have influenced speech production in the current patient sample.

A repeated measures ANCOVA, based on articulatory quality, indicated a main effect of lyric type [$F(2, 28) = 8.18$, $p = 0.002$], with higher means for original lyrics (mean articulatory quality [M] and confidence interval [CI]: $M = 63.53$, 95% CI [50.90, 76.17]) as opposed to formulaic lyrics ($M = 57.37$, 95% CI [44.84, 69.89], $p = 0.027$). To further explore whether this superiority may be age-dependent, the patients' age was included as a covariate. A contrast analysis revealed an interaction of age with original and formulaic lyrics [$F(1, 14) = 13.18$, $p = 0.003$, partial $\eta^2 = 0.49$]. As can be seen in Table 6, the group of elderly patients showed a higher production of original, familiar lyrics as compared with novel lyrics. This difference was not confirmed in the younger group. Finally, higher means were found for formulaic lyrics ($M = 63.53$, 95% CI [50.90, 76.17]) as compared with non-formulaic lyrics ($M = 43.48$, 95% CI [30.93, 56.03], $p < .001$). Figure 4 shows the means for the three lyric types.

Table 6: Memory and age

Patient subgroup	**Original lyrics**	**Formulaic lyrics**	**Non-formulaic lyrics**
Aged > 55 (n = 8)	71 (± 7.7)	57 (± 2.5)	43 (± 7.3)
Aged ≤ 55 (n = 9)	55 (± 2.6)	57 (± 3.3)	45 (± 4.1)

Values represent correct syllables (in %), here averaged over modalities. Values in brackets display confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

Part III

A longitudinal experiment

Chapter 6

Methods

This chapter describes the methods of a longitudinal experiment. Based on the theoretical and empirical body of work outlined above, the longitudinal experiment addresses *two* key issues. *First*, the experiment investigates whether singing therapy and rhythmic therapy are equally effective in recovery of *formulaic* language. *Second*, the experiment explores whether intense training of formulaic speech benefits the recovery of *non-formulaic*, propositional speech.

6.1 Participants

The present multicenter study was conducted at five rehabilitation centers located in Berlin, Germany, between 2009 and 2012. Fifteen stroke patients were included in the study. Table 7 provides an overview of the patients' individual case histories.

Table 7: Patient histories (longitudinal section)

Patient	Gender	Age (years)	Months since last infarction	Number of infarcts	Handedness	Aetiology
IK	M	61	9	1	R	left MCA ischemia
LS	F	53	36	2	R	left MCA ischemia
OK	M	62	12	2	R	left basal ganglia hemorrhage
PL	M	49	6	1	R	left MCA ischemia
PR	F	58	156	1	R	left MCA ischemia
AS	F	65	8	1	R	left MCA ischemia
DO	M	47	14	1	R	left MCA ischemia
GB	M	71	23	1	R	left MCA ischemia
HG	F	40	10	1	R	left MCA hemorrhage
PH	M	72	6	2	R	left MCA ischemia
CM	M	47	33	1	R	left MCA ischemia
HK	F	52	10	1	R	left MCA ischemia
HP	F	68	6	1	R	left basal ganglia hemorrhage
JD	M	53	16	1	R	left MCA ischemia
TJ	F	45	7	1	R	left MCA ischemia

Patients are sorted by treatment group (from *top* to *bottom*): singing therapy (patients IK, LS, OK, PL, PR), rhythmic therapy (patients AS, DO, GB, HG, PH), and standard therapy (patients CM, HK, HP, JD, TJ).

M = male; F = female; R = right; MCA = middle cerebral artery

Patients were German native-speakers, right-handed, and aged 40 to 72 years (mean age: 56 years; standard deviation: 10 years). Except for three patients with previous infarctions (patients LS, OK, PH), none of the patients had a pre-morbid history of neurological or psychiatric impairments, nor did any of the patients suffer from dementia. None of the patients had hearing problems or complained of impaired hearing. To restrict influences related to spontaneous recovery, all patients were at least six months post infarction at the time of testing, suggesting a chronic post-stroke stage. Eight independent speech-language pathologists tested the patients within one month prior to the study, using a German standard aphasia test battery (*Aachen Aphasia Test*, Huber *et al.*, 1984). Specified test scores are given in Table 8.

Table 8: Language assessment (longitudinal section)

Patient	Token Test	Comprehension	Naming	Repetition	Diagnosis
IK	16/50	90/120	57/120	100/150	Broca's aphasia; moderate AOS
LS	31/50	57/120	0/120	24/150	global aphasia; moderate-severe AOS
OK	26/50	74/120	19/120	37/150	global aphasia; mild-moderate AOS
PL	14/50	99/120	60/120	77/150	Broca's aphasia; severe AOS; mild dysarthria
PR	9/50	112/120	75/120	102/150	Broca's aphasia; moderate AOS
AS	2/50	120/120	99/120	122/150	Broca's aphasia; mild-moderate AOS
DO	29/50	58/120	8/120	53/150	global aphasia; moderate AOS
GB	36/50	61/120	2/120	102/150	global aphasia; mild-moderate AOS
HG	16/50	98/120	58/120	72/150	Broca's aphasia; severe AOS
PH	37/50	63/120	0/120	8/150	global aphasia; severe AOS
CM	5/50	102/120	0/120	61/150	Broca's aphasia; moderate-severe AOS
HK	26/50	72/120	0/120	58/150	global aphasia; mild-moderate AOS
HP	24/50	76/120	5/120	85/150	global aphasia; mild dysarthria
JD	10/50	115/120	92/120	103/150	Broca's aphasia; moderate AOS
TJ	19/50	72/120	5/120	11/150	global aphasia; severe AOS

Scores of the *Aachen Aphasia Test*. Token Test: no/mild disorder (0–6); light (7–21); middle (22–40); severe (>40). Comprehension (including words and sentences in both the visual and auditory modality): no/mild disorder (104–120); light (87–103); middle (58–86); severe (1–57). Naming: no/mild disorder (109–120); light (92–108); middle (41–91); severe (1–40). Repetition: no/mild disorder (144–150); light (123–143); middle (75–122); severe (1–74). Severity levels of apraxia of speech and dysarthria are based on the ratings in the patients' clinical files.

Patients are sorted by treatment group (from *top* to *bottom*): singing therapy (patients IK, LS, OK, PL, PR), rhythmic therapy (patients AS, DO, GB, HG, PH), and standard therapy (patients CM, HK, HP, JD, TJ).

AOS = apraxia of speech

Patients were diagnosed with Broca's aphasia ($n = 7$) or global aphasia with prevailing expressive deficits ($n = 8$). Applying the same criteria for the assessment of concomitant speech disorders as in the cross-sectional experiment (see 4.1 Participants), some of the patients were diagnosed with apraxia of speech ($n = 14$) and dysarthria ($n = 2$). Patients were eligible for inclusion in the study when the aphasia test results indicated preserved simple comprehension, with comparably limited verbal expression. It should be noted that the patients were considered 'non-fluent' based on the typological classifications indicated by the aphasia test (global or Broca's aphasia). Moreover, the speech-language pathologists diagnosed non-fluent aphasia as a prevailing disorder in all of the patients. All patients had undergone speech therapy, which did not comprise singing or explicit rhythmic speech. None of the patients displayed any specific musical training or experience in singing.

CT and MRI scans, as well as relevant medical reports, were obtained for all patients. A neurologist with special expertise in neuroradiology reanalyzed all CT and MRI scans to determine the homogeneity of the current sample in terms of lesion site. All patients suffered from ischemia in the left middle cerebral artery, except for three patients with left hemisphere hemorrhages (patients HG, HP, OK). The right hemisphere was intact in all patients. The study was approved by the Ethical Committee at University of Leipzig and by the participating clinics in Berlin, and informed consent was obtained from all patients.

6.2 Stimuli

The experimental design focused on singing, rhythmic speech, and lyric type. A schematic overview of the design is given in Figure 6.

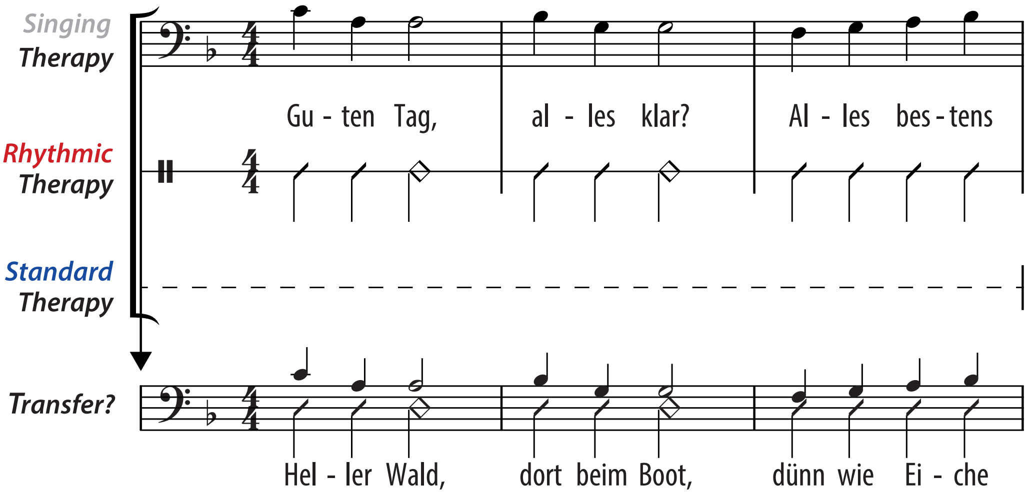

Figure 6: Schematic overview of the longitudinal design. Three types of treatment were applied: singing therapy, rhythmic therapy, or standard therapy. In *singing therapy*, patients underwent training of common, formulaic lyrics by singing them to a well-known melody (‘Hello, everything alright? Everything’s fine...’). In *rhythmic therapy*, patients were trained using the same formulaic lyrics, but rhythmically spoken with natural prosody. In *standard therapy*, patients attended speech therapy that did not include singing, rhythmic speech, or training with formulaic phrases. In each treatment group, the production of formulaic lyrics was assessed at different stages of the therapy. Finally, it was explored whether the patients showed a *training transfer* to the production of unknown, non-formulaic lyrics that were not part of any treatment (‘Bright forest, there at the boat, thin like oak...’).

Three types of treatment were applied: singing therapy, rhythmic therapy, or standard therapy. In singing therapy, patients underwent intense training of formulaic lyrics by singing them to a well-known melody. In rhythmic therapy, patients were trained using the same formulaic lyrics, but rhythmically spoken with natural prosody. In standard therapy, patients attended speech therapy that did not include singing, rhythmic speech, or training with formulaic phrases. In each treatment group, the production of formulaic lyrics was assessed at different stages of the therapy. Finally, it was explored whether the patients showed a training transfer to the production of unknown, non-formulaic lyrics that were not part of any treatment. Rhythmic therapy served as the control condition for singing therapy, whereas non-formulaic lyrics provided the control for formulaic lyrics. All stimuli were piloted in the cross-sectional experiment, as described in the second part of this thesis (see also Stahl, Kotz, Henseler, Turner, & Geyer, 2011).

A highly familiar well-known song was chosen (*Hänschen klein*). As indicated by the cross-sectional results, familiarity with the melody did not constrain the patients' sung production of lyrics that differed from the original ones. This result suggests that familiarity with a melody does not interfere with lyric production in aphasic patients (for discussion, see 8.2 Singing). Hence, the use of a familiar melody in the current experiment appears to be an appropriate choice. The melody mainly consists of thirds, while not exceeding the range of a fifth. Melodic intonation therapy is largely based on thirds, therefore the chosen melody is suitable as it exhibits similar properties.

Formulaic lyrics were composed of stereotyped phrases ('Hello, everything alright? Everything's fine...'). The phrases are highly relevant for communication in everyday life, ranging from salutations and farewells to well-being and food. The sequence of phrases showed high word transition frequencies, indicating high co-occurrences between adjacent words. As pointed out in the cross-sectional experiment, the sequence of formulaic phrases was based both on word transition frequencies as a psycholinguistic marker for overlearnedness, and on the judgments of eight clinical linguists. *Non-formulaic lyrics* included very unlikely, but syntactically correct phrases ('Bright forest, there at the boat, thin like oak...'). Low word transition frequencies were used as a psycholinguistic marker to avoid high co-occurrences of words. As a result, non-formulaic lyrics showed significantly lower word transition frequencies than formulaic lyrics [$t(66) = 2.23$, $p = 0.029$].

One may imagine that singing therapy favors sung production of phrases, whereas rhythmic therapy favors spoken production of phrases. For this reason, all lyrics were tested both sung and rhythmically spoken, whether they were part of the treatment or not. Notably, formulaic and non-formulaic lyrics did not differ in: word frequency [$t(68) < 0.01$, n.s.]; word frequency variance [$F(34, 34) = 1.09$, n.s.]; syllable frequency [$t(68) = 0.45$, n.s.]; number of consonants; and syntactic phrase structure. Both lyric types were consistent with the rhythmically required meter in German. The meter is trochaic, meaning that stressed syllables are always followed by unstressed syllables or a short pause (for further characteristics of the lyrics, see 4.2 Stimuli).

To assess speech production at different stages of therapy, the patients sang or spoke along to a playback composed of a pre-recorded voice to mimic and a percussion beat. Percussive accompaniments were chosen to control for tempo, as syllable duration may affect speech production (Beukelman & Yorkston, 1977; Laughlin et al., 1979; Pilon et al., 1998; Hustad et al., 2003). The cross-sectional experiment indicated that the presence or absence of rhythmic accompaniments did not interfere with speech production in four pilot patients (for discussion, see 8.3 Rhythmic speech). Hence, the use of percussion beats may provide an effective control of syllable duration in the present experiment.

Playback voice and percussion beat were mixed in the recording, with both tracks being separately normalized. The sound intensity level of the percussion beat was decreased by 10 dB to make both tracks clearly audible. A male singer performed both the sung and spoken vocal playback parts. The sung playback parts were recorded in two tonal keys (B and F major) to represent the patients' individual vocal range, with a piano sound indicating the initial note. Natural prosody was employed for the spoken playback parts. The playback voice was digitally edited to ensure that each syllable was precisely placed on the beat. For the percussion beat, a wooden metronome sound was used. The first percussion beat in every 4/4 measure was stressed by lowering the percussion frequency and by accentuating its intensity (first beat in every measure: fundamental frequency of 280 Hz, sound intensity level of 80 dB; all remaining beats: fundamental frequency of 420 Hz, sound intensity level of 70 dB). Based on pilot data, a tempo of 100 beats per minute was chosen, with a mean duration of 780 ± 25 ms per syllable. With this tempo, patients produced about half of the syllables correctly, thus indicating a medium difficulty level. Every condition was primed by two measures of percussion beats.

6.3 Treatments

The patients were allocated to one of the following treatment groups: singing therapy (patients IK, LS, OK, PL, PR), rhythmic therapy (patients AS, DO, GB, HG, PH), or standard therapy (patients CM, HK, HP, JD, TJ). It should be noted that the patients did *not* receive any other treatment throughout the entire study phase. Given the limited overall sample size, patients were systematically assigned to the different treatments based on the following criteria: clinical diagnosis (Broca's or global aphasia); severity of concomitant apraxia of speech; age; and gender. The purpose of this assignment process was to make the treatment groups as comparable as possible. As a result, each treatment group consisted of two patients with Broca's aphasia, except for three patients with Broca's aphasia in the singing therapy group. Furthermore, the treatment groups were comparable in terms of severity of concomitant apraxia, mean age (57, 59, and 53 years for singing, rhythmic and standard therapy, respectively), and gender (about half women). Also, Mann-Whitney *U* tests did not yield significant differences between any of the treatment groups in the language assessment scores shown in Table 8 ($z \leq 0.94$, always n.s). All patients underwent three one-hour long, weekly training sessions, over a period of six weeks. Every session was conducted individually in one rehabilitation center.

The singing therapy was structured into *three* training levels. Every two weeks patients advanced to the next level. This time interval was chosen based on pilot work with two patients. After about two weeks, patients were able to double the rate of correctly produced syllables, suggesting a distinct progress in treatment. At level *one*, patients were singing formulaic lyrics, with the experimenter singing along ('Guten Tag, alles klar...'). At level *two*, the experimenter was singing along just the metrically prominent syllables, thus omitting the unstressed syllables ('Gu— Tag, al— klar...'). The procedure was piloted with five patients, who could produce phrases much better if metrically prominent syllables were sung or spoken along. This may be due to the use of a trochaic meter in German, in which stressed beats often concur with initial word syllables. Hence, metrical cues may have helped the patients to overcome word initiation difficulties. At level *three*, the patients were singing alone without any help provided by the experimenter. One further aim at level three was to integrate the formulaic phrases in the patients' everyday environment at home. Small cards were labeled with single phrases and attached to objects that could be meaningfully related to each other (e.g., 'I'm thirsty' next to the sink, 'I am hungry' on the fridge). In other words, patients and their relatives were encouraged to use the phrases appropriately in a given everyday context. Also, at this level, the patients' relatives attended the therapy sessions, whenever possible.

Rhythmic therapy was structured in exactly the same way, the only difference being that patients were not singing the lyrics, but rhythmically speaking them. It may be obvious that both singing and rhythmic therapy contain rhythmic elements, simply because rhythm is naturally inherent in singing. However, singing and rhythmic therapy in the present experiment clearly differed in whether the patients were intentionally singing or not. Moreover, rhythmic left-hand tapping was not allowed in any of the treatment groups, as hand tapping may act as an additional therapeutic element, which would limit the validity of the data.

Singing and rhythmic therapy included additional daily homework sessions of 30 minutes duration. In these sessions, the patients produced formulaic lyrics to a recording, composed of a voice and a percussion beat. For the singing therapy group, the playback voice was sung and adjusted to the vocal range of each patient. For the rhythmic therapy group, the playback voice was spoken with natural prosody. The percussion beat displayed the same physical properties as the rhythmic accompaniment described above. The homework recordings always represented the current training level. That is, the patients received a new recording every two weeks. At level one, the patients sang or spoke along to a playback voice producing the entire lyrics. At level two, the playback voice omitted the unstressed syllables. At level three, the playback voice merely indicated the first lyric syllable without any further help.

Speech therapy usually involves a number of different elements. For the purpose of standardizing speech therapy, an experienced clinical linguist was asked to compose commonly used elements in the treatment of non-fluent aphasia and apraxia of speech. This composition was supposed to satisfy current clinical standards (Barthel, Meinzer, Djundja, & Rockstroh, 2008). The most frequent elements applied include: multi-modal stimulation (receptive: categorization, word-picture matching; expressive: repetition, reading aloud, naming, writing); simplifying strategies ('reduced syntax therapy'; Springer, Huber, Schlenck, & Schlenck, 2000); phonetic or phonemic approach ('minimal contrast treatment'; Wambaugh, Doyle, Kalinyak, & West, 1996); tactile-kinaesthetic speech-motor treatment ('prompts for restructuring oral and muscular phonetic targets'; Square-Storer & Hayden, 1989); and communicative-pragmatic approach ('promoting aphasics' communicative effectiveness'; Davis & Wilcox, 1985). Five experienced clinical linguists delivered the standard therapy in one rehabilitation center.

6.4 Measurements

The production of *formulaic lyrics*, both sung and rhythmically spoken, was tested before and after six weeks of each treatment. To explore gradual training effects, singing and rhythmic therapy involved additional interim measurements after two and four weeks. Furthermore, singing and rhythmic therapy included follow-up testing of formulaic lyrics three months after the end of the treatment. In both groups, interviews with the patients' relatives were conducted to explore how well formulaic phrases were used at home after therapy. The interviews focused on three questions: the patients' adequate use of formulaic phrases according to communicative contexts; the actual number of trained phrases transferred to everyday life; and the degree to which patients depended on external cues during phrase production over the course of the treatment. The production of *non-formulaic lyrics*, both sung and rhythmically spoken, was tested before and after six weeks of each treatment.

One may claim that several interim measurements are likely to cause learning effects induced by the testing itself. This especially applies to the testing of formulaic lyrics in standard therapy, as well as to the testing of non-formulaic lyrics in each treatment group. To rule out this issue, standard therapy did not include interim measurements of formulaic lyrics, nor did any of the treatment groups involve interim measurements of non-formulaic lyrics. Furthermore, one may argue that follow-up testing in standard therapy may have been desirable from an experimental point of view. However, follow-up testing in this group would have required the patients to not attend any kind of conventional speech therapy during a period of three months after the end of the experiment. Otherwise, it may have been difficult to ensure that the follow-up results actually arose from the experimental treatment. Since it poses ethical problems to exclude severely affected patients from treatment for such a long time, standard therapy did not include follow-up testing in the longitudinal experiment. In case of singing and rhythmic therapy, none of the patients received repetitive training of formulaic speech during a period of three months after the end of the experiment. Consequently, the follow-up results in both of these groups are likely to reflect experimental progress.

Each measurement took place in one session with pauses in between, according to the patients' individual needs. To avoid carryover effects, modalities (sung, spoken) and lyric types (formulaic, non-formulaic) were presented in separate blocks: formulaic lyrics spoken; formulaic lyrics sung; non-formulaic lyrics spoken; non-formulaic lyrics sung. Patients produced the stimuli in each block four times. Spoken stimuli were always presented first, as an association of melody and lyrics could have interfered with spoken lyric production.

It was assessed whether learning effects occurred during the measurements, separately for each time of testing. This is important because each testing session alone may have induced long-term learning effects, irrespective of the treatment applied. Note that this control analysis did not focus on progress in speech production over a period of weeks, but on possible progress occurring during each testing session. Given the limited number of trials per condition, non-parametric rank correlation analyses (Kendall's τ_b) between the rate of correct syllables and the corresponding trial number were performed separately for each time of testing and lyric type. The results suggested learning effects in two patients, always occurring during one testing session [formulaic lyrics: patients IK and TJ; $\tau_b = 0.69, 0.96$, $p = 0.018$ and $p < 0.001$; non-formulaic lyrics: patients IK and TJ; $\tau_b = 0.76, 0.89$, $p = 0.009, 0.003$]. However, none of the patients showed a deviant result pattern in how their speech production improved over a period of weeks in each treatment group. In other words, it seems rather unlikely that any testing alone may account for long-term learning effects in the patients.

For all measurements, patients were seated in front of two loudspeakers at a distance of 75 cm. Patients listened to the vocal playback to sing or speak along with, while being provided with separate sheets of text for each lyric type. It should be noted that lip-reading was not possible. Again, rhythmic hand tapping was not allowed as it may have facilitated speech production by engaging the sensorimotor system. The acoustic setting was conceived to resemble choral singing, with auditory feedback originating from the singer's own voice, as well as from surrounding sound sources. In pilot work with five healthy participants, the playback intensity was chosen to be approximately balanced with the singer's perceived own vocal loudness. Auditory feedback was not given via headphones to preserve natural vocal self-monitoring. Utterances were recorded using a head microphone (C520 Vocal Condenser Microphone, AKG Acoustics, Vienna, Austria) and a digital recording device (M-Audio Microtrack II, Avid Technology, Burlington, Massachusetts).

6.5 Data analysis

Two speech-language pathology students independently rated the articulatory quality of the produced utterances based on the digital sound files, with two raters for each patient. The speech-language pathology students were not aware of the expected outcome of the experiment. Articulatory quality was denoted as the percentage of correct syllables in each condition. Syllables were chosen over words as the critical unit to account for the fact that, in apractic patients, errors often occur at the syllable level (Aichert & Ziegler, 2004a; Ziegler, 2009, 2010).

A total number of 33,840 syllables were rated. The analyses focused on the segmental sound structure at both the phonemic and the phonetic level. The first two syllables in each condition were discarded from the analyses to control for onset difficulties. Correct syllables were scored with one point (formulaic lyrics: 48% of syllables; non-formulaic lyrics: 13%). Half points were given in two conditions: phonemic or phonetic errors occurring in one or more consonants per syllable, but not in the vowel — and vice versa (formulaic lyrics: 27% of syllables; non-formulaic lyrics: 27%). No points were allocated when errors occurred in both the vowel and in one or more of the consonants within a syllable (formulaic lyrics: 21%; non-formulaic lyrics: 56%). Further errors were classified as syllable substitutions for part of a different word (formulaic lyrics: 2%; non-formulaic lyrics: 1%) or omissions (formulaic lyrics: 2%; non-formulaic lyrics: 3%). This scoring procedure has proven efficient in previous studies, including the cross-sectional experiment (Racette et al., 2006; Stahl et al., 2011). Inter-rater reliabilities for articulatory quality in each patient resulted in correlations ranging from 0.97 to 1.00, with an overall inter-rater reliability across patients of 0.99, $p(218) < 0.001$.

Pitch accuracy was assessed for each sung syllable. It is noteworthy that pitch accuracy did not significantly differ between the lyric types [mean pitch accuracy of formulaic lyrics: 78%; non-formulaic lyrics: 75%; $t(14) = 1.33$, n.s.], nor did it significantly differ between any of the treatment groups (mean pitch accuracy in patients undergoing singing therapy: 77%; rhythmic therapy: 80%; standard therapy: 64%; for each group comparison: Mann-Whitney *U* test, $z \leq 0.84$, always n.s.). Moreover, the pitch accuracy scores before therapy failed to predict subsequent changes in speech production after six weeks of therapy in any of the treatment groups, as revealed by non-parametric correlation analyses (Kendall's τ_b), with an overall correlation across treatment groups of 0.34, n.s.

Average scores of articulatory quality were computed, composed of two raters' judgments for each condition and patient. Based on these scores, a repeated measures analysis of covariance (ANCOVA) was performed, including the factors time (before treatment, after six weeks of treatment), lyrics (formulaic, non-formulaic) and modality (sung, spoken), with treatment group as between-subject factor (singing therapy, rhythmic therapy, standard therapy). To control for pre-treatment differences between participants, baseline scores were included as a covariate (Overall & Doyle, 1994; Van Breukelen, 2006). Pre-treatment performances in the different conditions, including both modalities (sung, spoken) and lyric types (formulaic, non-formulaic), were averaged for each patient to compute individual baseline scores. For additional post-hoc frequency analyses the software *Praat* was used (Boersma & Weenink, 2011). The requirements for the repeated measures ANCOVA with small samples were met: according to Shapiro-Wilk tests, the data were normally distributed, and the standard deviations in each condition did not differ much in size, ranging from 16 to 22. An alpha level of 0.05 was applied.

Chapter 7

Results

A repeated measures ANCOVA, based on articulatory quality, revealed a significant interaction of time, treatment group, and lyrics [$F(2, 11) = 49.86$, $p < 0.001$, partial $\eta^2 = 0.90$]. Comparing the means before and after each treatment, strong increases in the production of formulaic lyrics were found for patients undergoing singing therapy (mean increase [*M*] and confidence interval [CI]: $M = 36.47$, 95% CI [28.24, 44.70]), and rhythmic therapy ($M = 50.40$, 95% CI [42.17, 58.63]). These effects proved to be stable over a period of three months after the end of singing and rhythmic therapy ($M = -0.74$, 95% CI [-3.84, 2.35]; $M = 2.76$, 95% CI [-2.82, 8.34]). Standard therapy patients showed a smaller increase in the production of formulaic lyrics ($M = 4.98$, 95% CI [-3.25, 13.21]). For the production of non-formulaic lyrics, the results yielded the reverse pattern: only standard therapy patients improved ($M = 6.21$, 95% CI [3.96, 8.47]), which was not the case with singing and rhythmic therapy patients ($M = -0.36$, 95% CI [-2.62, 1.90]; $M = -0.50$, 95% CI [-2.76, 1.76]). No significant interactions were found for modality and treatment group [$F(2, 11) = 1.44$, n.s.]. Moreover, the data did not reveal a significant interaction between time and baseline scores [$F(1, 11) = 1.24$, n.s.]. Estimated marginal means of the ANCOVA, averaged across modality and adjusted for baseline differences between treatment groups, are shown in Figures 7 and 8. Raw means are given in Tables 9 and 10.

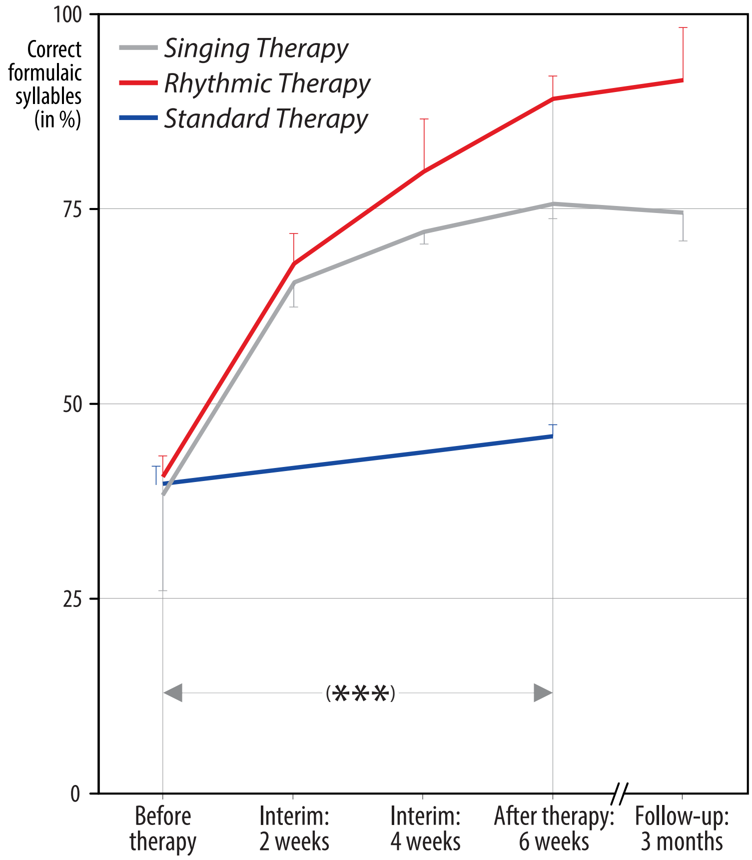

Figure 7: Correctly produced *formulaic* lyric syllables in each treatment group (singing therapy, rhythmic therapy, standard therapy). The results yielded a significant interaction of time, treatment group and lyric type (*** $p < 0.001$). Both singing and rhythmic therapy patients improved their production of formulaic phrases ('Hello, everything alright? Everything's fine...'). This progress occurred at an early stage of both therapies and was stable over time. Conversely, patients receiving standard speech therapy made less progress in the production of formulaic phrases. Values are averaged across modality (sung, spoken) and adjusted for baseline differences between treatment groups. Error bars represent confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

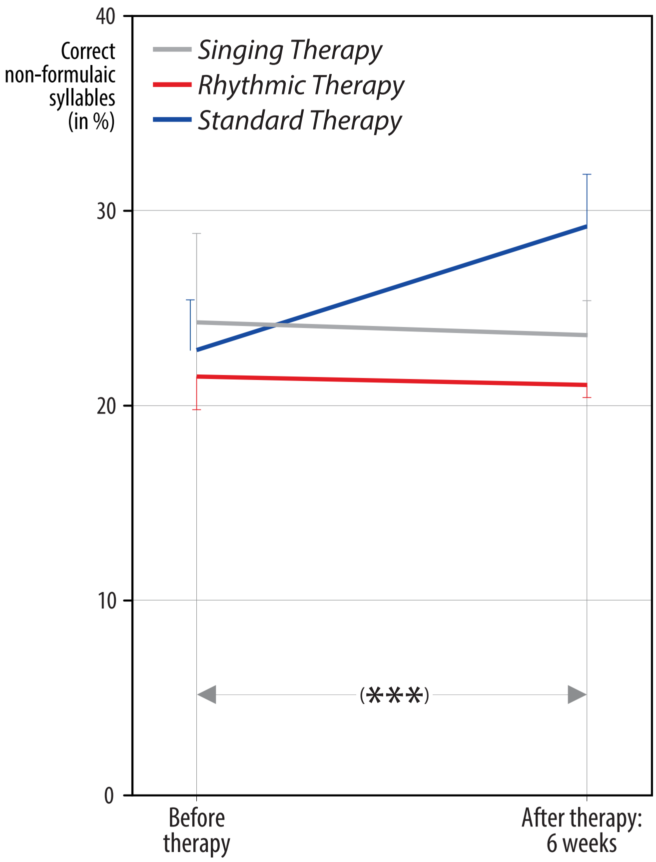

Figure 8: Correctly produced *non-formulaic* lyric syllables in each treatment group (singing therapy, rhythmic therapy, standard therapy). The results yielded a significant interaction of time, treatment group and lyric type (*** $p < 0.001$). Standard therapy patients improved their production of non-formulaic speech ('Bright forest, there at the boat, thin like oak...'), in contrast to singing and rhythmic therapy patients, who did not. Hence, only standard therapy patients showed a training transfer to the production of unknown phrases. Values are averaged across modality (sung, spoken) and adjusted for baseline differences between treatment groups. Error bars represent confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

Table 9: Formulaic lyrics

Time	Singing therapy	Rhythmic therapy	Standard Therapy
Before therapy: sung	43 (± 10.4)	27 (± 11.1)	42 (± 2.5)
Before therapy: spoken	47 (± 12.3)	28 (± 2.6)	49 (± 2.4)
Interim, 2 weeks: sung	71 (± 7.4)	56 (± 4.2)	—*
Interim, 2 weeks: spoken	72 (± 3.1)	57 (± 3.8)	—*
Interim, 4 weeks: sung	78 (± 5.1)	66 (± 7.0)	—*
Interim, 4 weeks: spoken	78 (± 1.4)	71 (± 6.8)	—*
After therapy, 6 weeks: sung	82 (± 3.4)	77 (± 1.4)	48 (± 1.8)
After therapy, 6 weeks: spoken	82 (± 1.8)	79 (± 2.9)	53 (± 1.5)
Follow-up, 3 months: sung	82 (± 3.4)	78 (± 4.5)	—*
Follow-up, 3 months: spoken	81 (± 3.5)	82 (± 6.9)	—*

Values represent correct syllables (in %) of formulaic lyrics at different stages of each treatment. Values in brackets display confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

* No interim or follow-up measurements were conducted in this group (see 6.4 Measurements).

Table 10: Non-formulaic lyrics

Time	Singing therapy	Rhythmic therapy	Standard Therapy
Before therapy: sung	27 (± 3.4)	11 (± 0.6)	23 (± 4.3)
Before therapy: spoken	32 (± 4.6)	13 (± 1.7)	32 (± 2.6)
After therapy, 6 weeks: sung	27 (± 2.8)	11 (± 1.9)	31 (± 1.5)
After therapy, 6 weeks: spoken	31 (± 1.8)	12 (± 0.6)	37 (± 2.7)

Values represent correct syllables (in %) of non-formulaic lyrics before and after six weeks of treatment. Values in brackets display confidence intervals corrected for between-subject variance (Loftus & Masson, 1994).

To further explore the current findings, *two* post-hoc analyses were performed, each based on the production of formulaic lyrics in singing and rhythmic therapy patients after six weeks of treatment. *First*, the analyses explored whether singing and rhythmic therapy may have altered the phonatory quality of the patients' voice. More precisely, it was assessed whether singing and rhythmic therapy affected the rate of continuous phonation in the patients' sung and spoken utterances. The rate of continuous phonation was denoted as the percentage of voiced articulation during each sung and spoken syllable, as measured with *Praat*. Syllable omissions were discarded from the analyses. The results revealed a higher average rate of continuous phonation during singing (79%) compared to rhythmic speech (68%; Wilcoxon signed-rank test: $z = 2.78$, $p = .005$). This finding was independent of whether patients had previously undergone singing or rhythmic therapy (Mann-Whitney *U* test for sung and spoken performances, $z \leq 0.63$, always n.s.). The *second* analysis investigated whether singing therapy has affected prosody or, more technically, the variance of vocal fundamental frequency. Fundamental frequency variances were computed based on frequency listings with ten data points per second, as indicated by *Praat*. The results revealed higher fundamental frequency variances during rhythmic speech (mean variance: 1531 Hz) as compared to singing [725 Hz; $F(9, 9) = 9.00$, $p = .002$]. This finding did not depend on whether patients had previously undergone singing or rhythmic therapy (Mann-Whitney *U* test for sung and spoken performances, $z \leq 1.04$, always n.s.).

Part IV

General discussion

Chapter 8
Cross-sectional experiment

8.1 Summary of the results

The question of whether singing may be helpful for stroke patients with non-fluent aphasia has been debated for many years. However, the role of rhythm and lyric type in speech production seems to have been neglected. The current cross-sectional experiment investigated the relative effects of melody, rhythm, and lyric type on speech production in seventeen patients with non-fluent aphasia. The experiment controlled for vocal frequency variability, pitch accuracy, rhythmicity, syllable duration, phonetic complexity and other influences, such as learning effects and the acoustic setting.

Contrary to earlier reports, the results suggest that singing may *not* benefit speech production in non-fluent aphasic patients over and above rhythmic speech. Previous divergent findings could be due to affects from the acoustic setting, insufficient control for syllable duration, and language-specific stress patterns (see 8.2 Singing). However, the data reported here indicate that *rhythmic pacing* may be crucial, particularly for patients with lesions including the basal ganglia. Overall, basal ganglia lesions accounted for more than fifty percent of the variance related to rhythmicity. The findings suggest that benefits typically attributed to singing in the past may actually have their roots in rhythm. Moreover, the results demonstrate that lyric type may have a profound impact on speech production in non-fluent aphasic patients. Among the studied patients, lyric familiarity and formulaic language appeared to strongly mediate speech production, regardless of whether patients were singing or speaking rhythmically. Lyric familiarity and formulaic language may therefore help to explain effects that have, up until now, been presumed to result from singing.

8.2 Singing

The results of the cross-sectional experiment do not confirm an effect of singing on speech production in non-fluent aphasic patients. This finding holds true when comparing singing with natural prosody in rhythmic speech. One may nevertheless claim that *prosody* could still have positive effects on speech production by engaging a frontolateral network in the right hemisphere (Meyer, Steinhauer, Alter, Friederici, & von Cramon, 2004). Yet, no relationship was observed between fundamental frequency variability in the patients' spoken utterances and articulatory quality. The results thus do not support the assumption that the amount of prosody may facilitate speech production. However, aphasia often concurs with deficits in musical performance, including the inability to sing the right notes (Brust, 2001; Peretz et al., 2003). One may therefore conclude that the patients failed to benefit from singing because they were lacking *pitch accuracy*. It should therefore be noted that pitch accuracy and articulatory quality were found to be unrelated in the current data. That is, patients with good pitch accuracy did not benefit more from singing, whereas patients with poor pitch accuracy did not benefit less from singing. In other words, neither singing nor prosody nor pitch accuracy were found to affect speech production in the present patient sample.

Whichever lyric type was used, an effect from singing was consistently absent. Surprisingly, even with original, well-known song lyrics there was no advantage to singing, as compared to the spoken conditions. Hence, high familiarity with the melody did not facilitate the patients' sung production of the original lyrics. This finding is in line with earlier work based on two aphasic patients (Hébert et al., 2003; Straube et al., 2008). Moreover, high familiarity with the melody did not constrain the patients' sung production of lyrics that *differed* from the original ones. That is, patients did not have any problem to sing a familiar melody while producing different lyrics. In summary, the current results suggest that familiarity with a melody may not hold the key to speech production in aphasic patients.

Taking a closer look at one of the few studies that provide evidence for the superiority of singing above natural speech (Racette et al., 2006), one reason for this result may be the use of *headphones* which could have altered natural vocal self-monitoring (for indirect evidence from stuttering patients, see Stuart, Frazier, Kalinowski, & Vos, 2008). Moreover, a post-hoc analysis in the study revealed *longer syllable durations* for singing as compared to natural speech. Hence, slowing down of tempo during singing may have caused these patients to commit fewer errors. One further reason may be that the study was conducted in French, a *syllable-timed language*. English or German, however, are stress-timed languages, which predetermine a clearly defined meter in each utterance. Consequently, singing in French could entail a distinct gain in rhythmicity above natural speech, whereas this would not apply similarly in stress-timed languages (for indirect evidence, see Schmidt-Kassow, Rothermich, Schwartze, & Kotz, 2011). Singing in a syllable-timed language such as French may therefore be thought of as 'rhythm in disguise'.

It is noteworthy that singing in French was only found to be an efficient tool when using a vocal playback with which patients were singing along (Racette et al., 2006). One may imagine that this sung accompaniment has served as a rhythmic pacemaker. Similar evidence comes from a study conducted in French, where seven aphasic patients underwent singing therapy (Belin et al., 1996). After the treatment, the patients produced words in two conditions: singing and natural speech. The patients' speech production was found to be significantly increased during singing as compared to during natural speech. Lack of rhythmicity during natural speech in a syllable-timed language may be responsible for this finding.

8.3 Rhythmic speech

The cross-sectional results suggest an effect of rhythmicity on speech production in non-fluent aphasic patients. This effect occurs at *two* different levels. *First*, singing did not benefit speech production over and above rhythmic speech in the current patient sample, irrespective of lesion location. *Second*, rhythmic pacing through percussion beats was found to facilitate speech production especially in patients with lesions including the basal ganglia. This finding supports the idea that the basal ganglia may mediate the segmentation of words and phrases into syllables (Kotz, 2006; Kotz et al., 2009; Schmitz-Hübsch et al., 2012). Among the studied patients, the extent of basal ganglia lesions accounted for about fifty-five percent of the variance related to the effects of rhythmicity on speech production.

Rhythmic percussion beats were used to accompany the patients' utterances in each of the experimental conditions. This method was chosen to keep syllable durations consistent throughout the experiment, as their impact on articulation is largely unknown. Yet, rhythmic percussion beats are usually not part of spoken utterances in everyday life. At least theoretically, the percussive accompaniment may have altered speech production in the patients. To rule out this possibility, four aphasic control patients were speaking with vocal playback, with only half of the playbacks including rhythmic percussion. In other words, the control patients were rhythmically speaking with and without percussive accompaniment. The results of this control experiment indicated that the presence or absence of rhythmic percussion beats did *not* affect speech production in the patients. Hence, it appears rather likely that percussive accompaniments do not interfere with speech production *as long as they are purely rhythmic*. Nonetheless, this finding may have to be viewed with caution, as the current experimental tasks were rather difficult to accomplish for aphasic patients. That is, the studied patients may have focused on speech production, while paying limited attention to the percussive accompaniment. A different research design may therefore deliver diverging results. For example, aphasic patients may participate in a non-verbal finger tapping experiment. In this case, it may make a difference whether a rhythmic playback is provided or not, as patients are able to concentrate on the rhythmic accompaniment.

Arrhythmic percussion beats were used to accompany the patients' utterances in the spoken arrhythmic control. As illustrated in Figure 3, patients were rhythmically speaking along to a vocal playback, with only the *percussive accompaniment* being arrhythmic. This arrhythmic interference paradigm was chosen to manipulate the degree of perceived rhythmicity while not confounding the results by different syllable durations. Nevertheless, rhythmic speech with arrhythmic accompaniment is *not* the same as arrhythmic, irregular speech. It should therefore be noted that the spoken arrhythmic control in the present experiment is *not* devoid of rhythm, but rather provides a *gradual decrease* in perceived rhythmicity, as indicated by pilot work with five healthy participants. The cross-sectional results are based on the assumption that perceived rhythmicity affects speech production, especially during syllabic segmentation. This view is in accordance with current speech production models (see 1.1 A neurocognitive model of word production). In everyday life, however, differences between rhythmic and irregular speech may be substantially more pronounced than in the current experiment. That is, rhythm may have an even *stronger* impact on speech production in aphasic patients than one may assume based on the data reported here (for neurophysiological support of this claim, see 10.2 Stimulating corticostriatal loops: rhythmic pacing in speech therapy). This also applies to the possible benefits of rhythm-related elements in aphasia and voice therapy, such as rhythmic hand tapping (Helm-Estabrooks et al., 1989; Helm-Estabrooks & Albert, 2004) and drumming (Thyme-Frøkjær & Frøkjær-Jensen, 2001).

8.4 Lyric familiarity and formulaic language

The cross-sectional data clearly indicate the importance of lyric familiarity for speech production in aphasic patients, regardless of whether the lyrics are sung or rhythmically spoken. This finding suggests that speech production may be mediated by *long-term memory*. Moreover, the results may help to understand why many aphasic patients are still able to sing well-known lyrics fluently (Ustvedt, 1937; Smith, 1966; Tomaino, 2010). In fact, it may not be singing that enables aphasic patients to produce well-known lyrics, but lyric memory.

At first glance, the cross-sectional results seem to suggest a positive relationship between *lyric memory* and *age*. Elderly patients showed increased production of familiar as compared with novel lyrics. This difference was absent in younger patients. One may try to explain this finding by increased lyric familiarity among elderly patients. However, age-dependency of song familiarity was ruled out in a pilot study with healthy age-matched controls. Upon closer examination, a different reason may account for the increased production of familiar lyrics in elderly patients. What seems like an age-dependent memory effect may actually be due to the fact that elderly patients had more difficulties during production of *novel lyrics*. That is, decreased production of novel lyrics in elderly patients may be construed as an advantage for familiar lyrics in this group — which is not necessarily true. It would therefore appear that age is a critical factor in this context. Notably, the cross-sectional analyses included age as a covariate. This is all the more important as many studies with aphasic patients are based on single cases, hence not considering systematic differences related to age.

Familiar lyrics are usually not recited on a daily basis. This does not equally apply to formulaic phrases, which involve a number of overlearned speech-motor sequences carried out in everyday life. In other words, one may argue that familiar lyrics and formulaic phrases differ in *motor automaticity*. Yet, surprisingly, the cross-sectional experiment yielded very *similar* results for the production of familiar and formulaic lyrics. That is, lyric familiarity seems to affect speech production in aphasic patients *irrespective* of motor automaticity. This finding is consistent with the idea that lyric memory and motor automaticity may rely on different neural mechanisms (for diverging patterns of brain activity during recitation of well-known lyrics and automatized counting, see Blank et al., 2002).

Finally, the cross-sectional results suggest that *formulaic language* may have a profound impact on speech production in aphasic patients. The performance of formulaic lyrics showed a considerable superiority over non-formulaic lyrics *in every single patient*. Hence, formulaic language may strongly mediate speech production — whether lyrics are sung or rhythmically spoken.

Chapter 9

Longitudinal experiment

9.1 Summary of the results

There is an ongoing debate as to whether singing helps left-hemisphere stroke patients recover from non-fluent aphasia through stimulation of the right hemisphere. However, the long-term impact of melody and rhythm on speech recovery remains largely unclear. The current longitudinal experiment investigated the relative effects of melody and rhythm on the recovery of formulaic and non-formulaic speech. Fifteen patients with chronic non-fluent aphasia underwent either singing therapy, rhythmic therapy, or standard speech therapy. The experiment controlled for vocal frequency variability, phonatory quality, pitch accuracy, syllable duration, phonetic complexity and other influences, such as the acoustic setting and learning effects induced by the testing itself.

The longitudinal results suggest that singing and rhythmic speech may be similarly effective in the treatment of non-fluent aphasia. Both singing and rhythmic therapy patients made good progress in the production of common, *formulaic phrases*. This progress occurred at an early stage of both therapies and was stable over time. Moreover, relatives of the patients reported that they were using a fixed number of formulaic phrases successfully in communicative contexts. Independent of whether patients had received singing or rhythmic therapy, they were able to easily switch between singing and rhythmic speech at any time.

Conversely, patients receiving standard therapy made less progress in the production of formulaic phrases. They did, however, improve their production of unrehearsed, *non-formulaic utterances*, in contrast to singing and rhythmic therapy patients, who did not. In other words, only standard therapy patients showed a training transfer to the production of unknown phrases. In light of these results, it may be worth considering the combined use of standard speech therapy and the training of formulaic phrases, whether sung or rhythmically spoken. This combination may yield better results for speech recovery than either therapy alone. Overall, treatment and lyric type accounted for about ninety percent of the variance related to speech recovery in the data reported here.

9.2 Melody, rhythm and formulaic language in speech therapy

The longitudinal results suggest that singing may not benefit speech recovery over and above rhythmic speech. One may nevertheless argue that singing could have a positive long-term effect on *phonatory quality*, for example by enhancing respiratory activity. Such an effect seems all the more possible, as the choral element of singing is used to increase the rate of continuous phonation in voice therapy, especially in stuttering patients (Thyme-Frøkjær & Frøkjær-Jensen, 2001). Indeed, the present data reveal a slightly increased rate of continuous phonation during singing as compared to rhythmic speech (for similar evidence in stuttering patients, see Colcord & Adams, 1979). However, this result was independent of whether patients had previously undergone singing or rhythmic therapy. That is, the current findings do *not* support the idea that singing may have a long-term effect on phonatory quality in aphasic patients. Rather, the results indicate that singing increases the rate of continuous phonation *without* any prior training. Although this effect appears to be relatively small, it nonetheless suggests that singing may provide a promising tool in voice therapy.

Both singing and prosody depend on vocal frequency, albeit in different ways. One may therefore imagine that singing has a long-term effect on *prosody*, such as by engaging a frontolateral network in the right hemisphere (Meyer et al., 2004). Yet, the current data do not support this claim. Variability in vocal fundamental frequency did not depend on whether patients had previously undergone singing or rhythmic therapy. That is, treatment type did not affect the amount of prosody in the patients' spoken utterances. Hence, it seems rather unlikely that singing has a long-term effect on the amount of prosody in non-fluent aphasic patients. Somewhat surprisingly, both singing and rhythmic therapy patients showed increased vocal frequency variability during *rhythmic speech* as compared to when singing. Upon closer consideration, this finding makes sense: the melody used in the present experiment did not exceed the range of a fifth, whereas natural prosody often does (Hammerschmidt & Jürgens, 2007; for critical discussion of this issue, see 10.1 Language and music beyond the classical left-right hemisphere dichotomy).

It should be noted that the longitudinal experiment did not include a control treatment for rhythmic therapy. Such a control treatment could be focused on the training of formulaic phrases, but in a non-rhythmic or rhythmically reduced way. Hence, the present results do not warrant any final conclusions with regard to clinical efficacy of rhythm *as such*. However, several longitudinal studies that did include non-rhythmic control conditions provide strong evidence for the efficacy of rhythmic pacing in aphasic and apractic patients (Rubow et al., 1982; Pilon et al., 1998; Brendel & Ziegler, 2008; for review, see Ziegler et al., 2010). Although the studies differ in the type of treatment and control condition, the results clearly indicate an articulatory benefit from rhythmic pacing. Moreover, a clinical effect from rhythmic pacing is consistent with current theories of auditory-motor learning (Thaut et al., 1999; Sakai, Hikosaka, & Nakamura, 2004). Acting as a pacemaker, rhythm may help to overcome problems initiating and segmenting words at the syllable level (Cutler & Norris, 1988). This may be especially important for patients with apraxia of speech, who typically have problems in speech-motor planning, including syllabic segmentation. That is, the crucial role of rhythmic pacing in speech recovery may be substantively dependent upon the fact that non-fluent aphasic patients commonly show apractic symptoms, as is the case with the present sample.

The longitudinal results suggest that training with formulaic phrases may play a critical role in recovery from non-fluent aphasia. This finding is crucial for *two* reasons. *First*, formulaic language is highly relevant in everyday life, as many communicative contexts require formulaic speech. *Second*, formulaic language is commonly preserved in left-hemisphere stroke patients. The more the left hemisphere is damaged, the more patients depend on preserved skills of the right hemisphere — such as formulaic speech. The use of formulaic speech may therefore open new ways of tapping into right-hemisphere language resources — even without singing. This may be particularly true for severe, chronic cases of aphasia. In these patients, formulaic language may be one of the few resources left to work with in speech therapy.

9.3 A two-path model of speech recovery

The longitudinal results are consistent with the idea that propositional and formulaic speech rely on different neural pathways (Van Lancker Sidtis, 2004). One may therefore propose that therapy of non-fluent aphasia should focus on *both* propositional and formulaic speech, as illustrated in Figure 9. Propositional speech may be improved through standard speech therapy, engaging left perilesional brain regions (Cao et al., 1999; Heiss et al., 1999; Warburton et al., 1999; Kessler et al., 2000; Rosen et al., 2000; Zahn et al., 2004; Meinzer et al., 2008; for review, see Heiss et al., 2003). Formulaic speech may be rhythmically trained, engaging right corticostriatal areas (Speedie et al., 1993; Van Lancker Sidtis et al., 2003; Van Lancker Sidtis & Postman, 2006; Sidtis et al., 2009; for review, see Van Lancker Sidtis, 2009, 2010). At least theoretically, singing could nonetheless mediate this training process, perhaps by motivating patients or — neurophysiologically — by triggering the reward system (see 10.4 Non-articulatory effects of melody and rhythm in speech recovery).

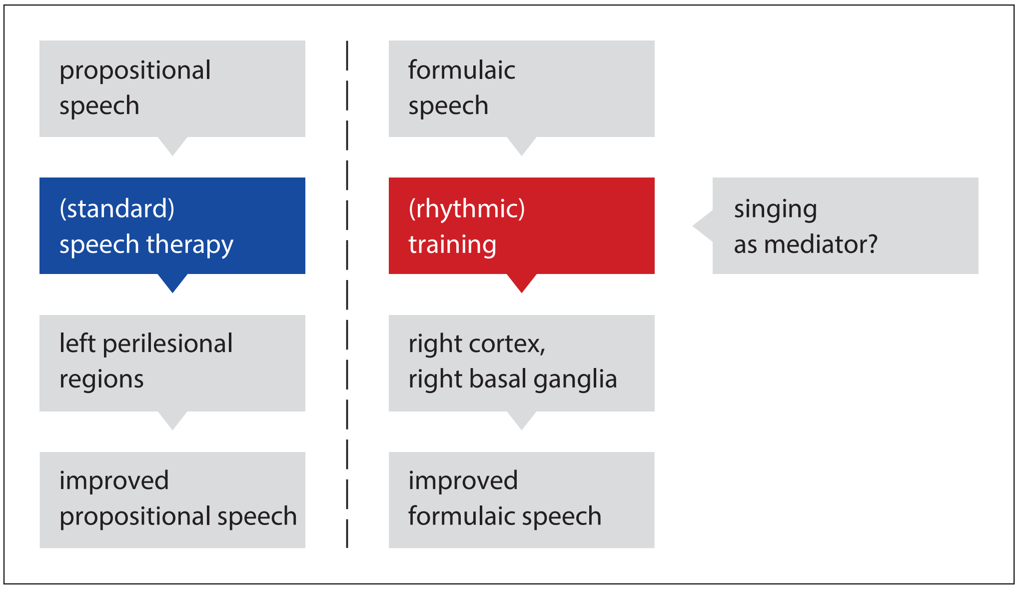

Figure 9: Two-path model of speech recovery. The recovery of propositional and formulaic speech may rely on two different neural pathways. Propositional speech may be improved through standard speech therapy, engaging left perilesional brain regions. Formulaic speech may be rhythmically trained, engaging right corticostriatal brain areas. At least theoretically, singing could mediate this training process.

It is likely that the model presented here oversimplifies a number of concurrent processes in the brain, about which little is known so far. For example, it remains unclear *to what degree* propositional utterances and formulaic speech rely on different neural mechanisms. The two-path model of speech recovery presented here serves *two* purposes. *First*, the model aims to critically appraise related findings from the last few decades and to integrate them with the findings from the current experiments in a meaningful way. *Second*, the model accounts for both propositional and formulaic language and may thus provide a useful heuristic in speech therapy. For instance, an innovative approach in speech therapy may be to imitate language acquisition strategies in children (Bannard et al., 2009). Aphasic patients could be trained to produce *formulaic strings* (e.g., 'I'm...'), followed by a *slot* to be filled with propositional utterances (e.g., 'not thirsty').

9.4 Methodological issues

As with any clinical trial study, a number of caveats associated with the longitudinal experiment deserve closer attention. The first critical point concerns *sample size*. One may argue that the sample size in the current investigation was too small to deliver universally valid results. In fact, large sample trials with aphasic patients are certainly more than desirable. Unfortunately, this claim is difficult to reconcile with the constraints of clinical practice. Homogeneous samples of motivated patients with specific lesions and speech production disorders are difficult to find — even in multicenter studies over the course of several years, as is the case in the present work. Although the current sample included only fifteen patients, the sample was comparably homogeneous in terms of lesion site and symptom variability across the different treatment groups. In contrast, previous longitudinal studies on related topics have been based mainly on single patient cases. Furthermore, all of the results reported here are statistically significant.

A look at the performance levels before treatment in the present study indicates *lower averages* for rhythmic therapy patients. Different baselines before treatment are critical, as they may limit the validity of comparisons between the groups. A closer look at the data reveals *two* important characteristics of the current sample. *First*, individual performances before treatment varied considerably in singing and rhythmic therapy patients. For this reason, baseline scores were included in the analysis as a covariate in order to control for pre-treatment differences between participants (Overall & Doyle, 1994; Van Breukelen, 2006). *Second*, lower pre-treatment averages in the rhythmic therapy group are mainly due to the poor performance of one patient (patient PH). If this patient is discarded from the analyses, the baseline differences between singing and rhythmic therapy patients disappear almost completely.

One further issue relates to differences in *treatment intensity*. Singing and rhythmic therapy included additional homework focusing on formulaic phrases. One may claim that standard speech therapy should have involved similar homework based on propositional speech. It may well be the case that standard therapy patients would have shown additional progress in the production of propositional speech if their training had been more intense. However, the experiment was *not* designed to assess the efficacy of speech therapy as such, but possible *transfer effects* between training of formulaic and non-formulaic speech. Moreover, there is a fundamental difference between training of formulaic and non-formulaic speech. Formulaic speech covers a typical communicative *repertoire* of phrases that can be repetitively trained. Propositional utterances are by definition *newly created* expressions that cannot be trained in a similarly repetitive manner. As a result, patients can easily practice formulaic phrases in homework sessions, whereas training of propositional speech requires regular monitoring by a therapist.

One last issue touches upon the *daily use* of formulaic phrases in communicative contexts. It is clear that interviews with the patients' relatives can only offer limited insight regarding the extent to which formulaic phrases are employed in real life. An observational study focusing on the patients' everyday environment might provide a more valid database. Nonetheless, the present interviews yielded *two* interesting results. *First*, patients were clinging to a fixed number of formulaic phrases. In a way, patients were establishing their own individual formulaic repertoire that varied substantially from patient to patient. *Second*, individual patients showed different patterns in how they depended on *external cues* to initiate phrase production. External cues involved: rhythmic beats of various kind; onset syllables, provided acoustically or visually via lip movements; small cards labeled with phrases. Two patients (patients LS and PH) showed difficulties in self-initiating phrase production throughout the treatment. Other patients (patients IK, OK, PL, PR, AS, DO, GB, and HG) became gradually independent of external cues, applying a number of self-pacing strategies — such as silent upbeat counting. In sum, the interviews suggest a considerable progress in most patients, notably in a short time.

Chapter 10
Concluding remarks and future perspectives

10.1 Language and music beyond the classical left-right hemisphere dichotomy

Benefits in speech recovery have often been attributed to singing in the past (e.g., Albert et al., 1973; Sparks et al., 1974; Helm-Estabrooks et al., 1989; Albert, 1998; Schlaug et al., 2008; Norton et al., 2009; Schlaug et al., 2009; Wan, Rüber, Hohmann, & Schlaug, 2010). The right hemisphere is supposed to assume the function of damaged left-hemisphere speech areas. Until now, this left-right hemisphere dichotomy may have provided a simple and reasonable neural underpinning for speech recovery as a result of singing. At first glance, a number of studies are in line with this view. The right hemisphere supports important features related to singing (Perry et al., 1999; Riecker et al., 2000; Jeffries et al., 2003; Callan et al., 2006; Özdemir et al., 2006; Hyde et al., 2008; Poeppel et al., 2008; Merrill et al., 2012). Moreover, it seems clear that the right hemisphere may have a compensatory function in speech recovery (Basso et al., 1989; Cappa & Vallar, 1992; Weiller et al., 1995; Ohyama et al., 1996; Musso et al., 1999; Blasi et al., 2002; Saur et al., 2006).

Given the results of the current two experiments, one may ask whether the suggested left-right hemisphere dichotomy still applies if singing does not prove to be crucial in speech recovery. It should be explicitly noted, however, that the results do *not* raise doubt about the compensatory role of the right hemisphere *per se*. Rather, they challenge the idea that *singing itself* may have a compensatory effect on speech recovery due to its role in facilitating a transfer of language function from the left to the right hemisphere. Moving beyond this left-right hemisphere dichotomy, the present section aims to discuss the critical role of articulatory tempo and vocal frequency variability in recovery from non-fluent aphasia.

Singing possesses at least one clear advantage for therapy: it slows down articulatory tempo. This, in turn, has been found to benefit articulatory quality, at least to some extent (Beukelman & Yorkston, 1977; Laughlin et al., 1979; Pilon et al., 1998; Hustad et al., 2003). Moreover, some work points to a particular sensitivity of the left hemisphere to *rapidly changing* speech sounds. Conversely, the right hemisphere may be especially involved in *slowly varying* speech sounds such as singing (Belin et al., 1998; Zatorre & Belin, 2001; Boemio, Fromm, Braun, & Poeppel, 2005; Schönwiesner, Rübsamen, & Von Cramon, 2005; Jamison, Watkins, Bishop, & Matthews, 2006). At this point, one may claim that singing is nevertheless useful in speech therapy, as singing engages the right hemisphere by slowing down articulatory tempo. However, singing and rhythmic pacing were found to be *similarly effective* in slowing down articulatory tempo (Pilon et al., 1998). In other words, it may not be singing that needs to be discussed in light of a left-right hemisphere dichotomy, but *articulatory tempo*. The classical left-right hemisphere dichotomy previously attributed to speech and song may actually be associated with *rhythmic* features.

Another rarely discussed issue concerns the actual performance of singing. It may be a common misunderstanding that vocal variability in fundamental frequency is *larger* when people sing than when they speak. There are *two* reasons why this is not necessarily true. *First*, prosodic variability in fundamental frequency during speaking may easily *exceed* the vocal range achieved during singing, at least with common melodies (for vocal ranges during emotional speech, see Hammerschmidt & Jürgens, 2007). Notably, the results of the longitudinal experiment yielded *higher* values for vocal frequency variability during rhythmic speech as compared to during singing. *Second*, singing actually means *not to change* fundamental frequency during a defined period of time — one note, for example. In contrast, speaking involves the *continuous change* in fundamental frequency — such as by gradually raising the voice at the end of a question. That is, it may be very misleading to think that singing inevitably *increases* spectral variability, hence engaging the right hemisphere. Instead, singing common melodies — suppose within the range of an octave — may have the opposite effect, *decreasing* spectral variability as compared to normal prosody in spoken utterances. In other words, we tend to vary more in vocal frequency when we speak than when we sing — at least when comparing natural prosody to simple melodies.

10.2 Stimulating corticostriatal loops: rhythmic pacing in speech therapy

Constituting an internal rhythmic pacemaker for syllabic segmentation in speech production, the basal ganglia have been proposed to communicate with cortical brain areas in an open-interconnected system of corticostriatal loops (Joel & Weiner, 2000; Kotz, 2006; Kotz et al., 2009; Sidtis, 2012). One may argue that patients with lesions constraining the corticostriatal system can not — or not fully — rely on this pacemaker. As a possible result, patients may show severe rhythm-related deficits in speech production. An *external* source of rhythmicity — a metronome, for example — may help to overcome this inability of internal self-pacing. More specifically, an external source of rhythmicity may *reinforce* residual activity in corticostriatal loops — or even partly *bypass* corticostriatal damage. At least theoretically, this view is in accordance with the current data. The cross-sectional results suggest that lesion size within the basal ganglia relates to the degree to which speech production in aphasic patients depends on external sources of rhythmicity.

The idea of stimulating corticostriatal loops through rhythmic cues could be all the more exciting when it comes to neurophysiological approaches in treatment of non-fluent aphasia (Schlaug, Marchina, & Wan, 2011). Deep-brain and transcranial magnetic stimulation, for example, have made groundbreaking progress possible in the treatment of Parkinson disease (Schiefer, Matsumoto, & Lee, 2011; Murdoch, Ng, & Barwood, 2012). Although non-fluent aphasia and Parkinson disease clearly differ in type and aetiology, both patient groups show a distinct responsiveness to rhythm (for apraxia of speech, see Brendel & Ziegler, 2008; for Parkinson disease, see McIntosh et al., 1997). Moreover, speech-motor disorders and Parkinson disease may both depend on damaged subcortical circuits (Whelan, Murdoch, Theodoros, Silburn, & Hall, 2005). Deep-brain stimulation could therefore help to at least partly restore corticostriatal dysfunction. Indirect evidence for this idea comes from research on rats (Alam, Heissler, Schwabe, & Krauss, 2012). In other words, deep-brain stimulation could open new ways of aphasia therapy in the future.

10.3 The neuroanatomy of formulaic language: open questions

Just as with rhythm, the neural underpinnings of formulaic language may challenge the classical left-right hemisphere dichotomy underlying speech recovery. It was shown that singing therapies mainly focus on training of common, formulaic expressions (Albert et al., 1973; Sparks et al., 1974; Albert, 1998; Helm-Estabrooks & Albert, 2004; Norton et al., 2009). Furthermore, the production of formulaic language was found to engage right corticostriatal brain areas (Speedie et al., 1993; Van Lancker Sidtis et al., 2003;

Van Lancker Sidtis & Postman, 2006; Sidtis et al., 2009). Thus, formulaic language is commonly preserved in left-hemisphere stroke patients (Lum & Ellis, 1994). Hence, there is obviously *no need* to assert a compensatory left-right hemisphere dichotomy underlying post-stroke recovery of formulaic language. Rather, the right hemisphere may need to be viewed as a valuable *resource* that patients are still able to access, even after an extended left-sided stroke. The present results suggest that this access does *not* depend on whether patients sing or rhythmically speak.

However, some questions still remain. Research on the right-hemispheric processing of formulaic language is mainly based on lesion studies (Speedie et al., 1993; Van Lancker Sidtis & Postman, 2006; Sidtis et al., 2009). Although the studies all point in the same direction, they offer only limited insight into the neuroanatomy of formulaic language. For example, the critical role of right corticostriatal regions in the production of formulaic language does not rule out support from *additional* brain areas. Accordingly, some authors reported activity in the *right cerebellum* during covert production of overlearned word strings (Ackermann, Wildgruber, Daum, & Grodd, 1998). Moreover, a case study reported on a patient with residual aphasic symptoms, but impaired production of overlearned word strings — even though the right hemisphere was intact (Marangolo, Marin, & Piras, 2008). Further research will have to specify the cortical areas and subcortical nuclei involved in the production of formulaic language.

In the current experiments, formulaic and non-formulaic speech stimuli clearly differed. Differences were based on judgments of clinical linguists and on word transition frequencies. In everyday life, however, transitions between formulaic and non-formulaic expressions are more fluent and dynamic. For instance, the contribution of the right hemisphere during formulaic speech tends to be strongest for *pragmatically oriented vocal elements*, such as swearing ('damn'), pause fillers ('uh') and discourse elements ('well'). In contrast, *conversational speech formulas* ('how are you?') tend to be less lateralized (Van Lancker Sidtis & Postman, 2006). Controlling for different formulaic language types may therefore be crucial in future work.

A further issue touches upon *perceptual* aspects of formulaic language. Comprehension of formulaic language is highly relevant for aphasic patients, as they constantly interact with other people, who in turn use formulaic phrases to respond. That is, aphasic patients are continuously exposed to formulaic language. Until now, it is unclear whether the right hemisphere supports both the production *and* perceptual aspects of formulaic language. If so, then left-hemisphere stroke patients should be able to understand formulaic language comparably well, whereas they should show more difficulties in capturing propositional content. Indeed, *two* observations point in this direction. *First*, aphasic patients often achieve very low scores in comprehension tests, while they seem able to react properly in communicative, formulaic contexts. Preserved comprehension of formulaic language may be one of the causes for this finding. *Second*, integrating formulaic phrases in the patients' everyday life was an essential part of the current longitudinal experiment. The success of this everyday use was especially surprising in patients who otherwise showed limited comprehension skills. Again, spared comprehension of formulaic language may have facilitated the patients' success.

10.4 Non-articulatory effects of melody and rhythm in speech recovery

The current work focused on the question of whether singing and rhythmic speech may affect articulatory quality in different ways. The results indicate that singing and rhythmic speech may be similarly effective, both from a cross-sectional and from a longitudinal view. The picture seems different if one focuses on possible *non-articulatory* effects arising from singing. One may think that, for example, singing motivates patients in a unique way, which in turn may be an important advantage in speech therapy. Indeed, some work supports this idea. A functional imaging study revealed activity in the mesolimbic system during music listening (Menon & Levitin, 2005), while professional musicians showed increased dopamine expression compared to non-musicians (Emanuele et al., 2009). Both findings suggest reward processing during and after exposure to music. It may be argued that these results alone warrant the use of singing in speech therapy. On the other hand, non-articulatory effects could just as well arise from *rhythmic* features. The critical question may therefore be: does singing have a non-articulatory advantage over rhythmic speech?

Little is known so far about the existence of non-articulatory effects arising from rhythm in speech therapy. Indirect support for such effects may be derived from a study on rhythmic tapping (Kokal, Engel, Kirschner, & Keysers, 2011). Participants who were able to synchronize their beat with another drummer showed increased activity in the caudate nucleus, suggesting reward processing. Different work suggests that metric regularity in language perception may facilitate semantic processing (Rothermich, Schmidt-Kassow, & Kotz, 2012). Yet, these results may have to be viewed with caution in the current context, as these studies did not compare melodic with rhythmic influences.

Non-articulatory effects from singing and rhythmic speech have not been the focus of the present experiments. Given the temporal scope of the longitudinal experiment, with about forty hours of training for each patient, it seems nonetheless striking that singing and rhythmic therapy patients showed very similar performances both during and after therapy. If singing had motivated the patients more than rhythm alone — then would one not have expected different results? Asked whether they preferred to sing or to rhythmically speak common phrases, the patients did not show any preference. Rather, the patients' attention mainly focused on *what* they were about to articulate — and not on *how* they articulated it. Nonetheless, the current experiments do not provide a satisfactory answer to the question of whether singing and rhythmic speech differ in terms of non-articulatory aspects of speech recovery.

An interesting point in this regard may be to consider singing and phrase production as *two separate*, but *simultaneous* tasks. This may not apply equally for rhythmic speech, as meter is an *inseparable part* of stress-timed languages. Given the numerous elements used in melodic intonation therapy (Helm-Estabrooks et al., 1989; Helm-Estabrooks & Albert, 2004), one may ask a provocative question: does singing consume additional cognitive resources that could otherwise be concentrated on articulatory quality — if patients were not singing, but just speaking rhythmically? In light of this question, it seems astonishing that the studied patients did not perform *worse* during singing compared to rhythmic speech. How did the patients succeed in mastering this additional task without any prior training in singing? Independent of whether singing is resource-consuming or not, the question may be an innovative extension of the present debate on non-articulatory effects in speech recovery.

10.5 Tapping into formulaic language: in search of more refined techniques

The current experiments highlight the importance of preserved formulaic language in left-hemisphere stroke patients with non-fluent aphasia. This finding is all the more intriguing in clinical practice. Many aphasic patients are able to *effortlessly* produce even phonetically complex utterances, if these utterances are part of a formulaic phrase. In contrast, patients often seem to struggle with each single letter in a *non-formulaic* utterance. Producing the consonant /k/, for example, sometimes poses insurmountable problems, especially in patients with apraxia of speech. However, many of these patients are nonetheless able to respond using the formulaic phrase 'ok' — *including* the consonant /k/. Commonly, patients are not aware of how flawlessly they articulate difficult consonants embedded in a formulaic phrase. This kind of preserved ability may hold the key to future therapies.

One may wonder why formulaic language has barely been studied so far considering its huge potential for therapy. The main reason for this scientific gap may be the problem of *how* to tap into formulaic language systematically. How can preserved motor automaticity in formulaic expressions be successfully transferred to the *deliberate* production of non-formulaic, propositional utterances? What may be the underlying mechanisms in the brain if patients learn to use right-side, formulaic chunks in an analytical, purposeful way? A lot of work will be necessary to address these questions. Given the paucity of effective therapies for patients with non-fluent aphasia, this may be a promising way forward.

A first step on the way to tapping into formulaic language may be to have a closer look at *meter* in stress-timed languages. Patients tend to have fewer difficulties with syllables that are preceded by metrically prominent syllables within a word. Let us suppose that the noun 'envelope' (['en.və.ləʊp]; stress on *first* syllable) and the verb 'envelop' ([en.'ve.ləp]; stress on *second* syllable) only differed in meter, being dactylic in the first and iambic in the second case. Now suppose that patients with non-fluent aphasia are provided with the first syllable of each word ([en] in both cases) and always asked to produce the remaining syllables ([və.ləʊp] and ['ve.ləp]). Would meter affect articulatory quality of the remaining syllables in each case? If yes, and if this finding is validated on a broader empirical basis, then meter could be more systematically used to facilitate word and phrase production in patients with non-fluent aphasia.

Appendix

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Curriculum Vitae

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Education

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Stahl, Benjamin

TREATMENT OF NON-FLUENT APHASIA THROUGH MELODY, RHYTHM AND FORMULAIC LANGUAGE

Doctoral dissertation

177 pages, 179 references, 9 figures, 10 tables

Paper Preserved singing in left-hemisphere stroke patients with non-fluent aphasia has inspired mainly *two* research questions. If the experimental design focuses on one point in time (*cross section*), one may ask whether or not singing facilitates speech production in aphasic patients. If the design focuses on changes over several points in time (*longitudinal section*), one may ask whether or not singing qualifies as a therapy to aid recovery from aphasia. The present work addresses both of these questions based on two separate experiments.

A *cross-sectional* experiment investigated the relative effects of melody, rhythm, and lyric type on speech production in seventeen patients with non-fluent aphasia. Contrary to earlier reports, the cross-sectional results suggest that singing may *not* benefit speech production in non-fluent aphasic patients over and above rhythmic speech. Instead, the current data indicate that *rhythmic pacing* may be crucial, particularly for patients with lesions including the basal ganglia. The findings suggest that benefits typically attributed to singing in the past may actually have their roots in rhythm. Moreover, the results demonstrate that lyric type may have a profound impact on speech production in non-fluent aphasic patients. Among the studied patients, *lyric familiarity* and *formulaic language* appeared to strongly mediate speech production, regardless of whether patients were singing or speaking rhythmically. Lyric familiarity and formulaic language may therefore help to explain effects that have, up until now, been presumed to result from singing.

A *longitudinal* experiment investigated the relative long-term effects of melody and rhythm on the recovery of formulaic and non-formulaic speech. Fifteen patients with chronic non-fluent aphasia underwent either singing therapy, rhythmic therapy, or standard speech therapy. The longitudinal results suggest that singing and rhythmic speech may be *similarly effective* in the treatment of non-fluent aphasia. Both singing and rhythmic therapy patients made good progress in the production of common, *formulaic phrases* — known to be supported by right corticostriatal brain areas. Conversely, patients receiving standard speech therapy made less progress in the production of formulaic phrases. They did, however, improve their production of unrehearsed, *non-formulaic utterances*, in contrast to singing and rhythmic therapy patients, who did not. In light of these results, it may be worth considering the combined use of standard speech therapy and the training of formulaic phrases, whether sung or rhythmically spoken. This combination may yield better results for speech recovery than either therapy alone. Standard speech therapy focusing on non-formulaic, propositional utterances may engage, in particular, left perilesional brain regions, while training of formulaic phrases may open new ways of tapping into right-hemisphere language resources — even without singing.

Referat Nach einem Infarkt in der linken Hirnhälfte erleiden die Betroffenen häufig einen tiefgreifenden Verlust der Spontansprache — eine sogenannte nicht-flüssige Aphasie. Doch oft können sie noch ganze Texte fehlerfrei *singen*. Aus dieser erstaunlichen Beobachtung haben sich insbesondere *zwei* wissenschaftliche Fragen herausgebildet. Liegt das methodische Augenmerk auf einem Messzeitpunkt (*Querschnitt*), stellt sich die Frage, inwiefern Gesang die Sprachproduktion für Patienten mit nicht-flüssigen Aphasien erleichtert. Werden mehrere Messzeitpunkte verglichen (*Längsschnitt*), liegt die Frage nahe, ob sich Gesang auch zur Therapie nicht-flüssiger Aphasien eignet. Die vorliegende Arbeit widmet sich diesen beiden Fragen mit zwei Experimenten.

Ein experimenteller *Querschnitt* untersuchte den jeweiligen Einfluss von Melodie, Rhythmus und Liedtextart auf die Sprachproduktion an siebzehn Patienten mit nicht-flüssigen Aphasien. Entgegen früheren Berichten erwies sich das Singen im Experiment als *nicht* über den Rhythmus hinaus entscheidend für die Sprachproduktion der untersuchten Patienten. Vielmehr lassen die Ergebnisse *rhythmischen Taktgebern* eine wesentliche Bedeutung zukommen, insbesondere für Patienten mit Läsionen einschließlich der Basalganglien. So könnten Befunde, die in früheren Arbeiten dem Singen zugeschrieben wurden, tatsächlich auf Rhythmus beruhen. Die Ergebnisse unterstreichen darüberhinaus den hohen Stellenwert der Liedtextart. Die *Vertrautheit* und *Formelhaftigkeit* der Texte hatte weitreichende Auswirkungen auf die Sprachproduktion der untersuchten Patienten — unabhängig davon, ob diese sangen oder rhythmisch sprachen. So mag für Patienten mit nicht-flüssigen Aphasien nicht das Singen selbst maßgebend sein, sondern das Erinnern vertrauter Liedtexte und der Abruf überlernter, formelhafter Ausdrücke.

Ein experimenteller *Längsschnitt* untersuchte, wie Gesang und rhythmisches Sprechen die Produktion formelhafter und nicht-formelhafter Sprache über einen therapeutischen Zeitraum hinweg beeinflussten. Fünfzehn Patienten mit chronischen nicht-flüssigen Aphasien erhielten entweder Singtherapie, Rhythmustherapie oder herkömmliche Sprachtherapie. Singen und rhythmisches Sprechen erwiesen sich im Experiment als *ähnlich wirksam* in der Behandlung nicht-flüssiger Aphasien. Sowohl mit Sing- als auch mit Rhythmustherapie erzielten die Patienten beachtliche Fortschritte in der Produktion *formelhafter Ausdrücke*, die nach derzeitigem Wissen von Teilen der rechten Hirnhälfte unterstützt werden. Patienten mit Sprachtherapie zeigten insgesamt weniger Fortschritte in der Produktion formelhafter Ausdrücke. Sie allein verbesserten sich jedoch bei der Produktion ungeübter, *nicht-formelhafter Äußerungen* — im Gegensatz zu Patienten mit Sing- und Rhythmustherapie. Aus den vorliegenden Ergebnissen lässt sich daher die vorsichtige Empfehlung ableiten, das Üben formelhafter Ausdrücke stärker als bisher in die gängige Sprachtherapie einzubinden. Nachrangig ist dabei, ob formelhafte Ausdrücke gesungen oder rhythmisch gesprochen werden. Eine um formelhafte Ausdrücke erweiterte Sprachtherapie könnte jeder der obigen Therapieformen in ihrer ausschließlichen Anwendung überlegen sein. Sprachtherapie mit Schwerpunkt auf nicht-formelhafter, propositionaler Sprache könnte insbesondere linke periläsionale Hirnregionen beanspruchen, während die Therapie formelhafter Sprache auf Ressourcen der unversehrten rechten Hirnhälfte zurückgreift — auch ohne Gesang.

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