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Simon Sollereder

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For Anna

Abstract

Introduction

Major theories from 20th century linguistics created abstract and purely symbolic units without any motor or acoustic substance to categorize speech sounds. This idea was also implemented in most linguistic subdisciplines such as Neurolinguistics, Neurophonology and its clinical counterparts. Thus, words are constructed as more or less linear strings of abstract segments, implying a clear boundary between amodal, phonological units and subsequent motor mechanisms involved in phonetic encoding. Modern neurophonetic theories attempt to solve this dualistic approach.

Neurogenic speech disorders provide an opportunity to observe the neurolinguistic phonological-phonetic interface when learned speech motor patterns break down. Two syndromes are of particular interest: apraxia of speech (AOS) and conduction aphasia (CA). Both appear after strokes in the left anterior and middle artery including different cortical and subcortical regions. AOS is considered as a disorder of speech motor planning, while CA traditionally represents an impairment afflicting the long-term storage of phonological units. This study investigates verbal repetition to describe mechanisms of phonetic-phonological encoding in spoken language.

Methods

Three participants with AOS and three participants with CA are examined. Three healthy speakers serve as control group. All groups are confronted with a speech production tasks: verbal repetition with two conditions: (1) normal speech rate with casual articulation (hypospeech condition) and (2) reduced speech rate with careful articulation (hyperspeech condition). The stimuli consist of disyllabic, initial stressed (i.e. trochee) words with different phonetic properties which elicit a natural elision of the /ə/ sound – the most used vowel in German.

Results and Discussion

Results confirm modern theories of Cognitive Neuroscience and neurophonetic approaches to speech processing. Speech rate variables seem to be grounded more extensively in motor-linguistic encoding stages as thought. Individuals with acquired language disorders are sensitive to these paralinguistic factors to a variable extent. Segmental and suprasegmental variables might be impaired differently as discrepancies arise in the capability of segmental vowel reduction between AOS and CA. More evidence was found for continuous phonetic accounts in vowel deletion for both language impairments than for categorical accounts. However, further research needs to address language-specific and cross-linguistic variables to identify mechanisms that influence grammatical processes of phonetic encoding.

Keywords: Syllabic Reduction Processes, Schwa, Neurophonetics, Neurogenic Language Disorders, Aphasia, Apraxia of Speech

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1. Introduction

The present work promotes the interaction of modern cognitive frameworks and theories of speech and language processing, a critical reflection on classical views on cognitive speech encoding levels, and their dynamic connection to speech and language impairments by conducting experiments dealing with verbal imitation and picture naming.

The following introduction frames the practical work that is described in section 2.

1.1. The theoretical framework

The following introduction provides the theoretical and historical background for modern cognitive theories of speech processing. Descriptive linguistic approaches in their structural implementation can partly be interpreted as a crucial source for the development of initial cognitive hypothesis about the human language faculty. Consequently, they were also adopted to explain psycho- and neurolinguistic phenomena. Since ever, these approaches have always caused a lot of controversy and are in constant revision, which ultimately reflects an ongoing discussion between cognitive (Neuro)phonology and (Neuro)phonetics about the substrates and properties of the cognitive organization of speech production and perception.

1.1.1. Formal approaches and phonological theories

Formal approaches have a long tradition in the attempts to explain human linguistic behavior. Grounded in a structuralistic tradition, the dominant paradigm to understand language was that observable language phenomena, i.e. actual produced words, syllables or speech sounds could only be described in terms of their relation to a larger, overstretching system: In this tradition, a word possesses – at least – a dual entity: The speech sound, based on articulatory characteristics, and its mirrored, abstract symbol representation. Likewise, this epistemological dualism found its correspondent in the terminology of descriptive linguistics as words are systemized on the one hand, by their motor-based articulatory and perceptual acoustic, i.e. their *phonetic,* properties and on the other hand by their overarching and categorical *phonological* reality. Even though this approach correctly provides a substantial part of most descriptive language research, such as the conventions made in the *International Phonetic Alphabet* (IPA), it faces a profound challenge within approaches of cognitive linguistics. Within the paradigmatic shift in syntactic theory, the formal approach with a clear separation in phonetics and phonology were adopted in pioneering works of generative grammar [1]. Roughly, phonology is described as a linguistic subsystem, detached from other components of grammar that transform an underlying phonemic sequence according to rules and constraints into a disconnected phonetic form pronounced by the speaker. This dichotomy branched into most cognitive-related linguistic subfields such as cognitive Neurophonology, Neurophonetics and its clinical counterparts.

Classical generative-phonological theories implement two major statements: Firstly, language is recognized as a kind of *knowledge* and secondly, this knowledge is formal. A milestone of this approach lies in the idea that human linguistic knowledge is completely transformed by some formal algebra. Abstract phonological tokens correspond to concrete, but discrete phonetic types in a closed phonetic space. The notion of *knowledge* or *competence,* in this sense, refers then to the ability to apply universal and innate rules, i.e. the grammar, to transfer a linguistic *competence* into a *performance* [1], [2], [3]. This explanation was entirely in agreement with the predominant interpretation of *knowledge* within the framework of *Cognitivism* by the time of the *Cognitive Turn* which implemented a structured, symbolic, representational and computational view on cognition detached from any materialistic substance. The interpretation of grammar might hold for theories of syntax or morphology and the influence on research of language acquisition is beyond doubt. Conversely, in the field of phonology, it is faced with several critical issues (see 1.1.3. for details). In a final step, the ongoing discussions represent the somehow unsolved *mind-body-dualism* dilemma within the domain of philosophy of mind [4], [5].

As stated, early formal phonological theories are grounded in a cognitivistic approach to the mind and represent a nativist and generativist view on language faculty. They again have undergone serious adaptations discussing the characterization of rules, the role of constraints and uniqueness or the sensorimotor groundings of abstract phonological features, i.e. phonetic properties such as [voiced] or [nasal], phonemes, such as [b] or [n], or syllables. With a strict phonological approach, the rules and constraints that guide the mapping process of abstract phonological units onto stable phonetic concepts should therefore be one of the main interests of linguistic subfields dealing with the nature of speech processing. With the background of connectionist models, more recent developments in phonological theories such as *Optimality Theory* (OT), *Harmonic* Grammar (HG) or *Maxium Entropy* Grammars (MEG) helped to develop new methods to explain the cognitive substrates of phonological representations, the constraints or rules which guide the well-formed combination of these units and how they interact between each other to determine the stable phonological and phonetic space [6], [7]. Interactive connectionist models that deal with the – in a generativist terminology – superficial phonological encoding, describe an ordered set of discrete phonemes as the input to an unspecified speech motor component at the end of the word retrieval process [8]. The idea implements a translation of selected phonemes into an articulatory code for the control of speech muscles [9]. Similar models can be found in [10].

Even though, the overarching cognitive architecture changes, these recent works collect and perpetuate modern generativist views on phonological processing in a rather direct terminological and explanatory manner [3], [11]. These approaches face complex challenges if they are interpreted within modern theoretical and neuroscientific – oriented frameworks such as *Embodied Cognition* or *Common Coding Theory* [4].

1.1.2. Phonological Principles

On a descriptive level, phonetic processes are described with IPA (i.e. *the International Phonetic Alphabet)*, pretending a closed phonetic space with a categorical and fixed inventory of vowels and consonants. However, phoneticians do assume a possible open phonetic space that is indefinitely large [12]. The IPA interprets the phonological description that languages differ in a small number of static segmental phonemic contrasts and their lexical-relevant properties rather precisely, while other phonetic characteristics such as anatomical features of the vocal tract, speaking rates, speaker idiosyncrasies, pitch or style of voice are neglected. The comprehension of statics is furthermore not easily compatible with phonetic oriented theories. Speech movements are produced and perceived as continuous events in a temporal space. This represents one of their crucial features for both speech perception and production and certainly discriminates it substantially from orthographic systems. In speech perception, the analog temporal information of speech sounds must somehow be stripped away or recoded in the mapping process to digital and categorical units, while In the process of speech production it happens contrariwise. Discrete rule-adapted mathematics that is based on integers only offers a metaphorical and limited interpretation of these continuous processes. And even though modern phonological theories implement stochastic and dynamic mathematical models, the algebraic and rule-approach in a cognitivistic tradition is still widespread in the early 21st century [13]. In phonological terminology, all systems of human *core knowledge*, such as naïve physics or primitive number systems, should therefore embrace a unique design that is universal, productive, inherent and adaptive. In the domain of cognitive phonology this has some major implications and serves as the main argument for the relative autonomy of the phonological system [13], [14]. Accordingly, Consonant-Vowel-syllables (i.e. *CV-syllables*) are not represented under a phonetic bottom-up pressure, but rather designed by an algebraic optimization process in sort of a top-down procedure. The concepts of vowels and consonants and their overlapping temporal appearance in concrete speech and essential phonetic properties form uniform categorical *equivalent classes* whose members all are threatened alike. The discussion about innateness of phonological principles deals with a rich system of apriori and hereditary available features such as [consonantal], [high] or [coronal], offering a set of 40 - 50 phonetic features [2]. Since generativism emerged, very few attributes have been added. Sonority restrictions, i.e. loudness profiles from speech sounds that guide the formation of preferred syllable structures, are not captured by functionally phonetic motivations, but arise by principles that are abstract and rule – oriented [3], [15]. Phonological approaches implement a universal perspective on phonology comprising shared processes across species, crosslinguistics aspects among all human spoken languages and crossmodal aspects between written, spoken and sign language, i.e. the same basic principles for graphemes and phonemes or, even further, for human sign languages [16], [17], [18]. Despite these strict phonological interpretations of language acquisition and processes, a rising number of models or theories within phonology call for stronger emphasis of the phonetic groundings of phonology, e.g. *gestural coordination grammar* [19], [20].

1.1.3. Phonetic Interpretations and Theories

Phonetic theories do not neglect at all the cognitive existence of a categorical processing level. A lot of empirical data from varying linguistic subfields do support their psycholinguistic reality. However, the critics comprise the properties of this module on a descriptive, psycholinguistic, cognitive and biological level. Exemplarily, some aspects shall be presented without any claim of completeness.

From a strong phonetic perspective, the descriptive transcription from a possible infinite number of phonetic sound combinations to finite number of phonemic symbols via the IPA definitely represents a very limited and decoupled way of interpreting the fine-grained articulatory capabilities. Transcription is very difficult, inconsistent and erroneous. Human spoken languages differ immensely in their temporal-phontotatic and rhythmic patterns and inappropriate timing is one of the prominent features in difficulties for second language learners. Spectral analyses reveal that speech is transitory and continuous and sounds overlap in extremely narrow temporal slots rather than being linear arranged. Word boundaries can spectrally be inexistent and are partially constructed on the basis of pre- and postlexical bottom-up processes. Furthermore, the phonetic spaces are highly asymmetrical, context-induced and shaped by interutterative, intra- and interpersonal differences in articulation and segmental and suprasegmental prosody: The acoustics of a given speech sound vary as a function of the vocal characteristics of different speakers, speech rate and changes due to coarticulation effects from adjacent speech sounds or cross-syllable boundaries [21], [22].

Lexical studies involving minimal pairs, i.e. pairs of words that change their meaning by replacing one or more critical feature, such as /disk/ [-rounded] and / dəsk/ [+rounded] or /bərri/ [+bilabial] and /vəri/ [-bilabial], support a lexical-categorical distinction between speech sounds. All languages have such language-specific tables of minimally distinct sets of features in their lexicon. But many of these phenomena are incompatible with serially ordered phonetic symbols and reflect language-specific regularities and not cross-linguistic universals. Already infants are extremely good at identifying the phonetic-phonological structure of languages: They are preferentially tuned to the characteristics of speech, they recognize the distinctive rhythm of their native language and pick up regular patterns in a speech stream (e.g. the pattern in *mokiki, ponini* or *solili)* only after a very short time of exposure [3], [23]. Children are able to distinguish between many sound contrasts of many languages, but as they lose this capability after the first year among features that are not employed in their own mother tongue, this calls for a huge perceptual bias in the time course of developing abstract phonological concepts [24].

Furthermore, a huge number of studies investigate phenomena associated with different *Voice Onset Times* (VOT), i.e. the lag between the consonantal release and the onset of voicing in voiced stop consonants, as it offers an in-depth analysis of continuous articulatory processes associated with categorical perception and production. Short or negative VOT (i.e. < 30ms) are perceived as voiceless consonants, (e.g. /p/ or /t/) while longer VOT (i.e. > 30ms) are perceived as voiced consonants (e.g. /b/ or /d/). Early studies already show a discrete interpretation of these phonetic features [2], [25]. Also neuroscientific investigations of both speech perception and production address the phonetic-phonological interface problem. Studies using *Event-Related-Potentials* (ERPs) – i.e. a neuroscientific method to collect electrical activity from neuronal and synaptic assemblies to nearby observable phenomena in order to predict cognitive operations in a high temporal resolution – provide evidence for both bottom-up and top-down processes of neuronal mechanisms involved in VOT processing [26], [27], [28]. Comparing a between-category VOT contrast to a within-category contrast, a significantly larger mismatch response at a very early step of cognitive processing was found for the between-category contrast than for the within-category contrast. This suggests that phonetic principles on low-level cortical systems already guide phonological processing. This leads to ideas of a continuous space for vowels or VOT, negating the ideas of cognitive abstract representations all together [26], [29], [30]. On a biological level, the complex mapping of discrete operations on symbols called "*Ontological Incommensurability Problem", " Granularity Mismatch Problem"* or *"lack of invariance"* [31], [32]. The considerations propose that phonological categories are deeply grounded in their phonetic roots and reflect the already stated question of how concrete and physical phenomena like temporal and spectral information of speech sounds are mapped onto biological systems that potentially create representations at a specific level of cognitive processing. In the domain of speech perception, the extremely specialized properties of such lexical representations arise from acoustic and auditory principles [33], [34]. These results also disagree with phonological views on the universality of phonological principles including issues as domain specificity, modularity and specialty of language and speech. Among all the communalities between human and nonhuman speech, human speech is still considered to be distinct in its anchorage in motor cortical areas with strong interconnections to auditory and somatosensory association areas and in its selected potential for planning and learning [35], [36], [37].

Recent theories from cognitive science seem to provide a more profound architecture for a phonetic interpretation of phonology [4], [38], [39]. The *embodied approach* redefines the term *knowledge* in a way that it is the result of an ongoing cognitive interpretation emerging from our situated biological embodiment, rooted in dynamic principles of action and perception of human cultural history and the enactment with the surrounding world. In this view, action and perception are inseparable and fundamental roots for cognitive processes. *Categorization*, as one of the most fundamental cognitive activities that all organisms perform, appears thus on a basic level to be the point at which cognition and environment become simultaneously connected [4]. Additionally the framework of *Common CodingTheory* offers a hypothesis of how perceptual and motor systems are linked and shape our understanding of the world [40]. Both speech production and comprehension literature propose theories involving motor substrates in the decoding of phonetic-phonological concepts, i.e. vocal tract gestures. Several theories and models likewise dispense with the same assumption of a strict division between phonology and articulation. *Articulatory Phonology*, for example, considers the abstract representations of words as bundles of gestural units which – unlike the phonemes of generative or structuralist phonology – are characterized by a transparent relationship with the unfolding speech movements [10], [22], [41], [42], [43]. In modern phonetics, task dynamic models incorporate this kinetic perspective whereby speech acquisition includes not only the learning process of the dynamics of each single articulatory gesture but also the *tuning* of the system to coordinate the gestural units into higher-order structures such as syllables or words. They are constrained by the frequency of occurrence and their intergestural links in the speaker's native idiom [44], [45].

1.2. Neuronal Substrates of Phonetic-Phonological Processing

Neuroimaging studies reveal different areas to be sensitive to phonetic and phonological processing in the brain. Below, an overview of the different brain regions involved in the temporal course of pre- and postlexical speech processing will be provided emphasizing also the contributions of frontal and subcortical motor areas as a direction for the current study.

Most models of initial speech perception agree (1) on major cortical areas involved in speech processing and (2) on parallel processing streams in terms of ventral and dorsal streams, but differ (1) in their precise localization and lateralization of functions and (2) in their assumption about the amount of neuronal streams and their functional role. Differences certainly arise out of task designs, analyzing methods, inter- and intrasubject variability and interfering subprocesses which are not yet revealed. For this study, the focus is preliminarily on the hierarchical model for speech processing proposed by Hickock and Poeppel (see Fig. 1 and Fig. 2) and the proposed neural architecture of phonological-phonetic processing by Ziegler and Ackermann [46].

In comprehension, speech is processed by the acoustic nerve and sent to the tonotopically organized primary auditory cortices (*PAC)* located bilaterally in a core region in the gyri temporales transverse, namely the Heschel's gyrus (*HG).* Evidence for this view is also brought by studies from nonhuman animals [47]. It is situated on the superior surface of the temporal lobe. Qualitatively functional differences between the right and the left hemispheres in processing speech and music are supposed to reflect subtle different neuronal response patterns sensitive to different acoustic spatial and temporal patterns in both domains. Even though music and speech share a variety of acoustic features, more evidences arise in specific neuronal circuits for the two. An idea that is shared also by neuropsychological dissociations in patients that show the inability to process a single non-speech related tone or music, i.e. *Amusia,* while normal processing in spoken language tasks [48]. Next to the HG, three regions are important in further acoustic processing: A region located posterior to the HG, the planum temporal *(PT)*, a region more anterolateral called planum polare *(PP)*, and a region at the lateral convexity of the cortex in the superior temporal gyrus *(STG)* extending to the superior temporal sulcus *(STS)*. PT and the region lateral to HG at the convexity of the STG developing into the STS were found to be active for phonetic parameters, but also to variations of spectral properties and frequency changes in non-speech sounds, suggesting that they are not exclusively supporting speech processing [49]. Preparing higher linguistic analyses and subsequent processes, a clear preference in activity patterns is seen in the left hemisphere. Middle and anterior parts of the left STG respond to prelexical stimuli, such as consonant - vowel discriminations or syllables. When focusing only on phonetic and phonological analysis, leaving non-speech stimuli apart, activation spreads on the left mid-posterior STS and mid-posterior ventrolateral STS, even though it is not easy to clearly separate phonetic from phonological task designs. The transition is silent. Within such studies, there is almost no activation pattern found in the right hemisphere. As described, short-range pathways within the temporal cortex, one from HG to PP and anterior STG via a rostral fiber pathway and another one from HG to PT and posterior STG via a caudal fiber pathway suggesting two auditory processing streams before higher lexical-based processing steps arise.

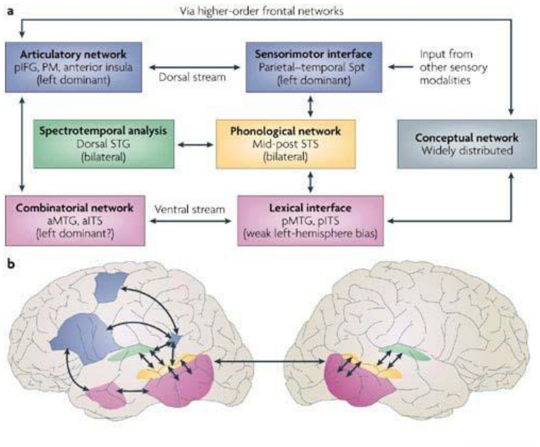

Fig. 1: The dual-stream model of speech processing (50).

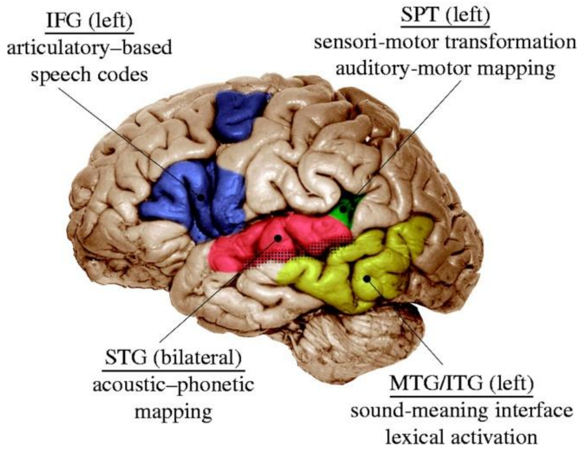

Fig. 2: Functional anatomy of sound – speech processing (32).

For a comprise review of underlying models and brain regions involved in acoustic-phonetic-phonological processing steps see [51], [52], [53].

For this study, it seems interesting to connect the domains of speech perception and production and review evidence that argue for an integration of both articulatory and acoustic features on a neuronal level supporting theories such as *Common Coding Theory* and *Articulatory Phonology*. Results from clinical behavioral investigations, i.e. lesion studies, are supported by studies using neuroimaging techniques. Data from more than one experiment agree that cortical regions in the left posterior superior temporal gyrus *(pSTG)*, the angular gyrus *(AG)* and the supramarginal gyrus *(SMG)* are involved in phonemic aspects of both speech production and perception [26], [52], [54]. Beside the established contribution of frontal areas to speech production, a different amount of studies report frontal areas as well to be involved in speech comprehension tasks. Within the *dual-stream models* apart from short-range temporal interconnections, long-range pathways connect temporal to frontal areas especially believed to be important for auditory-motor integration and sound-to-articulation mapping referred to as *dorsal pathway*. There is evidence for more than one *dorsal stream*, one from the pSTG to the premotor cortex via the arcuate fascile *(AF or dorsal pathway I)* and one from the temporal cortex to the PO via the AF and the superior longitudinal fascicle *(SLF or dorsal pathway II).* Still, the different functions of these streams are not yet clear, as dorsal pathway II seems to develop much later and is also accounted to serve higher-level language processes such as processing nonadjacent elements in syntactically complex sentences. The exact role of the IFG, and more specific Brodmann's area 44 (PO of Broca's area) and the motor and premotor area (Brodmann's area 4 and 6) in speech comprehension tasks are far from clear. Activation in the PO was found when the phonetic category of new stimuli was different compared to its predecessors suggesting a mismatch response in terms of a *prediction error*. This might occur when top-down expectations from earlier experience fail to predict the bottom-up inputs [52]. Furthermore, recent studies suggest activation of premotor areas such as Brodmann's area 6 and 4 during listening tasks leading to *motor theories of speech perception* [55]. Studies using low frequency transcranial magnetic stimulation (TMS) could show that rich speech stimuli such as sentences and words also lead to a decreased ability in phoneme discrimination tasks when the magnetic stimulation was applied to areas in the motor and premotor cortex in a somatotopic manner [56].

In speech production, the anatomic architecture of the articulatory-phonological system starts with a motor plan of an utterance at the end of the *dorsal stream* connecting anterior perisylvian speech motor areas to left superior-temporal and the inferio-parietal cortex [51], [54]. An early neocortical system originating in motor and premotor areas can be identified for the volitional control of the vocal tract muscles. It is in the core of speech motor control possessing only rudimentary functions in primate vocal behavior. A phylogenetically older motor system arises in limbic areas of the medial wall of the frontal lobe and is associated with intrinsic and emotional vocal behaviors. Both of these systems reach the motor nuclei along anatomically separate fiber tracts. The activity of the primary motor cortex is constantly modulated by a motor loop including the basal ganglia. It connects frontal motor areas with these subcortical centers and projects back via thalamic nuclei to its site of origin, supporting a facilitation of movement execution and a modulation of the motor commands. Additionally, cerebellar circuits are interpreted as *internal model* or *efference copies*, simulating cerebral cortical movement control mechanisms and predicting the sensory consequences of these motor commands [43], [46].

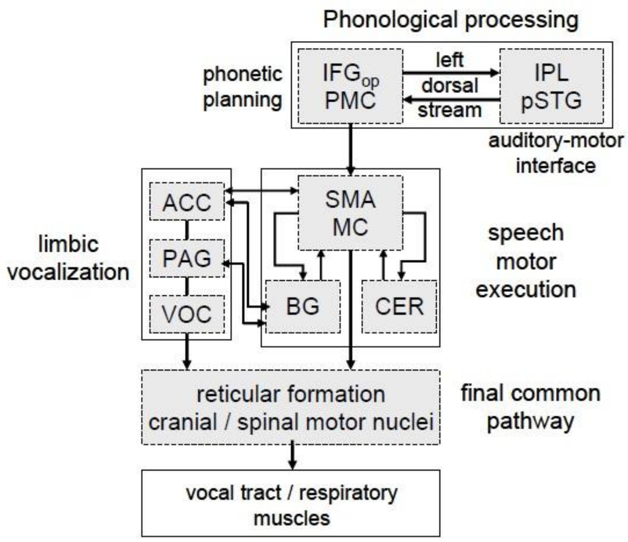

Fig. 3: Gross architecture of the neural network subserving phonological and articulatory processing, identifying the phonological and phonetic planning components (top), the speech motor execution and the limbic vocalization system (middle) and the final common pathway (bottom). ACC: Anterior cingulate cortex; BG: basal ganglia; CER: cerebellum; IFG_{OP}: inferior frontal gyrus, pars opercularis; IPL: (left) inferior parietal lobe; MC: (primary) motor cortex; PAG: peri-acqueductal grey; PMC: (left) premotor cortex; pSTG: (left) posterior superior temporal gyrus; SMA: supplementary motor area; VOC: vocalization-related pontine neuron pool.

Speech perception and production seem to be tightly interconnected and influence each other vice versa. On a neural level, both frontal areas are engaged in speech comprehension tasks and temporo-parietal areas in speech production tasks. Still, there are ongoing discussions whether there is a single phonological network serving both production and comprehension or if separate brain systems are responsible for those computations. In speech perception literature, theories agree on a link between perceptual units and gestural motor patterns but differ in the involved levels of this interface [22], [41]. If speech is perceived along gestural dimensions, it would offer a framework for explaining why one takes over not only the lexical-phonological relevant gestures of one's communication partners but also those which are suprasegmental and *paralinguistic*. Furthermore, it would help partly solving the invariance problem.

1.3. Phonetic-Phonological Processing in Acquired Language Disorders

Beside descriptive methods, neuroscientific investigations such as event-related potentials or imaging techniques (e.g. functional Magnetic Resonance Imaging – *fMRI*), behavioral measurements can reveal details about the time course of phonological-phonetic encoding steps. Corpora of mispronunciations or slips of the tongue *(SOTs)* in both first and second language learners add additional data to the investigated problem. Additionally, studies involving subjects with developmental or acquired language and speech disorders, i.e. lesion studies, are crucial for understanding cognitive and neural processes of word retrieval. The contribution of Cognitive Neuropsychology over the last thirty years was immense and helped to understand the fundamental principles of the cognitive-linguistic architecture [57]. However, in the dualistic tradition of the linguistic-motor dichotomy, neurolinguists did not pay much attention to motor processing steps subsequent to so-called higher-order linguistic modules. Coventional aphasiology identified the motor domain of speech production as completely detached and entirely irrelevant [58]. For the comprehension of lexical phonological and sublexical phonetic encoding, especially neurogenic speech disorders provide an opportunity to observe the phenomena when learned speech motor patterns break down. Two syndromes are of particular interest: apraxia of speech *(AOS)* and conduction aphasia *(CA).*

In the category of motor speech disorders *(MSDs),* AOS reflects a disturbance in motor planning, programming, coordination and execution processes of highly complex vocal tract gestures that result in their temporal assembly in words, phrases and sentences [59], [60], [61]. As a consequence, on a suprasegmental level, slow overall speech rate, errors of stress assignment on words and sentences, syllable segregation or prolonged but variable inter-word intervals, false articulatory starts and restarts and effortful visible and audible articulatory postures can occur. On a segmental level, an imprecise articulation appears mainly with distorted anticipatory or perseverative phoneme substitutions, additions or prolongations. Increased errors emerge for low frequency syllables, nonsense syllables, syllables with more phonemes or consonant clusters. Errors do occur on both imitative and spontaneous speech and reading tasks and the disorder is often co-associated with nonverbal oral or limb apraxia. Beside those, verbal comprehension or auditory processing skills, reading comprehension and writing are not affected in pure AOS. When all clinical speech disturbances are considered, AOS is not shaped by a homogenous assemblage of symptoms but rather occurs fairly different. It is not yet clear if there are further subtypes of AOS with different disorders between motor programming, planning and execution. AOS often co-appears with other language disorders such as aphasia or dysarthria resulting from neurological disorders, mainly as a consequence of apoplectic strokes or degenerative etiologies localized in left peri-sylvian language areas. That is the left STG, parts of STS and the left anterior insula, connecting fiber tracts to frontal motor areas such as SMA, IFG and Broca's Areas and subcortical areas in the basal ganglia involved in motor tasks [60], [61].

A second disorder in the domain of acquired language and speech impairments is conduction aphasia, a subtype of aphasia. In well-established paradigms, aphasia is an acquired central language disorder after disruptions to higher-order linguistic-organized principles of the language system following a neurological disorder such as an apoplectic stroke, a craniocerebral injury or brain inflammation. In classical descriptions and models, CA is interpreted as a disconnection between motor and sensory language areas leading to the basic clinical characteristics: (1) fluent conversational language, (2) almost normal comprehension and (3) significant impairments in verbal repetition tasks with frequent phonemic paraphasias (i.e. substitutions, metathesis, additions or elisions of speech sounds or phonemes) and repetitive self-corrections, i.e. *conduit d'approches.* Furthermore, word-finding difficulties and paraphrasing appear in all verbal tasks involving lexical processing while speech is well articulated without visible groping and –more or less – prosodic impairments [62]. The errors afflict either the long-term storage of phonological information (lexical type) or the translation of auditory into motor information (post-lexical type). More important for this work is post-lexical CA, as it is influenced by the same critical factors as AOS. Modern Neuroimaging techniques such as fMRI or diffusion tensor imaging *(DTI)* confirmed the neurolinguistic models that CA represents a disconnection syndrome due to damage to the fiber tracts, the arcuate fasciculus, connecting the classical Wernicke's Area (Brodmann area 22) and its sourrounding regions in the STG with inferior frontal areas such as Broca's Area (Brodmann area 44 and 45), motor and premotor frontal areas [62], [63]. The arcuate fasciculus is the main part of a larger tract known as the superior longitudinal fasciculus.

The separation of these two types of impairments represents the theoretical and dichotomic division in higher linguistic (phonological) processing steps and lower motor (phonetic) articulatory processing units. Accordingly, people with CA and (post)lexical phonological errors differ from speakers with AOS. However, delineating CA from AOS represents one of the major theoretical and clinical dilemmas as both show similar error distributions on the surface level of acoustic and perceptual interpretations. People with CA produces well articulated phoneme errors, while the phoneme errors in AOS are only perceived phonemic representing disfluent and phonetically distorted speech [60], [61], [64]. For further details about the phonetic-phonological interface in the context of phonetic and phonological disorders see [41], [61], [64], [65], [66].

1.4. The nature of Schwa deletion

The current study examines the phonological-phonetic encoding stage by investigating syllable reduction processes in individuals with acquired language disorders. Current phonological research is guided by an increase of pragmatic, conversational and idiosyncratic orientation, implementing phonetic-articulatory questions. In this approach, a common phenomenon in connected speech is the deletion of unstressed vowels, e.g. e-schwa vowel /ə/ in bi-or polysyllabic words, such as /kugəl/ articulated as /kugl/ or /murməl/ as /murml/, leading to an authentic and casual articulation. The variability of schwa deletion is recently discussed as it offers the possibility to investigate interactions between linguistic and extralinguistic factors and how variable phonetic styles shape phonological – canonical structure.

Corpora analyses show, e-schwa represents the highest occurring vowel in German and English [67], [68]. In the description of the IPA, a schwa is characterized as central vowel in the vowel space, predictable according to segmental and suprasegmental regularities, appearing only in unstressed positions (position-determined) and not restricted to a certain syllable position at all – i.e. it can appear in pre- and suffix syllables. Descriptive linguistics, furthermore, do not agree if schwa should be awarded (1) as full vowel and (2) as a phoneme at all, as the definition of vowel and phoneme includes the generation of possible minimal pairs, non-predictability and non-stress. For a review see [69]. As stated, there is some evidence that certain linguistic, i.e. lexical or sublexical variables and extralinguistic variables, could have an impact on schwa deletion. Earlier studies debated if it is influenced by lexical stress position, lexical frequency, sonority of the phonetic environment, word length, phonotactic environment or speech style, idiom and gender. For example, there was no agreement on the role of stress-environment or word frequency on deletion. For word frequency, both cases – i.e. high frequency and low frequency are targeted more by deletion processes – are reported. A recent statistical analysis of schwa deletion in American casual speech of the Buckeye Speech Corpus investigated the influence of stress position, sonority distance of the phonetic environment and word frequency. It could be shown that schwa is less likely to vanish in post-stress position in two-syllable words, while more likely in three-syllable words. Moreover, schwa tends to disappear as the sonority distance increases between the enclosing consonants and occurs more frequently in high frequency words than low frequency ones [68]. Recent studies addressed the nature of schwa deletion in careful and casual speech in both the French and English languages, trying to identify the influence of lexical and sublexical variables, i.e. to find the locus of variant productions, and the nature, i.e. categorical or continuous processes, on schwa alternation and schwa duration. In terms of phonology, schwa reduction processes are interpreted as (1) a competition between a tendency to delete lexical-phonological represented unstressed vowels and a pressure to maintain universal restrictions on syllable structure processes, e.g. temporal restriction, during phonetic encoding stages, (2) the result from phonological rules deleting the single lexical-phonological representation according to *Paradigm Uniformity Principles*, or (3) the cooccurence of both lexical representations from variants with schwa and without schwa [70], [71]. Consequently, schwa deletion should lead to well-formed /#CC-/ sequences with respectively clear acoustic-phonotactic properties such as no potential voicing, aspiration or formant structure present between the two consonants. This clearly does not hold for initial or final voiced consonants. Phonetic oriented theories interpret the same observed phenomena in /#CəC-/ sequences as an overlap effect between consonantal gestures and a gradual reduction trial in which the total elision represents the endpoint of a continuous process [72]. This approach is in line with *Articulatory Phonology* calling for a representation of temporal coordination of gesture in the phonological encoding stage and an influence of paralinguistic factors. It is debated how speech rate, as one example of *paralinguistic* factor, influences the manipulation of gestural patterns and phonological regularities. Fast speech influences segmental duration, velocity of the articulators and reduction in the magnate of articulatory gestures, suggesting that there is an obvious tendency to a greater gestural overlap and affecting the specification and implementation of their coordination. The findings from Davidson suggest that schwa deletion is not consistent with a phonological deletion rule that is applied at fast speech rate. Results did not show similar elision rates for different phonotactic environments such as voiceless stop-initial, voiced-initial sequences, fricative-initial or /l/ - second sequences. The former ones might better be explained by an aspiration or devoicing account, while the latter ones were identified by true schwa elision.

The findings from Bürki et al. instead do call for phonological-based categorical account and have different implications for the variables influencing schwa alternation, i.e. deletion processes. They might lead to different encoding levels from which schwa alternation or different schwa duration processes arise. The analysis of more than 4000 tokens in French connected speech from a large corpus of radiobroadcast news showed an influence of speech rate and schwa position in the word on both schwa alternation and schwa duration [71]. Besides that, more attractive were the findings that different variables affect schwa alternation and duration: word position in an utterance, number of consonants in the sequence and sonority principles, i.e. schwa is more often present in words in which its absence would result in a two-consonant sequence with decreasing sonority, seem to affect schwa alternation. Schwa duration, however, is affected by word predictability and voicing specifications of the consonants following and preceding the vowel. The results suggest different loci for schwa duration and schwa alternation (deletion) processes as schwa alternation arises before phonetic implementation and is driven by lexical or phonological processes, while different schwa durations are driven by a phonetic encoding stage. However, lexical frequency could not be identified as a crucial factor for schwa alternation.

Even though there is a slight agreement that rate is somehow encoded in the phonological encoding stage as it influences speech sound alignment, the exact top-down or bottom-up influence remains debated. One account explains that speech rate is governed by a central parameter that directly influences phonological coordination, such as constraints that specify syllable reduction processes or a more overlapping coordination. Accordingly, schwa deletion manifests a competition to maintain overarching syllable structure and a pressure of functional architecture of casual speech with the tendency to delete unstressed vowels. Another idea represents a compensatory mechanism that is not planned at a central level. In French schwa-less variants do occur frequently at slow and formal speech style, not explaining a main effect of pace at all. Differences and divergent results clearly reflect an overall distinction in the theoretical framework constraining or allowing temporal information to influence higher-order linguistic coordination and also variable cross-linguistic study designs as the task in Davidson's study was based on reading pace where no control for the coda consonant in the /#CəC-/ sequences occurred or no explicit link to sonority principles of the surrounding phonotactic environment took place. There is a clear indication for further research.

1.5. Verbal repetition: The imitation of paraphonological details

Repetition and imitation are fundamental cognitive concepts in human interactions and social arrangements. They have a huge impact on learning, intersubjectivity, empathy or affiliation in a social context. In already mentioned modern cognitive frameworks (e.g. the *Embodiment approach* and *Enactivism*), imitation and repetition form a dynamic and adaptive process between cognitive systems built on action and perceptional processes directly enacted with the world. In the domain of language and speech processing, the extraction from speech-relevant acoustic information, the consideration of lexical-relevant properties and the mapping onto articulatory pattern play an important role not only in language acquisition as it helps tuning slender vocal motor gestures but continues also even as first language development has been completed. In a socio-linguistic framework, the gradual adaptation of two speakers in their subfeatural, segmental or suprasegmental encoding of conversational aspects, imitation is interpreted as contribution to a decrease of social distance between them. While repetition is described as the intentional reproduction of only meaningful and relevant phonological units leaving seemingly acoustically irrelevant aspect apart, imitation is an unintended copying of also phonologically irrelevant acoustic properties of the speech stream such as speaking rate or pitch. It would be therefore expected, that in word repetition, one might not only extract the relevant lexical-phonological and categorial units but also reproduce acoustic, phonetic and phonotactic properties such as vocal, prosodic or articulatory contents. Apparently, there is an ongoing discussion about the behavioral and neuronal substrates of speech imitation with a competition of exemplar-based episodic accounts and prototype models. In line with current overarching frameworks, exemplar theory assumes a viability of idiosyncratic variables in the mapping process from an auditory stimulus to a speech motor output. For evidence and reviews on imitation of *extralinguistic* or *paraphonological* details, see [73], [74].

Studies did focus on a variety of phenomena influencing speech imitation to determine the neuronal and cognitive structures mediating such a capability by using different task design, e.g. *shadowing* - i.e. the imitation of an auditory input with extreme short delays, manipulating VOT or investigating changes in pitch imitation *(F0).* Not much research, however, did focus on imitation paradigms in the field of clinical neuropsychology by testing people with left and right hemisphere lesions to add further data to the scientific discourse. Two recent studies from Kappes et al. focused on lesions to the left anterior and posterior persylvian cortex to see if these interfere with imitation. Both studies agreed on an influence of posterior language areas on imitation of phonetic and prosodic details favoring continuous – episodic frameworks of speech processing [73], [74]. As described in the clinical section of the introduction, people with phonological-phonetic disorders can contribute to promote theories of cognitive science in general, specific models of language and speech processing and add data to clinical neuroscience and speech and language pathology.

1.6. Conclusion

In coarse agreement, phonologists do accept the importance of phonetic principles for abstract linguistic symbols and phoneticians admit higher-order categorical organization of phonological representations. However, in the entire consensus about the shared principles in the phonological-phonetic encoding stage, in both written, sign and spoken languages, there is an ongoing discussion about the potential primitives of speech encoding. The theoretical frameworks brought from afar reflect the blurred boundaries between the perceptual and motor-based component of speech processing and the linguistic-oriented domain. Many theories of language perception and production sustain a dualistic or trialistic approach where acoustic and motor processes stand on the extreme early or late stages of speech processing with fairly unrelated equivalent phonological representation at the important part of lexical processing. Auditory and motor principles are seen as nonlinguistic pressures that can impossible be interpreted as the creators of linguistic entities. On the other hand, phoneticians call for multiple dynamic *gesture-based* approaches, forming the bottom-up principles for categorical phonological processes, implementing the ubiquitous temporal dimension of speech, partly denying the notion of *representations* at all and underlining the perceptual shaping of cognition.

Future research needs to redefine several issues including the theoretical definition of linguistic knowledge and performance, the integration of biolinguistic, neuroscientific and linguistic approaches, the role of articulatory, acoustic and auditory, seemingly extralinguistic, processes, the role of pre- and sublexical variables and their influence on linguistic and articulatory fragments such as syllables, phonemes and features or the role of suprasegmental and speaker-based idiosyncrasies such as speaking style or further prosodic information. The clarification of these issues helps to promote cognitive frameworks of cognition, to shape theories of speech and language processing and its neuronal and cognitive substrates and to diversify clinical neuropsychological definitions and diagnoses of speech impairments.

2. The Current Study

The current study merges implicit raised questions from the above described scientific dilemmas with implications on different levels on a continuous, translational axis from cognitive theory to practical aspects.

Individuals with acquired language disorders (IWLDs), i.e. CA and AOS, and healthy controls were assessed with a verbal repetition paradigm of *hyperspeech (*i.e. careful articulated) and *hypospeech* (i.e. casual articulated) variants of bisyllabic words containing a closed schwa-syllable in the unstressed position. Results from this investigation should add further data to the discussion (1) how auditory units are mapped onto stable motor-patterns within the framework of cognitive theories and theories of speech and language processing, (2) to what extent different acquired language disorders show similar or divergent patterns in the repetition of carefully and casually pronounced words, (3) to what extent repetition can be accounted as *imitation* and (4) to what extent schwa deletion can be accounted as categorical deletion or gestural overlap.

Accordingly, expected results center around the overall repeated word duration between the group of IWLDs and healthy controls. If there is statistical significant difference in word durations between the hypo- and hyperspeech condition, this favors an embodied and exemplar-based account of speech imitation and production. Secondly, if there are differences between overall word duration within the subgroups of IWLDs results would favor a different awareness of paraphonological details supporting the classical clinical diagnoses based on lexical and sublexical encoding stages. Thirdly, the overall range of schwa duration in the copied words between and within the participating groups should be analyzed. If there is statistical difference in the duration range of produced schwas this would account for a continuous mapping process instead of a categorical – homogenous interpretation. Fourthly, in connection to the previous question, statistical differences in categorical schwa production and schwa duration in varying phonetic environments, i.e. /#CəC/, and sonority hierarchies would also help to promote phonetic accounts of phonological representations instead of categorical, phonetic-independent representations which should show the same overall patterns of deletion or duration. Conversely, if there is a different influence on lexical and sublexical variables among those correctly imitated schwa syllables and those correctly deleted schwas, this would speak for categorical cognitive mechanisms influencing schwa deletion, and continuous mechanisms in reduced schwa durations. The analyses should also respect individual profiles of the participants as clinical differences might interfere and obliterate explicit results.

2.1. Methods

2.1.1. Participants

The experiments in the current study were administered to neurologically healthy participants and to two groups of patients with lesions or neurological disorders affecting mainly the left brain hemisphere and damaging areas occupied by language- and speech-relevant functions. Each group included three subjects: healthy controls (Controls), patients with apraxia of speech (AOS) and conduction aphasia (CA). All participants gave informed consent prior to the investigations. No subject was paid for their participation.

Healthy subjects and patients are not balanced for mean age (*Controls:* M=47, SD=19; *AOS:* M=59.2, SD=10.1; *CA*: *M*=67.3, SD=15.8) or time post onset (*AOS:* M=107.3, SD=156.6.; *CA:* M=29, SD=16.2) Tab. 1 gives an overview on the demographic characteristics of all subjects. All participants were right-handed native German speakers, except participant AK's L1 which was Russian. Still, the subject has been settled in Austria for more than 15 years and was perfectly fluent in German pre-Onset. The handedness was inquired and confirmed verbally, no standardized handedness inventory was administered beforehand. Also, the participants were not tested for hearing problems, but verbally asked if hearing problems are known. All subjects denied. The selection of the participants with language disorders followed a procedure described below.

Tab. 1: Demographic and clinical characteristics of all participating subjects.

Group	Subject (age, gender)	Medical diagnosis	Time Post Onset (in months)
AOS	AK (48, f[1])	Anaplastic astrocytoma	24
	KH (65, m)	Ischemic infarction	10
	KF (66, m)	Ischemic infarction	288
CA	SH (77, f)	Ischemic infarction	13
	TH (49, m)	Hemorrhagic infarction	28
	GM (76, m)	Ischemic infarction	46
Controls	AH (47, f)	-	-
	RP (28, f)	-	-
	GH (66, m)	-	-

[1]m=male, f = female.

2.1.2. Clinical Diagnosis and Pretests

All patients suffered from neurological disorders affecting the language-dominant left hemisphere. Five of six participants suffered from infarction within the vascular territory of the middle cerebral artery. In the CA group two of three participants suffered from ischemic, one from a hemorrhagic infarction. In the AOS group two subjects had an ischemic strokes, one suffers from an anaplastic astrocytoma that attacked the temporal and frontal lobe. All disorders were structurally confirmed and documented by *CAT* (i.e. Computerized Axial Tomography), *MRI* scans (i.e. Magnetic Resonance Imaging) or histological reports.

Tab. 2: Neurolinguistic data of all participating subjects.

Test		Overall Scores					
		AK	**KH**	**KF**	**SH**	**TH**	**GM**
AAT[1]	Overall diagnosis	B	B	B	W	A	W
	Token test	7	9	9	23	16	31
	Repetition	139	47	116	107	99	99
	Reading / Writing	85	23	63	43	67	69
	Naming	114	21	110	58	87	69
	Comprehension	111	111	100	74	108	79
LeMO[2]	Verbal lexical decision (test 5)	U	I	U	I	U	U
	Auditory word-picture matching (test 23)	U	U	U	I	U	U
	Reading aloud (test 15)	U	I	I	I	U	U
	Confrontation naming (test 30)	U	I	I	I	U	I
HWL[3]	Phonological correct	75/96	12/46	65/96	-	55/96	52/89
	Phonetic correct	75/96	13/46	73/96	-	85/96	83/89
	Fluency correct	80/96	46/46	73/96	-	70/96	67/89
Auditory Schwa Discrimination		I	I	I	I	I	I

[1] Aachener Aphasie Test (AAT): B= Broca's Aphasia, W= Wernicke's Aphasia, A= Amnestic Aphasia.
[2] Lexikon, Modell-orientiert (LeMo): I= impaired, U= unimpaired, n= no clear statement possible.
[3] Hierarchische Wortlisten (HWL): - = not tested.

Subjects with the chosen language disorders were pre-selected by examined speech and language pathologists that are trained in diagnosis and treatment of neurological language disorders. Eight participants were selected and six of them were finally included in the study. The clinical pre-testing included (1) the confirmation of the overall neurolinguistic diagnosis by a standardized Aphasia test battery (i.e. *Aachener Aphasietest - AAT*), (2) specific cognitive-oriented tests (i.e. *Lexikon, Modell-orientiert - LeMo*) to assess lexical performances such as verbal lexical access (subtest 5 - *Lexikalisches Entscheiden Wort/Neologismus auditiv*, n=80 and subtest 23 - *Wort-Bild-Zuordnen auditiv,* n=20), a comparison of verbal-lexical output tasks such as reading aloud and confrontation naming (subtest 15 - *Lesen regelmäßiger Wörter,* n=20 and subtest 30 - *Benennen mündlich,* n=20), (3) an auditory discrimination task for words and non-words containing schwa and nonschwa-syllables (n=20) and (4) a word and non-word repetition test assessing errors associated with apraxia of speech such as phonlogical and phonetic errors or disfluency (i.e. *Hierarchische Wortlisten -HWL)* [75], [76], [77].

Aachener Aphasie Test (AAT)

The AAT creates a valid and reliable neurolinguistic profile of the person assessed and allows to group certain linguistic symptoms together to well-known aphasia syndroms, such as Broca's or Wernicke's Aphasia [75]. Since its appearance more than 30 years ago, the test battery and its terminology is still most widely used by clinicians and those professions working with IWLDs and can be understood as the diagnostic beginning in each neurolinguistic assessment of IWLDs in a subacute or chronic stage (i.e. 4 – 6 weeks post onset). It gives an overview of the main language performances, testing abstract color-token selection, verbal repetition, naming abilities, writing, reading and comprehension (verbal and written picture matching).

The six participants in this study were all tested to ensure for their pre-selected language diagnoses and further evaluated by selected additional tests in a close temporal distance to the main experiments. The whole tests were administered strictly according to the main test guidelines (i.e. the procedure of the subtests, temporal sequence or error registration and evaluation). The subtests were audio-recorded and transliterated. The transliteration and error transcription was performed by the author of this study. The evaluation of errors and the establishment of each patient's profile were executed by the computerized evaluation program ALLOC. As for the AOS group (i.e. patients AH, KH and KF), the main diagnosis was Broca's Aphasia, a diagnosis that matches with Apraxia of Speech. Within the test construction of the AAT, AOS was not independently implemented as main diagnosis. As Tab. 2 reveals, major clinical emphasis of AOS is confirmed such as good performances in speech comprehension and in the selection of abstract and colored symbol tokens, similar performances in verbal tasks such as confrontation naming, reading aloud and verbal repetition and an undisturbed faculty of writing. The CA group did not show the favored clinical diagnosis Conduction Aphasia in the first moment. The AAT revealed two Wernicke's Aphasia (SH and GM) and one Amnestic Aphasia (TH). As the test evaluation was only performed for the main syndromes, and Conduction Aphasia does not represent one of those, it is possibly shadowed. Secondly, all patients of CA group do show a relatively disturbed performance in the task of speech comprehension (i.e. auditory and orthographic word- and sentence-picture matching) that probably led to the clinical diagnosis of Wernicke's aphasia. An in-depth analysis although could confirm the favored aphasia diagnosis. Besides, an emphasis was on the appearance of CA-typical errors in spontaneous speech such as conduit d'approches (i.e. the repetitive attempt to correct phonetic-phonemic errors) which all three subjects of the CA-group showed in relatively high-amount and an adequate verbal comprehension in everday-life situations.

Appendix A provides a detailed computer-based neurolinguistic profile.

Lexikon, modellorientiert (LeMo)

A more extensive and more profound analysis of specific language encoding stages is provided by LeMo [76]. With a cognitivistic and connectionistic view on linguistic encoding, it implements a view on language with different modules and routes that can be impaired separately and are intrinsically organized by linguistic-cognitive variables. Cognitive oriented therapy methods had a major impact on speech therapy with IWLDs reflecting also trends in cognitive science in the last decades. Major confirmations of such a view on language come from a broad range of experiments, such as neuroscientific priming-experiments and special single-case studies of impaired patients. As it represents a huge test battery with a lot of different subtasks, it is not suited to replace AAT but provides an in-depth analysis of impaired language modules in a second diagnostic step.

For the purpose of this study, four different subtasks were identified to be useful to address specific cognitive encoding stages: The main goals were to guarantee (1) an unimpaired lexical access and (2) an unimpaired lexical retrieval at best, or, if impaired, an even distributed impairment level across the different lexical tasks (naming and reading aloud). As to the first goal, it seems important to be sure that errors in verbal repetition tasks (i.e. in this study, the repetition words containing schwa- and schwa-less syllables) do not arise due to impairments in the acoustic-auditory path from the periphery to the lexicon. To address such problems, all subjects were verbally inquired about actual hearing problems and were assessed with a lexical decision task (LeMo test 5, n=80) and a word-picture matching task for nouns (LeMo task 23, n=20). When assessing the second goal, it also seemed important to check for lexical retrieval deficits as the possible insertion (i.e. *epenthesis)* of schwas in the repetition of schwa-less syllables by the patients should not arise due to a dominant impairment of the lexicon itself but rather due to deficits in the (post-)lexical encoding stage. Therefore, an additional naming task (LeMo test 30, n=20) and a reading task (LeMo task 15, n=20) of concrete nouns should reveal a possible uneven error distribution in one of the modalities in a direct comparison. Additionally, also a paired-sample comparison to the word-picture matching task can reveal isolated problems between lexical access and lexical retrieval as the same items were tested.

The results from the different subtests can be seen in Tab. 3, providing the error rates per participant and test. Assessing lexical access deficits, the tests did reveal different error patterns for the patients. Unfortunately, an unimpaired lexical access could not be shown for all participants according to these tests. However, only patient SH did show both an impaired performance in both tasks (lexical decision and auditory word-picture matching). All others had slight divergent results. However, the error rates only showed slight impairments across all patients with error rates less the 12% except SH with an error rate of 18% in both lexical decision and word-picture matching.

Tab. 3: Specific error rates for the LeMo subtests.

Test		Error rates (in %)					
		AK	KH	KF	SH	TH	GM
LeMo	Verbal lexical decision (test 5)	8	11*	6	18*	10	8
	Auditory word-picture matching (test 23)	0	5	10	15*	0	10
	Reading aloud (test 15)	0	80*	12*	25*	10	0
	Confrontation naming (test 30)	10	80*	35*	45*	10	20*

* impaired according to LeMo evaluation (cut off < 10%).

To see if modality specific lexical retrieval deficits occur and if there are significant between-group differences, reading aloud was compared to a picture naming task including the same items (concret nouns, n=20). Within-group comparisons could not reveal modality specific differences for both the AOS group (M=11, SD=11.53, t(2)=1.65 p=.24) and the CA group (M=13.33, SD=11.54, t(2)=2 p=.18). Furthermore, also between-group comparisons did not reveal significant differences for the single tests (*reading aloud:* M=21.16, SD=30.26, t(4)=0.73 p=.50; *confrontation naming:* M=33.33, SD=26.77, t(4)=0.72 p=.50). However, participants from both groups do show lexical deficits to a certain extent. The results from the naming and reading tasks need to be interpreted carefully and must not be overemphasized. Firstly, patients with CA do show lexical deficits to a certain extent. There are hardly patients without any lexical contribution to their error patterns in verbal tasks as the lexicon is a major encoding level more or less always affected in different aphasia types. Secondly, if no qualitative assessment of the error patterns is executed, it is difficult to distinguish between lexical or postlexical errors in naming by solely looking at the presented error rates. To distinguish between lexical and postlexical errors, an evaluation of the patient's reaction, his lexical search strategy, possible self-cueing mechanisms and compensation answers need to be considered. As the clinical diagnosis of all patients was relatively settled, this investigation was not executed.

Auditory Discrimination of schwa- and schwa-less syllables

Additionally, to control for no deficits in the acoustic and auditory processing of schwa-vowels, an auditory discrimination tasks was added. Participants were given 40 pairs of words containing schwa- and schwa-less syllables and were asked to subjectively judge the even or uneven sound pattern of the two words. The participants had to answer a question such as *"Is there a difference in the two words you are going to hear?".* The pairs of words were designed in an orthogonal manner with 20 words and 20 non-words recorded by the same two trained radio-speakers that also participate in the main experiment (see section 2.3.1). 20 pairs differed acoustically, containing ten times a schwa in the first word and ten times a schwa in the second word (e.g. /korkən/ versus /korkn/ or /barsn/ versus /barsən/). The other 20 pairs did not differ acoustically, again ten words with both a schwa in the first and second word and ten words with no schwa in both words (e.g. /lakən/ versus /lakən/ or /truml/ versus /truml/). The whole set followed the same orthogonal design from the verbal repetition experiment respecting also the phonetic schwa-environment of C1- and C2-consonants. The whole set was evaluated for its reliability by eight healthy raters. Those pairs containing a schwa in the first or second item which did not show an agreement level higher than 0.5 (Fleiss' Kappa level of agreement) were changed and lengthened by the factor 1.3 (frequency spectrum 75-300hz) by the phonetic program PRAAT. Eight pairs were changed.

Assessing both healthy participants and patients with the test, the test revealed a significant insensitivity in discrimination between words containing schwa- and schwaless syllables in all patients and also in one healthy subject, namely AH (Fisher's Exact Test; p>.05). Interpreting the results might reveal a low sensitivity level of the items used in this test, rather than bad discrimination performance as also a healthy subject did perform relatively poor in this task. The test needs to undergo a substantial revision before being used again in further research in this direction. Tab. 4 provides an overview of error rates from the different subjects.

Tab. 4: Error rates and significant wrong discrimination performance (Fisher's Exact Test, p>.05).

Test	**Error Rates**								
	AK	**KH**	**KF**	**SH**	**TH**	**GM**	**AH**	**RP**	**GH**
Auditory Schwa Discrimination	60%*	55%*	50%*	20%*	35%*	40%*	20%*	5%	15%

<u>Hierarchische Wortlisten (HWL)</u>

Another test to assess for phonetic and phonological error distributions in all patients was applied with the Hierarchische Wortlisten (HWL) [77]. It is a verbal repetition tasks that controls for lexical status (i.e. nouns vs. non-words), word length (i.e. words with one to four syllables) and syllable complexity (i.e. open syllables - CV and closed syllables - CC). It allows a descriptive evaluation of phonetic, phonological and fluency errors.

Tab. 5 shows the reached scores labeled for the overall item number (n=96). Descriptively, a rather different picture can be identified within the AOS group reflecting also clinical differences in their symptom constellations. While AK shows a rather good scoring for phonetic, phonological and fluency performance in words but lower values at non-words, HK is highly and similar impaired at the phonetic and phonological level across both categories. In his case, the test could not be finished (n=15). KF showed a relative balanced error distribution with both segmental errors and suprasegmental problems in syllable pulsing, initiation and prosody. The CA group shows an observable difference in scores even less compared to the AOS group. For SH, no test results are given as the test could not be finished due to organizational matters. GM and TH show greater error rates in the phonological than in the phonetic or fluency performance mainly due to phonological paraphasias such as anticipations, elisions or metatheses and conduit d'approches.

Tab. 5: Illustration of error distribution for participants in a test for apraxia of speech (Hierarchische Wortlisten)

Test			Correct Performance					
			AK	**KH**	**KF**	**SH**	**TH**	**GM**
HWL	Words[1]	Phonetic Accuracy (PT)	38/48	4/31	37/48	-	44/48	46/46
		In %	79.2	12.9	77.1		91.7	100
		Phonological Accuracy (PM)	43/48	10/31	35/48	-	35/48	33/46
		In %	89.6	32.3	72.9		72.9	71.7
		Fluency Accuracy (RF)	46/48	31/31	39/48	-	36/48	29/46
		In %	95.8	100	81.3		75	63
	Non-words[1]	Phonetic Accuracy (PT)	37/48	9/15	36/48	-	41/48	37/43
		In %	77.1	60	75		85.4	86
		Phonological Accuracy (PM)	32/48	2/15	30/48	-	20/48	19/43
		In %	66.7	13.3	62.5		41.7	44.2
		Fluency correct (RF)	34/48	15/15	34/48	-	34/48	38/43
		In %	70.8	100	70.8		70.8	88.4
	Qualitative Characteristics[2]	Articulatory effort	1	0	2	0	1	0
		Misdirected gestures	2	2	0	1	1	1
		Syllabic articulation	2	2	3	0	0	0
		Errors in stress assignment	0	0	0	0	0	0

[1] achieved scores according to test items. Test items can vary according to the severity of a participant's disorder.
[2] 0= normal, 3= heavily distorted; -= not tested.

Contrasting between-group differences, as expected, significant differences could be shown for the Phonetic Accuracy (PT) ($M=83.14$, $SD=7.28$, $t(3)=5.7$ $p<.05$) but not for Phonemic Accuracy (PM) ($M=56.77$, $SD=20.8$, $t(3)=0.65$ $p=.95$) or Fluency Accuracy (RF) ($M=79$, $SD=11.87$, $t(3)=0.68$ $p=.54$). Analyzing the qualitative characteristics (i.e. articulatory effort, misdirected gestures, syllabic articulation and errors in stress assignment) no clear picture can be identified between the two groups but almost significant differences could be found for misdirected gestures and syllabic articulation (*articulatory effort:* c^2 (2, n=6) = 3.33, p=.18; *misdirected gestures:* c^2 (2, n=6) = 6.00, p=.05; *syllabic articulation*: c^2 (2, n=6) = 6.00, p=.05; *errors in stress assignment:* no c^2 values computed). Taken together, the results from HWL do not show consistent results for error accuracy or qualitative characteristics. As a consequence a clear demarcation between AOS and CA does not seem possible with this test as symptoms overlap.

Summary

The clinical pre-test phase was executed to ensure for the overall neurolinguistic diagnosis, to check for subtle lexical access and retrieval deficits, to reveal phonetic and phonological error distributions and to show discrimination sensitivity to words containing schwa- and schwa-less syllables. While the AOS group was clearly identified by the AAT, the members of the CA group revealed different aphasic syndromes. A possible reason lies in missing parametric in-depth analysis of the linguistic profiles. The specific cognitive-related language tasks could, unfortunately, not guarantee unimpaired lexical access and retrieval performances and an even distribution of lexical-related deficits in verbal tasks.

A test for phonetic and phonological accuracy show a symptom overlap making it hard to distinguish between CA and AOS, even though certain characteristics differ (e.g. misdirection of gestures or syllable processing). Additionally, reviewing poor discrimination performances among the patients between words containing schwa and schwa-less syllables, the results cannot fully exclude auditory access or retrieval deficits as a contributive part to possible problems in word repetition arising in the main experiment in this study and lowering therefore the possible interpretability of the results.

2.2. Materials

In this section, a short description of the included material used in the repetition task is provided.

Verbal repetition task

In a first account, a list of 400 bisyllabic, trochee singular and plural words were preselected by database researchs, including the CELEX database and the dlexDB database that is based on a reference corpus of the German language in the twentieth century (i.e. the core corpus of the digital dictionary of the German language - DWDS) containing around 1 billion tokens [78], [79]. The selection of the words followed lexical status (i.e. only nouns were selected) and they were controlled for lexical frequency and for initial and final phonemes of the second syllable that contain a schwa between them in careful articulated speech. The whole set was divided in high and low frequent items. The lexical frequency was extracted from the DWDS-corpus using the logarithmic annotated type frequency of each item as the logarithmic scale does emphasize the importance of low frequent words to a higher amount (n=408, M=2.19, SD=0.97). The mean of all words was taken as cut-off value to divide the set into high and low frequent words. The subsets then, (according to C1-environment) were further separated in a reduced set choosing the (very) low and (very) high frequent words. This list was used for the verbal repetition tasks (n=100 in each condition) (see Tab. 6).

Tab. 6: Orthogonal design of the stimuli used in the verbal repetition task.

Condition	Casual (n=100)				Careful (n=100)			
C2	/-əl/ (n=50)		/-ən/ (n=50)		/-əl/ (n=50)		/-ən/ (n=50)	
Frequency	low (n=25)	High (n=25)	low (n=25)	high (n=25)	low (n=25)	High (n=25)	low (n=25)	High (n=25)
C1	*-/dl/	*-/dl/	*-/dn/	*-/dn/	-/dəl/	-/dəl/	-/dən/	-/dən/
	*-/tl/	*-/tl/	*-/tn/	*-/tn/	-/təl/	-/təl/	-/tən/	-/tən/
	*-/kl/	*-/kl/	*-/kn/	*-/kn/	-/kəl/	-/kəl/	-/kən/	-/kən/
	*-/sl/	*-/sl/	*-/sn/	*-/sn/	-/səl/	-/səl/	-/sən/	-/sən/
	*-/ml/	*-/ml/	*-/mən/	*-/men/	-/məl/	-/məl/	-/mən/	-/mən/

The original whole set (n=400) were spoken by two professional radio speakers, one male and female and recorded with a portable digital recorder (Olympus LS-14 linear PCM recorder, PCM mono format, 54-60db recording amplitude, 100hz low cut filter, 30cm mouth-to-microphone distance). The items were spoken two times: once with casual (hypospeech) articulation and once with careful (hyperspeech) articulation. The phonetic variation was achieved by instructing the model speakers to volitionally produce explicit or reduced forms of the schwa-syllables (e.g. /mantəl/ versus /mantl/). To ensure that the current used stimuli are actually sensitive and reliable for the condition they are used for, the items were checked for (1) significant differences in word duration and (2) perceptually rated by three independent raters (two female, one male).

Word durations for the original overall set (n=400) were computed using PRAAT, a program for phonetic analyzes (*male casual:* n=100, M=0.68, SD=0.09; *male careful:* n=100, M=0.88, SD=0.12; *female casual:* n=100, M=0.69, SD=0.08; *female careful:* n=100, M=0.98, SD=0.13) [80]. In a first step, the samples were checked for significant differences within the conditions respecting the speaker (i.e. male careful words versus female careful words and male casual words versus female casual words). Within the casual condition, the items did not show a significant difference between gender (n=200, M=0.69, SD=0.09, t=1.3 p=.19) indicating no difference between the words spoken by the male and female speaker. However, there was a significant difference between the male and female words within the careful condition (n=200, M=0.93, SD=0.13, t=5.19 p<.001). As a consequence, the male words were all prolonged by the factor 1.108 with PRAAT (frequency spectrum 75-300hz). The factor represents the ratio by that the mean female and male words are different. In a second step, ignoring the gender aspect, paired sample comparisons were executed to check for differences between the careful and casual condition (*Careful and Casual:* n=400, M=0.28, SD=0.14, t=28.05; p<.001).

An auditory rating experiment should also check for consistent perceptual discrimination between the two conditions asking three raters for their judgment in perceived carefulness of the reduced set of stimuli (n=200). Three raters judged on a fluid likert-scale how casual or careful the words are articulated by the model speakers. The mean perceived carefulness is indicated in Fig. 4.The distribution reveals a rather adequate correspondence between the perceived carefulness and the labeled condition of each item. However, one can clearly identify a right-shifted skewness of the casual perceived words toward a *normal* articulation mode in the middle of the scale and revealing also some overlay with the careful labeled items in the lower histogram. Conversely, the careful labeled items are more clearly identified as favored for this experiment.

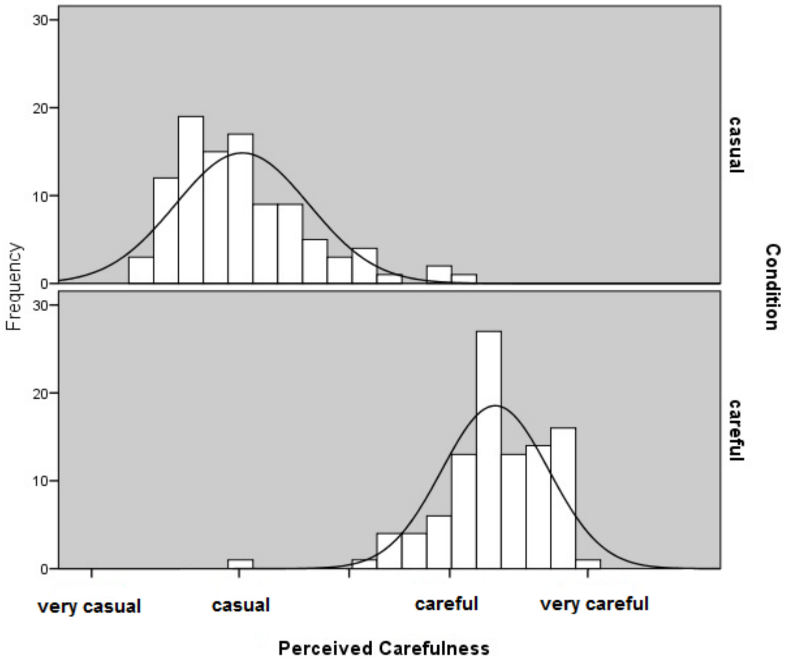

Fig. 4: Mean perceived carefulness of three raters for the stimuli (n=200).

In addition, a regression analysis between the mean duration of the model speakers as predictor variable (n=200, M=0.83, SD=0.28) and perceived carefulness as dependent variable (n=200, M=0.55, SD=0.18) was used to show if the articulation mode, and therefore the given instructions, of the model speakers really predicts their perceived carefulness by the three raters. The results of the regression analysis indicates a good correspondence and high sensitivity (b=0.79, t(199)=18.67 p<.001) and explains a significant proportion of variance in perceived carefulness, R^2=.63 F(1,199)=347.71, p<.001).

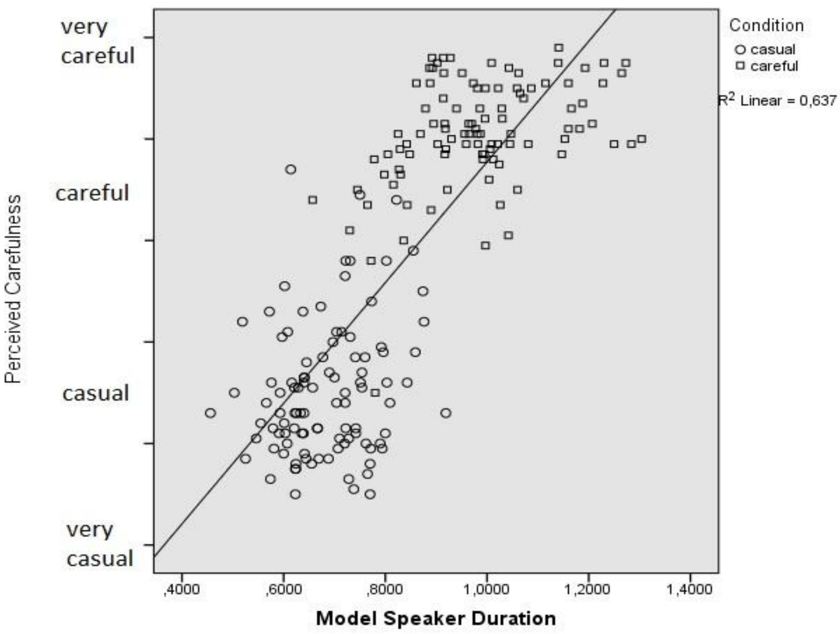

Fig. 5: Predicted perceived carefulness according to the model speaker's mean word duration (in sec.).

2.3. Procedure

The following section reviews the experiment procedure and the characteristics of the conducted acoustic and perceptual analysis.

2.3.1. Main Experiment: Verbal repetition

In the experiments, participants were sitting in front of the digital recorder (30cm distance). The items were conveyed to them via headphones (AKG K77 full ear headphones). Auditory stimuli were conducted using the Open Source Psychology Software PsychoPy [81]. Participants were tested at their home two times on two different dates with a minimum of 5 days between the test dates. Each session, the half set (n=100) was tested with a orthogonal distribution respecting articulation mode (careful versus casual), the gender of the model speakers (male versus female) and the phonetic environment (C1 and C2). Accordingly, it was checked that the same item was not presented either in both conditions or conveyed by the same model speaker within one testing session. Each new trial was always manually initiated by the experimenter and after every 25 items a break was induced to distract the participants and to avoid an articulation bias. Distractors were not included in the experiment. No explicit repetition or transformation rule or advice regarding the different articulation modes were given to the participants. The only instruction was to repeat the given stimulus as they hear it. Furthermore, the participants were not explicitly informed about the two different conditions within the test dates.

2.3.1.1. Acoustic and perceptual analysis

For each item, acoustic analyses were conducted measuring (1) word duration and (2) schwa duration if applicable with an overall scope of investigating the repetition competences (i.e. mapping perceived paralinguistic segmental and suprasegmental phenomena onto articulatory speech movements) of each participant. The duration measurements were executed by the author using the phonetic program PRAAT [80]. As word errors, such as phonological and phonetic distortions or repetitive self-repairs were expected to appear, the selection of the recorded answers for the acoustic measurements followed a constant procedure: (1) Always the first full recordable answer was labeled, (2) if sequences of self-repairs appear (i.e. conduit d'approche behavior), the first fully exploitable item was labeled, (3) extreme distorted speech items or neologistic answers were not identified as valuable. Word durations were labeled according to an initial and final appearance of word-related frequency spectrum or formant structure, additionally pitch algorithms helped to indentify the sharp start and the end of a given item. Final word aspiration was excluded. The identification of a given schwa followed a step-wise procedure: (1) The first judgment if a given word contained a schwa was assessed from an auditory perspective. If no clear decision could be made , (2) acoustic properties of the schwa were added to the decision: Together, a visually inspection of the spectrographic details of the word revealed the possible appearance of a voice bar (i.e. a constant energy at the bottom of the frequency spectrum that is raised and lowered with the schwa), (3) a change of F1 and F2 frequency course between C1 and C2 (e.g. a rise in F2 and a relative abrupt descent of F2 reveals vowel schwa vowel properties) and (4) a quantitative evaluation of F1 and F2 (i.e. /ə/ with F1 between 450 – 500hz, F2 between 1400 – 1700hz gender-dependent) helped to identify a possible articulated schwa. The start of a schwa was labeled as sharp as possible (e.g. easy with C1= /t/ and more complex if C1=/m/) and the end was indentified with the descent of F1 and F2.

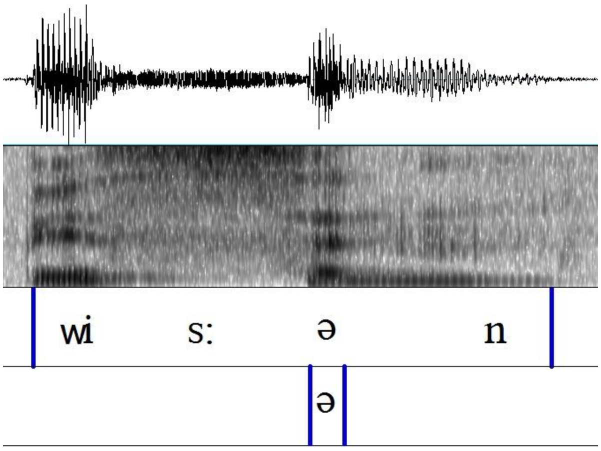

Fig. 6: Example of a patient's (KF) reaction contatining a schwa.

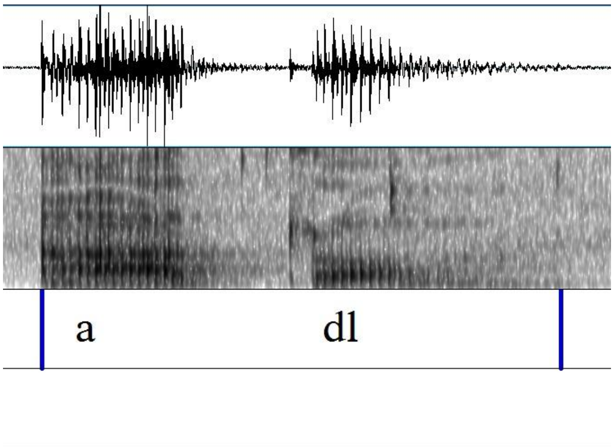

Fig. 7: Example of a patient's (KF) reaction containing no schwa.

Fig. 6 and Fig. 7 present two examples of word repetitions by the patient KF. A difference is recognizable in the formant structure between C1 and C2: While in /wis: ən/ a clear uplifted voice bar at low frequency levels and sharp F2/F3 formant structures are visible, in */adl/ no such structures can be identified.

Additionally, perceptual analyses were executed for all words. The responses were analyzed on a basis of broad transcripts by the author. For each response, errors addressing the segmental level such as phonological accuracy (PM) and phonetic accuracy (PT) and the suprasegmental level of fluency (RF) were labeled. Problems associated with word initiation such as repetitive self-repairs, lexical latency effects and reduced syllabic timing were labeled within the RF category. There was no evaluation of the first syllable. Phonemic and phonetic accuracy for C1, the schwa and C2 were only assigned to the second syllable. Reduced PM comprised phonemic substitutions, assimilations, elisions or additions, while reduced PT included reduced schwa timing or phonetic distortions (i.e. deletion, fortification or assimilation according to phonetic gestures). The errors were analyzed on the basis of an overall ten-point scale, assigning zero to two points to each category.

3. Results

The following section provides the results from the above described experiment.

3.1. Analyses on a suprasegmental level: word processes

In a first step, word level durations were in the scope of the analyses. Tab. 7 provides descriptive data for group means according to the condition. Descriptive data for all participants are provided in Tab. 13 in Appendix B. All data were controlled for normal distribution (Shapiro-Wilk, p>.05), skweness, kurtosis and homogeneity of variances (Levene's Test p>.05). Outliers were corrected. The inclusion of items was high with an overall rate of 97.2% after the correction of outliers. Only a few items were lost due to word-level deficits in the patient's groups such as neologistic answers that could not be evaluated, high answer-latency or missing answers.

Tab. 7: Descriptive Data of mean word durations according to group and condition (in sec.).

Group	Condition	N[1]	Mean	SD	Mean St. Error
AOS	Casual	96	.847	.120	.012
	Careful	100	.961	.120	.012
CA	Casual	98	.752	.098	.010
	Careful	99	.836	.103	.010
Controls	Casual	95	.632	.086	.009
	Careful	96	.753	.100	.010

Comparing the mean word durations among the groups and for careful and casual condition in an two-way ANOVA, significant results could be found for condition and group effects (*Condition effect:* F(1,531)=100.2 p<.001; *Group effect:* F(2,531)=200.5 p<.001) Interaction effects were non-significant: F(2,531)=1.55 p=.212. Paired sample t-tests were conducted to check for true significant differences of word durations according to the hypo- and hyper-speech condition. Significant results could be confirmed for every group (*Controls:* M=0.12, SD=0.08, t(91)=13.81 p<.001; *AOS:* M=0.11, SD=0.16, t(98)=8.99 p<.001; *CA:* M=0.08, SD=0.11, t(96)=7.11 p<.001). A Post hoc tukey test confirmed the found results (p<.05).

Fig. 8 visualizes the mean word durations per group labeled for both conditions. For a better comparison also the model speaker's targets are added. Both the casual and the careful condition should be compared across the subjects.

[1] The relative low number of items in this table arise due to an item-per-item calculated mean for all participants and then per group (item-wise exclusion).

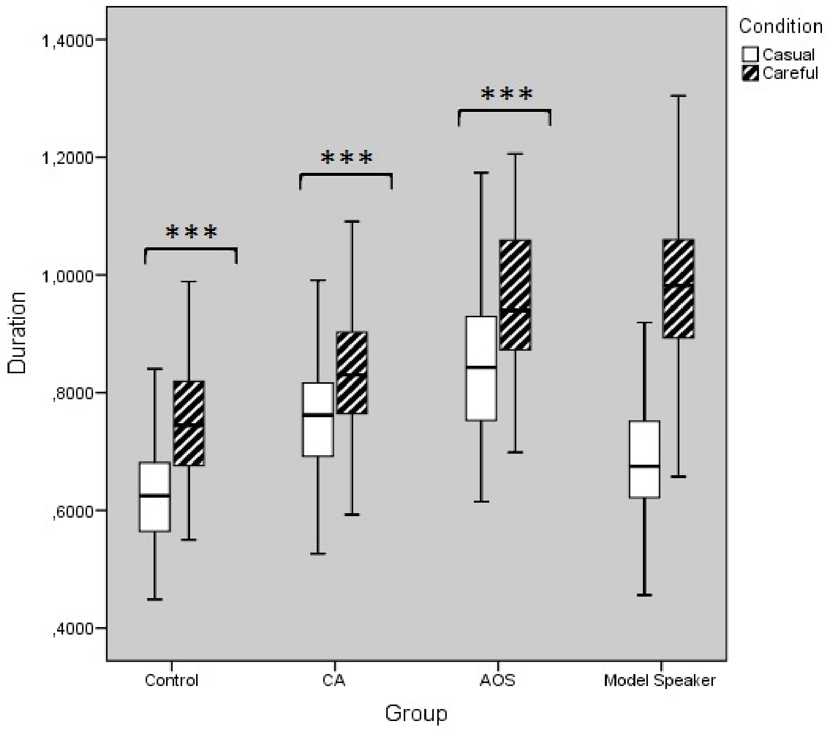

Fig. 8: Mean word durations per group and condition (in sec.).

Within the casual condition, the control group seems to perfectly imitate the hypospeech condition with a mean even smaller than the model speakers. Comparing both the AOS group and the CA group with the controls, a significant difference in means become evident (*Pair 1: AOS and Controls:* M=0.21, SD=0.1, t(91)=19.81 p<.001; *Pair 2: CA and Control:* M=0.12, SD=0.08, t(94)=14.87, p<.001), underlining the assumption that healthy participants show a high articulatory competence.

Reviewing the careful condition, it may impress that there seems to be ample duration difference between the participants in each group and the model speakers (e.g. comparing the careful condition in Controls and AOS). As instructed, model speakers show an extreme tendency to model a hyperspeech condition with a mean difference of mean to the hypospeech condition of 148msec. . Two things need to be mentioned: Firstly, there is no significant mean difference between the Apraxia of Speech group and the model speakers in the careful hyperspeech-condition (M=0.024, SD=0.12, t(99)=1.97 p=.51). Secondly, it seems interesting that the healthy controls do show the highest mean word duration difference compared to the model speakers (M=0.22, SD=0.11, t(95)=19.03, p<.001, see also results from the two-way ANOVA). Furthermore, within-group differences in word durations are significant for each of them (*Controls:* M=0.12, SD=0.85, t(91)=13.81 p<.001; *AOS:* M=0.11, SD=0.12, t(95)=8.68 p<.001; *CA:* M=0.08, SD=0.11, t(96)=7.14 p<0.001). Also single case analyses reveal significant different word durations across all groups including the two cases KF and GM (*KF:* M=0.19 SD=0.28 t(97)=6.8 p<0.001; *GM:* M=0.06 SD=0.13 t(95)=4.94, p<.001). A detailed explanation is provided under section 4.

As one consecutive step, correlation analyses should help to determine a imitation effect within each group.

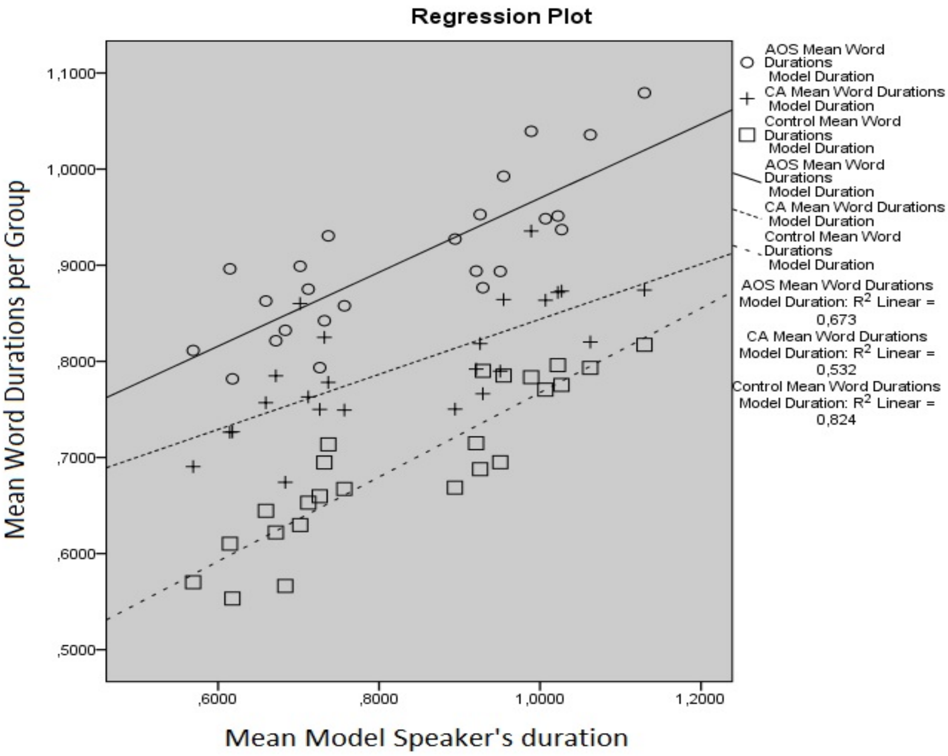

Fig. 9: Regression plot with mean model speaker's word duration as predictor variable and mean group's word duration as response variable (in sec.).

Regression analyses confirm the statistical tests revealing significant positive correlations (Fig. 9), (*Controls:* b=0.43, t(22)=10.15 p<.001; *AOS:* b=0.38, t(22)=6.72 p<.001; *CA:* b=0.29, t(22)=5 p<.001). The plot shows the mean aggregated word durations according to the groups Controls, CA and AOS. It clearly shows the two conditions with a left-skewed distribution of the casual condition and a right-skewed careful condition. The plots also illustrates the significant longer word durations between the Controls and the AOS group within the casual condition, confirming the assumed assumptions from the group mean analyses. A positive relationship can be identified between all three group means and the model speaker's target items (*Controls:* Pearson's r(22)=0.90 p<.01; *AOS:* Pearson's r(22)=0.82 p<.01; *CA:* Pearson's r(22)=0.72 p<.01).

Individual level analyses revealed different relationships. However, a positive correlation could be identified for all of the participants (Tab. 8).

Tab. 8: Regression analysis and correlation significance for all individual cases.

Group	Participant	N	B	R	t-value	Corr. Sig.[1]
AOS	AK	24	0.27	0.67	4.30	p<0.01
	KH	24	0.20	0.69	4.50	p<0.01
	KF	24	0.64	0.66	4.20	p<0.01
CA	TH	24	0.38	0.57	3.32	p<0.01
	SH	24	0.27	.074	5.28	p<0.01
	GM	24	0.21	0.65	4.06	p<0.01
Controls	AH	24	0.48	0.86	7.91	p<0.01
	GH	24	0.28	0.80	6.26	p<0.01
	RP	24	0.53	0.88	8.80	p<0.01

[1]predictor variable: model speaker's word durations, response variable: individuals mean word durations.

3.2. Analyses on a segmental level: schwa processes

3.2.1. Absolute produced schwa vowels

Appearance of schwa vowels were labeled according to the procedure explained under section 2.3.1.1. using the phonetic analyzing and annotation program PRAAT, ignoring their phonetic environment [80]. A descriptive evaluation of absolute produced schwas is provided in Tab. 9.

Tab. 9: Absolute produced Schwas per Participant and Condition.

Group	Participant	Casual Condition		Careful Condition	
		N	% Schwa Deleted	N	% Schwa present
AOS	AK	75	25	76	76
	KH	88	12	90	90
	KF	75	25	79	79
CA	TH	62	38	79	79
	SH	65	35	94	94
	GM	63	37	89	89
Controls	AH	13	87	97	97
	GH	21	79	96	96
	RP	14	86	93	93

Although an imitation of the casual condition could be assumed by interpreting the data from word duration, a missing schwa-deletion within the same condition is apparent for both the AOS and the CA group. The AOS group shows a significant less mean deletion rate of 20.6% (n=62, SD=7.5 U=0 p<.05), CA 36.6% (n=110, SD=1.5, t(4)=17.75 p<.05) compared with the control group with a deletion rate of 84% (n=252, SD=4.3) in the casual condition. Taking a look at the careful condition, the data should be interpreted carefully. A high imitation rate does not consequently arise from sensitivity to the overall condition as the higher percentage of produced schwas could simple arise due to articulatory mistiming or articulatory variation according to the phonetic C1 and C2 environment. However, the AOS group shows a significant difference in the repetition rate compared to healthy controls (n=245, M=81.66, SD=7.31, t(4)=3.09 p<.05), while the CA group seem to reproduce the schwa similar to healthy controls at higher rates in the careful condition (n=262, M=87.33, SD=7.63, t(4)=1.75, p=.15). Paired sample t-tests point in the same direction: A between-condition analysis within the groups revealed significant less inserted schwa vowels in the casual condition than repeated schwa vowels for CAs and Controls (*CA:* M=24, SD=6.24, t(2)=6.65, p<.05; *Controls:* M=79.33, SD=4.5, t(2)=30.47 p<.01) but not for the AOS group (U=2 p=2.68).

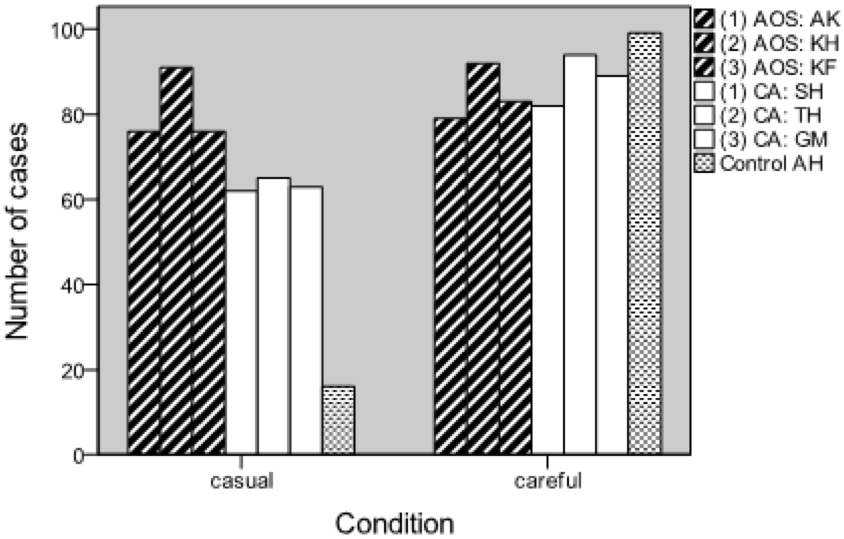

Fig. 10: Absolute produced schwas per participant and condition.

3.2.2. Schwa durations

Mean Schwa durations were controlled for normal distribution (Shapiro-Wilk, p>.05), skweness, kurtosis and homogeneity of variances (Levene's Test p>.05) according to the group and on single case level[2]. Outliers were corrected.

Tab. 10 provides an overview on the mean schwa duration per group, participant and condition. Individual descriptive data is illustrated in Tab. 14 in Appendix B.

Tab. 10: Mean Schwa durations per group and condition (Mean and SD are given in sec.).

Group	Condition	n[3]	Mean	SD	Mean St. Error
AOS	Casual	96	.082	.0014	.013
	Careful	97	.090	.0014	.014
CA	Casual	90	.086	.0015	.014
	Careful	99	.094	.0014	.014
Controls	Casual	27	.090	.0025	.013
	Careful	99	.096	.0016	.015

[2] Two cases did not show a homogeneity of variance: Levene's test *KH:* F=4.88 p=0.28; *KF:* F=5.815 p=0.17). However, this appeared on single case level, overall rates did show good distributions.

[3] The calculated N in this table arise through a item-wise mean calculation. Missing durations from one or more participants within a group led to the exclusion of the whole item.

Comparing mean schwa durations among the groups and between the careful and casual condition in a two-way ANOVA indicates an influence of articulation mode on schwa durations (*Condition effect:* $F(1,467)=21.97$ $p<.001$; *Group effect:* $F(2,467)=6.36$ $p<.005$) Interaction effects were not significant: $F(2,467)=.004$ $p=.99$. Analyses of variances were conducted for further investigations on schwa's phonetic environment and its influence on schwa duration. These results, however, are not part of this work. Paired sample t-tests and a post hoc test were conducted to check for true significant differences of schwa durations according to the hypo- and hyperspeech condition. Significant results could be confirmed for every group (*Controls*[4]*:* M=0.016, SD=0.018, $t(26)=4.73$ $p<.001$; *AOS:* M=0.008, SD=0.018, $t(92)=4.176$ $p<.001$; *CA:* M=0.008, SD=0.018, $t(88)=4.15$ $p<.001$). A post hoc Tuky test showed significant differences in mean schwa durations between AOS and healthy controls ($p<.05$) but not between CA and healthy controls ($p=.49$).

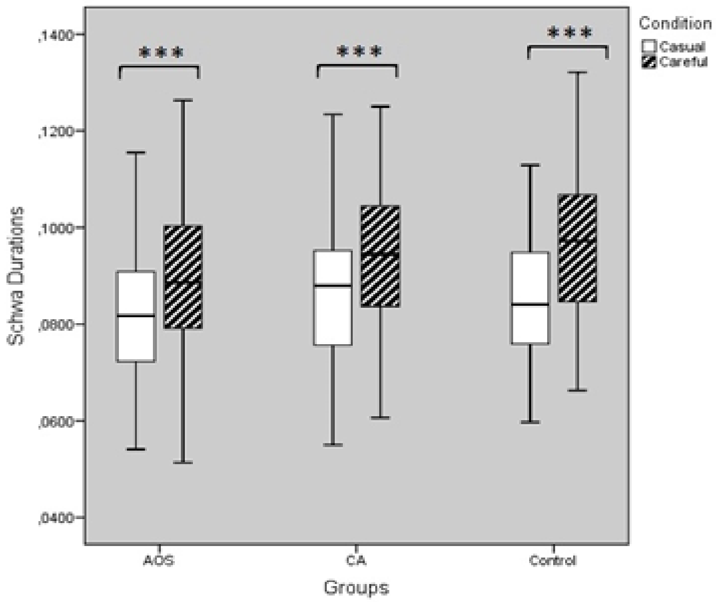

Fig. 11: Mean Schwa Durations per Group and Condition (in sec.).

Interestingly there is no huge difference in the repeated and inserted schwa durations within the healthy controls (M=6ms), even though they rarely insert a schwa in the casual condition. For explanations see section 4. However, on a single case level, ANOVAs did not reveal significant differences between the schwa durations for careful and casual condition and Paired-Sample Tests confirmed this trend. The results appear rather different per group and participant. Tab. 11 provides an overview.

[4] Within the control group, attention should be guided towards the different items between conditions to patient's group restricting the analysis and interpretation to a certain amount (Controls: casual n=28, careful n=95).

Tab. 11: Results from paired sample tests on individual level (means and SD are given in sec.).

Group	Participant	Mean	SD	t-value	Df	Sig. (2-tailed)
AOS	AK	.0098	.026	2.977	64	.004
	HK	.0043	.023	1.710	81	.091
	KF	.0130	.037	2.814	66	.006
CA	SH	.6327	.095	53.212	64	.000
	TH	.0049	.031	1.139	52	.260
	GM	.0045	.023	1.498	58	.139
Control	AH	.0187	.023	2.886	12	.014
	GH	.0159	.017	4.211	20	.000
	RP	.0124	.024	1.868	13	.084

As a next step, to see if the repetition or imitation of schwa vowels has an influence on longer word durations, correlations were built with model speaker's word durations. Schwa Durations were aggregated and plot on model speaker's word durations.

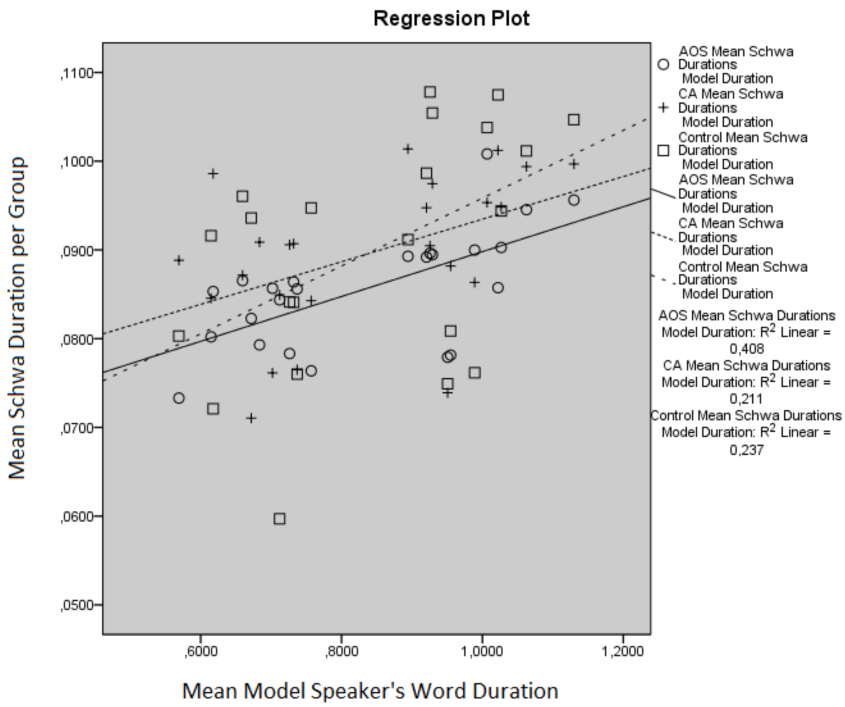

Fig. 12: Regression plot with mean model speaker's word duration as predictor variable and mean group's schwa durations as response variable (in sec.).

Regression analyses showed that prolonged schwa durations can be predicted to a certain extent by the model items (Fig. 12), (*Controls:* b=0.038, t(22)=2.49 p<.05; *AOS:* b=0.025 t(22)=3.89 p<.01; *CA:* b=0.024, t(22)=2.43 p<.05). However, the predictability varies and schwa duration can clearly not be accounted as the only factor influencing prolonged articulation mode in the hyperspeech condition. Surprisingly, the AOS group did show the highest correlation between condition and schwa durations, patients with Conduction Aphasia showed the less significant correlation*: (Controls:* Pearson's r(22)=0.48 p<.05; *AOS:* Pearson's r(22)=0.63 p<.01; *CA:* Pearson's r(22)=0.45 p<.05). Furthermore, the influence of schwa duration on word durations within the casual condition was determined for both the AOS and CA group to see if word durations can be predicted by schwa durations. However, no such correlations could be found for CAs (Pearson's r(88)=0.067 p=.53) but for the AOS group (Pearson's r(90)=0.25 p<.05).

On a single-case level, regression analyses were not significant for all participants indicating more subtle articulatory processes that might influence word and vowel imitations. Results, however, are provided in Tab. 12. Among the patients group, only one (SH) shows significant correlations whereas 49% of schwa variation can be explained by the articulation conditions. Also among the healthy controls only two out of three show significant results.

Tab. 12: Regression analysis and correlation significance for all individual cases (predictor variable: model speaker's word durations, response variable: mean individuals schwa durations).

Group	Participant	N	B	R	t-value	Corr. Sig.
AOS	AK	24	0.011	0.15	0.71	p=.48
	KH	24	0.015	0.37	1.90	p=.06
	KF	24	0.043	0.34	1.71	p=.10
CA	TH	24	0.011	0.16	0.77	p=.45
	SH	24	0.043	0.49	2.64	p<.05
	GM	24	0.010	0.22	1.07	p=.29
Control	AH	24	0.084	0.61	2.88	p<.05
	GH	24	0.083	0.61	3.33	p<.01
	RP	24	0.055	0.46	1.91	p=.07

In a last step, mean schwa duration from both the patient's group in the casual condition were plotted to check for temporal interference. Thus, duration overlap would favor continuous mechanisms in schwa epenthesis.

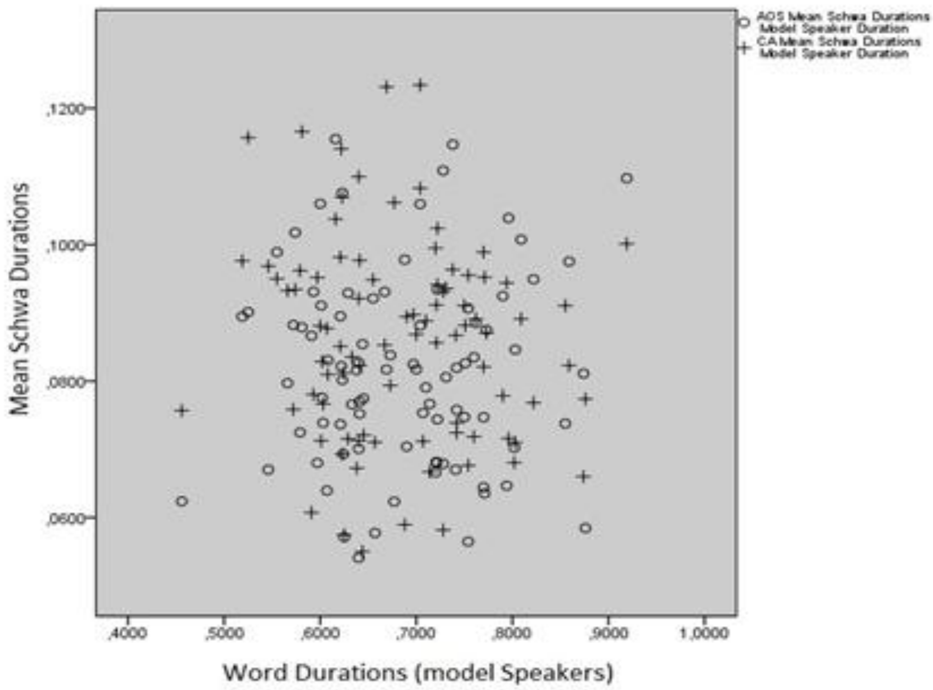

Fig. 13: Duration overlap of Schwa vowels between CA and AOS in the casual condition (in seconds).

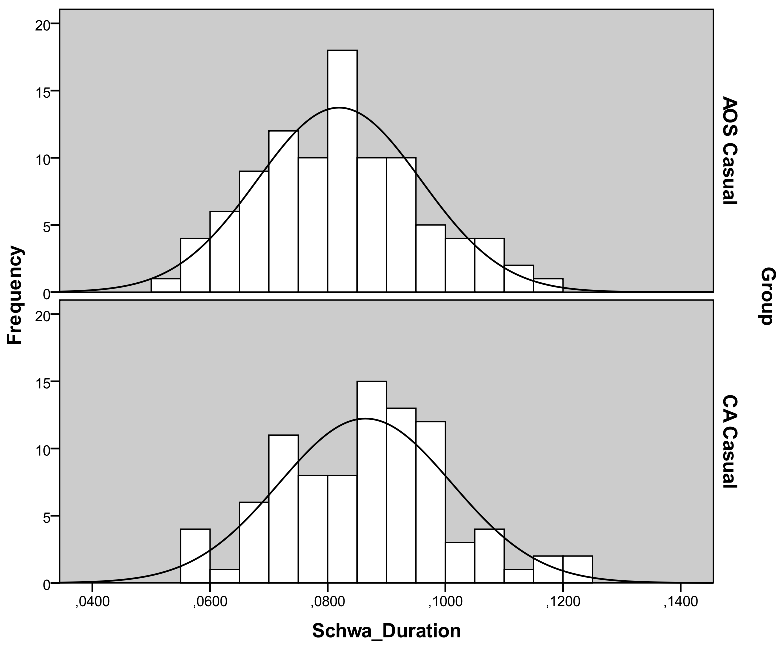

Fig. 14: Schwa duration overlap between AOS and CA group within the casual condition (in sec.).

Fig. 13 and Fig. 14 clearly illustrate a duration overlap in the casual condition for both the AOS and the CA group indicating similar mechanisms involved in schwa epenthesis. Furthermore the range from schwa durations is compared to identify differences between the two groups. However, no such statistical significances could be found (*M-W-U Test AOS and CA:* U=0 p=3.17). Within the next section, a detailed description of the reported results will be provided on the background of the theoretical framework that is essential for this work.

4. General Discussion

The present work reviewed phonological-based and phonetic-oriented theories and their explanation paradigms for speech processing. In a generativist and cognitivistic tradition, phonological theories are still deeply grounded in a dualistic, amodal, linear and representative approach. Recent phonetic interpretations, however, argue for profound phonetic interpretations of phonological processing steps. In line with recent developments in Cognitive Neuroscience, modern theories integrate a dynamic link of both motor and perceptual encoding as materialistic roots of language processes [4], [38], [39], [41]. A dualistic division of low-level motor-based and high-order linguistic-based processing should therefore be neglected, redefining the relationship between phonological and phonetic processing.

Clearly, this work only adds a small piece of scientific understanding to the overall epistemological discussion about the nature of linguistic knowledge and behavior by investigating a narrow phenomenon: Syllabic reduction processes in individuals with acquired language disorders. Investigating the variables affecting speech rate is an interesting phenomenon that can shed light on the way how gestural patterns are aligned and coordinated. Therefore, investigating schwa insertion or imitation and deletion offers the possibility to expand the knowledge of how phonological patterns are shaped by phonetic principles, how *paraphonological* or *extralinguistic* properties are implemented in the phonological-phonetic encoding stage and how segmental or suprasegmental restrictions are modified. This possibly allows new insights into the cognitive, motoric and perceptual components of phonological complexity. Below, the findings of the conducted experiments will be discussed (1) under aspects of overall phonetic-phonological theories, (2) in contrast to literature reviewing schwa deletion and (3) in review to verbal imitation behavior of people with language disorders.

In the present study, three groups of participants, i.e. healthy controls and patients with two different neurolinguistic disorders, these are Apraxia of Speech (AOS) and Conduction Aphasia (CA), were examined. One aim of this study was, if the three groups show a sensitivity of paraphonological details by repeating a casual and careful speech condition. Different articulatory variables are responsible for imitating a hypo- and hyperspeech condition. Their impact should be discussed below.

Reviewing the results from the careful condition, patients with AOS and CA reveal higher mean word durations compared to healthy controls due to their underlying phonetic-phonological speech impairment [60].

Patients with Apraxia of Speech showed the highest overall mean word durations (*AOS casual vs. careful:* 847ms. vs. 961ms., *CA casual vs. careful:* 751ms. vs. 836ms., *Controls casual vs. careful:* 632ms. vs. 753ms.), revealing different articulatory problems that can be rather diverse. Still, results appeared different among the participants: reasons for this rather heterogenic picture might arise from impaired auditory (schwa)-processing steps, selective impaired cognitive submodules in the articulatory mapping process, the nucleus of the speech impairment or post-onset time of the disease. However, all three groups showed significant differences in their mean word durations between the casual and the careful condition. The lack of a significant mean difference between the Apraxia of Speech group (AOS) and the model speakers in the careful hyperspeech condition ($M=0.024$, $SD=0.12$, $t(99)=1.97$ $p=.51$) suggests that this patients group perfectly imitates the careful condition. However, this might not be the case. The author explains this detail with the already high word durations in the casual condition and the described fluency disorders in AOS that minimize the relative imitation effect. Also an overlap of both conditions is observable in the AOS group. Still, sensitivity to the hyperspeech condition for AOS is interpreted on the basis of schwa duration analyses which are provided below.

As stated under section 3.1, ample word duration differences appear between the participants in each group and the model speakers (e.g. comparing the careful condition in healthy Controls and AOS). As advised, model speakers should present an extreme tendency to express a hyperspeech condition with a mean word difference of 148msec. to the hypospeech condition. The high mean word duration differences between the healthy controls and the model speakers could indicate no imitation to the hyper speech condition at all. An absolute comparison to the model speaker's word durations, however, does not seem to be valid. Further explorations of the positive correlations between the model speaker's and the participant's word durations in combination with qualitative analysis of error distributions need to be executed to investigate this observation. Still, healthy controls showed the highest correlation effect (*Controls:* .9, *AOS:* .82, *CA:* .72) and the highest relative increase in word durations (*Controls:* 121ms, *AOS:* 114ms, *CA:* 84ms.).The results are interpreted as healthy controls relatively imitate paraphonological details at best. Relative word durations differences according to each group seem therefore a better scale to interpret the existing data. Positive correlations between the model speaker's items and the patient's word durations could also be identified for every participant regardless of the overall clinical diagnosis, which was not the case in previous works. The results, however, are in line with them dealing with the unintentional transfer of phonologically irrelevant phonetic information [73], [74].

Speech rate – as stated – is executed by several variables such as segmental durations, velocity of the articulators, magnitude of articulatory gestures and intra- and intersyllabic breaks. However, not all of the described details can be accounted as paralinguistic, as segmental entities can carry lexical information. Further insights are gained by interpreting the absolute production of schwa vowels and their durations in the careful condition. The absolute schwa production rate does not consequently arise from sensitivity to the overall condition, which is interpreted as imitation rate, as the higher percentage of produced schwas could simple arise due to articulatory mistiming or articulatory variation according to the phonetic C1 and C2 environment. The present data from absolute produced schwa can also not clearly distinguish between an imitation effect and an articulatory mistiming effect. The AOS group repeats or imitates significantly less schwas compared to the CA and the healthy controls possibly due to different C1 environments. Investigating schwa durations, the results for all groups showed significant duration differences between the casual and the careful condition for both healthy and impaired groups, highly suggesting sustained motor-speech competences to a certain extent that allow to process nonlinguistic parameters such as segmental durations and map them onto articulatory patterns. Schwa vowel duration was significantly higher for all three groups in the careful condition compared with the casual condition, showing correlation effects with word durations of each group (*Controls:* .48, *AOS*: .63, *CA:* 0.45*).* As the correlation only partly explains prolonged word durations within each group, the data can be interpreted as maintained sensitivity not only for segmental durations but possibly also for other non-lexical linguistic factors as described above. Even though all groups showed imitation effects in the careful condition, left-hemispheric lesions to the language systems interfere with the degree of imitation. As past studies did not investigate segmental imitation phenomena compared to other variables responsible for realizing speech rate in a hyper- and hypospeech condition, a comparison to existing research is not possible. However, the author interprets the reported results that also speech-impaired individuals suffering from different disorders to the motor-linguistic systems of speech processing are sensitive to paraphonological details on a segmentel level. Further research contrasting it with other variables such as intersyllabic breaks or consonant prolongations with long sonorant parts is required.

A detail that interferes with the relatively sustained imitation performance of perceived schwa vowels in the careful and casual condition is the poor auditory discrimination rate for schwa-syllables versus non-schwa syllables reported in the pre-test phase (Tab. 4 under section 2.1.2). Significant higher error rates arise for the two patient's groups, suggesting different explanations for this behavior: Impaired perception of schwa- and non-schwa-syllables is not identified as problem as casualness and carefulness are processed partly correctly and are identified in the verbal imitation paradigms. Certainly, the challenging task design, the task duty, the selection of the stimuli (i.e. words and non-words) and their phonetic adaptation (as the stimuli were pre-tested and adapted according to an interrater agreement) might interfered with a reliable identification of preserved auditory schwa-processing. Further research of auditory processing of schwa discrimination and their connection to the imitation of schwa syllables is highly indicated.

Results described above indicate a maintained sensitivity to paraphonological details responsible for a careful articulation mode at higher speech rates. However, imitation of the casual condition needs more scientific support. Based on the fact that participants imitate the careful condition, one cannot automatically infer a sensitivity to the casual condition, as it could also be perceived as normal articulation condition and not as a fast and hypospeech one. Perceived absolute segmental deletion (schwa vowel deletion) was significant for both the control and the CA group (*Controls:* deletion rate 84%, *CA:* deletion rate 36.6%) suggesting that these groups imitate the casual condition and are sensitive to segmental duration and consonantal overlap. The AOS group, instead did not show significant differences (deletion rate 20.6%). Still, one cannot differentiate if the significantly more inserted vowels of the AOS group reflect a missing sensitivity to segmental deletion or problems in the realization of articulatory overlap and rapid consonantal transition as auditory discrimination performance was poor within this group. The second account is still believed to be more likely, as it reflects a core symptom in Apraxia of Speech. To a certain extent, inserted schwa vowels (in the casual condition) do explain the word durations as a positive correlation was found (*AOS:* .25). Interestingly, also patients with CA showed significantly longer word duration within the casual condition than healthy controls, suggesting similar mechanisms also for this patient group. The significant longer word durations within this group, however, could not be explained by the duration of the inserted schwa vowels. These results possibly suggest AOS and CA to be different in their sensitivity of paraphonological details. As patients with Conduction Aphasia showed less effects in the overall word imitation and the schwa vowel imitation in the careful condition, these results are in line with general research from Aphasiology, postulating that language disturbances affect the auditory-motor mapping process. As no correlations were built between the schwa vowel discrimination experiment and the schwa insertion, the influence of the auditory analysis cannot be identified. In-depth analyses of perceptual and articulatory phenomena in segmental deletion, qualitative research specifying phonological, phonetic and fluency accuracy and research on the different paraphonological factors with both healthy and impaired participants are required. Findings can identify further differences between neurogenic speech disorders per se and help to understand speech modifications under nonlinguistic pressure. The finding that aphasic and apractic patients absorb qualitative different paraphonological details to a different extent and reproduce them in their motor output might be of importance to therapeutic approaches in the remediation of motor-linguistic disturbances.

Phonological and phonetic theories do not agree on language specific and cross-linguistic phenomena of speech production and perception: Phonological theories have focused intensively on the role of universal – and therefore phonological – constraints such as markedness constraints as explanation mechanisms [3], [16]. The results were interpreted as evidence for the cognitive reality of universal phonological principles that are responsible for phonetic variations. Phonological evidences suggest that coordination of articulatory gestures is defined at a more abstract, phonological level [19], [41], [45]. However, phonetic oriented theories argue for nonlinear models integrating several levels of speech motor planning from metrical and sub- to suprasyllabic factors such as gestural and metrical or coarticulatory timing effects that work in both consonant cluster production and perception [27], [41], [43], [82]. A central question that was raised in the theoretical framework centers on categorical and continuous mechanisms that can be identified for vowel imitation, deletion or epenthesis. A number of studies address this issue by investigating schwa deletion in the course of fast and normal speech with the scope of identifying categorical (phonological) or continuous (phonetic) accounts of schwa deletion, e.g. [66], [71], [72], [82]. The nature of schwa epenthesis in AOS and CA is still discussed. As described, the occurrence of inserted vowels in AOS is explained with insufficient temporal overlap, CA patients are meant to insert discrete phonological units to resolve the appearance of marked structures [66]. Acoustic studies suggested that glottal schwa gestures are still present in casual speech and that speakers also retain the same glottal-oral timing found in careful speech, denying a categorical schwa deletion mechanism. Apparent schwa deletion is then interpreted as the extreme endpoint of a continuum of vowel reduction and overlap. Two findings from the present work corroborate categorical accounts of schwa processing: First, significant differences in schwa durations between the casual and careful condition in the CA groups indicate non-categorical schwa insertion. If categorical insertion and imitation would be responsible for schwa processing, no differences in durations would be expected. Furthermore, investigating the range of schwa durations for both AOS and CA group, an overlap could be found and no statistical difference between the mean ranges could be identified. If a categorical mechanism would be responsible, no overlap and a more narrow range of schwa durations would have been expected for the CA group. Additionally, the statistical significant difference between inserted and imitated schwa durations among healthy controls, CA and AOS is not high (6-8ms.) indicating that the similar phonetic-guided mechanisms are operating. Still, the reported results cannot sufficiently distinguish between overlap accounts and categorical mechanisms. No analyses of phonetic environments were executed that could indicate distinctive schwa duration distributions according to phonetic principles such as sonority hierarchies or phonological factors such as markedness. Furthermore, no analyses of possibly produced marked structures or the influence of lexical factors were executed. The results, therefore, cannot be interpreted with a background of linear or dynamic models and the phonological-phonetic encoding stages.

5. Conclusion

Findings from the present work are in line with modern theories of Cognitive Neuroscience and neurophonetic approaches to speech processing. As previous studies showed, also individuals with acquired language disorders are sensitive to paralinguistic factors implemented in speech rate that seem to be more deeply grounded in the acoustic-motor mapping process as thought, even though to a less extent than healthy controls. Different paralinguistic factors seem to work within the disorders associated with linguistic-motor disturbances as segmental and suprasegmental variables might be impaired differently. Differences arise in the capability of segmental vowel reduction between AOS and CA. More evidence was found for continuous phonetic accounts for vowel deletion for both language impairments than for categorical accounts. However, further research needs to address language specific and cross-linguistic variables to identify phonetic and phonological mechanisms that influence grammatical processing, the influence of phonetic environments and their modification processes that interfere with segmental vowel deletions with clear methodological boundaries and further combinations of perceptual and motor-articulatory encoding levels.

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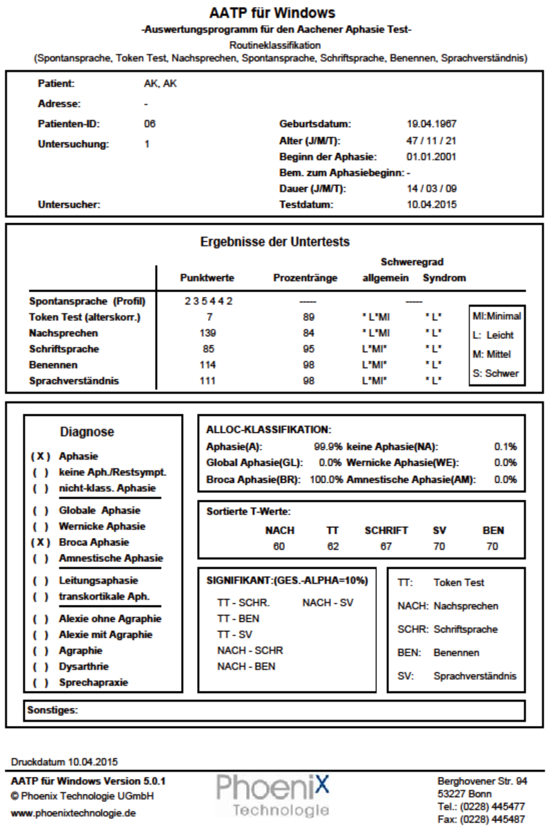
Appendix

A. Detailed neurolinguistic profile of all participants with language disorders according to the Aachener Aphasie Test (AAT)

Group: Apraxia of Speech



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Routineklassifikation
(Spontansprache, Token Test, Nachsprechen, Spontansprache, Schriftsprache, Benennen, Sprachverständnis)

Patient:	AK, AK		
Adresse:	-		
Patienten-ID:	06	**Geburtsdatum:**	19.04.1967
Untersuchung:	1	**Alter (J/M/T):**	47 / 11 / 21
		Beginn der Aphasie:	01.01.2001
		Bem. zum Aphasiebeginn:	-
		Dauer (J/M/T):	14 / 03 / 09
Untersucher:		**Testdatum:**	10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	2 3 5 4 4 2	-----	-----	
Token Test (alterskorr.)	7	89	* L*MI	* L*
Nachsprechen	139	84	* L*MI	* L*
Schriftsprache	85	95	L*MI*	* L*
Benennen	114	98	L*MI*	* L*
Sprachverständnis	111	98	L*MI*	* L*

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
( ) Wernicke Aphasie
(X) Broca Aphasie
( ) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 99.9% keine Aphasie(NA): 0.1%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 0.0%
Broca Aphasie(BR): 100.0% Amnestische Aphasie(AM): 0.0%

Sortierte T-Werte:

NACH	TT	SCHRIFT	SV	BEN
60	62	67	70	70

SIGNIFIKANT:(GES.-ALPHA=10%)
TT - SCHR.
TT - BEN
TT - SV
NACH - SCHR
NACH - BEN
NACH - SV

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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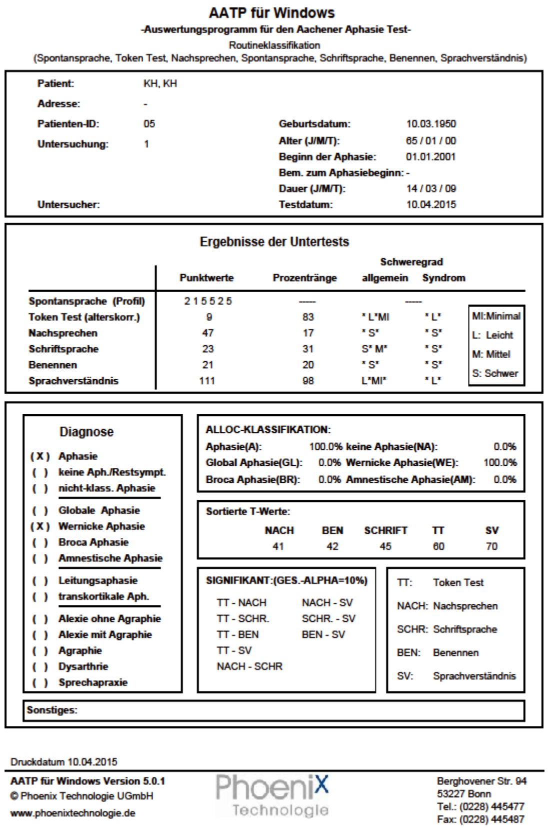
Fig. 15: Patient AK



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Patient:	KH, KH		
Adresse:	-		
Patienten-ID:	05	**Geburtsdatum:**	10.03.1950
Untersuchung:	1	**Alter (J/M/T):**	65 / 01 / 00
		Beginn der Aphasie:	01.01.2001
		Bem. zum Aphasiebeginn:	-
		Dauer (J/M/T):	14 / 03 / 09
Untersucher:		**Testdatum:**	10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	2 1 5 5 2 5	-----	-----	
Token Test (alterskorr.)	9	83	* L*MI	* L*
Nachsprechen	47	17	* S*	* S*
Schriftsprache	23	31	S* M*	* S*
Benennen	21	20	* S*	* S*
Sprachverständnis	111	98	L*MI*	* L*

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
(X) Wernicke Aphasie
( ) Broca Aphasie
( ) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 100.0% keine Aphasie(NA): 0.0%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 100.0%
Broca Aphasie(BR): 0.0% Amnestische Aphasie(AM): 0.0%

Sortierte T-Werte:

NACH	BEN	SCHRIFT	TT	SV
41	42	45	60	70

SIGNIFIKANT:(GES.-ALPHA=10%)
TT - NACH
TT - SCHR.
TT - BEN
TT - SV
NACH - SCHR
NACH - SV
SCHR. - SV
BEN - SV

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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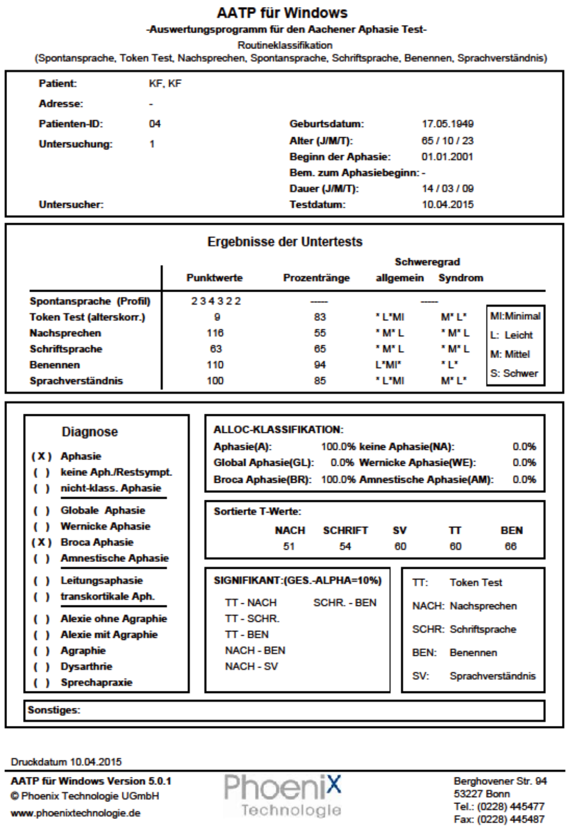
Fig. 16: Patient KH



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Routineklassifikation
(Spontansprache, Token Test, Nachsprechen, Spontansprache, Schriftsprache, Benennen, Sprachverständnis)

Patient:	KF, KF		
Adresse:	-		
Patienten-ID:	04	**Geburtsdatum:**	17.05.1949
Untersuchung:	1	**Alter (J/M/T):**	65 / 10 / 23
		Beginn der Aphasie:	01.01.2001
		Bem. zum Aphasiebeginn:	-
		Dauer (J/M/T):	14 / 03 / 09
Untersucher:		**Testdatum:**	10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	2 3 4 3 2 2	-----	-----	
Token Test (alterskorr.)	9	83	* L*MI	M* L*
Nachsprechen	116	55	* M* L	* M* L
Schriftsprache	63	65	* M* L	* M* L
Benennen	110	94	L*MI*	* L*
Sprachverständnis	100	85	* L*MI	M* L*

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
( ) Wernicke Aphasie
(X) Broca Aphasie
( ) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 100.0% keine Aphasie(NA): 0.0%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 0.0%
Broca Aphasie(BR): 100.0% Amnestische Aphasie(AM): 0.0%

Sortierte T-Werte:

NACH	SCHRIFT	SV	TT	BEN
51	54	60	60	66

SIGNIFIKANT:(GES.-ALPHA=10%)
TT - NACH
TT - SCHR.
TT - BEN
NACH - BEN
NACH - SV
SCHR. - BEN

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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Fig. 17: Patient KF

Group: Conduction Aphasia

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Routineklassifikation

(Spontansprache, Token Test, Nachsprechen, Spontansprache, Schriftsprache, Benennen, Sprachverständnis)

Patient: SH, SH
Adresse: -
Patienten-ID: 03 | Geburtsdatum: 25.03.1938
Untersuchung: 1 | Alter (J/M/T): 77 / 00 / 15
Beginn der Aphasie: 01.01.2001
Bem. zum Aphasiebeginn: -
Dauer (J/M/T): 14 / 03 / 09
Untersucher: | Testdatum: 10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	2 5 4 3 2 3	-----	-----	
Token Test (alterskorr.)	23	58	* M* L	* L*
Nachsprechen	107	47	* M*	* M*
Schriftsprache	43	47	* M*	* M*
Benennen	58	40	* M*	* M*
Sprachverständnis	74	44	* M*	S* M* L

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
(X) Wernicke Aphasie
( ) Broca Aphasie
( ) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 100.0% keine Aphasie(NA): 0.0%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 100.0%
Broca Aphasie(BR): 0.0% Amnestische Aphasie(AM): 0.0%

Sortierte T-Werte:

BEN	SV	SCHRIFT	NACH	TT
47	48	49	49	52

SIGNIFIKANT:(GES.-ALPHA=10%)

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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Fig. 18: Patient SH

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Routineklassifikation

(Spontansprache, Token Test, Nachsprechen, Spontansprache, Schriftsprache, Benennen, Sprachverständnis)

Patient: TH, TH
Adresse: -
Patienten-ID: 02 | Geburtsdatum: 24.08.1966
Untersuchung: 1 | Alter (J/M/T): 48 / 07 / 16
Beginn der Aphasie: 01.01.2001
Bem. zum Aphasiebeginn:
Dauer (J/M/T): 14 / 03 / 09
Untersucher: | Testdatum: 10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	4 4 5 4 3 4	-----	-----	
Token Test (alterskorr.)	16	72	* L*	* S* M
Nachsprechen	99	41	* M*	* S*
Schriftsprache	67	69	M* L*	* S*
Benennen	87	59	* M* L	* S*
Sprachverständnis	108	95	L*MI*	M* L*

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
( ) Wernicke Aphasie
( ) Broca Aphasie
(X) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 100.0% keine Aphasie(NA): 0.0%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 0.1%
Broca Aphasie(BR): 0.0% Amnestische Aphasie(AM): 99.9%

Sortierte T-Werte:

NACH	BEN	SCHRIFT	TT	SV
48	52	55	56	67

SIGNIFIKANT:(GES.-ALPHA=10%)
TT - NACH
TT - SV
NACH - SCHR
NACH - BEN
NACH - SV
SCHR. - SV
BEN - SV

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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Fig. 19: Patient TH

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Routineklassifikation

(Spontansprache, Token Test, Nachsprechen, Spontansprache, Schriftsprache, Benennen, Sprachverständnis)

Patient: GM, GM
Adresse: -
Patienten-ID: 01 | Geburtsdatum: 12.03.1939
Untersuchung: 1 | Alter (J/M/T): 76 / 00 / 28
Beginn der Aphasie: 01.01.2001
Bem. zum Aphasiebeginn: -
Dauer (J/M/T): 14 / 03 / 09
Untersucher: | Testdatum: 10.04.2015

Ergebnisse der Untertests

	Punktwerte	Prozentränge	Schweregrad allgemein	Schweregrad Syndrom
Spontansprache (Profil)	2 5 5 4 2 4	-----	-----	
Token Test (alterskorr.)	31	44	* M*	* M*
Nachsprechen	99	41	* M*	* M*
Schriftsprache	69	72	M* L*	* L*
Benennen	69	44	* M*	* M* L
Sprachverständnis	79	50	* M* L	M* L*

MI:Minimal
L: Leicht
M: Mittel
S: Schwer

Diagnose
(X) Aphasie
( ) keine Aph./Restsympt.
( ) nicht-klass. Aphasie
( ) Globale Aphasie
(X) Wernicke Aphasie
( ) Broca Aphasie
( ) Amnestische Aphasie
( ) Leitungsaphasie
( ) transkortikale Aph.
( ) Alexie ohne Agraphie
( ) Alexie mit Agraphie
( ) Agraphie
( ) Dysarthrie
( ) Sprechapraxie

ALLOC-KLASSIFIKATION:
Aphasie(A): 100.0% keine Aphasie(NA): 0.0%
Global Aphasie(GL): 0.0% Wernicke Aphasie(WE): 100.0%
Broca Aphasie(BR): 0.0% Amnestische Aphasie(AM): 0.0%

Sortierte T-Werte:

BEN	NACH	TT	SV	SCHRIFT
48	48	48	50	56

SIGNIFIKANT:(GES.-ALPHA=10%)
TT - SCHR.
NACH - SCHR
SCHR. - BEN

TT: Token Test
NACH: Nachsprechen
SCHR: Schriftsprache
BEN: Benennen
SV: Sprachverständnis

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Fig. 20: Patient GM

B. Descriptive Data on Single – Case level

Level: Word durations

Tab. 13: Descriptive data of mean word durations according to group, participant and condition.

Group	Participant	Condition	n	Mean	SD	Std. Error Mean
AOS	AK	Casual	97	.771	.131	.013
		Careful	98	.845	.115	.012
	KH	Casual	100	.736	.112	.011
		Careful	95	.803	.120	.012
	KF	Casual	98	1.080	.287	.029
		Careful	95	1.232	.251	.026
CA	TH	Casual	98	.915	.243	.025
		Careful	97	1.017	.218	.022
	SH	Casual	98	.658	.079	.008
		Careful	98	.725	.083	.008
	GM	Casual	96	.711	.109	.011
		Careful	96	.776	.104	.011
Controls	AH	Casual	99	.652	.110	.011
		Careful	94	.777	.126	.013
	GH	Casual	99	.643	.091	.009
		Careful	97	.730	.093	.009
	RP	Casual	99	.603	.124	.012
		Careful	96	.748	.126	.013

Level: Schwa durations

Tab. 14: Descriptive data of mean schwa durations according to group, participant and condition.

Group	Participant	Condition	n	Mean	SD	Mean St. Error
AOS	AK	Casual	75	.057	.002	.017
		Careful	79	.066	.002	.020
	KH	Casual	88	.100	.002	.017
		Careful	92	.104	.001	.014
	KF	Casual	83	.103	.004	.039
		Careful	75	.083	.003	.024
CA	TH	Casual	65	.095	.003	.023
		Careful	94	.109	.002	.021
	SH	Casual	62	.092	.003	.024
		Careful	82	.098	.003	.027
	GM	Casual	63	.073	.002	.014
		Careful	89	.078	.002	.016
Controls	AH	Casual	13	.070	.004	.014
		Careful	97	.087	.002	.021
	GH	Casual	21	.094	.002	.010
		Careful	96	.108	.001	.012
	RP	Casual	14	.081	.004	.016
		Careful	93	.090	.002	.022

Abstract

Einführung

Linguistische Theorien des 20. Jahrhunderts entwarfen abstrakte und rein symbolische Einheiten ohne motorische- oder akustische Eigenschaften um Sprachlaute zu kategorisieren und zu beschreiben. Diese Idee wurde auch in Teildisziplinen wie der klinischen Neurolinguistik übernommen. Wörter werden demnach als lineare Ketten von abstrakten Segmenten beschrieben, die durch amodale, phonologische Einheiten kognitiv repräsentiert und anschließend durch motorisch - artikulatorische Mechanismen ausdifferenziert werden. Moderne neurophonetische Theorien versuchen diesen dualistischen Ansatz zu überwinden.

Neurogene Sprachstörungen bieten die Möglichkeit diese Schnittstelle zu beobachten. Zwei Syndrome sind von besonderem Interesse: Die Sprechapraxie (AOS) und die Leitungsaphasie (CA). Beide treten nach Schlaganfällen in den linken Zerebralarterien auf und betreffen sprachrelevante Regionen. AOS ist eine Störung der sprechmotorischen Planung, während bei CA traditionell die lexikalisch- und postlexikalisch-phonologische Enkodierung gestört ist. Diese Studie versucht einen Einblick in die kognitive Realität phonetisch-phonologischer Mechanismen anhand eines Nachsprechexperiments zu geben.

Methoden

Jeweils drei TeilnehmerInnen mit AOS und CA und drei gesunde SprecherInnen werden mit einem Nachsprechexperiment unter zwei zufällig geordneten Bedingungen konfrontiert: Eine mit schneller Sprechgeschwindigkeit bei salopper Artikulation (d.h. hypospeech / casual - Bedingung) und eine mit reduzierter Sprechgeschwindigkeit bei sorgfältiger Artikulation (hyperspeech / careful Bedingung). Die Stimuli bestehen aus zweisilbigen, initial-betonten (d.h. trochäischen) Worten mit unterschiedlichen phonetischen Eigenschaften, bei denen eine natürliche Tilgung des /ə/-Lautes erwartet wird - jener am meisten verwendeten Vokal im Deutschen.

Ergebnisse und Diskussion

Die Ergebnisse bestätigen Theorien der kognitiven Neurowissenschaften und Neurophonetik und deren zugrundeliegenden Annahmen. Demnach scheinen paralinguistische Faktoren zur Sprechgeschwindigkeit kognitiver *höher* verarbeitet zu werden als angenommen. Sprachstörungen wie AOS und CA zeigen sich unterschiedlich sensibel bei segmentalen und suprasegmentalen Faktoren, wie in der Fähigkeit zur natürlichen Vokalreduktion. Weitere Indizien sprechen für einen kontinuierlich-phonetischen Mechanismus bei Lautelisionen bei beiden Sprachstörungen. Weitere Forschung ist notwendig, um sprachspezifische und sprachübergreifenden Variablen zu identifizieren, die die phonetische Ausdifferenzierung bestimmen.

Schlagwörter: Silbische Reduktionsprozesse, Schwa, Neurophonetik, Neurogene Sprachstörungen, Aphasie, Sprechapraxie

C. Curriculum Vitae

Simon Sollereder

Master in Cognitive Science (ongoing)
Speech and Language Pathologist

Academic Curriculum

since 10/2012 **Participant of the Midde European Interdisciplinary Master in Cognitive Science (Mei:CogSci)**
University of Vienna and Medical University of Vienna, AT

- Masterthesis: Syllabic Reduction Processes in People with Acquired Language Disorders
  Supervisor: Prof. Dr. Wolfram Ziegler, EKN Munich
- Internships at
  - the Austrian Academy of Sciences, Neuropsycholinguistic Department, Vienna, AT
    Supervisor: Dr. Jacqueline Stark
  - EKN – Clinical Neuropsychology Research Group Munich, DE
    Supervisor: Prof. Dr. Wolfram Ziegler
  - Laboratory of Psycholinguistic Research,(EEG) Zagreb, HR
    Supervisor: Dr. Marijan Palmovic

since 10/2009 **Continuation of the Studies in Linguistics (BA)**
University of Vienna, AT

- Paused at the moment

10/2006 – 10/2009 **Education in speech therapy (diploma) at the academy for logopedic, phoniatric and audiological service**
Ausbildungszentrums West für Gesundheitsberufe (AZW), Innsbruck, AT

- Several internships in the field of neurorehabilitation and neurolinguistics in Austria and Germany

10/2005 – 06/2006 **Studies in Linguistics and Roman Languages**
Leopold-Franzens University, Innsbruck, AT

- First stage degree in linguistics in summer term 2006

01/2005 – 08/2005 **Abroad Studies in Italian language and Linguistics**
Università per Stranieri, Perugia, IT

1996 – 2004 **High School**
Bundesgymnasium Sillgasse, Innsbruck, AT

Publications / Scientific Work

2014 **Sollereder, S., Ziegler, 2014**
Schwa Epenthese und Elision bei Personen mit Aphasisch-Phonologischen Störungen; Talk at Mei:CogSci Conference 2014, Krakow, PL

2013 **Sollereder, S., Stark, J. and Pons, C. 2013**
Qualitative Analysis of Conduite d'approche Behavior in a Person with Wernicke's Aphasia. *Procedia - Social and*

	Behavioral Sciences Posterpresentation at Academy of Aphasia 2013, Lucerne
	Sollereder, S. and Stark, J. and 2013 Patterns of Verb Recovery and Their Influence on Sentence Production in Broca's and Wernicke's Aphasia – *Proceedings of the Mei:CogSci Conference 2013 (Posterpresentation)*

EMPLOYMENT

Since 10/2009	**Speech and Language Pathologist** Neurologisches Zentrum, Otto-Wagner-Spital Baumgartner Höhe (Vienna, AT) Beside the diagnostic and treatment of language, speech, voice and swallowing disorders, the field of duty includes: ‣ Leading tasks within the speech therapy team ‣ support and assistance to trainees of SLP ‣ project work

EXTRAOCCUPATIONAL TRAINING

2008 - 2015	**Various training courses for Speech and Language Therapists specializing in Neurorehabilitation**

PERSONAL SKILLS

Languages	‣ Englisch (fluent – certified with TOEFL[5]® IBT Level good – high, Score 102/120) ‣ Italian (fluent – certified with CELI[6] Grado B) ‣ Croatian (B1 Level) ‣ German (mother tongue)
Memberships	‣ Editor of Austrians SLP magazine LogoTHEMA ‣ Logopaedieaustria - professional association of austrian SLPs ‣ GAB (Gesellschaft für Aphasieforschung- und Behandlung) ‣ Austrian Society for Persistent Vegetative State

Vienna, May 2015

[5] ***Test of English as a Foreign Language** (**TOEFL**)*
[6] ***Certificato Di Conoscenza Della Lingua Italiana***

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources or resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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date   (signature)