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Review

Overview of Conditions that Immediately Reduce Stuttering and A Unifying Account for Their Effect

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Abstract: It has been known for a long time that many people who stutter are immediately fluent in certain conditions, for instance, when they speak in unison with others, in sync with the clicking of a metronome, or when they hear themselves speak in an altered manner. To under-stand why stuttering is reduced or even eliminated in such conditions is desirable because it may help understand why stuttering occurs in normal speaking conditions. However, empirical findings in this area appear conflicting and confusing, especially with regard to the role of auditory feedback. The article gives an overview of the variety and diversity of fluency-enhancing conditions and of theories proposed to explain their effect. These theories are evaluated in the light of recent empirical findings. A new hypothesis is proposed, based on findings showing that speech processing is limited without attention to the auditory channel. It is assumed that fluency-enhancing conditions draw the speaker's attention to the auditory channel and, thereby, improve the processing of auditory feedback and its use in speech control. Implications of this account for a causal theory of stuttering and for the treatment of the disorder are discussed.

Keywords: developmental stuttering; attention; auditory feedback

1. Introduction

One of the most peculiar features of developmental stuttering is the fact that it immediately decreases or even disappears in some condi-tions. These conditions are commonly are referred to as fluency-inducing or -enhancing conditions (FCs). Well-known FCs are choral speech, speaking in time with a regular rhythm, or altered auditory feedback (AAF). However, as Bloodstein and Bernstein Ratner (2008, p. 288) state, "virtually any change that can be made in the way a person normally talks is apt to result in much improved or essentially fluent speech in the majority of stutterers". Even a change in the way people who stutter (PWS) hear themselves speak can markedly reduce stuttering, as was demonstrated with delayed auditory feedback (DAF), frequency-altered auditory feedback (FAF), and with masking the speaker's voice by loud noise (for an overview, see, e.g., Blood-stein & Bernstein Ratner, 2008).

FCs reduce stuttering frequency, i.e., the number of repetitions, prolongations, and tensed pauses (blocks, postural fixations) in the majority of PWS. Many studies were done, and several accounts were proposed to explain how FCs operate. An answer to this question could be a key for understanding the nature of stuttering: Understand-ing why stuttering disappears in some special conditions might help us understand why it occurs in normal conditions.

One aim of this paper is to evaluate earlier theories on how FCs ope-rate. To this end, I will first call to mind some of these earlier theories: those that concern all or most of the well-known FCs. Then I will propose a new, unitary explanation. In the subsequent overview of FCs, I will discuss these theories in the light of findings and argu-ments concerning particular FCs.

1.1. The distraction hypothesis

1.1.1. Distraction from stuttering

'Distraction' might have been the most common account for the effect of many FCs – but distraction from what? One possibility is distrac-tion from stuttering – either from hearing one's own stutter or from anticipating a stutter – which supposedly saves from responses like excitement, fear, or tension. This hypothesis implicates that stuttering is caused or triggered by attention to stuttering. Even if stuttering may partly be a vicious circle wherein secondary behaviors like anticipa-tion, excitation, tension, and unsuitable coping strategies exacerbate the disorder – a reduction of secondary behaviors by distraction can hardly account for the nearly complete fluency of most PWS in some FCs.

1.1.2. Distraction from auditory feedback

Another possibility is that FCs distract PWS from auditory feedback (AF), that is, from hearing and monitoring their own speech. Some observations seem to confirm this view: PWS are more (and often completely) fluent when their voice is masked by white noise (e.g., Cherry and Sayers, 1956; Maraist & Hutton, 1957; Webster & Lubker, 1968). Further, stuttering is rare in deaf people, and there are reports that lifelong stuttering disappeared after hearing loss (see, e.g., Van Riper, 1982, for an overview). This seems to suggest that hearing own speech worsens or even causes stuttering.

Therefore, some hypothesized that either AF or its use in speech con-trol is disturbed in PWS. For instance, Maraist and Hutton (1957) supposed a misevaluation of AF by the control system: it "finds error where, in reality, no error exists" (p. 385). Vasic and Wijnen (2005) proposed a similar but more specific hypothesis: An over-sensitive monitoring system in PWS interprets normal discontinuities in speech flow as errors. However, more recent empirical findings do not sup-port this hypothesis: If AF-based monitoring was over-sensitive in terms of timing, one would expect stronger responses to time manipulation of AF, but the opposite was found: Adults who stutter (AWS) showed weaker articulatory compensation of unexpected time-varying AF perturbations than fluent controls (Cai et al., 2014). Moreover, Devaraju et al. (2020) found AWS, as compared with fluent controls, to be less sensitive to temporal fluctuations in speech rhythm.

In a different kind of distraction hypothesis, Max et al. (2004) assu-med that some FCs, particularly AAF, help PWS overcome their (sup-posed) over-reliance on AF-based speech control. However, if AF played an excessive part in speech control in PWS, one would expect stronger corrective responses to AF perturbations, compared to fluent speakers. Again, the opposite was found: As mentioned, AWS showed weaker articulatory responses to time-varying AF perturbations (Cai et al., 2014); further, their corrective vocal responses to AF perturbations in pitch were delayed (Loucks, Chon, & Han, 2012; Nudelman et al., 1992) and weaker (Bauer et al., 2007; Cai et al., 2012; Daliri et al., 2018).

If AF played an excessive part in speech control in PWS, one would further expect overactivation in brain areas involved in the self-monitoring of speech, that is, in the superior and middle temporal cortex (e.g., Guenther, 2006; Indefrey, 2011; Indefrey & Levelt, 2004; McGuire, Silbersweig, & Frith, 1996; Price et al., 1996; Tian, Zarate, & Poeppel, 2016; Tourville, Reilly, & Guenther, 2008). Neuroimaging studies showed these areas to mostly be under- or deactivated during speech in PWS, compared to fluent controls (see, e.g., meta-analyses by Brown et al., 2005, and by Budde, Baron, & Fox, 2014). In other studies, reduced auditory-motor coupling was found in AWS during speech (Kell et al., 2018) and in children who stutter (CWS) in resting state (Chang & Zhu, 2013).

Several authors therefore concluded that PWS seem to poorly monitor their speech (e.g., Braun et al., 1997; Fox et al., 1996; Ingham et al., 2003; Kell et al., 2018). This contradicts the premise of the distraction hypothesis by Max et al. (2004), PWS would overly rely on AF. Taken together, distraction from AF does not seem to be the way FCs reduce stuttering.

1.1.3. Distraction from monitoring own speech movements

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It is an old idea that stuttering may result from the attempt to cons-ciously control something that much better runs unconsciously and automatically. FCs thus may pose an additional task (e.g., in chorus reading) or a stimulus that distracts from the monitoring and conscious control of speech movements. Eichorn, Pirutinsky, and Marton (2019) and Eichorn and Pirutinsky (2022) found that dual task conditions (narrative speech plus a task that required sustained attention) reduced stutter-like disfluencies in adults and children, respectively. However, the reduction was rather small and was similar in stuttering and nonstuttering participants.

These findings indeed support the hypothesis that a less cognitively demanding secondary task can enhance the automaticity of speaking, but it is questionable whether lacking automaticity is the core problem in stuttering. Regarding the theoretical rationale for their approach, Eichorn and colleagues refer to studies in sport psychology showing that an attentional focus on intended movement effects, rather than on the physical movements themselves, tends to optimize performance. The intended (immediate) effect of speaking is audible speech; hence, focusing on this may improve speech fluency in PWS more than does distraction by a secondary task. I will take up again this thought below.

1.2. Change of speech patterns

Speaking in FCs is often associated with increased phonation and decreased rate. This, so Wingate (1969, 1970) assumed, could ameliorate fluency. Empirical studies did not support this hypothesis. For example, the fluency of PWS during choral speech is neither attri-butable to increased loudness nor to decreased rate (Adams & Ramig, 1980; Andrews et al., 1982; Ingham & Packman, 1979). DAF usually makes speakers slow down their rate, but it reduced stuttering in near-ly the same degree when PWS were speaking in a high rate (Kalinow-ski et al.,1993, 1996; Macleod et al., 1995). Masking by noise usually leads to a spontaneous increase of voice intensity, but its fluency-inducing effect is equal or even greater when PWS speak in a low voice (Garber & Martin, 1977).

Howell (2002, 2004) proposed a more specific slowdown theory: Some FCs, among them FAF and choral speech, operate as an additio-nal synchronous rhythm that causes a local slowing of speech. This, so they assume, reduces stuttering by giving PWS more time for speech planning (see also Howell & Sackin, 2000). However, Kalinowski et al. (1993), MacLeod et al. (1995), and Stuart et al. (1996) found that – compared to speaking in habitual rate and with unaltered AF – FAF reduced stuttering even when PWS were speaking "as fast as they possibly could while maintaining intelligible speech" (Kalinowski et al., 1993, p. 6). Therefore, it appears doubtful if local slowing causes the enhanced fluency under FAF.

For choral speech, the idea of local slowing is difficult because rate is generally slightly slower in choral reading (little more than 3 sylla-bles/s; Kiefte & Armson, 2008). However, Kiefte and Armson (2008) tested a condition where PWS read in unison with a recording of a normal speaker's voice in a normal rate (4.4 syllables/s). This condi-tion eliminated stuttering as effectively as life choral reading. There-fore, slowing cannot be the crucial fluency-enhancing factor in choral speech.

Wingate (1981) hypothesized a change in prosody to cause enhanced fluency in choral reading, rhythmic speech, shadowing, and singing: "a monotone quality is common to all" (p. 102). But Ingham and Carroll (1977) and Ingham and Packman (1979) found that listeners could not always differentiate fluent speech of PWS in solo and cho-rus reading; thus, the prosodic change is rather subtle, if existing. Overall, FCs indeed cause or are associated with changes in the man-ner of speaking, but there is no specific change common to all FCs, which could explain their effect.

1.3. Mirror neurons

Kalinowski and Dayalu (2002) emphasize the fact that some FCs, e.g., choral speech and AAF induce effortless, natural-sounding fluent speech. This, so they propose, is due to the presence of a sensory sti-mulus: a second speech signal. Based on this, Kalinowski and Saltu-klaroglu (2003a, b) and Saltuklaroglu, Kalinowski, and Guntupalli (2004) proposed a theory according to which “all forms of stuttering inhibition primarily occur as a result of sensory stimuli” (Saltuklarog-lu et al., 2004, p. 444).

The sensory stimulation, so the authors, can come about in two ways: The stimulus can be present externally, as in choral speech, metro-nome-paced speech, and with AAF, or PWS can quasi stimulate them-selves by speaking in another than their normal manner, as in whisper-ing, adopting a foreign dialect, or singing. Such sensory stimulation, so the authors propose, activates the mirror neuron system, which sup-ports fluency by “the matching of sensory targets via mirror neuronal activity, either to an exogenous model or to an endogenously imposed model” (ibid., p. 445).

Saltuklaroglu and colleagues (2004) further claim that the effect of FCs like whispering, speaking in a foreign dialect, or singing (where no external second speech signal is provided) is due to the imitation (by mirror neurons) of an endogenously imposed model. From that, the question arises: If imitating the internal model of a song or of a foreign dialect reduces stuttering – why do PWS not imitate their undoubtedly existing internal model of normal, fluent speech? Stut-tering should easily be eliminable this way if the mirror neuron theory were true. Besides, imitation cannot account for the fluency-inducing effect of loud noise, of a second speech signal clearly not imitated, e.g., recorded speech played backwards (see Section 2.2), or of ‘re-versed shadowing’ (see Section 2.3). The mirror neuron theory is thus not convincing as a general account for FCs, but I will hark back to it below in explaining a special sort of FCs, the so-called response contingent stimulation (Section 2.7.1).

1.4. A new hypothesis

In the past, the influence of AF on speech control was mostly suspected to be detrimental to PWS, and FCs were assumed to reduce this influence by distraction or in another way. Recently, Max and Daliri (2019) proposed a hypothesis that may cause a paradigm shift. Daliri and Max (2015) found that the amplitude of the N1 com-ponent of the auditory-evoked potential elicited by a probe tone just before speech onset was consistently attenuated in fluent speakers. This “pre-speech auditory modulation” (PSAM) was greatly reduced or absent in AWS. Max and Daliri (2019, p . 3075) hypothesize that PSAM reflects “neural processes involved in priming and selectively biasing the auditory system for its role in monitoring auditory feedback during speech production”.

Lange (2013) explains the influence of attention and prediction on the auditory N1 amplitude in a model. Expectation (prediction) of an event reduces the N1 amplitude related to the event. Hence, PSAM in normal speakers can be interpreted as reflecting the expectation of hearing one’s voice. Expectation is “assumed to lead to an orienting of attention to the expected stimulus” (Lange, 2013, p. 2). By contrast, the lack of PSAM in AWS suggests that they don’t expect auditory input when they start speaking. The larger N1 amplitude in AWS in response to the probe tone can be interpreted as an “attention call sig-nal” (ibid., p. 1) reflecting orienting of attention to the auditory channel.

Max and Daliri also found that the expectation of DAF normalized PSAM in PWS (see also Daliri & Max, 2018). The expectation of hearing their speech with a delay (i.e., in an unaccustomed manner) possibly made PWS to direct more attention to the auditory channel at speech onset than the expectation of natural AF did. Thais suggests regarding the effect of DAF as an FC: DAF reduces stuttering by mo-dulating auditory attention in a way improving the use of AF in speech control. This, in turn, rises the question if other – and perhaps all – FCs operate in a similar way.

1.4.1. The role of attention in speech processing

Empirical findings suggest that proper processing of spoken language requires sufficient auditory attention. In a behavioral experiment (dichotic listening) with normal speakers, Cherry (1953) found speech comprehension to be very limited without attention to the speech sig-nal. Functional MRI studies with normal speakers showed attention to auditory speech stimuli to be associated with activation in auditory as-sociation areas involved in receptive speech processing (Jäncke, Mir-zazade, & Shah, 1999; Hugdahl et al., 2003; Sabri et al., 2008). Some cortical areas involved in speech processing were deactivated when participants did not listen to the speech signal (Sabri et al., 2008).

These findings indeed concerned the processing of speech of others, not of own speech feedback; but in line with Levelt (1983, 1989), we can assume that AF of speech is processed by the same comprehen-sion system in nearly the same way as is speech of others. Neuroimag-ing findings support this view. In PET studies, McGuire, Silbersweig, and Frith (1996) and Price et al. (1996) found no difference in the activation of the temporal cortex during overt speech (and hearing one's speech), on the one hand, and hearing the same words spoken by someone else, on the other hand. We can thus assume that also the processing of AF of own speech requires sufficient attention to the auditory channel.

To my knowledge, there is no literature about the impact of attention on the processing of AF of speech in the brain. However, in a behavio-ral study with normal speakers, Scheerer, Tumber, and Jones (2016) investigated the impact of attention on the use of AF in speech control. Their results "suggest that attention is required for the speech motor control system to make optimal use of auditory feedback for the regu-lation and planning of speech motor commands." (p. 826)

1.4.2. The attention hypothesis

The term 'attention' refers not merely to a psychological, but also to a neurological phenomenon. Selective attention can be described as the allocation of limited perceptual and processing resources (see, e.g., Anderson, 2004; Wahn & König, 2017 for an overview). This is not far from the concept of executive function, defined by Smith, Choo, and Foster (2021) as "the set of capacities that are needed to manage and allocate one's cognitive resources during cognitively challenging activities" and, by these authors, considered as a crucial factor in stut-tering. I prefer using the term 'attention allocation' (instead of 'capacity allocation') to express that it is not only about brain proces-ses uninfluenceable by the person. The allocation of attention is con-trolled by external stimuli and inherent mechanisms, but also by the person's will, and by behavioral habits.

The idea that FCs operate by changing the allocation of attention is not new, since the distraction hypothesis claims the same. The differ-ence to the hypothesis proposed is the direction of the change. Assu-me, as a hypothetical premise, PWS habitually allocate their attention inappropriately during speech: They overly focus on speech planning and/or motor control, such that insufficient attention is left for audito-ry perception. Since receptive speech processing depends on auditory attention, this imbalance impairs the processing of AF and its use in speech control, which results in stuttering.

Indeed, I do not assume that normal speakers deliberately listen to their voice in everyday talking; I think their attention is distributed habitually in a way that AF is properly processed and integrated. But this seems not to be the case with PWS. FCs, I submit, operate as fol-lows: They draw attention to the auditory channel, thereby improving the processing of AF and its use in speech control in PWS. In doing so, FCs transiently change a pattern typical of stuttering: reduced au-ditory-motor coupling and overreliance on somatosensory feedback (Kell et al., 2018).

In the following overview of particular FCs, I will not only discuss earlier theories that aimed to explain their effect, but also the follow-ing unitary account: FCs reduce stuttering by changing the allocation of attention in PWS, namely by drawing their attention to the auditory channel and in this way improving the processing of AF and its use in the control of speech. I will refer to this as the 'attention hypothesis'.

2. Overview of FCs

2.1. Rhythm

At least since the middle of the eighteenth century, exercises involving rhythm had been advocated as a means of recovery from stuttering (cf. Wingate 1969). Stuttering is eliminated or greatly reduced in most PWS when they time their speech to a rhythmic beat such as hand clapping or the clicking of a metronome. Van Dantzig (1940) showed that PWS immediately became fluent when they timed each syllable with a tipping of the finger. The striking effect of metronome pacing was shown in many studies, with either syllable or word initiation being paced (e.g., Johnson & Rosen, 1937; Martin & Haroldson, 1979; see Bloodstein & Bernstein Ratner, 2008, for an overview).

Several hypotheses on the rhythm effect were tested: Barber (1940), Fransella and Beech (1965), and Hanna and Morris (1977) examined the impact of rate and found that rhythmic speech reduced stuttering significantly even with rates faster than usual. Stager, Jeffries, and Braun (2003) compared the voicing duration of PWS during natural and metronome-timed speech and found no difference. Fransella (1967) tested the rhythm effect in a dual-task condition and concluded from their results that the effect of rhythm could not be reduced to distraction. Brady (1969) found that neither rate nor distraction and not even rhythmicity caused the effect of metronome-paced speech. He supposed that the beat had a 'cue' function signaling when the next syllable or word should start.

The cue hypothesis appears tempting at first sight. However, the idea behind is that PWS cannot produce a proper speech rhythm by themselves, butt most PWS are quite able to produce an even rhythm in hand clapping or singing. More important, PWS produce a normal speech rhythm during fluency in other FCs, e.g., with FAF or masking noise. Besides, the cue hypothesis is implausible: If you each time wait for the next click to start a syllable, you are never synchronous with the metronome, but too late because of the reaction time. Instead, you must capture the presented rhythm, produce it by yourself, and continuously monitor if you are still in sync with the metronome.

The proposed attention hypothesis explains the rhythm effect on stut-tering as follows: Speaking in time with a rhythm entails listening to both, the metronome (or, e.g., the clapping hands) and the speech rhythm; hence, attention is drawn to the auditory channel and to AF. This improves the processing and integration of AF and reduces stuttering.

This view is consistent with the results of an experiment done by Howell and El-Yaniv (1987): PWS read a short story in three condi-tions, (1) without metronome (control condition), (2) syllable by sylla-ble in time with the clicking of a metronome, and (3) while listening to clicks that sounded at the beginning of each syllable, triggered by the intensity of the voice. The third condition, in which the partici-pants were speaking in their natural rate and rhythm, reduced stutter-ing nearly as much as the second condition. This indicates that not the evenness of the presented rhythm reduced stuttering in condition 2, but probably the fact the participants listened to the clicks.

The effect of rhythmic speech on brain activation in PWS was exami-ned in several neuroimaging studies. In most of them (Braun et al., 1997; Stager, Jeffries, & Braun, 2003; Toyomura, Fujii, & Kuriki, 2011), activation in auditory association areas was greater during metronome-paced than with habitual speaking. This was not only due to the metronome signal because fluent controls showed no similar increase in auditory activation in the metronome condition. The find-ings support the view that, as Stager and colleagues conclude, metro-nome-timed speech reduces stuttering "by enabling more efficient use of auditory information" (Stager et al., 2003, p. 333).

Other than the studies mentioned above, Frankford et al. (2021) found no auditory activation difference between rhythmic and habitual speech of AWS in an fMRI study, However, the rhythm (eight beats) was not presented during but only prior to speaking; the participants did not hear the rhythm while speaking and could not monitor synchrony. During imaging, participants spoke eight-syllable sentences which they had practiced before until they could produce them iso-chronously in a rate not slower than their natural speech rate. Due to this experiment design, and because it is doubtful whether isochronous speech without support by a concurrently presented rhythm actually works as an FC (this was not tested), the results of Frankford et al., in my view, do not contradict the attention hypothesis.

2.2. Speaking in unison

Most PWS have no difficulty when speaking in unison. The fluency-inducing effect of choral reading was confirmed experimentally by Johnson and Rosen (1937). Choral speech is one of the most effective FCs, it usually reduces stuttering by 90-100% (see, e.g., Kiefte & Armson, 2008, for an overview). Several accounts for this effect were proposed, among them distraction, reduced rate, increased loudness, or a more continuous vocalization (e.g., Wingate, 1969). However, Adams and Ramig (1980) found no increase in loudness during choral reading, and they observed that PWS even shortened syllabic vowel duration. Ingham and Packman (1979) and Andrews et al. (1982) concluded from their data that the effect of choral reading cannot be explained by a reduced rate.

Pattie and Knight (1944) hypothesized that the co-speaker acts as a 'pacemaker', but Cummings (2003) points to the fact that live choral speech is a collaborative activity: Both speakers modify the timing of their speech about equally. Kiefte and Armson (2005) found that the reduction of stuttering in choral speech was highly robust even when the co-speaker's voice temporally lagged that of PWS, and Park and Logan (2015) concluded from the results of their behavioral study, that cueing alone could not account for the fluency of PWS during choral speech. Besides, just as in metronome-timed speech, someone who each time waited for the cue before starting a word or syllable would never be in sync with co-speaker(s) but always too late.

Hickok, Houde, and Rong (2011) proposed an account similar, in some respect, to the cue- or pacemaker hypothesis. Stuttering, so they assume, occurs when the sensory system receives inaccurate predict-ions from an internal feedback mechanism, and in choral speech, "the sensory system (which is coding the inaccurate prediction) is bombar-ded with external acoustic input that matches the sensory target and thus washes out and overrides the inaccurate prediction allowing for fluent speech" (p. 417). In other words, PWS are fluent because they hear the words they are speaking at the same time from their co-speaker(s).

This account can be true at most for 'classical' choral speech, with PWS and co-speaker(s) producing the same words. However, a nearly similar reduction of stuttering was observed when the co-speaker read different material than that read by the person who stutters (Barber, 1939; Bloodstein, 1950; Cherry & Sayers, 1956), or when the co-speaker changed without warning to gibberish (Cherry & Sayers, 1956). Stuttering was even reduced when tape-recorded speech played backward was presented as a 'co-speaker' (Cherry & Sayers, 1956; Rami & Diederich, 2005), or a continuous audio signal like /a/ (Da-valu et al., 2011). Obviously, not only acoustic input matching the sensory target (as premised by Hickok, Houde, and Rong), but nearly all kinds of auditory stimulation concurrent with speech can reduce stuttering.

The attention hypothesis assumes that both, 'classical' life choral speech and other auditory stimuli reduce stuttering in the same way, namely by enhanced auditory attention during speech. This view is consistent with results of an MEG study by Salmelin et al. (1998). They found reduced sensitivity in the left auditory cortex in PWS, compared to fluent controls, during solo reading. During choral read-ing, the left-hemispheric sensitivity was restored in PWS, possibly by enhanced auditory attention.

In neuroimaging studies, greater activation in auditory association areas in PWS was found during choral reading as compared with solo reading (Fox et al., 1996; Stager, et al., 2003; Toyomura et al., 2011; Wu et al., 1995). The increase of auditory activation in PWS was not due to listening to the co-speaker only, since fluent controls did not show similar increase. These findings support the attention hypothesis because enhanced auditory attention increases activation in auditory association areas (see Section 1.3.1).

In 'classical' choral speech, PWS need to listen to both, the other speaker(s) and to their own speech to monitor synchronicity; hence, listening is task-relevant. This explains the powerful effect of this of life choral speech. By contrast, a task-irrelevant auditory stimulus, such as gibberish or a continuous audio signal, draws attention to hearing, but there is no need for active listening. It is thus not surpris-ing that the effect of task-irrelevant auditory stimuli is weaker and individually more different. For example, Rami and Diederich (2005), other than Cherry and Sayers (1956), found no significant effect on stuttering (but a large effect size) when speech played backward was presented. Rami et al. (2005) found that choral reading did not reduce stuttering when the co-speaker's voice signal was lowpass filtered so that it became very deep and hardly intelligible.

Some auditory stimuli that are felt unpleasant or irritating may make PWS rather ignore what they hear. However, these differences in efficacy rather support the view that the reduction of stuttering by an acoustic stimulus depends on its effect on the attention of PWS. Taken together, choral speech requires active listening, and many other unfamiliar 'side tones' induce attention to the auditory channel; therefore, enhanced auditory attention during speech can explain the effect of these FCs.

2.3. Shadowing

In shadowing, the person who stutters immediately copies what another person, e.g., a therapist says, having only a vague (or no) idea of the words to be spoken until hearing them (see, e.g., Cherry & Sayers,1956; Marland, 1957; Wingate, 1969). That is, the therapist (or lead speaker) and the person who stutters speak concurrently most of the time, but not synchronously; PWS get no cues for syllable or word initiation because of the time lag between lead speaker and shadower. The method proved very effective; Andrews et al. (1982) found 95% reduction of stuttering on average. Shadowing was applied in stuttering treatment mainly in the sixties and seventies (e.g., Kelham and McHale, 1966; Kondas, 1967; MacLaren, 1960; Shelton, 1975; but see also Rongna et al., 2018).

The effect of shadow speech was explained mainly in two ways: by imitation or by distraction. In the framework of a theory that consider-ed stuttering a learned incorrect pattern of speaking, the fluency during shadowing was attributed to the exact imitation of a correct speech pattern (e.g., Kelham & McHale,1967; MacLaren, 1960). Hudock (2012) refuted this assumption by examining shadowing in two conditions: (1) the person who stutters, as usual, shadows a normally fluent person's speech, (2) the person who stutters is the leader whose speech is shadowed by a fluent speaker. Stuttering fre-quency was reduced by approximately 80% in both conditions. This clearly shows that the effect of shadowing is not attributable to imitation.

Cherry and Sayers (1956) assumed that PWS were distracted from their anyway distorted AF during shadow speech, and Kelham and McHale (1966) even asserted that "shadowing prevents feedback from taking place at all" (p. 114). However, the distraction hypothesis is as implausible for shadowing as it is for choral speech: The shadower needs to listen to the lead speaker, but also to his/her own speech to check whether the last segment was repeated completely before the repetition of the next, already heard and memorized segment can start.

The attention hypothesis can explain both, the effect of 'normal' shadowing and of 'reversed shadowing': The former requires active listening to the lead speaker and to one's own speech, the latter makes PWS listen to the unfamiliar 'echo', similarly as with DAF (see be-low). DAF can be regarded as a simulation of reversed shadowing. Such similarity between at first view different FCs suggest the existence of a sole underlying effect mechanism.

The attention hypothesis can also explain the results of an experiment done by Saltuklaroglu and Kalinowski (2011): PWS read short text passages, either after shadowing syllables or after listening to the same syllables. Both, shadowing and listening reduced stuttering in the ensuing readings. The common feature of both conditions was: PWS had to listen before speaking. This attentional shift to audition probably improved the processing and use of AF in the ensuing readings.

2.4. Singing

Almost all PWS do not stutter in singing. Wiechmann and Richter (1966) reported that 31 out of 1582 stuttering German school-age children (2%) stuttered in singing. Andrews et al. (1982) found stuttering reduced by 98% on average during singing, compared to speaking.

Some authors (e.g., Johnson & Rosen, 1937) considered the absence of stuttering in singing to be an effect of rhythm, but Wingate (1969) pointed to the fact that the correspondence between words, melody, and beat is often not close in songs. He instead suggested that a chan-ge in vocalization, an integral part of singing, makes stuttering disappear. Healey, Mallard, and Adams (1976) examined the role of reduc-ed rate and familiarity with melody and lyrics, and they found that both factors contributed to the fluency of PWS in singing. Colcord and Adams (1979) investigated the change of vocalization during singing and concluded that the extension of voicing duration was the main cause for the elimination of stuttering.

Glover et al. (1996) came to different conclusions. They asked PWS to read and to sing prose passages at a normal and at a fast rate. Stutter-ing was reduced by 75% on average in singing as compared with reading, and there was no difference in stuttering frequency with rate. In the two singing conditions (normal and fast), participants had to spontaneously create idiosyncratic melodies or melody-like structures, and their singing was not always very 'musical', but they experienced a great improvement in fluency. The authors conclude that the absence of stuttering in singing can neither be attributed to memorized material nor to an imposed rhythm, nor to reduced rate.

Stager, Jeffries, and Braun (2003) searched for a common feature of rhythmic speech and singing that may cause their effect on stuttering. They found an increase in voicing duration in singing, but not in rhythmic speech, and conclude that extension of voicing duration cannot be the common mechanism searched. Using PET, they found greater auditory activations in the bilateral STG during both, rhythmic speech and singing, compared with two control conditions (narrative speech and a sentence construction task). Stager and colleagues con-clude that rhythmic speech and singing may reduce stuttering "by enabling more efficient use of auditory information" (p. 333).

The attention hypothesis is consistent with Stager and colleagues' conclusion. When singing a familiar song, one automatically listens to the own voice to monitor correct intonation according to the melody. Listening to the voice might be necessary even more if one creates a melody, as in the experiment by Glover et al. (1996). Therefore, enhanced auditory attention and better integration of AF may eliminate stuttering in singing.

An additional factor supporting auditory-motor integration in singing is that the phonation of usually short-spoken syllables is often signifi-cantly prolonged in song, and their duration must be timed exactly according to the melody. The timing of long syllables (other than that of short syllables) is controlled by 'audio-phonatory coupling', a mechanism that ensures the integration of AF in speech control (see below).

2.5. Slow, prolonged speech

Slow speech as a means to reduce stuttering has been applied in treat-ment at least since the 19th century (see, e.g., Van Riper, 1973 for an overview). Empirical studies showed that slowing down the rate by syllable prolongation strongly reduces stuttering: Perkins et al. (1979) found stuttering essentially eliminated when the rate was reduced by approximately 75%. He assumed that stuttering resulted from a disco-ordination of phonation, articulation, and respiration to cause stutter-ing, which was overcome by adapting the rate to the limited motor control capacity of PWS (see also Perkins et al., 1976).

This account is hardly consistent with the finding that speaking in a high rate (50% above normal or "as fast as possible", resp.) did neither significantly increase stuttering frequency (Ingham, Martin, & Kuhl, 1974; Kalinowski, Armson, & Stuart, 1975) nor reduce the fluency-enhancing effect of DAF and FAF (Kalinowki et al. 1993, 1996). However, speech rate has some influence on the effect of other FCs: Hargrave et al. (1994) and Macleod et al. (1995) found a smaller reduction of stuttering by DAF and FAF at fast compared to normal rates, and with metronome-paced speech, Fransella and Beech (1965) found less stuttering at slower than at faster rates.

Nevertheless, a high speech rate alone is certainly not the cause of stuttering. This rises the question: Why does slow, prolonged speech so strongly reduce or even eliminate stuttering? Studies of brain acti-vity provided some suggestions. Using fMRI, Hashimoto and Sakai (2003) investigated the brain activation during speaking under DAF and during slowed speech (with natural AF, as a control condition) in fluent speakers. Their results suggest that speaking under DAF as well as slowed speech seem to be associated with a change in atten-tion: participants probably paid more attention to the task than they did with speaking in their habitual rate. Kittilstved et al. (2018) exa-mined the brain activity during slowed speech in normal speakers using EEG. They conclude that "prolonged speech was characterized by increased feedback due to the novelty of the task and/or increased monitoring" (p. 11).

A study of the effect of slowed speech on brain activation in PWS was done by De Nil et al. (2008) using fMRI. At habitual rate, left auditory association areas were less activated in PWS as compared with con-trols, but this group difference disappeared during slowed speech. Right auditory areas were greater activated during slowed than during habitual speech in PWS. Together, the results of brain research suggest that increased auditory attention is a possible explanation for the fluency-inducing effect of slow, prolonged speech.

2.5.1. Audio-phonatory coupling

The efficacy of prolonged speech is similar to that of choral reading, metronome-paced speech, or shadowing – FCs that require active listening. This is not the case with prolonged speech, but something else 'chains' prolonged speech to AF: Kalveram (1983) found the duration of long syllables, and thus the start of the subsequent sylla-ble, to be controlled based on AF. He called this mechanism 'audio-phonatory coupling' (see also Kalveram & Jäncke, 1989; Natke, 1999).

In a series of experiments, Kalveram and colleagues asked German native speakers to produce the pseudoword /tatatas/ with stress on the second syllable. That is, this syllable was spoken not only louder but also longer; the mean duration of phonation in the stressed syllable (with normal AF) was about twice as long as in the unstressed sylla-bles (Kalveram & Jäncke, 1989; Jäncke, 1991). A delay in AF by about 40ms (below the threshold of conscious perception) lengthened phonation in the stressed syllable by up to 80% of the delay time. Pre-mature AF (30ms earlier than natural AF) shortened phonation in the stressed syllable. The unstressed syllables remained unaffected by the feedback manipulations.

From a literature analysis, Borden (1979) had concluded that AF was too slow to be useful for the control of ongoing speech. However, she refers only to the control of stop consonants, for which AF "provides information to the speaker too late; he has already spoken and can only correct it after the fact." (p. 309). Audio-phonatory coupling shows that feedback control of ongoing speech is possible if the con-trolled unit is not too short, as it is the case with the vowel core of a stressed syllable. Unstressed, short-phonated syllables, by contrast, are too short to be controlled based on AF (Jäncke, 1992). Kalveram and Natke (1998) noted that, in audio-phonatory coupling, AF is not used as 'negative feedback', i.e., not for error correction, but as a feedfor-ward signal for determining the duration of the current syllable, and thereby for the start of the next syllable.

We can thus assume that the duration of long-phonated syllables is controlled by audio-phonatory coupling. If all syllables of an utterance are long-phonated, as in slowed, prolonged speech, then AF is perma-nently involved due to audio-phonatory coupling; speech control cannot uncouple from AF. This may explain the great reduction of stutter-ing in prolonged speech, but also, as already mentioned, in singing.

A special kind of prolonged speech is the avoidance of short-phonated syllables (Ingham et al., 2001). This speech technique ensures perma-nent audio-phonatory cou-pling but avoids the (for the reduction of stuttering unnecessary) prolongation of natu-rally long-spoken sylla-bles.

2.6. Altered auditory feedback

Altered auditory feedback (AAF) is usually understood as "the elec-tronic manipu-lation of an individual's speech signal such that the individual perceives his or her speech differently in some way." (Lincoln et al., 2010, p. 1122). I think this definition is too narrow. AF can be altered in many ways, e.g., by room acoustics (we hear oursel-ves delayed, with an echo, when speaking in a large cathedral) or by speaking louder or lower than normal, in a higher or lower pitch, or in a foreign dialect. Such natural alteration in AF is not rarely associated with enhanced fluency in PWS (see Bloodstein & Bernstein Ratner, 2008, for an overview). Furthermore, choral speech, metronome-paced speech, shadowing, and other FCs in which a special 'side tone' is presented also alter what is heard while speaking, compared to a normal speech situation.

There is no fundamental difference between technically and naturally altered AF. Howell (2004, p. 31) notes about DAF and FAF: "The former creates a speaking situation like that in an echoey auditorium, and the latter gives the speaker the impression of speak-ing at the same time as another speaker (either one with a deeper voice or one with a higher voice, depending on which way the speech spectrum is shift-ed)." As already men-tioned, DAF can further be interpreted as 'revers-ed' shadowing which was found to re-duce stuttering in a similar de-gree as 'normal' shadowing (Hudock, 2012).

A simple way of altering AF is its amplification. Harris (1955) report-ed an experi-ment where PWS read aloud (A) in their habitual manner, without earphones, (B) with AF through earphones at a "comfortable loudness" level, and (C) with AF through ear-phones at 20 dB above comfortable loudness level. The number of stuttered words was reduced on average in condition B as compared with A, and also in condition C as com-pared with B (cf. Martin et al., 1984). Likewise, Ham and Steer (1967) report reduced stut-tering with amplified AF, but only with levels of 60dB and 75dB above the participants' natural loudness. Martin et al. (1984) found that amplified AF reduced stutter-ing after a condition in which AF was masked by noise. Fiorin et al. (2021) found reduced stuttering in children and adolescents with AF amplification up to 65-90dB.

AF through earphones is AAF because it excludes the impact of envi-ronmental acoustics on auditory perception. MacLaren (1960, p. 458) noted: "Headphones help to cut out distractions, give speech a more direct impact on the attention." Unger, Glück, and Cholewa (2012) and Foundas et al. (2013) examined the efficacy of wearable speech aids that generate DAF and FAF. In both studies, stuttering frequency was significantly re-duced in a control condition, where PWS heard their speech through the device, but with DAF and FAF functions being switched off.

As stated above, not only electronic devices can alter AF. Stuart et al. (1997) found a reduced stuttering frequency when AWS were speak-ing into a passive resonator – a toy, shaped like a mic, that mechani-cally generated an echo. Pelczarski and Hoag (2018) found a reduc-tion of stuttering when PWS were speaking in a resonant voice, i.e., in "an easy, but strong, clear voice that can be heard over a distance as well as in background noise".

The four examples – speaking in a resonant voice, speaking into a passive resonator, amplified AF, and the 'headphone effect' illustrate that the fluency-enhancing effect of AAF is not restricted to DAF and FAF. This should be considered in explaining the effect of DAF or FAF. It suggests that not a specific delay or frequency shift compen-sates for an unknown defect in the brain of PWS. Instead, a more general mechanism seems to underlie the fluency-enhancing effect of AAF..

2.6.1. Delayed auditory feedback

Lee (1950) found that a delay in the AF of speech by about one sylla-ble length (1/4–1/5 second) evoked speech disfluencies in healthy individuals. Repetitions (often at the end of multisyllabic words) and prolongations (often of vowels) occurred, but also omissions and other speech errors (see analyses by Fairbanks & Guttman, 1958, and Venkatagiri, 1980). These behaviors are referred to as the 'Lee effect'. Lee (1951) called them "artificial stutter", but they markedly differ from true stuttering (Neelley, 1961; Stuart et al., 2002; Wingate, 1970). Venkatagiri (1980), although emphasizing similarities between Lee effect and stuttering, found no tensed pauses with healthy indivi-duals speaking under DAF, i.e., no involuntary blocks as typical of stuttering.

What causes the Lee effect? Fairbanks and Guttman (1958) assumed speakers produce repetitions and prolongations under DAF in the spontaneous attempt to restore the time match between speech produc-tion and AF. Howell, Powell, and Khan (1983) and Howell and Archer (1984) demonstrated that it is not the delayed phonological feedback which causes slowing and errors: They found similar effects when DAF of a Morse sequence instead of speech, and when a delayed noise signal of the same intensity profile as the original speech were presented. They hypothesized that DAF operates as a displaced rhythm, but their results are better explained by audio-phonatory coupling (Section 2.5.1). This mechanism as well does not depend on phonological feedback, but on the feedback of syllable starts, i.e., increasing voice intensity.

Since audio-phonatory coupling controls the duration of all long-phonated syllables, it is not surprising that a 200ms-DAF causes pro-longations and errors. The Lee effect can therefore be seen as the result of an 'overstretched' audio-phonatory coupling. A much greater delay, e.g. 500ms or more, is less effective because it is no longer in-terpreted as AF, i.e., as reflecting the actual timing of own speech, but rather as an echo, an additional signal irrelevant for speech control.

Howell and Archer (1984) further found the Lee effect to increase with increasing loudness of the DAF signal (at 200ms delay). This suggests that the Lee effect is not independent of attention: the louder the DAF signal, the more it attracts auditory attention and affects speech control.

Nessel (1958) discovered that DAF reduced stuttering, and this was confirmed in many further studies (see Bloodstein & Bernstein Ratner, 2008, for an overview). Initially, DAF was viewed primarily as a tool for making PWS slow down their speech rate. To this end, long delay times of 200ms or more were used, and the improved fluency was interpreted as due to slow, prolonged speech (e.g., Curlee & Perkins, 1969; Ham & Steer, 1967; Langová et al., 1970). But Lotzmann (1961) and Webster, Schuhmacher, and Lubker (1970) showed that shorter delay times (100ms or 50ms) reduced stuttering more effec-tively than longer ones did. Eventually, Kalinowski et al. (1993, 1996) and Macleod et al. (1995) instructed PWS to speak in a fast rate under DAF, and it turned out that the effect on stuttering was independent of rate (see also the discussion of these findings by Stuart & Kalinowski, 1996).

Stuart et al. (2002) hypothesized that, like choral reading and paced speech, also DAF enhances the activity in the auditory cortex in PWS. In fact, using fMRI, Watkins et al. (2008) found increased activation in the superior temporal cortex bilaterally in PWS and fluent controls in reading under DAF (200ms delay), compared to reading with nor-mal AF. There were further studies with fluent speakers: Using MRI, Hashimoto and Sakai (2003) found greater activation in the superior temporal cortex bilaterally whit DAF (200ms delay). In a PET study, Takaso et al. (2010) tested three delay times, 50ms, 125ms, and 200ms, and found increasing auditory activation with increasing delay. Kittilstved et al. (2018) examined the effect on brain activity of DAF and choral speech in an EEG study

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with normal speakers. They inter-pret their results as reflecting increased feedback control in both conditions.

These findings suggest that DAF operates similarly as do choral read-ing, metronome-timed speech, or singing: It draws the speaker's attention to the auditory channel because it sounds unfamiliar and odd. This view is consistent with Daliri and Max's (2018) finding that DAF normalized (i.e., increased) PSAM in AWS (see above, Section 1.4). The participants in this study knew before speaking (when the event-related potential in response to the probe tone was recorded) whether they would speak with normal AF or with DAF. The anticipation of hearing oneself delayed probably drew their attention more to the auditory channel than did the anticipation of hearing oneself in the habitual manner.

As the above neuroimaging findings show, the effect of DAF on brain activation is similar in PWS and fluent speakers. Why then does DAF reduce stuttering in PWS, but cause disfluencies in normal speakers? This seeming paradox results from the different delay times for stutter-ing reduction and Lee effect. The delay best for reducing stuttering is 50–75ms (Armson & Kiefte, 2008; Kalinowski et al., 1996; Lincoln, Packman, & Onslow, 2006). AF with such a short delay hardly evokes disfluencies in normal speakers (Foundas et al., 2004, 2013; Stuart et al., 2002); it is still useful for speech control without problem. Even a delay by 120ms has little effect on normal speakers (Foundas et al., 2004).

However, an AF delayed by 50-75ms sounds unaccustomed; it enhan-ces auditory attention and, therefore, reduces stuttering by improving the processing and use of AF. The delay time maximally disrupting for normal speakers is about 200 or 250 ms (Fairbanks & Guttman, 1958; Stuart et al., 2002). Such long delays disturb self-monitoring and affect audio-phonatory coupling, which results in markedly prolonged speech, disfluencies and errors – not only in normal speakers but also in PWS (Chon et al., 2021).

2.6.2. Frequency-altered auditory feedback

FAF means hearing one's voice through headphones higher or lower than one's natural AF, usually 1/4 to 1 octave up or down (Lincoln, Packman, & Onslow, 2006). Howell, El-Yaniv, and Powell (1987) discovered that FAF reduces stuttering. Previously, Ham and Steer (1967) had found a similar effect using frequency-filtered AF that also makes AF higher or lower, but associated with impaired distinctness. The frequency shift needs to be consciously perceptible to reduce stuttering, but beyond that, the effect of FAF does not depend on a specific degree or direction of frequency shift. There is no significant difference in this respect between small (1/4 octave) and larger fre-quency shifts, or between shifts up- and downward (Hargrave et al., 1994; Stuart et al., 1996).

FAF can be interpreted as a simulation of choral speech (Howell, 2004; Kiefte & Armson, 2008). Accordingly, Ingham et al. (1997), referring to the PET study by Fox et al. (1996), supposed that if choral reading increases the activation in auditory association areas in PWS up to a normal level, then FAF might do the same. In fact, Watkins et al. (2008) found greater activation in bilateral superior temporal cortex in both, PWS and fluent controls during reading with FAF (half an octave upwards), compared to unaltered AF. This supports the view that the way FAF reduces stuttering is similar to that of choral speech

The effect of FAF on stuttering is smaller than that of choral speech. Kiefte and Armson (2008) found that all of their 12 participants exhi-bited a stable pattern of less than 2% stuttering with choral reading, but only 3 of the 12 participants exhibited an effect similarly strong and stable with reading under FAF. The authors report an average reduction of stuttering in choral reading and FAF of 90-100% and 60-90%, respectively. The best explanation for the difference might be: Listening, also to one's own voice for monitoring synchrony, is task-relevant in choral reading, but not in solo reading with FAF. Speaking under FAF does not require active listening; FAF is merely a stimulus tempting to listen to one's voice because it sounds odd.

The fluency-enhancing effect of FAF decreases with time by familiari-zation. Armson and Stuart (1998) report that 6 of their 9 participants who benefited from FAF showed approximately 50% reduction of stuttering at the beginning of a reading task with FAF, but within 10 minutes, percent stuttering returned to the baseline values assessed with natural AF. The reduction of stuttering by FAF is also smaller on average during self-formulated speech than during reading (Armson & Stuart, 1998; Ingham et al., 1997). Together, the overall smaller and more inconsistent fluency enhancement by FAF supports the view that it, as an unaccustomed, odd-sounding auditory stimulus, operates by modulating the allocation of attention in PWS.

Howell, Sackin, and Williams (1999) found a smaller reduction of stuttering during reading with FAF in CWS than in AWS. This finding is not astonishing if the FAF effect is an effect on attention. In addition to AF, many other factors influence a speaker's attention, and there may be differences in this respect between children and adults, e.g., regarding the cognitive demands in reading, or the 'headphone effect' (unaltered AF, as baseline, was delivered through headphones).

Often, FAF and DAF have been used combined in electronic speech aids, However, MacLeod et al. (1995) who tested the effect of this combination did not find a greater reduction of stuttering than with DAF or FAF alone. This is not surprising if DAF and FAF operate in the same way, by drawing attention to AF as much as possible for the person and in the situation. DAF and FAF cannot do much more toge-ther than alone in this respect. Yet, their combination makes sense because of the individually different sensitivity to DAF and FAF, and for reducing familiarization by changing DAF or FAF settings.

2.7. Other than auditory stimulation

All FCs discussed above, in some way, alter what PWS hear when speaking, by an alteration of speech, by an additional verbal or non-verbal auditory stimulus, or by AAF. But also visual, tactile, and other non-auditory stimuli were found to reduce stuttering. Barber (1940) showed that visual and tactile rhythmic stimulation was as effective as auditory one when PWS were speaking in time with it. However, just as in speaking paced by an acoustic rhythm, one must pay attention to both, the rhythm presented and the AF of one's own rhythm to moni-tor synchrony. In this way, visual or tactile rhythmic stimulation might improve the processing and integration of AF.

In some studies, non-auditory feedback of speech was applied merely as a means for slowing down speech rate. For instance, the varying intensity of a light or of a vibrator at the hand reflected vocal varia-tions of the speech output. This feedback was presented with different delay times, and the participants were instructed to speak "synchronically" with that feedback (e.g., Smolka & Adamczyk, 1992). The mo-derate reduction of stuttering in these studies was thus rather caused by slowed speech than by visual or tactile feedback.

Auditory stimulation was replaced by visual one even in choral speech: Kalinowski et al. (2000) found stuttering frequency to be reduced by approximately 80% when AWS recited a memorized text in time with (looking at the visible speech movements of) another person silently 'mouthing' the text. This FC might operate similarly as real choral speech does: PWS must attend to both, the other person's silent speech gestures and their AF to monitor synchrony.

Hudock et al. (2011) showed that delayed visual feedback can reduce stuttering without slowing down speech rate: PWS recited memorized material at normal and at fast rate while viewing their own mouth and jaw movements on a screen. This visual feedback was displayed with delay times of 0, 50, 200, and 400ms. Compared to a baseline condit-ion without visual feedback, all visual feedback conditions reduced stuttering between 27% (0ms) and 62% (400ms). It is, however, unclear whether the visual stimulus alone reduced stuttering. The participants were instructed to look at the screen, but they concurrent-ly heard themselves speak because AF was not masked. So, they perceived the synchrony or asynchrony between natural AF and delay-ed visual feedback and, while looking at the screen, they possibly listened to their voice, also to not get confused by the 'wrong' visual feedback. The attention hypothesis is thus consistent with the results of that experiment.

2.7.1. Response contingent stimulation

A special kind of experiments was done mainly in the 1960s and 70s: A stimulus was presented immediately after each stutter. This method was called 'response contingent simulation' according to the theory behind that assumed stuttering to be a psychological response. These experiments, some of which may appear ethically doubtful today, are relevant in our context because they represent FCs associated with auditory, but also non-auditory stimulation (see Bloodstein & Bern-stein Ratner, 2008 for an overview). Some of those studies dealt with punishment for stuttering. For instance, Martin & Siegel (1966) report that they reduced stuttering "essentially to zero" by electric shocks contingent on stuttering events.

However, many studies applying response contingent stimulation used auditory stimuli as a punishment, e.g., a 105dB tone, the reproof "wrong!", or recorded laughter. In other studies, neutral or reinforcing auditory stimuli were presented after each stutter, or stutter-free speech was "penalized" (see Bloodstein & Bernstein Ratner, 2008, pp. 292–294). All these conditions reduced stuttering. In all experiments that used auditory stimuli as 'penalty', 'reward', or as a neutral reply to a stutter, the presentation and even more the anticipation of these stimuli probably draw PWS' attention to the auditory channel.

Martin and Siegel (1996) who applied electric shock as a 'punishing' stimulus tested merely 3 participants, and with only one, the reduction of core symptoms (sound and word repetitions) was tested. With the two other participants, only the reduction of secondary behaviors like nose wrinkling was examined. Such habits can be suppressed by the will, if they imply penalty. The transient reduction of repetitions by electric shock can be explained in the by the attention hypothesis as follows: The participant knew that the experimenters were attentively listening to him to detect each stutter and punish it with a shock. In this situation, the participant spontaneously 'mirrored' the experimen-ter's behavior and, quasi by the experimenter's ears, listened to his speech in the attempt to anticipate the electric shock and to avoid startle. That is, the improved fluency resulted from enhanced auditory attention.

2.8. Masked auditory feedback

"For many years, it had occasionally been noted that stutterers are likely to have less speech difficulty in the presence of loud noise – for example, near ocean surf, a waterfall, or a passing train, Kern (1932) demonstrated this effect experimentally by means of a Barany drum." (Bloodstein & Bernstein Ratner, 2008, p. 295; a Barany drum is a mechanical device driven on a spring). Shane (1955) and Cherry, Sayers, and Marland (1955) first-time used white noise to mask AF, which, so they report, often completely eliminated stuttering. The white noise effect was confirmed repeatedly (e.g., Garber & Martin, 1974, 1977; Maraist & Hutton, 1957; Martin & Haroldson, 1979). The first idea to explain the effect was: AF is anyway harmful for PWS; therefore, they become fluent once they do not hear themselves speak (e.g., Cherry & Sayers, 1956; Maraist & Hutton, 1957; Webster & Lubker, 1968).

Further experiments showed that noise reduced stuttering even if PWS still heard themselves speak: Sutton and Chase (1961) as well as Webster and Dorman (1970) presented noise only in the silent periods between phonation, which reduced stuttering as effectively as conti-nuous masking. Others used noise of lower intensity that allowed hearing one's voice for sure: Martin et al. (1984) found a significant reduction in stuttering at a noise level of 60dB. Maraist and Hutton (1957) presented noise at levels of 30, 50, 70, and 90dB and found a progressive decrease in stuttering with increasing noise intensity.

These findings indicate that PWS are not more fluent with masking noise because they do not hear themselves speak. Wingate (1970) hypothesized that increased voice intensity during speaking in noise reduces stuttering, but Garber and Martin (1977) found the effect of noise to be greatest when PWS were speaking with normal voice intensity.

To my knowledge, the effect of noise during speech on the brain in PWS has not yet been studied, but there are studies with fluent speakers. Using PET, Paus et al. (1996)

found activation in the audito-ry association cortex during whispered speech with AF being masked by noise. In fMRI studies, Christoffels, Formisano, and Schiller (2007), Zheng, Munhall, and Johnsrude (2010), and Christoffels et al. (2011) compared speaking with normal AF, speaking with AF masked by noise, and listening to own prerecorded speech. The activation in auditory association areas during speech with masking noise was greater than with normal AF, and as great as during listening.

These neuroimaging findings show that masking noise has a similar effect on the brain as AAF or choral speech have. This is not surpris-ing because, as Stephen and Haggard (1980) note, DAF and FAF as well have a masking effect, as they partially overlay natural AF, and the same goes for a second speaker's voice in choral speech. Seen from this angle, white noise seems to be nothing than a further unaccustomed acoustic stimulus, drawing the speaker's attention to the auditory channel – however, only if PWS can still hear themselves speak despite the noise. But what if AF is masked completely?

Cherry and Sayers (1956) reported that the loudness of the noise they used to eliminate stuttering approached pain level, and participants were unaware of their speech sound. This seems to clearly contradict the attention hypothesis. Furthermore, normal speakers have no diffi-culty when their AF is completely masked (e.g., Pittman & Wiley, 2001), This and the fact that PWS are more fluent with complete auditory masking seems to show that AF is irrelevant for speech control, as Borden (1979) claimed.

This, however, is hardly consistent with the results of Lind et al. (2015) and Kell et al. (2017), according to which AF is the main channel in the self-monitoring of speech. Further, the view that AF is irrelevant for speech control is inconsistent with audio-phonatory coupling (see Section 2.5.1); and the Lee effect (see Section 2.6.1); both show that AF plays a role in speech control. To resolve these inconsistencies, it is useful to consider another highly effective FC in which seemingly no AF is available: silent mouthing.

2.9. Whispering and mouthing

Whispering proved to be an effective FC in several studies (e.g., Cherry & Sayers, 1956; Commodore, 1980; Commodore & Cooper, 1978; Johnson & Rosen, 1937; Perkins et al., 1976). Whispered speech is not vocalized; vocal cords do not vibrate, but articulation modulates the sound of the air flowing through the vocal tract. The speaker hears him/herself whisper; the condition is comparable to incomplete masking of AF by noise, insofar as AF is degraded in both FCs. A further FC degrading AF is speaking with blocked ears, which restricts AF to its bone-conducted component. Sandow (1898) already recommended PWS plugging their ears with cotton to eliminate stuttering.

In all these cases, enhanced fluency was commonly attributed to re-duced impact of AF on speech control or on the mind (distraction from hearing one's own stutter). But the opposite might be true: Similarly to amplified AF (see Section 2.6), lower-than-normal AF probably ope-rates as an unaccustomed stimulus that enhances the speaker's attention to AF.

Mouthing, also referred to as 'lipped speech' or 'pantomime speech', means articulation without or with extremely low expiration such that the air flowing through the vocal tract does not cause audible sound. Mouthing reduces stuttering by nearly 100% (Commodore, 1980; Commodore & Cooper, 1978; Hudock et al., 2015; Perkins et al., 1976). Perkins et al. (1976) assumed that the lack of phonation simplifies motor coordination and thereby eliminates stuttering. This account is not convincing, since FCs that might increase the demands of motor coordination (choral speech, shadowing, DAF) still effective-ly reduce stuttering.

Mouthing can be compared with complete auditory masking by noise insofar as in both FCs, articulation takes place without external AF being available. However, it was ascertained in several studies that speakers 'hear' and monitor their words *internally* in these conditions (Reisberg et al., 1998; Smith, Wilson, & Reisberg, 1995). It is there-fore possible that PWS are fluent during mouthing and with complete auditory masking not because they cannot hear themselves speak, but because they do hear themselves speak

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internally. The same may be true for cases like that reported by Van Riper (1982, p. 383) where life-long stuttering disappeared after hearing loss: The affected people were now forced to monitor their speech internally, and this eliminated their stutter.

2.10. Inner speech

The ability of hearing oneself speak internally did not develop to enable mouthing or talking in extreme noise. It enables us to speak and to hear our words internally in thinking and in silent reading. Most PWS do not experience disfluency during that 'inner speech' (see below). Inner speech is included in this overview of FCs because the reason why PWS are fluent during mouthing, with complete audi-tory masking, and during inner speech (verbal thinking and silent reading) may be the same.

Inner speech, 'the little voice inside our head' was investigated inten-sively in the context of reading and writing ability, working memory, and schizophrenia (see Alderson-Day & Fernyhough, 2015; Perrone-Bertolotti et al., 2014, for an overview). Two aspects or components of inner speech have been distinguished: a production aspect, sometimes referred to as 'internal articulation' or 'subvocalization', and a percep-tion aspect, sometimes referred to as 'inner hearing' or 'audito-ry verbal imagery' (e.g., Hurlburt, Heavey, & Kelsey, 2013; Oppenheim & Dell, 2014; Tian, Zarate, & Poeppel, 2016). Smith, Wilson, and Reisberg (1992, 1995) simply distinguish between 'inner voice' and 'inner ear'. Tian and Poeppel (2010, 2012) describe the link between the production and perception of inner speech as motor-to-sensory transformation.

Inner speech is not objectively observable, it has been investigated indirectly, e.g., by having subjects speak overtly with complete audito-ry masking (Brocklehurst & Corley, 2011; Oppenheim & Dell, 2008; Postma & Kolk, 1993). Oppenheim and Dell (2010, p. 1147) distin-guish between "inner speech without articulatory movements" and "articulated (mouthed) inner speech"; according to this, mouthing can be considered inner speech plus silent articulation. If so, PWS may be fluent during mouthing and during inner speech for the same reason.

There is hardly any literature about stuttering in inner speech. In a study by Netsell, Ashley, and Bakker (2010), six of the seven stutter-ing participants reported they were 100% fluent during inner Speech (cf. Perrone-Bertolotti, 2014). This suggests that at least most PWS are fluent during inner speech. This is not trivial given the many similarities between inner and overt speech. Inner speech has nearly the same articulatory richness as overt speech, including syllabic structure, linguistic stress, and prosody (e.g., Ashby & Clifton, 2005; Alderson-Day & Fernyhough, 2015). One can speak internally in a low or high rate (Alexander & Nygaard, 2008; Shergill et al., 2002), in a disguised voice (McCarthy-Jones & Fernyhough, 2011; McGuire et al., 1995, 1996), and with voluntary (pseudo-) stuttering (Ingham et al., 2000).

Further evidence for the similarity of inner and overt speech comes from studies of error detection by the speaker during overt versus inner speech. Postma and Noordamus (1996) conclude from their results that inner speech depends on the same phonetic plan as overt speech does. Likewise, Oppenheim and Dell (2010) conclude: "plan-ning processes may be highly comparable in conditions that require actual speech motor execution [...] compared to those which do not" (p. 390). Brocklehurst and Corley (2009) found the phonemic similari-ty effect (the tendency of phoneme substitution errors to occur most readily with similar phonemes) to have the same magnitude in overt and inner speech. They conclude that "plans for inner speech were fully specified at the featural level, even in the absence of any inten-tion on the part of the speaker to utter the words overtly." In a similar study, Corley, Brocklehurst, and Moat (2011) conclude that "our 'inner voice' sounds much like our overt speech, and is produced in much the same way, whether overtly articulated or not" (p. 172).

The absence of difficulty during inner speech in most PWS is asto-nishing not least because motor control is involved in both, overt and inner speech. According to Tian and Poeppel (2010, 2012), inner speech depends on motor simulation; it is controlled by sequences of motor commands just as is overt speech. Neuroimaging studies show-ed that inner speech is associated, among others, with activations in motor and premotor areas (Brumberg et al., 2016; Kell et al., 2017; McGuire et al., 1996; Palmer et al., 2001; Shergill et al., 2002; Tian & Poeppel, 2012; Tian, Zarate, & Poeppel, 2016). Electromyography studies revealed that inner speech is accompanied by almost unnotice-able movements of lips, tongue, and laryngeal muscles (see, e.g., Edfeldt, 1960; Locke, 1970, for an overview). Even respiration shifts from the basic mode to the speech mode during inner speech, despite the lack of phonation (Conrad & Schönle, 1979).

Fernyhough (2004) has sketched out a model of how inner speech develops in childhood: A gradual transition takes place from loud self-talk via whispering and mouthing to inner speech/verbal thinking (see also Alderson-Day & Fernyhough, 2015). First, children learn to form sentences overtly until, roughly around the age of five, their overt speech reaches a functional stage that allows internalization (Conrad, 1971). Four-year-olds usually have no knowledge and no awareness of inner speech (Flavell et al., 1997). This is, inner speech/verbal think-ing is not the basis of overt speech, but conversely, overt speech forms the basis of inner speech. This being so, the absence of disfluency during inner speech in most PWS calls for an explanation.

2.10.1. Internal auditory feedback may save from stuttering

According to the above-mentioned model proposed by Tian and Poep-pel (2012), inner speech depends upon a close coupling of motor and auditory system. Smith, Wilson, and Reisberg, (1995) already found an 'inner-ear/inner-voice partnership' to be essential for the function-ing of inner speech, a close coupling of speech production and speech perception. Inner speech means speaking to oneself, which makes no sense and does not work without listening to oneself. The inner voice cannot work without the inner ear; thus, inner speech is speaking and listening in one.

Overt speech, by contrast, is usually not produced for oneself, but for others; coupling between production and perception is not as essential as in inner speech. But AF is not irrelevant for the control of overt speech, as the Lee effect indicates. Lacking partnership between speech production and speech perception in PWS in normal condi-tions, suggested (i) by overactivation in motor and premotor areas together with deactivation in auditory areas and (ii) by the lack of PSAM, might underlie developmental stuttering.

Accordingly, the reason why PWS are fluent during mouthing or with complete auditory masking is not that they do not hear themselves speak. They hear themselves speak internally and monitor their speech by the 'inner ear', just as during inner speech. The close coupling between speech production and auditory processing, so I assume, saves them from stuttering in these conditions.

2.10.2. Internal AF cannot compensate for external AF

When we hear ourselves speak internally during silent reading or thinking, we perceive speech feedback in the auditory modality. Therefore, I refer to this as internal AF. If the use of internal AF, in inner speech and in FCs in which external AF is not available, pre-vents stuttering, then the question arises: Can internal AF compensate for a deficit in the processing or integration of external AF? This question is important because, if so, the assumption that such a deficit causes stuttering would be implausible and, with that, also the attention hypothesis.

The compensation in question would be possible only if both, external and internal AF were available concurrently. This, however, seems not to be the case. Smith, Reisberg, and Wilson (1992) found that input from the 'outer ear' interfered with the use of the 'inner ear'. The use of the inner ear was the more disrupted, the more a concurrent exter-nal auditory input was phonologically similar to what should be heard internally. White noise did not impair the inner ear, but externally presented speech stimuli blocked the perception of inner speech. This suggests that internal AF is not available when one's own voice is heard externally because, in this case, the two signals are phonologically equivalent.

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Moreover, the Lee effect (Section 2.6.1) could not occur if internal AF compensated for the control problems caused by delayed external AF. Internal AF is not available because, in speaking under DAF, external and internal signal are phonologically similar despite the asynchrony. This explains the seeming paradox that normal speakers are disfluent when their external AF is delayed by 200ms, but not when it is com-pletely masked by white noise. In the latter condition, but not in the former one, speech control can shift to internal AF (as mentioned above, white noise does not impair the inner ear, but an external, phonologically similar speech signal does).

A further argument against the concurrency of external and internal AF comes from Vigliocco and Hartsuiker (2002): If internal and exter-nal AF worked concurrently, we would hear ourselves twice with a time lag between the two signals because they need different time (Lackner & Tuller, 1979).

Whether external and internal AF work concurrently is related to the question whether speakers monitor their speech internally to detect errors before articulation. This seems to be the case (Nooteboom & Quené, 2017; Seyfeddinipur, Kita, & Indefrey, 2008); however, experimental findings suggest that it is not based on internal AF. Huet-tig and Hartsuiker (2010) registered speakers' eye-movements in an object naming task and found them driven only by the perception of overt, not inner speech. They conclude that there is no speech moni-toring based on internal sensory perception. Lind et al. (2014) covertly manipulated the participants' external AF in real time such that they said one thing, but heard themselves saying something else. In most cases, the participants believed they had said what they heard. The authors conclude that internal AF is either unavailable during overt speech, or it is overridden by external AF.

Nozari, Dell, and Schwartz (2011) proposed and tested a model of speech errors detection prior to articulation. The model is not based on internal sensory feedback, but on conflict monitoring during produc-tion. Support for this model comes from EEG studies. A specific, event-related potential (error-related negativity) was identified, among others, in speech tasks when an error was detected. This brain respon-se seems related to conflict monitoring during speech formulation (Ganushchak & Schiller, 2008; Ries et al., 2011; Trewartha & Philips, 2013). Therefore, pre-articulatory error detection during overt speech is no evidence of external and internal AF to work concurrently.

We can thus assume: (i) Auditory predictions derived from speech motor commands provide an internal AF which is available when (and only when) external AF is not available, and which cannot compensate for poor processing of external AF. This being the case, the attention hypothesis explains the fluency-inducing effect of mouthing and of complete auditory masking as well as the fact that almost all PWS do not experience difficulty in silent reading and verbal thinking: In these conditions, attention shifts to internal AF, with the 'inner ear/inner voice partnership' ensuring proper processing and integration of (internal) AF.

2.11. Types of FCs

Trying to categorize FCs, we first can distinguish between those where PWS hear themselves speak externally and those where no external AF is available. According to the attention hypothesis, FCs of the first type draw the speaker's attention to the auditory channel. In FCs of the second type, PWS monitor their speech internally, which ensures proper processing and integration of (internal) AF. FCs of the first type can further be divided into those that require active listening and those that merely attract auditory attention by altered, odd-sound-ing AF, or by an additional, unaccustomed acoustic stimulus.

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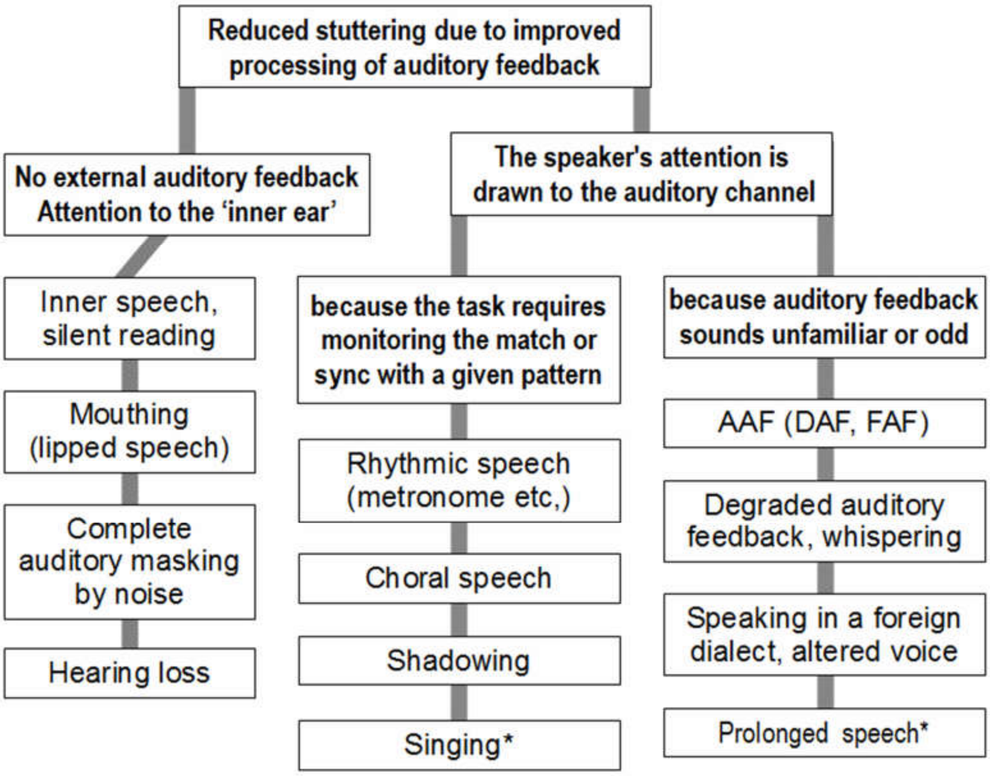

Figure 1. Overview of FCs and the way they work.

Figure 1 gives an overview of well-known FCs and the way they ope-rate according to the attention hypothesis. There is some overlap between the types of FCs in the figure: As already mentioned, DAF and FAF partially mask natural AF, and of course, whisper-ing is also an altered manner of speaking. Singing and prolonged speech are special cases insofar as, in song, the pattern (the tune) is represented internally, and in prolonged speech and in song, audio-phonatory coupling might contribute to the powerful fluency-inducing effect.

A well-known FC not included in Fig. 1 is private speech (talking to oneself). With almost all PWS, stuttering disappears or is radically reduced when no listener is present (Jackson et al., 2021; Kalinowski et al., 1999; Langová & Sváb, 1973; Martin & Haroldson, 1988). This has commonly been explained by the absence of communicative pre-ssure and of the fear of unfavorable listener reactions. However, a factor more important might be that talking to oneself usually implies listening to oneself, i.e., to AF. Self-talk belongs to the middle column in Fig. 1 insofar as listening to oneself is quasi task-immanent. Some PWS say they may stutter when they are alone but talk 'as though' to a listener (cf. Bloodstein & Bernstein Ratner, 2008). The allocation of attention may then resemble more that in conversational speech, and stuttering is more likely to occur.

At the end of this overview, let us look at a study by Vasic and Wijnen (2005). To test their hypothesis that oversensitivity to normal disconti-nuities in speech flow causes stuttering, they examined the effect of two distracting conditions: (1) playing the computer (table tennis) game Pong while speaking, and (2) monitoring the occurrence of a function word ('the'). The intended function of both conditions was to distract from discontinuities in speech flow. Both conditions, the latter more than the former, reduced the number of blocks, seemingly confirming the authors' hypothesis. However, there is an alternative interpretation: The first condition enhanced the automaticity of speak-ing, so as presumedly did the similar dual task conditions in the stu-dies conducted by Eichorn and colleagues (Section 1.1.3).

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The greater effect of the second condition in the Vasic and Wijnen study resulted from active listening to AF, required by the task. It is unlikely that participants checked an internal plan for the occurrence of 'the', since Lind et al. (2014) showed that external AF is the source of knowledge of the words we have just spoken (see also Sec. 2.10.2). Instead, the participants attentively listened to the words they produ-ced. If so, this condition belongs to the middle column in Figure 1.

3. Discussion

A unifying explanation for the effect of FCs is preferable not only for reason of theoretical parsimony, but is also suggested by the above-mentioned many similarities between seemingly different FCs: Each kind of auditory stimulation including DAF, FAF, rhythm, or a co-reader's voice partially masks the speaker's voice; FAF can be seen as a simulation of choral speech (and vice versa); each alteration in the manner of speaking (altered voice, foreign dialect, etc.) produces unaccustomed AAF; whispering and mouthing as well as white noise attenuate or prevent external AF. Therefore, it is plausible to assume that all FCs operate in a similar way, with some differences explaining their different power.

As was shown in the overview, the attention hypothesis provides a unifying account for the effect of very diverse FCs: They reduce stu-ttering by improved 'voice-ear partnership', that is, they improve the processing of AF and its use in speech control. FCs either draw the speaker's attention to external AF or, if external AF is not available, they cause an attentional shift to internal AF. As a result, more percep-tual and processing capacity is deployed for AF.

3.1. How FCs reduce stuttering at speech onset

At least some FCs, among them choral reading (Saltuklaroglu et al., 2009) reduce stuttering at speech onset where AF is not yet provided. This seems to contradict the attention hypothesis. However, the adap-tation of auditory attention to the requirements of speech control might be a necessary part of speech network preparation. Lacking attention to the auditory channel or, in other words, no expectation of hearing one's voice at speech onset may reduce the readiness of the entire speech network and thereby cause stuttering at speech onset.

Whillier et al. (2018) found a facilitation of excitability in the motor cortex prior to speech onset in fluent speakers, but not in PWS. This lack of pre-speech motor facilitation in PWS may be related to the lack of PSAM (see Section 1.4). PSAM may reflect the anticipation of hearing one's voice, i.e., the immediate sensory consequence of speech initiation. It is psychologically plausible to assume that the anticipation of the sensory consequence, i.e., the anticipation of success facilitates the initiation of a voluntary motor act. Conversely, the lacking anticipation of AF, suggested by the lack of PSAM in PWS, may thus hamper the initiation of speech.

The anticipation of DAF normalized PSAM in PWS (see Section 2.6.1). Similarly, the anticipation of FAF, of hearing the clicking of a metronome or a co-speaker's voice, as well may normalize PSAM in PWS. This can be tested, and if it proves true, it can explain why some FCs reduce stuttering even at speech onset: They support the prepara-tion of the speech network by modulating the allocation of attention before speaking such that AF is properly processed.

3.2. What FCs tell us about the cause of stuttering

The fact that some FCs immediately evoke fluency in most PWS sug-gests that stuttering is not directly caused by an anomaly in brain structure or by a relatively invariable dysfunction. Instead, the under-lying cause must be variable itself and influenceable by varying factors and conditions, including FCs. The immediate elimination of stuttering in some FCs further suggests that the speech motor system works well in PWS when certain requirements are fulfilled. If the attention hypothesis is correct, an essential requirement is sufficient attention to AF.

Persistent stuttering may develop if a child does not develop a suffi-ciently stable allocation of attention (of perceptual and processing resources) appropriate for the production of fluent speech – an alloca-tion that automatically attunes in speech network preparation, and that ensures sufficient capacity for AF processing. A less stable speech-related attention allocation in PWS may easily come 'out of balance', e.g., by increasing speech planning demands, in a challenging commu-nication situation, or by the anticipation of stuttering, with the result that not sufficient capacity remains for AF processing. Two factors may contribute to the difficulty CWS have in developing an appropri-ate and stable speech-related attention allocation: problems with atten-tion regulation and a subtle deficit in auditory processing.

3.2.1. Problems in attention regulation

Deficits in attention regulation in children and adults who stutter were found in many behavioral studies (see, e.g., Alm, 2014; Anderson & Wagovich, 2010; Eggers, De Nil, & Van den Bergh, 2012; Eggers & Jansson-Verkasalo, 2017; Ntourou, Anderson, & Wagovich, 2018; Wagovich, Anderson, & Hill, 2020). PWS, on average, seem to be less able to divide or shift attention under dual-task conditions and to sup-press a planned motor action when stop is signaled. The former sug-gests inflexible attention control, the latter a predominance of action over perception. Kaganovich, Hampton Wray, and Weber-Fox (2010) conclude from an examination of auditory processing in CWS that stuttering may be associated with less efficient attention allocation.

Chang et al. (2018) investigated functional connectivity networks in the brain in CWS and controls. Among others, they found CWS to exhibit aberrant functional connectivity within and between networks that are involved in attention control. Anomalous functional connecti-vity in CWS was even present in the visual network and its connec-tions with the dorsal attention network. In behavioral studies, CWS showed deficits in attention regulation also in non-speech tasks (e.g, Eggers, De Nil, & van den Bergh, 2012, 2013; Eggers & Jansson-Verkasalo, 2017). We can thus assume that deficits in attention regula-tion are not, or not primarily, a consequence of stuttering, but a causal factor.

3.2.2. Deficit in auditory processing

The second factor contributing to an attentional imbalance, particular-ly to the disadvantage of auditory perception, seems to be a subtle deficit in auditory processing. PWS showed deficits in the processing of speech stimuli (e.g., Beal et al., 2010, 2011; Chang et al., 2009; Halag-Milo et al., 2016; Jansson-Verkasalo et al., 2014; Liotti et al., 2010; Lu et al., 2016; Maxfield et al., 2010, 2012; Neef et al., 2012; Tahaei et al., 2014). Salmelin et al. (1998), examining the processing of AF during reading, found differences between PWS and controls in the functional organization of the auditory cortices.

More important, abnormalities were found even in the processing of non-speech auditory stimuli (e.g., Arcuri, Schiefer, & Azevedo, 2017; Chang et al., 2009; Devaraju, Maruthy, & Kumar, 2020; Dietrich, Barry, & Parker, 1995; Hampton & Weber-Fox, 2009; Howell et al., 2000; Howell, Davis, & Williams, 2006; Kikuchi et al., 2011, 2017: Saltuklaroglu et al., 2017). The results of these studies are not well comparable because of different approaches and methods; however, some authors (Kikuchi et al., 2011, 2017; Saltuklaroglu et al., 2017) point to impaired sensory gating during the basic processing of audi-tory input, that is, the processing of redundant input is insufficiently suppressed.

Poor or aberrant auditory processing was correlated with stuttering frequency or severity in several studies (Beal et al., 2010, 2011; Ho-well et al., 2000; Jansson-Verkasalo et al., 2014; Kikuchi et al., 2017; Liotti et al., 2010). The fact that deficits in auditory processing were also found when non-speech stimuli, e.g. click sounds, were presented suggests that these deficits are not a consequence, but a causal factor of persistent stuttering.

3.2.3. Interaction between attention and auditory processing

Given the variability and contingency of stuttering, it is unlikely that a rather invariable trait like an auditory processing deficit immediately causes the symptoms. The allocation of attention, by contrast, is varia-ble and influenceable by situations, expectations, and emotions and may operate as an 'interface' between the mechanism underlying stuttering, on the one side, and the environmental and psychological factors that influence stuttering frequency and severity, on the other side.

The role of an auditory processing deficit in stuttering may be that it contributes to an inappropriate attention allocation during speech. For example, one may speculate that poor auditory gating at a low level of processing is compensated for by the suppression of auditory process-ing at a higher level: To avoid overload by redundant auditory input, young children may habituate to ignore auditory input, i.e., they may learn to habitually draw their attention away from the auditory channel except they are actively listening. This would explain the lack of PSAM in PWS, if we interpret auditory modulation as the modulation of auditory attention.

3.3. Testability

The attention hypothesis predicts that enhanced attention to AF redu-ces stuttering. This is testable by comparing stuttering frequencies in conditions that require or support attention to AF and in conditions that do not or in which attention is distracted from AF.

A further prediction concerns PSAM. Not only the anticipation of DAF, but also of FAF, of masking noise, or of a pacing signal norma-lizes PSAM in PWS. This would suggest that all these FCs modulate the auditory system. PSAM should also increase, if PWS focus on AF (anticipate hearing their voice) before speech onset, and decrease with distraction from audition. This would show that PSAM depends on attention.

3.4. Implications for therapy

The attention hypothesis predicts that enhanced attention to AF redu-ces stuttering. Possibly, some well-established treatment methods work for other reasons than they are commonly believed to work. Studies of brain activation in PWS before and after fluency-shaping therapy have revealed greater auditory activation after therapy (Ing-ham et al., 2003; Neumann et al., 2003), although no effect on audi-tory processing was intended in those therapy programs. Kell et al. (2018) found increased functional connectivity between auditory and motor regions after fluency-shaping therapy. They speculate the therapy may normalize the over-reliance on somatosensory feedback typical of stuttering, potentially by more efficient auditory-motor mapping. In participants of the same therapy program, Korzeczek et al. (2021) found enhanced fluency to be correlated with increased resting state connectivity between left inferior frontal gyrus and right STG. They conclude that increased auditory-motor coupling contri-buted to the therapy success.

As already mentioned, prolonged speech applied in fluency shaping, and the avoidance of short-phonated syllables applied in the Modify-ing Phonation Intervals therapy (Ingham et al., 2001) enable perma-nent audio-phonatory coupling (timing of syllable starts based on AF; see Section 2.5). Resonant voice therapy (Pelczarski & Hoag, 2018) may work not primarily by muscular relaxation, but because it makes PWS listen to their voice. Generally said, not a specific manner of speaking may reduce stuttering in these therapies, but improved AF processing by a re-allocation of attention.

If so, the long-term effect of stuttering treatment may improve if such a re-allocation of attention becomes an explicit therapeutic aim. PWS should learn to anticipate the sound of their voice before they start talking, and to listen to themselves while speaking. Perhaps, electronic speech aids can be applied for such an attention training instead of using them as a kind of prosthesis. In the treatment of CWS, simple means like Echo Mic (a passive resonator; see Stuart et al., 1997) and Toobaloo (a bent tube transmitting sound from the mouth to the ear) can be used for supporting attention to the voice while speaking. Furthermore, stuttering treatment could be supplemented by a general training of auditory attention.

Abbreviations: AAF: altered auditory feedback, AF: auditory feed-back, AWS: adults who stutter, CWS: children who stutter, DAF: delayed auditory feedback, EEG: electroencephalography, FAF: fre-quency-altered auditory feedback, FC: fluency inducing/enhancing condition, fMRI: functional magnetic resonance imaging, MEG: mag-netoencephalography, PET: positron emission tomogra-phy, PSAM: pre-speech auditory modulation, PWS: people who stutter, SMA: supplementary motor area, STG: superior temporal gyrus.

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