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The impact of threat and cognitive stress on speech motor control in people who stutter

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ABSTRACT

Purpose: In the present study, an Emotional Stroop and Classical Stroop task were used to separate the effect of threat content and cognitive stress from the phonetic features of words on motor preparation and execution processes.
Method: A group of 10 people who stutter (PWS) and 10 matched people who do not stutter (PNS) repeated colour names for threat content words and neutral words, as well as for traditional Stroop stimuli. Data collection included speech acoustics and movement data from upper lip and lower lip using 3D EMA.
Results: PWS in both tasks were slower to respond and showed smaller upper lip movement ranges than PNS. For the Emotional Stroop task only, PWS were found to show larger inter-lip phase differences compared to PNS. General threat words were executed with faster lower lip movements (larger range and shorter duration) in both groups, but only PWS showed a change in upper lip movements. For stutter specific threat words, both groups showed a more variable lip coordination pattern, but only PWS showed a delay in reaction time compared to neutral words. Individual stuttered words showed no effects. Both groups showed a classical Stroop interference effect in reaction time but no changes in motor variables.
Conclusion: This study shows differential motor responses in PWS compared to controls for specific threat words. Cognitive stress was not found to affect stuttering individuals differently than controls or that its impact spreads to motor execution processes.

Educational objectives: After reading this article, the reader will be able to: (1) discuss the importance of understanding how threat content influences speech motor control in people who stutter and non-stuttering speakers; (2) discuss the need to use tasks like the Emotional Stroop and Regular Stroop to separate phonetic (word-bound) based impact on fluency from other factors in people who stutter; and (3) describe the role of anxiety and cognitive stress on speech motor processes.

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1. Introduction

Speaking is a complex fine motor skill that requires mapping intended abstract linguistic structures to dynamic sequences of movements executed in a relatively fast pace. This makes the production of speech a very challenging motor task. As part of the phylogenetic development of the human species, the oral motor system has acquired specific adaptations to this relatively new behavioural repertoire (compared to chewing or swallowing) in terms of neural control (Lieberman, 2007) and changes to the physical/physiological characteristics of the structures involved in producing speech (Kent, 2004). It is no surprise then that learning a complex motor skill such as speaking typically takes time. Infants have to learn to control the many degrees of freedom involved in generating movement patterns that have acoustic consequences that can be interpreted by other humans as a (potentially) meaningful message. For some of these functions, it can take years before they reach the level of adult performance (Smith & Zelaznik, 2004).

For all motor tasks, some individuals will have a more suitable physical and neural makeup by genetic predisposition to become very efficient in motor performance while others may struggle. For most motor tasks, the latter is not a problem as one can simply discontinue them and focus on other tasks that may be more suitable. Hence, not everyone will become a professional tennis or soccer player, or a master concert pianist. For speech, so we argue, this is not different. Some infants will have the innate qualities to learn to speak in a very smooth and fast manner, without showing any obvious interruptions or breakdowns. Others however, will struggle and at best, are able to produce speech relatively fluent most of the time but with occasional problems especially when demands on speech motor control are high, such as when speaking fast and at the same time, in an intelligible manner. These are the basic premises of the Speech Motor Skill (SMS) theory, detailed further down (Namasivayam & Van Lieshout, 2011; Van Lieshout, Hulstijn, & Peters, 2004).

When applied to stuttering, the SMS theory claims that people who stutter (PWS) are at the low end of the speech motor skill continuum, similar to individuals who may be very bad at for example, playing tennis. Unlike those who are bad at playing tennis, children who struggle with speaking do not have the option to simply quit. They have to continue using a speech motor system that is presenting them with considerable difficulty controlling all these different degrees of freedom in producing sound patterns without interruptions. For some, their limitations are such that almost every attempt in controlling this complex system leads to failure and virtually every syllable is "stuttered". For others, when demands are not too high and natural practice during development has allowed for achieving some level of performance, most of the time their speech is fluent. However, add some difficulty (e.g., increasing rate; more complex linguistic structure, complex clusters of sounds) and their ability to remain relatively fluent will be jeopardized. In essence then, according to the SMS theory, stuttering at its core is a problem in controlling the many degrees of freedom involved in producing speech in a relatively fast and stable way. If such problems become audible (as articulator movements often have acoustic consequences) they can perceptually become noticeable in the form of sound or syllable repetitions, sound prolongations or blocks.

1.1. The speech motor skill (SMS) theory

Developmental stuttering typically begins in childhood. From the perspective of the SMS theory, stuttering has its basis in how the speech motor system of these individuals learns to cope (or not) with demands posed by linguistic, motor, cognitive and emotional conditions. The notion that different factors play a role in stuttering is a common viewpoint of other theories proposed in recent years such as the Demands and Capacity model (Starkweather & Gottwald, 2000) or a similarly inspired model proposed by Zimmermann, Smith and colleagues (Kleinow & Smith, 2000, 2006; Smith, 2006; Zimmermann, Smith, & Hanley, 1981). The SMS theory is unique by not positing any need for deficits in any of these functions while proposing a very specific mechanism by which such factors influence speech motor control (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 2004). Specifically, the theory claims that all these factors impact on speech movements, in particular on their range of motion (amplitude). Within the SMS theory, movement amplitude is critical to the stability of the speech motor control system. It is presumed that kinesthetic feedback from speech articulators is used to stabilize the output of a coupled neural oscillatory system. Within such a system, larger amplitudes are thought to increase feedback gain which may result in an increase in the neural oscillator-effector coupling strength and system stability. Conversely, if certain conditions restrict the movement range, the theory assumes that it will reduce feedback gain to the neural oscillatory networks that control the effectors and if this feedback-gain reduction reaches a certain idiosyncratic threshold, the entrainment between the neural oscillator network and the speech effectors destabilizes (Atchy-Dalama, Peper, Zanone, & Beek, 2005; Peper & Beek, 1998; Peper, de Boer, de Poel, & Beek, 2008; Van Lieshout et al., 2004; Williamson, 1998). The end result of this is instability of the articulator movements and a possible breakdown in their coordination, and in a worst case scenario, it could lead to a cessation of the ongoing movements (aka a block). This particular mechanism was elegantly demonstrated in a robot model by Williamson at MIT (Williamson, 1998). Recent studies across different speech disorder populations, including stuttering individuals, have shown evidence for this mechanism to apply to speech motor control as well (Namasivayam & Van Lieshout, 2008; Namasivayam, Van Lieshout, McIlroy, & De Nil, 2009; Van Lieshout, Rutjens, & Spauwen, 2002; Van Lieshout, Bose, Square, & Steele, 2007). These studies have indicated that for bilabial closure gestures the amplitude of upper lip movements is a critical factor in maintaining stability. This does not mean that other effectors (e.g., jaw or tongue) will not show similar features, but the lips are so far studied most extensively.

1.2. Role of threat on speech motor control

One of the factors that may influence speech motor control (or any type of motor control for that matter) is related to emotion. Compare for example, top performers who even under stress keep control over their movements whereas less skillful individuals may show smaller or significant breakdowns in their performance (see e.g., Hagtvet & Hanin, 2007; Robazza, Bortoli, & Nougier, 1998; Yoshie, Kudo, Murakoshi, & Ohtsuki, 2009 on the interaction between emotion and performance). Emotions are assumed to affect speech fluency through pathways in the central nervous system that are involved in motor control, in particular through amygdala and basal ganglia loops (Alm, 2004). However, the exact mechanisms underlying the effect emotion exerts on motor control is not entirely clear. The impact of different emotions on speech fluency is obvious from daily observations, not only in people who stutter (Goberman, Hughes, & Haydock, 2011). However, it is particularly salient for PWS because they already have difficulty remaining fluent without the extra emotional component added to their control system. Although both positive and negative emotions can influence speech fluency, for PWS it is mainly anxiety that has gained focus in the literature. Anxiety is often described in two ways: trait and state anxiety. Whereas trait anxiety refers to a general inherent (and stable) disposition to be anxious, state anxiety refers to a elicited response (behavioural, cognitive and physiological) to specific situations (Craig, Hancock, Tran, & Craig, 2003; Davis, Shisca, & Howell, 2007; Iverach, Menzies, O'Brian, Packman, & Onslow, 2011; Mahr & Torosian, 1999). More recently, people have argued to consider both forms of anxiety to be multi-dimensional in nature, such that people may differ in what type of context (social evaluation, physical danger, ambiguity, or daily routines) predisposes them to feel under threat and within that context, which situations elicit a particular threat response (Ezrati-Vinacour & Levin, 2004). For PWS, it is typically the social evaluation context that relates to their state anxiety, where situations that would expose them to verbal communication are most likely to induce specific feelings of threat (Davis et al., 2007). Although at this point there is no clear evidence that anxiety plays a causal role in the origin of developmental stuttering (e.g., Alm, 2014; Blumgart, Tran, & Craig, 2010; Craig, 1990; Kefalianos, Onslow, Block, Menzies, & Reilly, 2012), several studies (including in this volume) have shown that PWS have higher levels of state anxiety as measured with standardized questionnaires (Blumgart et al., 2010; Craig & Tran, 2006; Craig, 1990; Iverach et al., 2009; Iverach et al., 2011; Kefalianos et al., 2012; Menzies, Onslow, & Packman, 1999; Tran, Blumgart, & Craig, 2011). Recent work by Bowers, Saltuklaroglu, and Kalinowski (2012) has pointed to a relationship between what they refer to as anticipatory anxiety (in this case for sounds that were deemed threatening towards fluency by their group of PWS) and stuttering. They demonstrated that for those stimuli that contained these threat sounds there was an increase in an autonomous threat response, regardless of them being stuttered on or not. In other words, the autonomous response was interpreted as reflecting a perceived threat (something that could happen), but not causal to the actual event (stuttering).

In the literature, there is evidence that perceived threat (real or not) manifests itself in some form of a freezing response (Alm, 2004; Öhman, 1993; Sagaspe, Schwartz, & Vuilleumier, 2011). This response is thought to be part of a defense mechanism and reflects the typical flight or fight conflict in the presence of a threat, especially when one is not sure how to respond to a threat, or when feeling helpless. This phenomenon is amplified for individuals with heightened anxiety. Specifically, anxious individuals will be very fast in detecting threat (Frenkel, Lamy, Algom, & Bar-Haim, 2009; Öhman, Flykt, & Esteves, 2001). This hyper-sensitive threat detection prioritizes resources for efficient action in the face of threat, akin to automatic vigilance (Estes & Adelman, 2008a, 2008b). For speech, a similar response may be characterized by decreased movement amplitude and halted vocalization (see also Alm, 2004) and hence, according to SMS theory it would lead to more unstable movement execution and coordination. Alm (2004) suggested accordingly that PWS often report feeling helpless during instances of stuttering, and therefore are more likely to freeze when they encounter a difficult task where they would expect to stutter.

The study by Hennessey, Dourado, and Beilby (2014) published in this volume, used the Emotional Stroop task (see below) and found evidence for a slower reaction time to general threat words in PWS compared to matched control speakers. However, contrary to their expectations the group difference was not magnified by a higher speech rate. This may argue against a specific speech motor control limitation for PWS in the face of threat, but as argued in SMS theory, simply increasing rate, especially when using single and relatively simple words, is not likely to be a real challenge to a speech motor system, even when skill limitations are present (Van Lieshout, Hulstijn, & Peters, 1996a).

The SMS theory proposes that for PWS, the mere presence of threat-evoking stimuli could impact on their ability to control their speech motor system. Yet, the evidence thus far is lacking and inconsistent (Bowers et al., 2012; Hennessey et al., 2014). It is possible that threat (and the assumed invoked anxiety) may indeed not affect speech motor control to the extent that it induces disfluency. Perhaps the bulk of its impact will be on processes preceding motor preparation and execution (linguistic planning; memory; attention) and once that threat has been dealt with and a response selection is made, the effect has been neutralized. This can be compared to the rabbit seeing the snake and after a moment of conflict (and freezing), it may choose to flee and this motor action will proceed without further interference (see also Woody & Szechtman, 2011, for a theoretical account on the adaptation to threat).

1.3. Emotional Stroop and Classic Stroop tasks

Re-examining the negative findings of threat on motor control (and stuttering), it is important to realize that none of these studies examined motor control directly. Reaction times (Hennessey et al., 2014) and autonomic nervous system arousal responses (Bowers et al., 2012) reflect the involvement of many different systems and in general provide limited information on the way the motor system copes with threat. It is also imperative to examine the effects of threat on speech motor control ensuring that the presumed effects of anxiety are not confounded with other factors that may lead to problems with fluency. For example, phonetic and phonological complexity can put demands on the speech motor system and thus have a negative impact on the stability of movement execution (Howell, Au-Yeung, Yaruss, & Eldridge, 2006; Smith, Sadagopan, Walsh, & Weber-Fox, 2010). To avoid this problem, one should pick a verbal task that isolates the effect of anxiety from phonetic and phonological complexity. This can be accomplished by using the emotional Stroop (ES) task (Algom, Chajut, & Lev, 2004), where participants are asked to name the font colour of neutral (e.g., TABLE) and threat-inducing emotional words (e.g., RAPE). The latency difference between emotional and neutral words is termed the emotional Stroop effect (ESE). Note that participants are not asked to read aloud the actual word, but to name the font colour only (e.g., say “purple” and not “rape”).

It is important to realize that the title “Emotional Stroop task” is a misnomer. Although it shares the task of naming font colours with its namesake, the classical Stroop task as created by Stroop (1935), it is different from the latter in many ways (Algom et al., 2004; Ben-David, Chajut, & Algom, 2012). In the classic Stroop (CS) task, people are asked to name the font colour of words while ignoring their content. The Stroop interference effect (SIE) is measured as the slowdown in RT for naming the font colour of incongruent trails, where the content of the colour-words differs from their font colour (e.g., PURPLE in blue font), as compared to naming the font colours of coloured strings that have no semantic content (baseline, neutral trials). If participants can completely ignore the content of the words, Stroop interference is 0. Yet, the vast literature in over 75 years shows that people fail to ignore the conflicting content of the words, and the SIE ensues (Ben-David & Schneider, 2009; Ben-David, Nguyen, & van Lieshout, 2011c; Ben-David, Tewari, Shakuf, & Van Lieshout, 2014; Melara & Algom, 2003; Williams, Mathews, & MacLeod, 1996). The size of SIE can indicate the extent to which participants fail to ignore the content of the words. Obviously, naming the font colour of incongruent words does not carry a threat, although it is assumed to invoke cognitive stress (Caruso, Chodzko-Zajko, Bidinger, & Sommers, 1994).

In the ES task, individuals are specifically asked to name the colour of threat words. Yet, the reaction time differences between such stimuli are exaggerated when the emotional stimuli are related to individual fears, phobias or anxieties (Dawkins & Furnham, 1989) as indicated in a a review by Phaf and Kan (2007). For example, in the original demonstration of ES, Watts, McKenna, Sharrock, and Trezise (1986) presented phobia related words (e.g., SPIDER) printed in various colours to patients with spider phobia (arachnophobia) alongside neutral words. The literature in the decades after this seminal paper has repeatedly demonstrated the existence of topic specific ESE. That is, words that are semantically related to the clinical topic can engender an effect specific for that population, even if they present no (or little) threat for healthy individuals (e.g., alcohol related words in alcoholics; Waters & Green, 2003). Since the task is to name a common colour word, there is no high demand on motor preparation and execution and there is also no real phonological complexity to deal with. The ES task is therefore well suited for research on anxiety in PWS as reaction times can be considered to reflect the impact of the emotional valence of a particular word (Hennessey et al., 2014). There are different explanations as to how threat may impact on reaction times, varying from a purely cognitive/attention based mechanism (threat draws attention away from other processes; McKenna & Sharma, 2004) versus a more automated defence mechanism (Algom et al., 2004) that responds to threat by prioritizing resources, triggering the above mentioned freezing response, as explained in the automatic vigilance model (Estes & Adelman, 2008a, 2008b).

Another factor that needs to be evaluated in the context of the ES task is the fact that such a task also requires a degree of cognitive processing and attention. Thus it seems relevant to compare the performance on the ES task with the performance on the CS task. As mentioned above, the latter involves a cognitive conflict arising from the well-practiced reading response and the colour-naming response. It is thus possible that for PWS, even the simple classic Stroop task may involve some sort of threat, as it emulates stress related to a speech task. Indeed, Caruso et al. (1994) found a larger SIE for PWS than PNS (although this could also have been the result of a more generalized slowing in responses, see Ben-David et al., 2014). Thus, comparing the performance of individuals on the ES task with their performance on the CS task provides a window on the relative contribution of cognitive/attention processes versus threat (anxiety) related influences.

1.4. The current study

In the current study, we will present data on the acoustic (RT) and kinematic manifestations of the production of colour names in both the CS task and the ES task by a group of PWS and a matched group of PNS. The reaction time data are included to replicate the well-known effects for CS and ES tasks as reported in the literature for control speakers (Algom et al., 2004; Lansbergen, Kenemans, & Van Engeland, 2007; MacLeod, 1991). In addition to a list of neutral stimuli we used three different sets of emotional words as stimuli, viz., general emotional words, stutter-specific words, and individually emotional words. A set of Neutral baseline words (e.g., TABLE) paired with a set of General emotional words (e.g., RAPE) were found to generate a threat response in healthy individuals (Ben-David, Joshi, & Van Lieshout, 2011a). It is likely that this set will generate an even larger effect for PWS compared to PNS (Hennessey et al., 2014) if they have a general higher level of anxiety as heightened anxiety has been found to inflate ES effects (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007). Next, the stutter-specific words (e.g., AUDIENCE) are expected to elicit a delayed response only in the experimental group, because we predict that PWS will have a conditioned emotional response to words related to stuttering or speech in general (cf. Bowers et al., 2012), while there is no reason for PNS to have formed such associations. Finally, the individually emotional words are taken from a reading passage and are chosen specifically for each individual. These are words that the individual had difficulty with and that resulted consistently in stutter responses even after reading aloud the same passage five times (as in a typical reading adaptation paradigm; Bloom & Silverman, 1979). It is anticipated that PWS may develop highly specific threat responses to words that are likely to result in a stutter, even though the content of the word is typically neutral. This is similar to the study by Bowers et al. (2012) who picked sounds that were deemed (subjectively) threatening to fluency by their PWS participants, but in the context of a word naming task it makes more sense to focus on units that are meaningful and thus represented in the mental lexicon. For the CS task, we used a set of stimuli traditionally used in such paradigms, which included colour names printed in a neutral (white) font, a string of symbols in one of the target colours, and the two lists of stimuli where the font colour either matched (congruent) or not (incongruent) the colour name. As mentioned above, most likely both groups will show a significant SIE, as this is a highly robust paradigm. Yet, based on the findings from the Caruso, Abbs, and Gracco paper (1994), it is expected that the effect will be stronger for PWS.

The present study expands on the sparse literature on the potential impact of anxiety and cognitive stress on speech motor control. However, unlike previous studies we took measures that are based on actual motor performance using the movements of upper lip and lower lip in a well-defined context of bilabial stops at the onset of the colour names we chose for our tasks. From the movement signals we extracted measures of movement duration, amplitude and cyclic spatio-temporal variability (based on the original STI measure developed by Smith and colleagues; Smith, Johnson, McGillem, & Goffman, 2000), as well as indices that quantify lip coordination (Van Lieshout et al., 2007). Thus, we were able to investigate if and how threat content influences speech motor control in PWS versus PNS. In the context of the SMS theory we would hypothesize to find smaller upper lip movements for threat related and/or cognitive stressful stimuli, which would lead to more variability in motor control. Given the exploratory nature of this study and it being the first of its kind, there is a need to include a wide range of motor variables. If indeed significant effects are found with a small population, it warrants larger scale future studies along similar lines.

2. Method

2.1. Participants

The experimental group consisted of ten PWS: 7 males and 3 females (average age was 30.6 years; SD = 7.6; range 22–48 years) who were recruited either from the Speech and Stuttering Institute in Toronto or from a list of participants from previous studies who expressed interest in being contacted for additional studies. Every participant in this group had a clinical diagnosis as a person who stutters and stuttering severity was assessed using the Stuttering Severity Instrument-3 (Riley, 1994) based on speech samples acquired during conversation, monologue, and reading a passage aloud. The SSI qualifications varied from very mild to moderate (average SSI score = 14.3, SD = 8.22), with all individuals but one in the very mild-to-mild range. Stuttering individuals all completed therapy in the past, but it was completed at least one year prior to the start of the study.

The control group consisted of ten PNS, who were matched to the experimental group for age (average age = 28.4, SD = 9.2, range = 20–47 years; $t < 1$), sex, and years of education (PWS average = 16.22, SD = 2.95; PNS average = 17.9, SD = 5.1; $t < 1$).

Before the actual experiment began, participants were screened on a variety of inclusion criteria. All participants were native English speakers that have been using the language extensively, as indicated by a self-report questionnaire and all achieved a minimum score of 10/20 on the Mill Hill Vocabulary Test (Raven, 1958), corresponding to normal vocabulary levels for native English speakers. The average Mill Hill scores for PWS and PNS participants were not statistically different (PWS: 14.1/20, SD = 2.7/20; PNS: 14.4/20, SD = 1.4/20; $t < 1$). A questionnaire was used to ensure all participants had good ocular health and no history of visual or auditory pathologies. A Snellen test of visual acuity (Ferris, Kassoff, Bresnick, & Bailey, 1982) was conducted for each participant and participants wore their own corrective eyewear when necessary. All participants had a minimum Snellen fraction within clinically normal limits (20/20) in the left eye, the right eye (monocular vision), or in both (binocular vision) using a Landolt's *C* test (Hohmann & Haase, 1982), and colour-vision scores on a Munsell D-14 test (Munsell, Sloan, & Godlove, 1933) indicating clinically normal colour vision. All participants had pure-tone air-conduction hearing thresholds within clinically normal limits ($\leq$20 dB HL) from 0.25- to 3-kHz in the better ear. All participants signed an informed consent and the study was approved by the Health Sciences Research Ethics Board at the University of Toronto.

2.2. Instrumentation

For this study, we acquired time-aligned audio and Electro-Magnetic Articulography (EMA) position signals using the 3D AG500 articulograph system (Carstens Medizinelektronik, GmbH, Germany). The EMA AG500 system tracks articulatory movements inside and outside the vocal tract with high temporal and spatial precision (Hoole & Zierdt, 2010; Kroos, 2012; Yunusova, Green, & Mefferd, 2009; Zierdt, Hoole, & Tillmann, 1999). The EMA system uses alternating electromagnetic fields generated by transmitter coils attached to a cube measuring 58.4 (*L*) by 53.3 (*W*) by 49.5 (*H*) cm. The head of the participant is located inside this cube, but is not connected to the cube and thus able to move freely. In order to record movements, small sensor coils (~2 mm) are attached to specific articulators using surgical glue (PeriAcryl® blue; GlueStitch). When these sensor coils are placed in the magnetic field, a current is induced which is proportional to the distance and angle of the coil to each of the transmitters. This system uses 6 transmitter coils and records movement data at a rate of 200 Hz per channel for up/down (*z*), front/back (*x*) and left/right (*y*) movements, as well as angular information on azimuth and elevation (Henriques

& Van Lieshout, 2013; Kroos, 2012). Acoustic data are sampled at 16000 Hz. For the purpose of this study, transducer coils were placed on the midline just above the vermillion border of the upper and lower lip, the tongue tip (1 cm behind actual tongue apex), the tongue body (2 cm behind tongue tip coil), the tongue dorsum (as far back as possible, but at least 1 cm from tongue body coil) and the lower jaw. For the latter, the coil is attached to the posterior surface of a thin thermoplastic custom made mould covering the lower incisors to ensure a stable and reproducible placement (Henriques & Van Lieshout, 2013). Additional coils were placed on the participant's head (left and right skin covering the mastoid process) and the bridge of the nose for reference purposes (i.e., to record head motion). For this study, only data from upper lip and lower lip are presented.

Following coil attachment, we measured the occlusal bite plane using a plastic device held in the mouth by the participant. On top of the device we attached a 3D bubble level. The device had to be placed exactly parallel to the horizontal axis of the EMA system and positional information was gathered using two coils attached in a midline position at a fixed distance of 3 cm to create a standard reference frame. This reference frame was used to remap raw position data of individual articulators in order to be able to compare data across participants (Henriques & Van Lieshout, 2013; Westbury, 1994).

2.3. Stimuli

All participants completed two tasks: the Emotional Stroop task (ES) and the classic colour naming Stroop task (CS). For both tasks they had to name the colour of the font in which the words were depicted on the monitor. The choice of font colours was not conventional. As we were interested in measuring the influence of threat content and cognitive stress on articulatory movements, we wanted to select movements associated with clear phonetic targets like found in stops. For this reason, we used colour names that started with a bilabial stop (/p/or/b/) as these are easy to measure and have a clear closure and release part associated with upper lip and lower lip movements. Another necessary restriction was to ensure that the font colours would be easy to discriminate from each other. Based on pilot work, the colours selected were pink, blue and brown.

2.3.1. Emotional Stroop task

There were four lists of words for this task. One list consisted of words with a neutral connotation (Neutral Words or N; e.g., names of furniture items that could be related to any of the font colours; e.g., TABLE, CHAIR). The second list consisted of emotional words which were used in a previous study with healthy (fluent) speakers (Threat Words General or TWG; e.g., RAPE, LOSER), and for which we found a significant emotional Stroop effect (Ben-David et al., 2011a; Ben-David, Van Lieshout, & Leszcz, 2011b; Ben-David et al., 2011c). The third list consisted of words that bear a relationship to communication and stuttering (Threat Words Stutter or TWS). These words refer to typical situations that are considered to be anxiety inducing in PWS, such as “restaurant”, “audience”, “microphone”, “talk” and are also encountered in tools like the Speech Situation Checklist developed by Brutten and Shoemaker (1967). The individual words for these first three lists are provided in Appendix A.

Using the English Lexicon Database project website (Balota, Yap, Hutchison, & Cortese, 2007), the three word lists were balanced for length, frequency of usage (log word frequency based on the Hyperspace Analogue to Language (HAL) frequency norms; Lund & Burgess, 1996), number of phonemes, mean bigram frequency and number of orthographic neighbours. The means, standard deviations and relevant *t*-test results (independent samples, assuming unequal variances, two-tailed) are also presented in Appendix A. This analysis is required to control for the possible bias of lexical characteristics on reading and emotional Stroop performance (see, Ben-David et al., 2011b; Hennessey et al., 2014; Larsen, Mercer, & Balota, 2006).

In addition to these three lists, a fourth list consisted of words that for a given individual PWS were likely to trigger a stutter event (Threat Words Stutter Individual or TWSI). For this we used a reading adaptation task (Bloom & Silverman, 1979), where each individual PWS would read aloud a text and we selected those words on which that person had consistent stuttering across 5 repeated readings of the same text. These words are considered to be “fear” words, that is, words that for a given PWS would present some threat (leading to anticipatory anxiety; Bowers et al., 2012) in terms of having the potential to evoke disfluencies.

2.3.2. Classical Stroop task

For the Classical Stroop (CS) task, participants were asked to name the font colours of words that depict colour names (e.g., the word PINK printed in blue) on a black background. For this task we used four different types of stimuli. One block of stimuli, called the Neutral or baseline condition (BC) consisted of non-linguistic symbols (a string of five 0s; “00000”) depicted in one of the three target colours. Another block of stimuli consisted of colour names depicted in a white font and the participant simply had to read aloud the words. We refer to this as the reading condition (RC). The other two blocks consisted of stimuli where the font colour either matched the colour name (Congruent Condition or CC, e.g., PINK presented in a pink font) or not (Incongruent Condition or IC; e.g., PINK depicted in a blue font).

2.4. Procedures

Participants were tested individually. Each participant performed the two tasks (ES and CS) one after the other, but the order of tasks was varied across participants such that one half received the ES task first and the other half the CS task first.

We randomized the order of the four word lists in the ES task across participants. Stimuli were presented on a computer screen in front of the participant one at a time. The participant was instructed to respond with the colour of the stimulus shown on the screen. As a result, the response was always a colour name (blue, brown, or pink). The participant was also asked to respond as quickly as possible, but without making errors. After the initial response, the participant was asked to repeat the word over and over again until a buzzer sound was presented (after 8 s). For example, if the word “chair” was written in pink font, the correct response would be “pink pink pink pink...”, etc. until the buzzer sounded. The average number of repeated items (colour names) was 15.6 (SD = 3.8) for PNS and 13.9 (SD = 4.4) for PWS, which equals to slightly less than 2 colour name productions per second (1.9 for PNS; 1.7 for PWS).

2.5. Analysis and dependent variables

Data processing steps followed a standardized protocol developed in the lab of the first author (Henriques & Van Lieshout, 2013; Van Lieshout et al., 2007; Van Lieshout & Moussa, 2000). Movement data were smoothed using an 11-point triangular filter (effective low-pass frequency 27.5 Hz) prior to processing. Reference positions on the nose and one behind the ear when the head was in an upright position with the bite-plane parallel to the *x*-axis, were used to align all movement data. For the individual articulator data, movement signals were band-pass filtered with a 7th-order Hamming-windowed Butterworth filter using 6.0 Hz and 0.1 Hz as the high and low cutoff points. This procedure removes DC drift and higher frequency noise components but preserves the motion components of interest.

For individual upper lip (UL) and lower lip (LL) movements, we first applied an automated segmentation procedure which finds maximum and minimum values in a time series based on specified amplitude and time criteria (Van Lieshout et al., 2007). Subsequently, for each upward and downward movement we derived the following kinematic measures:

- Movement range (MR): distance covered in the motion from lowest/highest to highest/lowest position.
- Movement duration (MD): duration of the motion from lowest/highest to highest/lowest position.
- Cyclic Spatio-Temporal index (cSTI): index reflecting the sum of standard deviations of overlaid amplitude and time-normalized individual movement cycles (defined by their maxima and minima as described above) based on 50 points on the corresponding trajectories (Smith et al., 2000). In essence, cSTI quantifies the consistence of repeated movement cycles for a given task, with lower numbers signalling higher degree of consistency.

To study inter-articulator coordination, we focused on the superior-inferior displacements of lip movements, in particular the relative phasing between upper lip and lower lip (+jaw) for the production of the initial bilabial stops. To measure phasing patterns we used a cross-spectral coherence analysis with an effective frequency resolution of 0.1 Hz (e.g., Aoyagi & Ohashi, 2003; Kay, 1999). This analysis provides a measure of correlation between individual spectral bins of Fourier transformed position signals. The frequency component for each trial-set that showed the highest power and/or the highest spectral correlation across the two signals was selected as the input for the subsequent relative phase analysis, being a clean estimate of the dominant control influence on the motion patterning over time (e.g., Van Lieshout et al., 2007). Point-differentiation was used to obtain velocity versus time functions from the position signals. The position and velocity signals were then band-pass filtered using the dominant peak (identified in the cross-spectral analysis procedure described above) as the center frequency (±0.2 Hz). These signals were processed further to obtain continuous estimates of relative phase. Since the relative phase values between lips can be expected to vary around 180° out of phase, we calculated a difference measure (180 – actual relative phase value = PHIDEV) to estimate the degree of deviation from the expected phase relationship. To measure the stability of coordination, within-trial-set (circular) standard deviations of relative phase were calculated (SDPHI). All relative phase variables are expressed in degrees.

In addition to movement data, we also collected reaction times to the first pronunciation of a colour name and these measurements were done automatically by a laptop running Direct RT software, which records voice responses (Stahl, 2006). In addition, we digitally recorded all verbal responses using a microphone for off-line acoustic analysis. For the reaction time data, we only analyzed the latencies for correct responses. For all variables, we took the median value for repeated utterances within and across trials for a given word list condition in order to reduce the influence of potential outliers (Chau, Young, & Redekop, 2005). We prefer taking the median as opposed to outlier classifications that choose relatively arbitrary cut-off points like 2 SD values above or below a certain mean.

2.6. Statistical analysis

We evaluated all dependent variables on the normality of their distribution using a Shapiro–Wilks test. Most distributions differed significantly from normality. Hence, to keep the analysis consistent across all variables we applied a log transform to all data and used R with the lme4 package (Linear mixed-effects models using S4 classes. R package version 0.999375-42. http://CRAN.R-project.org/package=lme4) to conduct a linear mixed effects analysis with an unstructured covariance matrix of the changes in the dependent variables with Group and Word List contrasts (see below) as fixed effects, separately for the ES task and the CS task. We used the intercepts for participants as our random effect. Subsequent to this, the models generated by these analyses were used as input for an Analysis of Variance (Anova) to provide an estimate for the F-values and corresponding levels of significance for the fixed effects (Group and Word List contrasts). For the ES task we specified

Table 1
Mean values and SDs for all dependent variables for the Emotional Stroop task (ES; A) and Classical Stroop task (CS; B), separately for People who Stutter (PWS) and People who do Not Stutter (PNS).

A (ES)	PWS – N	PWS – TWG	PWS – TWS	PWS – TWSI	PNS – N	PNS – TWG	PNS – TWS	PNS – TWSI
Mean								
RT	994.9	1,105.25	1,109.40	1,015.20	674.15	774.6	654.3	663.4
ULA	1.79	2.15	1.72	1.75	2.39	2.5	2.35	2.44
LLA	7.13	7.73	7.44	7.25	5.68	6.15	6.06	5.83
ULD	538.13	523.03	514.64	548.68	455.03	451.61	468.83	447.31
LLD	553.91	517.86	528.45	555.51	508.68	487.93	511.96	485.81
cSTI UL	22.53	20.36	22.18	20.54	16.82	18.38	17.59	18.74
cSTI LL	14.81	14.4	14.1	14.26	14.16	15.86	15.09	15.56
SD Phi	12.13	11.16	12.61	11.11	9.77	8.5	10.82	10.28
PHI DEV	29.53	23.27	31.41	26.51	16.22	19.1	19.25	20.13
SD								
RT	248.46	305.69	345.8	305.87	110.38	232.68	140.37	96.83
ULA	0.67	0.91	0.77	0.65	0.71	0.76	0.52	0.57
LLA	2.19	2.26	2.15	2.07	2.08	2.14	2.33	2.03
ULD	154.19	144.74	148.18	174	49.17	42.26	48.25	62.03
LLD	83.49	85.09	81.19	146.45	71.97	56.65	70.36	69.78
cSTI UL	4.98	6.91	6.43	5.86	7.11	4.91	6.9	7.34
cSTI LL	6.79	7.87	7.78	7.02	6.3	5.96	5.84	6.47
SD Phi	6.26	5.41	5.15	3.27	2.03	1.78	6.71	7.31
PHI DEV	11.48	17.32	22.83	13.49	8.03	7.23	13.09	12.91

B (CS)	PWS – BC	PWS – RC	PWS – CC	PWS – IC	PNS – BC	PNS – RC	PNS – CC	PNS – IC
Mean								
RT	932.1	898.3	1,005.35	1,100.90	614.7	645.1	612.4	690.4
ULA	1.94	1.66	1.55	1.9	2.33	2.49	2.33	2.49
LLA	7.85	7.87	7.93	7.89	5.51	6.35	6.1	6.14
ULD	484.2	478.47	455.65	486.28	461.13	466.53	472.05	469.89
LLD	513.67	522.74	528.44	526.93	490.26	493.73	513.99	474.89
cSTI UL	20.52	21.13	20.47	20.2	17.25	16.46	16.48	16.95
cSTI LL	12.41	12.53	11.68	12.67	14.33	15.2	13.83	16.05
SD Phi	11	10.16	12.04	12.47	10.65	9.33	9.54	10.4
PHI DEV	30.04	25.88	32.36	29.38	25.8	25.84	22.32	22.55
SD								
RT	317.47	219.25	328.26	404.5	74.97	149.56	141.38	105.09
ULA	0.84	0.53	0.58	0.69	0.73	1.07	0.45	0.61
LLA	2.98	2.39	2.92	2.57	2.43	2.21	2.2	2.51
ULD	111.54	122.42	79.01	124.92	54.53	63.82	57.48	51.11
LLD	74.31	71.84	89.8	90.83	67.22	69.64	84.28	79.02
cSTI UL	7.64	6.8	7.53	7.56	6.52	5.47	5.55	5.57
cSTI LL	6.45	6.76	6.21	6.79	5.82	6.11	5.58	5.31
SD Phi	6.07	5.08	6.03	5.77	3.88	2.99	2.29	4.47
PHI DEV	19.88	16.54	27.18	21.76	11.61	8.72	12.04	9.14

N = Neutral Words; TWG = Threat Words General; TWS = Threat Words Stutter; TWSI = Threat Words Stutter individual; BC = baseline condition; RC = reading condition; CC = congruent condition; IC = incongruent condition. RT = reaction time; ULA = upper lip amplitude; LLA = lower lip amplitude; ULD = upper lip duration; LLD = lower lip duration; cSTI UL = cyclic spatio-temporal index upper lip; cSTI LL = cyclic spatio-temporal index lower lip; SD Phi = standard deviation relative phase; PHI DEV = relative phase deviance (difference from 180°).

three a-priori contrasts, namely between N and TWG stimuli (ES_1), between N and TWS stimuli (ES_2) and between N and TWSI stimuli (ES_3). For the CS task we focussed on SIE, the contrast between BC and IC stimuli (for a discussion on the advantages for using SIE as a measure of selective attention in Stroop task, see Ben-David & Schneider, 2009; Ben-David & Schneider, 2010). We performed separate analysis for all dependent variables (RT, UL_MR, LL_MR, UL_MD, LL_MD, UL_cSTI, LL_cSTI, PHIDEV, SDPHI). Given the small group size and the exploratory nature of this study, we did not perform a Bonferroni correction (Nakagawa, 2004) and used alpha at 0.05 level as our statistical threshold for significance. Effect sizes are reported as partial eta squared ($\eta^2 p$) values, showing the proportion of the dependent variable variance that is uniquely associated with a given factor. As a rule of thumb we use Cohen's (Cohen, 1988) suggestion to interpret these values as large (.14), medium (.06), and small (.01) effect sizes.

3. Results

Table 1 shows the mean values and SDs for all dependent variables for the ES (A) and CS (B) tasks, separately for PWS and PNS. We will first present Group effects, followed by main effects for specific contrasts based on the different word lists, and finally, Group by Word list contrast interaction effects.

3.1. Group differences

In terms of group differences for the ES and CS tasks, we found significant main effects for reaction times in both the ES [$F(1,18) = 10.80$, $p = 0.004$, $\eta^2 p = 0.38$] and CS [$F(1,18) = 19.77$, $p = 0.0003$, $\eta^2 p = 0.52$] tasks. These effects indicate that PWS were on average slower to respond in both these tasks, as compared to their matched controls (ES: PWS $M = 1056$[1] ms, SD = 296; PNS $M = 692$ ms, SD = 156; CS: PWS $M = 984$ ms, SD = 321; PNS $M = 641$ ms, SD = 121). Upper lip amplitude was also found to be significantly different between the two groups for both tasks [ES: $F(1,18) = 4.87$, $p = 0.041$, $\eta^2 p = 0.21$; CS: $F(1,18) = 10.67$, $p = 0.004$, $\eta^2 p = 0.37$]. PWS in general showed smaller upper lip amplitudes for ES ($M = 1.85$ mm, SD = 0.75) and CS ($M = 1.76$ mm, SD = 0.66) compared to the upper lip amplitude values for PNS in ES ($M = 2.42$ mm, SD = 0.63) and CS ($M = 2.41$ mm, SD = 0.72). For ES only, we found a significant group effect for the relative phase difference measure [PHIDEV, $F(1, 18) = 4.57$, $p = 0.047$, $\eta^2 p = 0.20$] with PWS showing on average higher values ($M = 27.68°$, SD = 16.48) than PNS ($M = 18.68°$, SD = 10.35). There were no other significant group effects.

3.2. Word list differences

3.2.1. ES task

For the ES task we found the reaction time values for N words ($M = 835$ ms, SD = 249) to be shorter than for TWG stimuli ($M = 940$ ms, SD = 314). This was true for both groups. However, the difference was not found to be significant [$F(1.54) = 1.488$, $p = 0.2278$, $\eta^2 p = 0.03$]. In contrast, we did find a significant difference between N and TWG stimuli for LL_MR [$F(1,54) = 8.05$, $p = 0.006$, $\eta^2 p = 0.13$] and LL_MD [$F(1,54) = 9.03$, $p = 0.004$, $\eta^2 p = 0.14$]. For LL_MR, neutral stimuli showed smaller ($M = 6.41$ mm, SD = 2.21) movement ranges than TWG stimuli ($M = 6.94$ mm, SD = 2.29). For LL_MD, neutral stimuli had longer durations ($M = 531.30$ ms, SD = 79.33) than TWG stimuli ($M = 502.89$ ms, SD = 72.01). This means that in repeating a colour name of TWG stimuli, individuals in general made larger movements in a shorter period of time which is equivalent to making faster movements. There were no other main effects for N vs. TWG stimuli.

With respect to differences between N and TWS stimuli in the ES task, there was a main effect for SDPHI only [$F(1,54) = 5.90$, $p = 0.019$, $\eta^2 p = 0.10$], showing larger values for the TWS stimuli ($M = 11.72°$, SD = 5.89) compared to neutral stimuli ($M = 10.95$, SD = 4.69). For the difference between N and TWSI stimuli there were no main effects.

3.2.2. CS task

For the CS task, we found a significant effect for SIE [$F(1,54) = 9.61$, $p = 0.003$, $\eta^2 p = 0.15$] with shorter reaction times for BC stimuli (mean = 773 ms, SD = 277) than for IC stimuli (mean = 896 ms, SD = 356). There were no significant main effects for this contrast in any of the speech motor variables.

3.3. Group x word list interactions

3.3.1. ES task

Group by word list contrasts interactions for the ES task were found for RT, showing a significant interaction for group differences between N and TWS stimuli [$F(1,54) = 8.59$, $p = 0.005$, $\eta^2 p = 0.14$] as shown in Fig. 1.

Importantly, for PNS the RT differences between the two lists were extremely small, but the PWS group showed a clear delay (~115 ms) when confronted with the TWS stimuli that contain words referring to stuttering and/or speech situations. For UL_cSTI we also found a significant difference across the two groups for the contrast between N and TWG stimuli [$F(1.54) = 6.39$, $p = 0.014$, $\eta^2 p = 0.01$]. For PWS there was less UL variability for TWG stimuli ($M = 20.36$, SD = 6.91) compared to N stimuli ($M = 22.53$, SD = 4.98). In contrast, PNS showed a larger UL variability for the same stimuli ($M = 18.38$, SD = 4.91) compared to N stimuli ($M = 16.82$, SD = 7.11). We also found a significant group by N vs. TWG contrast interaction for PHIDEV [$F(1,54) = 4.79$, $p = 0.033$, $\eta^2 p = 0.08$]. PWS had a larger relative phase difference for N stimuli ($M = 29.53°$, SD = 11.48) compared to TWG stimuli ($M = 23.27°$, SD = 17.32). For PNS, this was reversed with PHIDEV values larger for the TWG stimuli ($M = 19.10°$, SD = 7.23) compared to the N stimuli ($M = 16.22°$, SD = 8.03).

3.3.2. CS task

For the CS task, there were no significant Group differences for SIE, although nominally the classical RT based SIE was nearly double in size for the PWS group compared to the PNS group (168 ms vs. 75 ms).

4. Discussion

This study was set up to investigate the impact of anxiety and cognitive stress on speech motor preparation and execution processes in a group of PWS and a matched group of control speakers using two different tasks. The ES task tests attention under threat, as the participant is asked to name the font colour of words that carry a potentially threatening content versus

[1] In accordance with custom in Cognitive literature, we display RT values in milliseconds only.

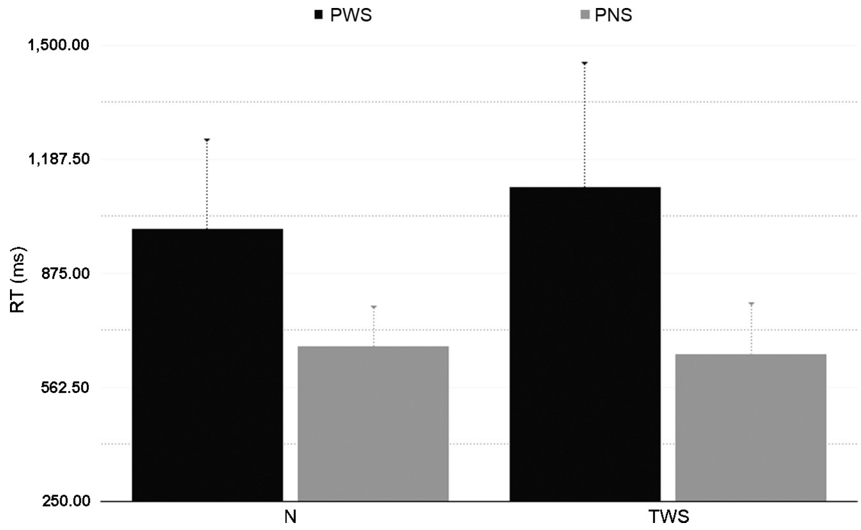

Fig. 1. Reaction times (ms) for N (Neutral) and TWS (Threat Words Stuttering) stimuli for each group (PWS = People Who Stutter; PNS = People who do Not Stutter). Error bars reflect standard deviations.

others with a neutral content. We used a set of general threat words (TWG), a set of stutter-specific threat words (TWS), and a set of words that elicited a reliable stuttering response for individual PWS participants (TWSI) using a repeated passage reading task. In the CS task, participants were asked to name the font colour of a set of stimuli that did not carry any threatening content. For this task we measured the classical SEI (difference between BC and IC stimuli) in RT, in addition to a set of speech motor variables.

4.1. Summary main findings

Comparing the two groups, we found that PWS in both tasks were slower to respond and motorically, they showed smaller upper lip movement ranges (amplitudes). For the ES task only, PWS were found to show larger phase differences between the upper lip and lower lip compared to PNS. With respect to main task effects, the ES task data showed a clear numerical difference in RT values between N and TWG stimuli for both groups, but the difference was not found to be significant. However, we did find that for this particular contrast lower lip movement range and duration were affected such that lower lip movements for the colour names of the general threat words were executed with significantly greater range and shorter durations (i.e., faster). For the TWS stimuli, we found a significant increase in the SD of relative phase values, meaning that overall the coordination between the lips was more variable for stutter related threat words. With respect to the CS task, we replicated the well-known SIE for both groups: Incongruent stimuli showed longer reaction times compared to baseline condition.

In terms of group by word list interactions in the ES task, these were apparent for stutter related threat words (TWS). For PNS there was virtually no difference in reaction times for TWS words compared to neutral words, but for PWS there was a clear delay as would be expected if such words are perceived as threatening (cf. Hennessey et al., 2014). For upper lip cSTI values, PWS showed smaller values for the TWG stimuli compared to neutral words whereas PNS showed the opposite. This was paralleled in smaller phase differences for PWS in TWG stimuli compared to neutral stimuli in contrast to PNS who again showed the opposite effect. In other words, for TWG stimuli PWS showed more stable upper lip movements with smaller inter-lip phase differences whereas the opposite pattern was found for PNS. Finally, for the CS task there were no significant interaction effects.

4.2. Impact of emotional threat and cognitive stress on speech motor control

Our data present the first findings on motor response variables in addition to more traditional reaction time data for both Emotional Stroop and Classic Stroop tasks with people who stutter and matched control speakers. Given the relatively small sample size that is typical for this type of study, and the fact that most of our PWS participants were in a restricted severity range (very mild to mild), we consider our findings as preliminary and exploratory only. Nonetheless, the effects that we report here are very interesting. First of all, PWS in general were slower to start responding than controls. This is a well-known and often replicated reaction time effect for this population (Peters, Hulstijn, & Van Lieshout, 2000). Hennessey et al. (2014) also found such a group difference, but the effect was not significant. We also found PWS in general to show smaller upper lip movement ranges, which fits well with claims from the SMS theory that postulate that they are in general at the lower end of the speech motor skill continuum and this could be reflected in a tendency for smaller upper lip movement ranges that would bring them closer to critical destabilizing thresholds for the entrainment between effector systems and neural control oscillatory networks (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 2002, 2004, 2007). PWS also showed larger phase deviations from the expected 180° out of phase patterns (considered the target coordination pattern for inter-lip coordination) but only for the ES task. Previous studies have suggested that PWS differ from controls in the timing of articulator movements (e.g., Caruso et al., 1988; Van Lieshout et al., 1996a; Van Lieshout, Hulstijn, & Peters, 1996b), but such findings were not always replicated due to methodological issues (e.g., De Nil, 1995). In the present study, we used a relative phase measure which is claimed to be a better method to study movement coordination as it is less susceptible to variations in movement duration and movement range (Tuller, Kelso, & Harris, 1982). Therefore, finding larger phase deviations in PWS may provide some support for theories that state that such timing differences do exist and as such may serve a specific purpose, for example, in the context of a feedback guided motor control strategy. Such a strategy could be expected from individuals learning a new skill or those who are not very skillful even after years of practice (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 1996b, 2004). In sum, the overall group differences with longer delays in preparatory processes, smaller upper lip movement ranges and (for ES), larger phase deviations provide some support for the general claim that PWS are at the lower end of a speech motor skill continuum as argued in SMS.

With respect to more specific within-task differences, our study generated some interesting new findings. To start with the emotional Stroop task, we can compare our reaction time data to similar data reported in the study by Hennessey et al. (2014), who for their verbal Stroop task used a single list of general threat words, similar to our TWG list. They did not find a significant general threat effect for both groups, but only a significant increase for stuttering individuals, despite the fact that their threat words were not specific to stuttering as our TWS list. For our TWG list, we did see that both groups showed an increase in reaction time to these words but the effect was not significant. However, both groups in our study did show that lower lip movements were executed faster for these words (based on larger ranges and shorter durations). Although there is no study in speech that could speak to this effect directly, a paper by Coombes et al. (Coombes, Janelle, & Duley, 2005) showed that when people are exposed to unpleasant (i.e., threatening) stimuli, there was an increase in force production, which typically results in faster movements. Interestingly, these authors also found that such faster movements were not more variable, which fits well with speech studies that have demonstrated that faster movements often tend to become more prototypical in terms of movement cycle patterns and therefore less variable (Van Lieshout et al., 2007; Van Lieshout & Moussa, 2000). Thus, it can be argued in the current study that both groups responded in a similar and predictable manner to the general threat stimuli by executing their lower lip movements faster.

It is interesting to note that this effect was not found for upper lip movements. A possible explanation is that upper lip movements in general are relatively small and faster movement execution (with a tendency to make smaller movements) would make them more likely to reach critical thresholds for reduced feedback gain as argued in the SMS theory. This is especially true for PWS, who as shown in this study are already at the lower end of upper lip movement ranges in general, which makes them more vulnerable to such destabilizing influences (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 2004). In contrast, we argue that PWS are more likely to pick a stabilizing control strategy in those circumstances, in particular by making larger upper lip movements in order to increase feedback gain (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 2004). We did not find significant group differences for these variables with TWG stimuli, but both upper lip cSTI values and phase differences were smaller for PWS compared to PNS. This points to a more stable mode of execution, suggesting some form of (subtle) motor execution adaptation in upper lip movements and intra-lip coordination.

What then about the words that we considered to reflect a more specific threat to PWS (the TWS and especially the TWSI list). The main significant kinematic effect that we found was a more variable lip coordination pattern (as expressed in SDPHI) for TWS words in both groups of speakers. This is perhaps understandable for PWS, but it is not very clear why controls would show this effect. In contrast, when we look at reaction times, it is indeed the PWS group that showed an increase in reaction times for TWS words, unlike the controls. So, in terms of preparatory processes the stuttering group manifested possible anxiety related delays for words that refer to speech and stuttering situations akin to what is found in the literature for patients with specific phobias when presented with phobia-specific stimuli (e.g., a picture of a spider for individuals suffering from arachnophobia, Kolassa, Musial, Kolassa, & Miltner, 2006; Öhman et al., 2001). However, to keep things in perspective, the actual difference in relative phase variability between neutral and TWS stimuli was small (less than 1°) with a medium effect size. Future studies would have to replicate this finding to see if it is indeed robust across a larger sample.

With respect to the CS task, we could replicate the well-known SIE for both groups of speakers in that reaction times were slower for incongruent stimuli compared to baseline conditions. However, we did not find any indication for group differences in this contrast (or any of the other variables), contrary to the findings presented in the study by Caruso et al. (1994). Thus, if indeed the incongruent nature of colour stimuli induces a cognitive stress situation, its impact was not different for PWS when compared to controls. In fact, the impact was only seen for preparation processes, which makes perfect sense as the cognitive conflict is likely to be resolved prior to executing the first colour word. This shows that cognitive stress and threat induced anxiety have different effects on motor processes and that only threat seems to have a more widespread influence.

4.3. Anxiety and speech motor skills

So what can these findings tell us about the role of anxiety on speech motor control, in particular regarding PWS? The clearest indication that anxiety might change the way speech movements are executed was found for the ES task, where words that are known to generate an emotional stroop effect (our TWG stimuli) induced faster lower lip movements (larger ranges with shorter durations) in speakers of both groups. As this effect has been found in other motor systems for unpleasant stimuli (Coombes et al., 2005), it is likely that anxiety played a role. However, the pattern of changes in upper lip movements for these TWG stimuli found only for PWS suggest some adaptation in motor responses for this group. Especially, the reduced variability in UL cSTI and smaller phase difference between the lips suggest the use of specific control strategies to handle the potential destabilizing impact of anxiety. That the two lips show a different response pattern in the presence of a semantic threat is expected in the context of SMS. In particular, the upper lip has been found to show specific changes in kinematic behaviours that changed the stability of the overall inter-lip coordination pattern (Namasivayam & Van Lieshout, 2011; Van Lieshout et al., 2002, 2004, 2007). In other words, in the current study the lower lip data show evidence for a general impact of anxiety on the speech motor control system and in response to that, only PWS show a change in upper lip movement control and lip coordination that we take to reflect stabilizing motor control mechanisms. For PNS there is no need to invoke such strategies as they would have the speech motor skill level to handle the impact of anxiety caused by general threat words on their speech motor control system, especially since threat to fluency is not a usual situation they would have to deal with, unlike PWS. It would be interesting to see however, what happens with control speakers if the levels of anxiety are raised using stronger threat stimuli/situations.

Interestingly, our findings also show that for words that can be considered to be more specific to people who stutter in terms of perceived threat (the TWS list), there is only a group difference in reaction times, suggesting that if this is caused by anxiety its main impact is on processes prior to motor execution. This fits with the findings from Bowers et al. (2012) who showed anticipatory autonomic arousal effects for stutter-specific threat stimuli (sounds in their case) in PWS but no immediate relationship to behavioural outcomes (stuttered or fluent speech). They argued that the elevated autonomic arousal found in their stuttering participants was indicative of a general disposition of higher state anxiety towards specific speech stimuli (related to fear of stuttering). Higher levels of state anxiety for PWS have been confirmed in many studies (Craig & Tran, 2006, 2014; Craig et al., 2003; Iverach et al., 2011; Mahr & Torosian, 1999; Menzies et al., 1999) and our study findings seem to suggest a similar pattern for the stutter specific threat words. However, in contrast to Bowers et al. (2012) we did not find a specific impact of individual stimuli that our stuttering participants consistently stuttered on, even after five readings of the same text. We considered those words similar in terms of anxiety inducing properties to the threat sounds presented in the Bowers et al. study. Bowers and colleagues argued that elevated levels of anxiety prior to motor execution do not predict speech fluency. Perhaps we can reverse the argument by stating that actual stuttering on words does not predict the presence of (word-specific) anxiety. That is, the fact that our individuals stuttered on these words does not entail that they had become sensitized to these words in such a way they were more anxious when seeing them (without the need to actual speak them!). They seem to have a general predisposition to be more anxious about words that remind them of their stuttering (TWS) and also show a differential motor execution pattern for words known to elicit a threat response in most people (TWG). However, it appears that words that they stuttered on prior to participating in our study do not stick in their mind as being specifically threatening. Perhaps it would take a longer history of being disfluent on specific words (e.g., like saying their own name) before they are perceived as a true threat to fluency. This resonates with a recent paper on the role of emotion on learning (Nelson, Lau, & Jarcho, 2014), where the authors describe the important role of emotion in inducing a complex response pattern at different processing levels and attributing salience to a particular stimulus which is closely linked to the specific occurrence in time (during development) and (as we would argue) persistence of such stimuli. The authors also claim that it is especially the amygdala that plays a large role in highlighting stimulus saliency during such sensitive periods of development. In the context of the current study, attributing saliency to negative stimuli (words that are stuttered on) may require a certain critical period in development which is hard to reproduce in the context of a single experiment. The potential role of the amygdala in influencing speech fluency was also highlighted in the paper by Alm (Alm, 2004) and future studies will need to address the relationship between specific verbal stimuli, context, and emotional response as mediated by activity in the amygdala and associated structures at different age groups in people who stutter to determine critical periods that may play a role in the development and variability of stuttering.

4.4. Limitations

This study is the first of its kind in assessing the impact of different potential threat stimuli on speech motor control using direct measures of articulator movements and inter-articulator coordination (upper lip and lower lip in this case). Due to the more invasive nature of this type of study, our sample size was relatively small and this obviously limits the power of finding more subtle effects. Despite finding indications of the presence of anxiety in speaking colour names of words that have general or stutter-specific threat properties, we were less successful in finding such effects for words that we considered to be more threatening to individual stuttering speakers. Future studies will have to look into this aspect further, in particular in how long it really takes for a particular stimulus (word or sound) to become truly anxiety inducing for a given individual.

The other limitation is the fact that most of our stuttering participants were in the very mild-to-mild category. We have to reiterate that all individuals at one point in their life were diagnosed and treated for stuttering in a specialized clinic in Toronto. Although, they had not been in therapy for at least a year and were instructed not to use their treatment strategies it is still possible that some treatment effects may have influenced our results by showing a reduced stuttering frequency (as measured by SSI). Of course, stuttering frequency does not necessarily relate in a simple manner to stuttering severity and the issues around being a person who stutters (including anxiety related behaviours; DiLollo, Manning, & Niemeyer, 2011; Craig, Blumgart, & Tran, 2009). Therefore, future studies need to include larger numbers of stuttering participants with different degrees of severity as measured in stuttering frequency and other aspects that would be relevant in this respect.

Finally, we used a reiterated speech paradigm where colour names were repeated for 8 s and this may have dampened the effect of threat/anxiety on speech motor execution. On the other hand, one could also argue that repeated exposure to threat words should not change the impact for more anxious individuals (if such an impact is actually there), as patients with anxiety disorders maintain their anxiety and associated behaviours in the presence of prolonged threat unlike non-anxious individuals (Somer, Keinan, & Carmil, 1996). Either way, the amount of exposure is something that could be varied more systematically in future studies.

5. Conclusions

In conclusion, our study shows evidence for differential motor response patterns in PWS compared to controls for words that have a conceptual relationship to general and stutter specific threatening stimuli, but not for words that individuals actually stuttered on. We argue that this shows that preparing and executing motor patterns in PWS can be influenced by a more general disposition to being anxious (state anxiety), but not by immediate previous experiences in terms of fluent or disfluent behaviours. We also did not find evidence that cognitive stress induced by conflicting information as created in the classic Stroop task affects stuttering individuals differently than controls or that its impact spreads to motor execution processes. Thus, it can be argued that threat and cognitive stress impact speech motor processes differently with threat content of words being more salient for both preparatory and execution stages.

CONTINUING EDUCATION

The impact of threat and cognitive stress on speech motor control in people who stutter

QUESTIONS

(1) How treat content changes speech motor processes is
  a. Well established
  b. Not researched at all
  c. Researched in a very small number of studies but mostly using acoustic data only
  d. Researched in a very small number of studies using state-of-the-art technology
  e. Researched only for stuttering individuals

(2) This study shows that cognitive stress and threat content
  a. Affect the same processes in the same way
  b. Have no effect at all
  c. Affect speech motor processes in different ways
  d. Show the same effect for motor execution processes
  e. Show different effects for motor execution processes only

(3) People who stutter compared to those who do not stutter
  a. Are basically the same when it comes to motor execution processes when performing an emotional Stroop task
  b. Are different in all motor variables when performing both emotional and classic Stroop tasks
  c. Are different in specific motor variables only for the emotional Stroop task
  d. Are different in specific motor variables only for the classical Stroop task
  e. Are different in reaction times and upper lip movement ranges for both tasks

(4) Words that individuals who stutter had trouble with speaking fluently even after repeated readings
  a. Showed no differences from neutral words in either motor preparation or motor execution
  b. Showed clear differences from neutral in motor preparation variables
  c. Showed clear differences from neutral words in motor execution variables
  d. Showed no differences from neutral words in motor execution variables but a clear change relative to general threat words
  e. Showed only a difference from words that refer to stutter specific content

(5) Overall, effects of general threat content show that
  a. People who stutter and matched control speakers always use the same motor control strategies
  b. People who stutter might use different motor control strategies to handle threat impact
  c. Controls shows evidence for different motor control strategies but not people who stutter
  d. Controls and people who stutter are different in preparation but not execution processes
  e. Controls and people who stutter are same in preparation but not execution processes

Correct answers:(1) C; (2) C; (3) E; (4) A; (5) B

Conflict of interest

None of the authors Van Lieshout, P., Ben-David, B., Lipski, M., and Namasivayam, A. reported any financial conflict-of-interest.

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Appendix A.

Word lists, lexical characteristics and *t*-tests (independent samples, assuming unequal variances, two-tailed) results for Neutral Words, Threat Words General, and Threat Words Stutter.

	Length (# graphemes)	Log word frequency	# Phonemes	Average bigram frequency	# Orthographic neighbours
Neutral Words (N)					
Clock	5	10.1	4	1853.5	8
Clothes	7	9.6	4	4113.2	2
Container	9	8.6	7	7076.4	1
Cup	3	10.2	3	1021.5	10
Furniture	9	8.5	6	3054.8	0
Kitchen	7	9.2	5	3316	1
Spoon	5	7.9	4	3469.8	5
Towel	5	8.1	4	2215.3	6
Window	6	10.9	5	4274.4	1
Mean	6.2	9.2	4.7	3377.2	3.8
SD	2	1	1.2	1745.3	3.6
Threat Words General (TWG)					
Abortion	8	9.7	6	4640.9	0
Abuse	5	10.2	5	2534.5	2
Aids	4	10	3	1466.3	10
Cancer	6	9.8	5	5902.8	5
Depressed	9	8.3	7	5682.6	2
Failure	7	10.1	5	2992.7	0
Loser	5	8.3	4	5523.5	7
Rape	4	9.5	3	3621	16
Suicide	7	9.2	6	2523.8	0
Mean	6.1	9.5	4.9	3876.5	4.7
SD	1.8	0.7	1.4	1618.3	5.5
Threat Words Stutter (TWS)					
Audience	8	8.4	6	3156	0
Classroom	9	10	7	2596.9	0
Interview	9	9.9	7	6044.4	0

Appendix A (*Continued*)

	Length (# graphemes)	Log word frequency	# Phonemes	Average bigram frequency	# Orthographic neighbours
Microphone	10	8.2	8	3520.1	0
Restaurant	10	9	9	6078.3	0
Speech	6	10.5	4	2452	0
Stutter	7	5.7	5	5676	2
Talk	4	11.4	3	3251	11
Repeat	6	10	5		3
Mean	7.7	9.2	6	4096.8	1.8
SD	2.1	1.7	1.9	1563	3.6
N vs. TWG	$t(16) = 0.13$, $p = 0.9$	$t(16) = 0.54$, $p = 0.60$	$t(16) = 0.36$, $p = 0.72$	$t(16) = 0.63$, $p = 0.54$	$t(16) = 0.41$, $p = 0.69$
N vs. TWS	$t(16) = 1.51$, $p = 0.15$	$t(16) = 0.9$, $p = 0.38$	$t(16) = 1.75$, $p = 0.1$	$t(15) = 0.01$, $p = 0.99$	$t(16) = 1.17$, $p = 0.26$
TWG vs. TWS	$t(16) = 1.72$, $p = 0.105$	$t(16) = 0.29$, $p = 0.78$	$t(16) = 1.41$, $p = 0.18$	$t(15) = 0.37$, $p = 0.72$	$t(16) = 1.32$, $p = 0.21$

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