Complexity of Rhythmic Tapping Task and Stuttering

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Abstract

The study investigated whether people who stutter (PWS) differed in rhythmic tapping behavior compared to people who do not stutter (PNS). 16 PWS and 16 PNS, matched in age and gender, were instructed to synchronize with a metronome beat, to continue this pattern once the beat stopped, or to fill in the time between two metronome beats with several taps. Tapping measures on variability, mean inter response intervals, and the number of missed taps were retrieved. The results showed that, compared to PNS, PWS differed in tapping behavior. Tapping variability was higher in PWS than PNS on all the tasks. In addition, PWS missed more taps then PNS, especially in the condition in which they had to fill in the time with extra taps. Finally, musical experience affected tapping variability: the most experienced participants showed the lowest degree of variability. These findings lay the groundwork for our larger study that includes more complex tapping patterns and speech production data.

Keywords: Rhythm, stuttering, internal clock, finger tapping

1. Introduction

The study explores whether people who stutter (PWS) differ in rhythmic tapping behavior compared to people who do not stutter (PNS). Stuttering is a neuro-motor disorder, presenting itself as disfluent speech production (Bloomstein, & Bernstein, 2008). Evidence suggests that stuttering is not limited to speech movements, but that upperlimb and non-speech orofacial movements are also affected (Daliri et al., 2014; De Felicio et al., 2007; Max et al., 2003). One of the theories proposed is that deficiencies in temporal processing, originating at the neural level, play a role in the difficulty to execute movements (Chang, et al., 2016). It has been proposed that stuttering involves a deficiency in the basal Ganglia (Alm, 2004), which play a role in generating timing cues to initiate movements. When synchronizing with an auditory stimulus, PWS show, for example, larger asynchrony with the beat than PNS and perform less accurate and consistently (Hulstijn, et al., 1992; Falk, et al., 2015). At the same time, speech is more fluent with external sensory triggering, suggesting that the external trigger compensates for the internal deficiency (Alm, 2004).
Most studies to date explore the differences in temporal processing between PWS and PNS with simple rhythmic tasks, such as the ability to synchronize with an external predictable beat. Speech, however, is characterized by a quasi-rhythmic structure that likely requires more skill to estimate the underlying temporal structure of the consecutive events (see e.g., Tilsen, 2011). This temporal structure is resulting from an intricate interplay between duration, pitch, and energy variation in prosodic patterns. To the authors' knowledge, it has not been explored whether PWS have a deficit in estimating temporal dimensions between beats, for example when they are asked to fill up the time between two predictable auditory metronome beats with self-generated taps. The current study explores whether, compared to PNS, PWS differ in their ability to fill an empty time interval with a sequence of regular beats. In the current study, the working hypothesis is that the speaker employs an internal clock, which specifies how these upcoming syllables must be timed (see Grahn, 2012 for a review on models). Taking the concept of an internal clock as a framework, it is expected that, compared to PNS, PWS face more difficulties filling up the time gaps with self-generated taps. In addition, to evaluate our participants in the light of paradigms used in earlier publications, the study examines whether PWS differ in their ability to continue tapping a periodic rhythm without an external metronome when the external driving metronome stops and whether they differ in their tapping behavior when synchronizing with a metronome beat. Based on findings in earlier studies (Hulstijn et al., 1992; Sares, et al., 2019; Falk et al., 2015), it was expected that PWS can synchronize and sustain a periodic beat but show more variability than PNS.

2. Methods

2.1. Participants

16 French PWS (13 M, mean age =39; SD = 14) and 16 French PNS (13 M, mean age = 39, SD = 15) were recruited. PWS were identified as persons with developmental stuttering by a speech language pathologist. The severity of stuttering was self-assessed and indicated on a scale from 1 to 3, with 3 being the most severe. 4 PWS labeled themselves as "1", 6 PWS as "2", and 6 PWS as "3". The participants were matched in age and gender.

2.2. Task

Speakers synchronized tapping with their dominant index finger (left or right) with an auditory beat played binaurally through earplugs. Their arm and wrist were resting on a table; only the finger moved during tapping. The finger taps were measured, using a gauge strain sensor (EPL-D11-25P from Meas France), and the signal was recorded using a Biopac acquisition system, at a rate of 20 kHz, over 16 bits.

Three different rhythmic tasks were distinguished, all based on an eight-beat cycle at a pace of 120 beats per minute (BPM) (see figure 1).

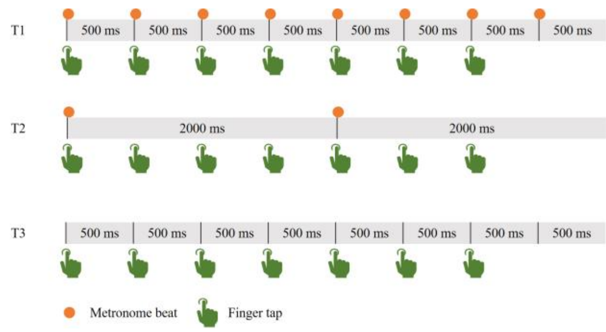

Figure 1. T1: synchronization task (500ms intervals: 120 BPM); T2: 4 taps on one metronome beat (2000ms intervals; 30 BPM); T3: continuation task (The taps must be spaced with the predetermined 500ms interval; 120 BPM).

For each rhythmic task, the participant listened to at least 2 cycles of the rhythmic pattern before starting to tap, and then produced at least 3 tapping cycles of that pattern until the participant was instructed to stop. For T1 and T3 this meant that the participant heard two 8 beat cycles and continued this pattern with or without the external auditory beats, respectively. During T2, the preceding cycles were identical to T1; during the experimental phase only the first and fifth beat were played. Such trains of tapping cycles were recorded 2 times for T1, T2 and T3 so that at least 6 cycles (of 8 taps) of each rhythmic pattern were considered for analysis.

2.3. Analysis

Tapping events were annotated semi-automatically with MATLAB scripts (figure 2) and checked post-hoc for inconsistencies in PRAAT, which were then manually corrected. The onset of a tap was taken as the moment the finger hit the sensor.

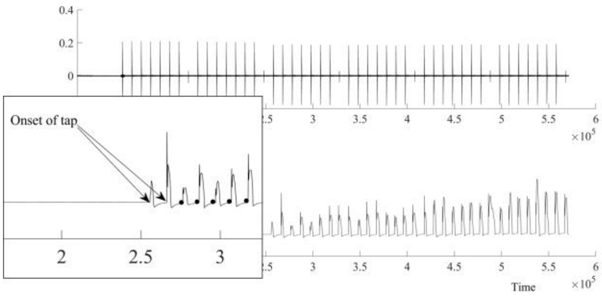

Figure 2. Example of a tapping signal, recorded with a gauge strain sensor, during task 1. The upper part shows the metronome beat signal, the lower part the realized tap. The onsets of the tapping events are marked with a black dot in the enlarged part of the figure and are indicated with the arrows.

The first step determined whether participants were able to produce taps with a sufficiently regular pattern and to estimate its actual period (mean Inter Response Interval (mIRI)), knowing that, at a rate of 120 BPM, the theoretical period (Tt) should be around 500ms. No participant demonstrated any erratic tapping patterns, although some participants inserted an extra tap, or skipped a tap. To estimate mIRI of each 8-taps cycles (i.e., train), we considered the time difference between a tap and the following one within a train and removed values which were larger than 1.5*Tt (appr. 750ms; considered to reveal a missed tap) or smaller than 0.5*Tt (appr. 250ms considered as a “double” tap). Next, for each train, mIRI was calculated based on the average values of the acceptable values within a train. Finally, the individual IRI values were normalized, and for each train, the tapping variability (TV) was expressed as the standard deviation of the distribution of normalized IRI values, according to equations 1 and 2:

$$\text{IRI\_norm} = \frac{\text{IRI} - \text{mIRI}}{\text{mIRI}} \times 100 \quad (1)$$

$$\text{TV} = \sqrt{\frac{\sum_1^N \text{IRI\_norm}^2}{N}} \quad (2)$$

In addition to these quantitative measures, all the missed and double taps, identified earlier to clean up the data, were counted as a measure of the occurrence of errors, and a percentage was calculated.

2.4. Statistical analysis

The data were analyzed with General Linear Mixed Models in R (R version 3.6.0 (2019-04-26)), using the lmer (Kuznetsova et al., 2017) and the anova function from the lme4 package. Rhythmic task with 3 levels (T1, T2, T3) and group with 2 levels (PWS, PNS) were fixed effects. In addition, musical experience was considered in this study as a fixed effect affecting rhythmic tapping abilities. Three levels were distinguished: no musical experience (indicated with 0; 10 PNS, 10 PWS), somewhat (labeled with 1; 3 PNS, 3 PWS), and serious amateur musicians (2; 3 PNS, 3 PWS). Participants were considered as a random effect. The level of significance was $\alpha = 0.05$. Tukey posthoc comparisons were computed using the emmeans package.

3. Results

3.1. mIRI

For both PWS and PNS, the results in figure 3 indicate that mIRI was significantly smaller in the first task, in which the participant synchronized with an external auditory beat, compared to the second and third task, in which they had more freedom to tap. These observations were statistically confirmed (($\chi 2(2) = 61.05$, $p<0.001$; T1 < T2: $p < 0.0001$), T1 < T3 ($p < 0.01$) and T3 < T2 ($p<0.0001$). No significant interactions between group and task were observed for mIRI.

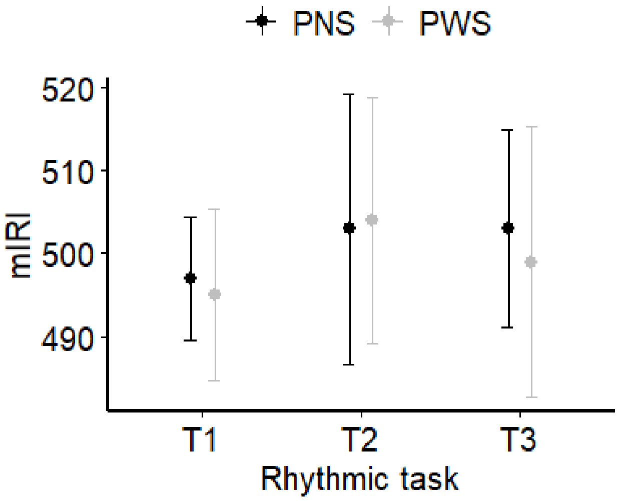

Figure 3. Vertical axis: the median of mIRI (ms) during a train, shown for each rhythmic task T1, T2 and T3 and group (PNS, PWS). The error bars represent median absolute deviations.

3.2. TV

Inspecting figure 4, it can be observed that PWS showed higher tapping variability than PNS, which was confirmed statistically ($\chi 2(1) = 7.24$, $p<0.01$; PNS<PWS: $p = 0.02$).

In addition, tapping variability varied significantly with rhythmic task (figure 4; ($\chi 2(2) = 67.38$, $p<0.0001$) with a greater TV observed in T2 compared to T1 ($p<0.001$) and T3 ($p < 0.001$). In addition, T1 resulted in smaller TV values than T3 ($p < 0.01$).

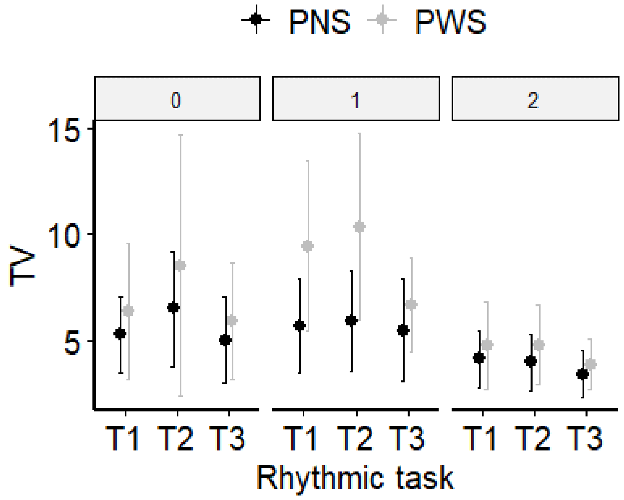

Figure 4 vertical axis: TV (median tapping variability); horizontal axis: rhythmic task (T1, T2, T3) for the three levels of musical experience; "0" no experience, "1" moderate experience and "2" highly experienced. Black: PNS; Grey: PWS. The errors bars represent median absolute deviations.

Tapping variability was also significantly influenced by the level of musical experience of the participants (see figure 4; $\chi 2$ (2) =8.06, p=0.02). It can be observed in figure 4 that speakers with advanced experience showed smaller tapping variability in all tasks. Participants with no musical experience (0) and with some experience (1) differed from those with the most experience (2) (p = 0.03 and p = 0.04 respectively). The results revealed no significant interaction effect between musical experience and group on tapping variability.

3.3. Missed taps

Finally, it can be observed from figure 5 that PWS missed more taps than PNS; especially in T2 and to a lesser extent in T3 and T1. These were the cases in which the IRI was longer than 750 ms in the T2 and T3 tasks. Very few taps were inserted, so these are not reported.

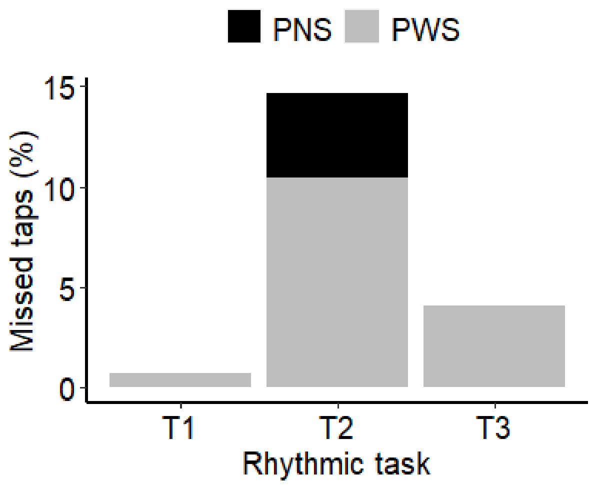

Figure 5: Missed taps in percentages for the 3 tapping tasks. Black indicates PNS; PWS are labeled with gray bars.

4. Discussion and conclusion

Our study confirmed the expectation that PWS differ from PNS in their tapping behavior and the data support a possible deficit in temporal processing by PWS. Although PWS can synchronize with an external auditory reference and keep a regular beat once the auditory reference stops, they present more tapping variability than PNS on all the tasks, confirming earlier studies (Hulstijn et al., 1992; Falk et al., 2015). The prediction that PWS would show even more difficulty with filling up a time frame with extra taps in task T2, compared to T1 and T3, was not confirmed with our IRI and variability measures; however, in T2, PWS missed more taps than PNS, suggesting that filling up empty temporal spaces with taps is more difficult for PWS. This finding suggests that PWS benefit from external triggering; however, the continuation task does not show more missed taps for PWS. An alternative explanation is that this task is more complex at the level of motor planning, and the internal clock interacts with this task complexity. This idea would be in line with theories on stuttering considering deficient motor planning as a major contributor to stuttering (see e.g., Namasivayam & van Lieshout, 2011).

Musical experience improved the tapping accuracy of both groups, which suggests that the temporal deficiencies PWS face can be mitigated by musical training. However, the number of people being highly skilled musicians was low in our study, so it is not possible to make strong claims about the effect of musical experience yet. Again, this finding suggests a contribution of motor planning skill, as mentioned earlier.

The IRI was not affected in the synchronization task, in which the participants tapped with an approximately 500 ms. tapping interval. On the other hand, the continuation task and the second task, in which the participants had to fill up empty spaces, showed higher values. One of the factors that possibly affected the IRI in these tasks is the inflexibility of an imposed frequency of the required tapping pattern; it has been shown that humans have their own preferred movement frequency in repetitive tasks (Naruse, Sakuma, & Hirai, 2001).

It is concluded that PWS differ in their tapping behavior. Future studies will include more complex tapping rhythms and build a bridge to speech production. Compared to finger tapping, producing speech is a complex motor task. Implementing this motor task on a more complex rhythmic structure possibly reveals larger differences between PWS and PNS.

5. Acknowledgements

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