



Tonguing on brass instruments - Highspeed Visualization and Benchmarks of fastest Tempi

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[PART A, Visualization of Tongue Motions] The tongue is crucially involved in playing wind instruments and in the articulation of speech. The documentation of the playing techniques with respect to the shape and the motion of the tongue started first with the use of syllables (tata,...) for didactic reasons; techniques such as x-ray or MRI have been used to visualize tongue motion in high quality. However, modern MRI recordings are limited to 4-20 images per second and spatial resolution is restricted by manual data acquisition. This research shows results of a 3D recording of tongue-movement, visualizing a four point high-resolution trajectory inside the mouth recorded at a sample rate of 250Hz by means of an Electromagnetic Articulography (Carstens AG501).

[PART B, Benchmarks of Tonguing Tempi] Another quantitative study (n=206) has been done to evaluate the maximum tempi that can be played on brass instruments. Benchmarks of tempi for different instruments and various experience-levels of the players for 'SINGLE TONGUING' and 'DOUBLE TONGUING' have been evaluated over 30 seconds for continuous sixteenth notes. The average tempi (median) in BPM (Metronome values) for four 1/16 notes in the first two seconds have been for 'SINGLE TONGUING' 109 for amateur, 120 for students and 123 BPM for professional players (167 for the fastest player, i.e. 11 notes per second). For 'DOUBLE TONGUING' the averages are 149 for amateur, 170 for students and 172 BPM for professional players (238 for the fastest player, i.e. 16 notes per second).

Visualization of Tongue Motions [A]

1 Introduction

All the fascinating sounds on brass instruments start by a small activation of the player's tongue; many variables are involved, leading to a huge variety of brass instrument sounds [1]. As in speech, the complex muscles inside the mouth form the articulation and the tongue is engaged for attack of notes. Corticomotor control of the human tongue musculature regulates an open control loop of five main extrinsic muscles (M. genioglossus, M. chondroglossus, M. styloglossus, M. hyoglossus, M. palatoglossus) and four paired intrinsic muscles (M. longitudinalis superior, M. longitudinalis inferior, M. transversus linguae, M. verticalis linguae).

Since the beginning of brass playing pedagogy there have been assumptions about the tongue positions used for playing different attacks. But wind players have always remained curious about what happens behind the walls (of the cheeks) and all kinds of visualization techniques have been engaged since they have been available.

Hall [2] and Meidt [3] have been pioneers in the investigation of wind instrument performance through the use of radiographic methods; they demonstrated that specific vowel formations do not correspond to particular pitches or registers, as stated in different method books since Altenburg 1795 [4]. According to Hall, the most common oral shape utilized during trumpet performance approximated the position of the tongue and jaw when saying the vowel /b/ as in 'pod', but players tend to assume individualistic positions of the tongue and jaw. Modern teaching methods include audio-visual material that can be found on YouTube, or from specific DVD as e.g. the "Brass Master-Class" by Burba [5].

Recent MRI and endoscope studies from Spahn et al [6] demonstrate internal activations very clearly, but all visualization techniques by means of optical methods are restricted to a maximum samples numbers of 4-24 images per second. And they are also restricted to a lower spatial resolution that can be used for quantification as e.g. the

impressive MRI analysis of trumpet performance by Schumacher et al [7].

The method of electromagnetic articulography used for this study records 250 values per second and allows a spatial resolution of 0.5mm. For the first time, exact paths of several tongue positions can be visualized and quantified.

1.1 Method

As a pilot study in this area, the first author of this paper performed as test subject and recordings of his trumpet playing were made at the phonetics lab at the Ludwig-Maximilians-University Munich. Four sensors have been placed on the tongue with cyanoveneer (Hager und Werken): One at the TIP of the tongue and three sensors on the dorsum portion behind the tip, named MID-L, MID-R and BACK.

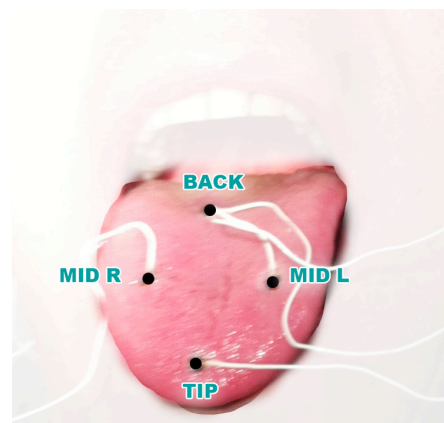


Figure 1: Positions of the 4 tongue sensors

Movement data were acquired by means of electromagnetic articulography (AG501, Carstens Medizintechnik). The AG501 consists of 9 transmitter coils, located around the head of the subject, that generate an alternating electromagnetic field at 9 different frequencies in the region of 10kHz. After demodulation and down sampling to 250Hz a nonlinear optimization procedure uses a model of the magnetic field to solve for the three Cartesian coordinates (x, y, z) and two angular coordinates (azimuth and elevation) of each sensor that give

the best prediction of the nine raw transmitter signals induced in the sensor. Increased values of the lateral x coordinate represent motions from right to left, the anterior-posterior y coordinate motions from front to back and the vertical z coordinate motions from low to high.

After position calculation, the sensors attached to the tongue were low-pass filtered using a Kaiser design at a cut-off frequency of 60 Hz. Additional 4 sensors used to factor out head movement from the tongue movements (upper incisors, bridge of nose, head left and right) were smoothed with a cut-off frequency of 5 Hz. For a general discussion of issues in the processing of data from electromagnetic articulography see Hoole & Zierdt [10] (though note that the AG501 used for the present experiment provides much more reliable data than the preceding model AG500 mainly discussed in [10], essentially thanks to an increase in the number of transmitters from six to nine).

Quantification and visualization have been made with the GNU-R software (3.0.2) from the R Foundation for Statistical Computing. A script imported all five sensor-values (sampling frequency 250 Hz), calculated statistical values and created a lateral and a coronal graph for each sample. In the plots, the actual sensor value is marked as black dots. The values for the upcoming 25 values (100 ms) are plotted as smaller red dots, the next 25 values as orange dots, and the values 50-250 samples afterwards are represented as grey dots. That is, each plot shows the path of all sensors for one second.

Several playing tasks with durations of 10 seconds have been recorded and short sequences have been analyzed in detail:

- 'SINGLE TONGUING' of the Note F4 (350 Hz) played with increased tempo". For analysis we chose one articulation of a 1/8th quaver (IOI 500 ms), a 1/16th semiquaver (IOI 250 ms), a 1/16th semiquaver triplet (IOI 166 ms) and a 1/32th demi semiquaver (IOI 125 ms).
- 'DOUBLE TONGUING' of the Note F4 (350 Hz) played with and without accented notes as 1/32th hemi semiquaver (IOI 77 ms).
- 'TRIPLE TONGUING' played as scale from Bb3 (233 Hz) to F5 (700 Hz) as semiquaver (1/16th) triplets (IOI 110 ms). The triplets of the notes "F4", "Bb4" "F5" have been chosen for analysis.
- 'Legato SLURS in different registers': "slur F4-D4" in the middle register, "slur Bb3-F3" in the lower register and "slur F45-Bb5" in the upper register.

1.2 Results

The results of the motion analysis can be best seen on the animated graphs. A movie of the performed tasks together with sound in slow motion can be found on YouTube [9]. The graphs on fig. 2 show the trajectory for four short sequences. The three-dimensional motion patterns are rather rounded movements involving the whole tongue for all articulations. The back of the tongue rises for faster notes and is (as is well-known) crucially involved in 'DOUBLE TONGUING' and 'TRIPLE TONGUING'.

Nevertheless, the trajectory has been visualized for the first time.

Table 1 lists the approximate distance of the movements from TIP and BACK, and the duration for the movement of the TIP at the start of the attack. It can be seen that the action for 'SINGLE TONGUING' is shorter and quicker for faster notes. The trajectories for slurs depend on the register and the interpretation. Further replication tests, and experiments with more players could demonstrate the variabilities in playing techniques. It is suggested to add also sensors on the jaw and the instrument, to have further information.

In summary, this pilot study demonstrates the usefulness of electromagnetic articulography for the documentation of playing techniques on wind instruments and for singing.

Benchmarks of Tonguing Tempi [B]

2 Introduction

Instruction books from Altenburg [4] to Arban [10] hardly explain techniques of tonguing, let alone mention tempi, except the fact to always start practicing slowly in order to achieve a better regularity.

Budde [11] documented in 2011 a collection of literature and method books on wind instrument articulation. He found very little common facts for brass instrument tonguing beside general principles: "The tongue should create a seal when articulating on brass instruments; as such, the exact amount of tongue contact changes as the jaw is lowered or raised to accommodate the various pitch ranges within a specific instrument". While some professionals say that they have a slow 'SINGLE TONGUING' technique but good control in the use of 'DOUBLE TONGUING', others explain that they are not good in 'DOUBLE TONGUING', but they have a very fast 'SINGLE TONGUING' technique. This variability is relevant in performance within a brass section, where similar attacks and articulations are required. This depends on how fast the player is able to produce each playing technique. This quantitative study aims to find the critical tempi, where individual preferences and abilities influence the interpretation of the brass section. The evaluation of benchmark tempi by brass players of various expertise levels is the objective of this paper.

2.1 Methods

The presented results are based on 206 participants. Recordings were made with professionals from successful brass quintets, amateur and professional participants of a brass players' summer camp in 2012 in Samedan (CH), in Linz (A), in Ghent (BE), Beijing (China) and at the University of Music in Vienna (A). Mean age is 27 year (SD 13,6) and the average years of playing experience is 14,8 years (SD 11,6). The grouping of the brass players is: Female (N=24), Male (N=178), Amateurs (N=102), Professionals (N=25), Students (N=79), Trombone (N=44), Horn (N=24), Other (N=14), Trumpet (N=106), Tuba (N=18).

Figures ad part A: Visualization of Tongue Motions

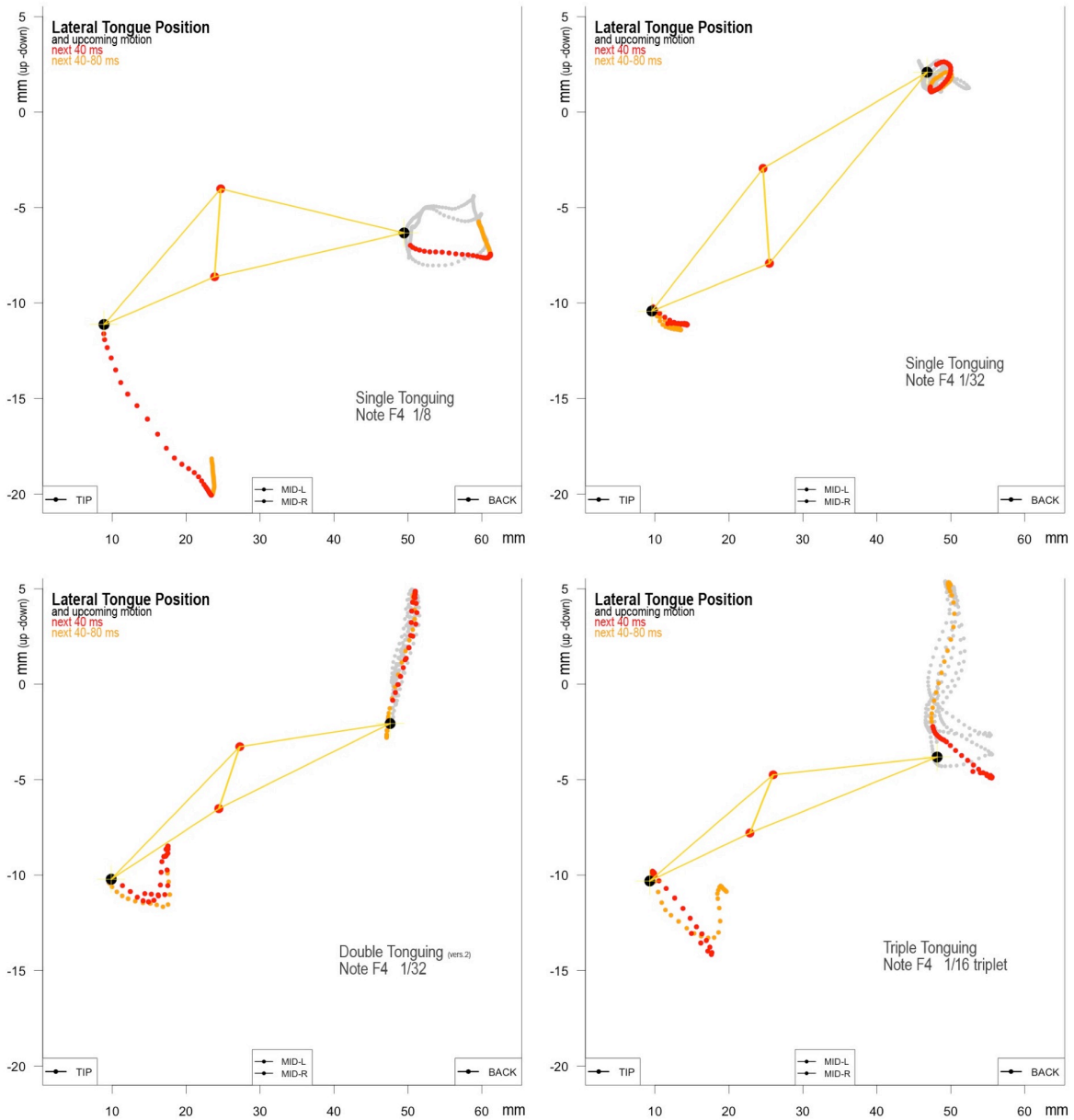


Figure 2: Lateral trajectories of all sensors performing 4 short sequences: Slow and fast 'SINGLE TONGUING', 'DOUBLE TONGUING'- and 'TRIPLE TONGUING'

	F4 1/8 SINGLE Tonguing	F4 1/16 SINGLE Tonguing	F4 1/24 SINGLE Tonguing	F4 1/32 SINGLE Tonguing	F4 1/32 DOUBLE Tonguing	Bb4 1/24 TRIPLE Tonguing	F5 1/24 TRIPLE Tonguing	Bb3 -F3 legato slur	F4 -D4 legato slur	F5 -Bb5 legato slur
Approximate Distance (in mm)	17,63	11,80	7,58	4,86	7,72	12,26	12,95	7,08	21,82	2,73
TIP Distance (mm)	17,63	11,80	7,58	4,86	7,72	12,26	12,95	7,08	21,82	2,73
BACK Distance (mm)	16,60	9,61	5,24	5,69	8,02	12,49	12,25	4,45	14,50	4,38
Duration Tip down (ms)	128	96	64	56	60	40	44			

Table 1: Distance of the movements from TIP and BACK sensors in mm, and the duration for the movement of the TIP at the start of the attack in ms.

Figures ad part B: Benchmarks of Tonguing Tempi

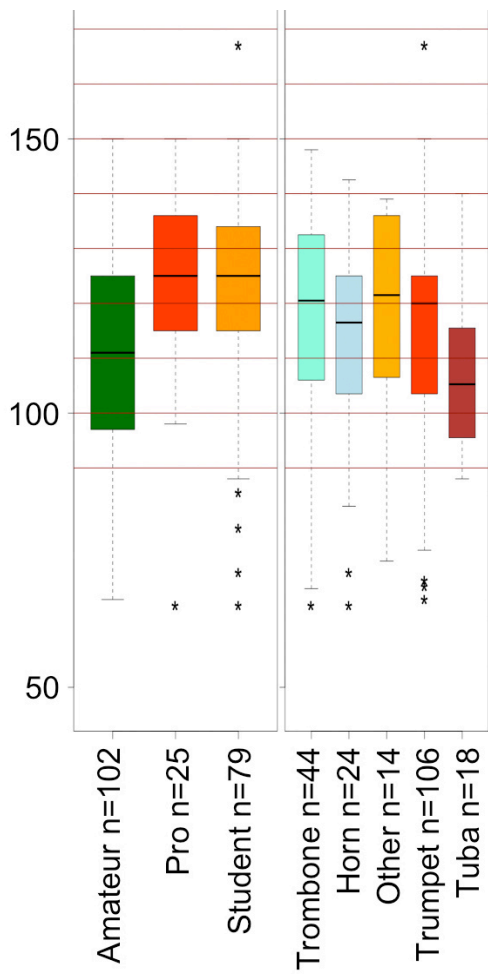


Figure 3: Maximal Tempo for 2 seconds 'SINGLE TONGUING'

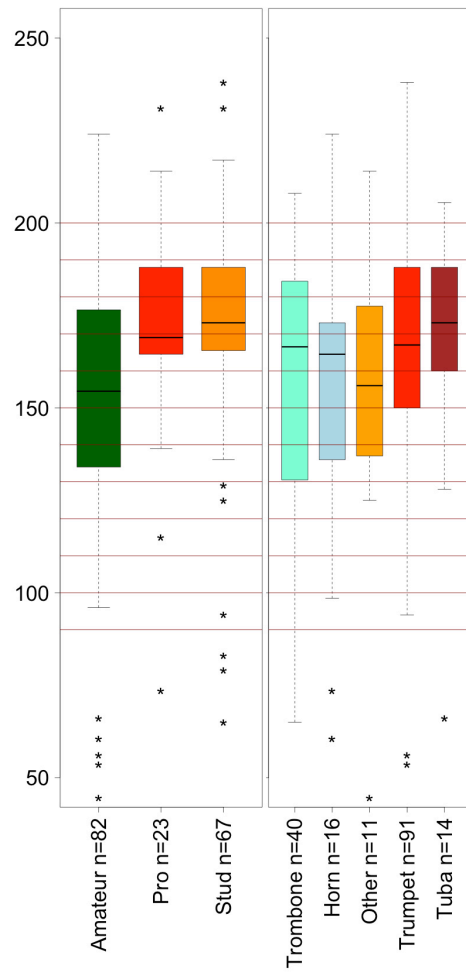


Figure 4: Maximal Tempo for 2 seconds 'DOUBLE TONGUING'

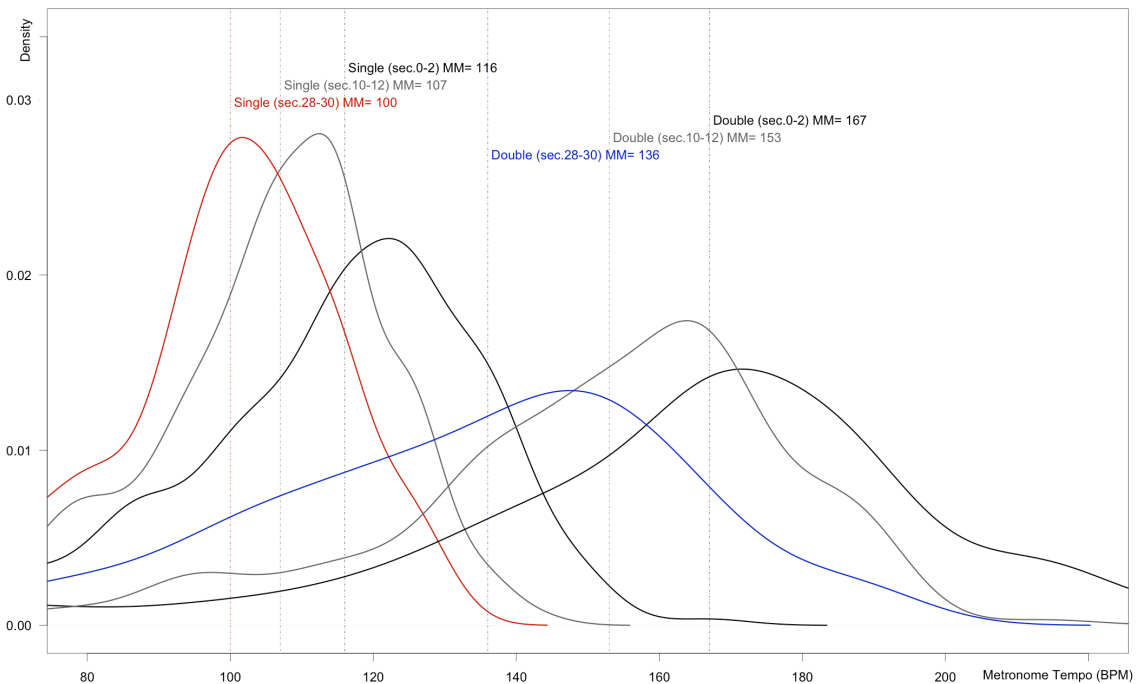


Figure 5: Density for tempi for 'SINGLE TONGUING' and 'DOUBLE TONGUING' played at the beginning (seconds 0-2), after some playing (seconds 10-12) and at he the end of the task (seconds 28-30)

Each musician has been recorded for 30 seconds, playing his or her maximum tempo with 'SINGLE TONGUING' and 172 players also performed 'DOUBLE TONGUING'. It was recorded by any kind of equipment (e.g. a laptop computer or smartphone video). With the exception of the fastest players, all participants have been assured to remain anonymous. They could choose their preferred natural open note in the middle register. The sound quality and the playing style have not been taken into account. They could perform soft or hard attacks; therefore only the onset numbers have been measured, when the tongue opens the lip-valve.

The recordings have been analyzed semi-automatically with the "Audio Beat Tracking System BeatRoot 0.5.8" of Simon Dixon. The accuracy of discrimination for IOI intervals is about 5-10 milliseconds. Data are analyzed and visualized by self-made Gnu-R statistic scripts. As intuitive tempo description, the timing is displayed in typical players' specifications units, that is to say in quarter metronome numbers (BPM) playing semiquaver (1/16th) notes. Additionally, the numbers of notes played in 30 seconds; the median values and standard variations for fifteen two-second sections have been calculated.

2.2 Results

The evidence shows a large difference between amateur players and "students or professional players" and within these groups. Figures 3 and 4 shows a boxplot representation of the maximal tempi played with 'SINGLE TONGUING' and 'DOUBLE TONGUING' within the first two seconds for different groups.

'SINGLE TONGUING': The averaged maximal tempo played for the first two seconds were for Amateurs 109,2 BPM, for Professionals 123,8 BPM and for Students 120,1 BPM. (Fig 4.) A professional trombone player (Gerhard Füssl of Mnozil Brass) played 262 notes. Fastest Players at the start – that is the first two seconds of the task - were a 19 year old trumpet student (Paolo) with tempo MM=167, followed with tempo 150 by a professional trumpet player tempo (Ludwig Wilhelm of Bozen Brass) and a clarinet player, who could only play a few notes on the trumpet, but indeed very fast.

'DOUBLE TONGUING': The averaged maximal tempo played for the first two seconds were for Amateurs 149,3 BPM, for Professionals 172,1 BPM and for Students 170,7 BPM. (Fig 4.) Most notes in 30 seconds (386 notes) have been played by a professional trumpet player (Ludwig Wilhelm). Fastest Players at the start were a trumpet student (Thomas Liesinger) with tempo MM=238, followed by a professional trumpet player (Herbert Zimmermann, Munich Philharmonic) with tempo MM=231.

Noticeable is the fact that most more experienced players tend to start with tempi that they think they can maintain for longer periods, and do not start with absolute maximum tempi. Many advanced players distinguish themselves by more regularity.

Astonishing is also the fact that individual professionals can reach the same speed on trumpets or tubas, playing 11-13 notes per second (max 240 BPM).

The individual ability for maximum tempo of either articulation is individual and the critical tempo for

'SINGLE TONGUING' is about MM=120, representing the median of all participants. Half of all participants, mainly amateur players, were not able to play 'SINGLE TONGUING' faster than 120 BPM. So they had to play faster tempi with 'DOUBLE TONGUING'. Other musicians could choose the type of articulation up to 140 BPM and beyond.

Figure 5 shows the mean values of the tempo at the beginning (seconds 0-2), after some playing (seconds 10-12) and at the end of the task (seconds 28-30) as density plot over the metronome tempo. The peak values for 'DOUBLE TONGUING' slows down from 167 BPM to 136 BPM, and for 'SINGLE TONGUING' from 116 BPM to 100 BPM but graph also indicates the huge variability within both playing techniques.

References

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