

Adaptation to a new tuning standard in a musician with tone-color synesthesia and absolute pitch

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Abstract

Developmental synesthesia is a neurological condition in which certain perceptions or cognitions trigger atypical supplementary perceptions (e.g. tones evoke specific colors). Tone-color synesthesia is prevalent in musicians and is associated with enhanced music processing and increased connectivity in auditory cortex. We report the case of NTM, a professional violinist with tone-color synesthesia as well as absolute pitch. When she switched from modern (A440 tuning standard) to baroque (A415 tuning standard) interpretation, NTM experienced a serious incongruence in her synesthesia and absolute pitch which severely interfered with her musical performance. However, through explicit self-training over months using color cues from her synesthesias, she learned new pitch associations for her note concepts which cancelled this interference. This ability was validated through a second evaluation four years after the initial evaluation. NTM can now switch between both standards with little interference. She also reported changes in her non-musical synesthesia and developed new synesthesia to a tonal language (mandarin). This case indicates that synesthetic associations can be used as anchors to learn a new tuning standard when interference is high. It also suggests that tone concepts can undergo important perceptual modifications and still maintain their stability as inducers of synesthesia.

Key words: synesthesia, perfect pitch,

Word count : 4965 words

Introduction

Developmental synesthesia is a neurological condition in which certain perceptions or cognitions (inducers) trigger atypical supplementary perceptions (concurrents) (e.g. letters trigger colors, names evoke tastes) (Caspar & Kolinsky, 2013). Developmental synesthetic associations generally appear in early childhood and show key characteristics: the inducer-concurrent associations are consistent (an inducer always triggers the same concurrent), concurrents are automatically triggered and the associations remain generally stable throughout life (Ward, 2013). In some cases, the specific associations can be linked to specific childhood learning experiences such as toys with colored letters (Withoft & Winawer, 2013) or person-taste associations (Richer, Beaufile & Poirier, 2011). The neural basis of synesthesia is still unclear but an increased functional or structural connectivity between distinct brain regions is often postulated (Grossenbacher & Lovelace, 2001).

In tone-color synesthesia, some musical notes, melodies or musical movements automatically trigger the perception of specific colors. Tone-color synesthesia is frequent in musicians and has contributed to high musical talent, as in the cases of Messiaen, Scriabin, Debussy and Liszt. Tone-color synesthesia is associated with enhanced musical processing and an increased connectivity in auditory cortex (Loui, Zamm & Schlaug, 2012). It can also be associated with absolute pitch, the ability to identify pitch class with no external pitch reference (Cytowic & Eagleman, 2009; Gregersen et al., 2013).

Here, we report the case of a professional violinist with tone-color synesthesia and absolute pitch who experienced a serious incongruence in her synesthesia as she switched from modern (A440 tuning standard) to baroque (A415 tuning standard) music. Synesthesia and absolute pitch have been known to strongly interfere with adaptation to a new tuning standard (Sacks, 2007; Folan, 2013). To

compensate for the interference, she adjusted her tone concepts to the pitches of the new tuning standard through intensive training, and in doing so, developed a new perceptual system, which is now as automatic as the normal standard developed in her childhood.

Materials and Methods

Case description

In order to evaluate NTM's synesthetic experience, we used a mixed-methods approach including standardized tests and a semi-structured interview. NTM is a 28 year-old woman with no history of neurological or psychiatric conditions. She is a professional violinist who has played the violin since she is four years old. From four to eight years old, she was trained with the Suzuki method and learned to play by ear, without reading any scores. At eight, while starting to play in orchestra, she then slowly learned to read scores by matching the sound to the written notes on the paper. She claims that she is still not excellent in sight reading and needs to know how a musical piece sounds in order to play it on a professional level. NTM never stopped playing violin and studied music in university. She obtained a Masters Degree in baroque music. Beside music, NTM also excels in visual arts (painting, drawing). Her parents are not musicians, even if they leisurely play music. NTM has an older half-sister (same father) who is a professional musician and singer, but the two sisters did not grow up together because of their age gap.

Like her half-sister, NTM shows absolute pitch. She claims that she has had absolute pitch since her childhood and thought for a long time that everybody did. NTM thinks that learning to play by ear at a young age may have allowed her to develop absolute pitch. As a child, she was able to identify the tonality of a song and to play it after having only listened to it. She was able to identify and remember the starting note of many songs. She remembers excelling in musical dictation during her

college years. She has difficulty identifying when and how she discovered that she had absolute pitch, but believes her parents probably told her about it when she was a young teenager.

NTM reports experiencing synesthesia for musical tones and musical excerpts (e.g. first movement of a piece of music). The sight of the note on the score and the pitch alone (frequency in Hertz) can both elicit the tone concept (e.g. C₅) that induces her synesthetic colors and underlies her musical processing.

NTM also experiences several other types of synesthetic associations including colors triggered by numbers, letters, weekdays and months. She began noticing all these types of synesthesia at the beginning of her teenage years.

In 2014, at age 22, NTM switched from modern (A440 tuning standard) to baroque (A415 tuning standard) music learning during her studies and experienced a serious incongruence in her musical processing because of the semitone difference. Absolute pitch often interferes with adaptation to a new tuning standard but for NTM, her synesthetic color associations made the interference so intense that it prevented her from playing for a semester. Using intensive self-training, NTM succeeded in adjusting her tone concepts in order to play baroque music. During this transition period, in 2016, NTM completed her first online synesthesia battery (www.synesthete.org) (Eagleman, Kagan, Nelson, Sagaram & Sarma, 2007). A semi-structured interview was also conducted with her, in 2019, in order to gather more details about her synesthetic experiences and how they interacted with her musical performance. Finally, in 2020, NTM underwent a second evaluation which included a home-made tone-color synesthetic test and a second synesthesia battery.

Materials

The synesthesia battery (www.synesthete.org; Eagleman et al., 2007) is an online standardized battery designed to validate developmental synesthesia using the test-retest principle. NTM filled up the tests corresponding to her different types of synesthesia, namely the Grapheme Color Picker Test, the Weekday Color Picker Test, the Month Color Picker Test and the Piano Scale Color Picker Test. This last one was used to evaluate her musical tone-color synesthesia. In this test, each tone (ex: C₅) is randomly presented three times (the pitch *and* the note are simultaneously presented in the A440 tuning standard). Each time, the participant must select the color triggered by the musical tone. Two sliders allow the participant to adjust the hue and the saturation level in order to find the exact color associated with each tone. In synesthetes, the variance between the three colors selected for a given tone will be very low. In non-synesthetes, this variance will be high. Thus, the synesthesia battery is designed to discriminate between real synesthetes who experience the color as a perception from non-synesthetes who can only rely on their memory during the test-retest procedure. In the synesthesia battery, scores under 1.0 are ranked as synesthetic.

Results

First synesthesia evaluation

NTM completed her first synesthesia battery in 2016. She scored as synesthetic for colors associated with numbers, letters, weekdays and months. She also obtained a score of 0.376 on the Piano Scale Color Picker Test, confirming the authenticity of her tone-color synesthesia. She reported that she experienced interference while completing this test, attributing this interference to her experience of two years learning baroque music. Despite this interference however, she is confident that, her results on the first battery are representative of her tone-color synesthesia in the A440 tuning standard. She

added that, although the A came up ochre in this first battery, she also perceives it as red; both colors suiting the A₄ tone in her synesthetic associations. She was unable to explain why this particular tone could be associated with two different colors, but specified that the A₄ is a crucial tone on the violin, since it serves as a reference for tuning the entire instrument.

The musical tone-color associations reported in NTM's first synesthesia battery were also documented in a poem she wrote in 2008 (she was 16 years old) in which she described her tone-color synesthesia using color words associated with seven tones. We asked her to indicate the corresponding color beside each verse. The colors she drew for C₅, E₄, F₄, A₄ and B₄ were similar to her responses on the first synesthesia battery. The colors drawn beside the verses of D and G differed significantly from the ones in the battery. Asked about this incongruence, NTM explained that those verses were describing tones in other octaves than the one used in the Piano Scale Color Picker Test of the synesthesia battery. The Piano Scale Color Picker Test displays seven tones of the 4th octave (from C₄ to B₄) and one tone of the 5th octave (High C or C₅). Thus, even if she had learned baroque for two years at the time of her first battery, those results are representative of her tone-color associations in A440.

We also observed that some letters of the Grapheme Color Picker Test and their associated tones on the Piano Scale Color Picker Test showed the same color. For example, in the Grapheme Color Picker Test, the A is ochre and the F is purple. Those colors correspond to the color picked, on the Piano Scale Color Picker Test, for the A and the F tones. The color of the letter C, for its part, corresponds to the color of the high C tone. However, the colors of the letters B, D, E, G did not correspond to the colors of their associated tone.

Semi-structured interview

NTM reported that, in her tone-color synesthesia, many different elements interact: the physical sound heard (pitch), the color, but also the visual representation on the score and the finger position on the violin neck. As she was switching from modern (A440) to baroque (A415) music, the sounds heard were therefore not matching with the visual representations on the score, the elicited colors and the finger positions (since A415 is a semitone lower than A440), creating tone-color incongruences. For example, in A440, when NTM sees a C₅ on the score, she takes the second finger position, plays, hears a C₅ and automatically associates it with the color blue. In that situation, visual, motor, and auditory perceptions and the synesthetic concurrent are all congruent. When NTM tunes her violin in A415, she still sees a C₅ on the score and takes the second finger position, but when she plays, the physical sound she hears is equivalent to a B₄ and the color yellow is triggered (Figure 1). Therefore, when NTM started to learn baroque music and switched from A440 to A415, the visual, motor and auditory elements were discordant, leading to incongruent tone-color associations causing interference so intense that it prevented her from playing baroque music for a whole semester. Using explicit self-training, NTM succeeded in pairing her tone concepts to new pitches in order to play baroque music. Since the notation on the scores and the finger position on the violin neck are unalterable, NTM used colored cues that she added on her scores to help her attenuate the interference (Figure 2). She drew color cues in the color normally triggered in the A440 standard on top of each of the notes on the scores. In doing so, she slowly forced her tone-color synesthetic associations to be linked to new pitches. For example, while tuned in A415, the C₅ sounds like a B₄ and triggers yellow. However, because of the blue drawn over the C₅ on the score, NTM started to associate the physical pitch heard (a B₄) to her already existing synesthetic associations pairing the tone C₅ with the color blue. With time and practice, the synesthetic C₅-blue association became paired with a new pitch. She

thus developed two different perceptual systems in which the tone-color (e.g. C₅-blue) associations are paired with different pitches.

[Figure 1 near here]

[Figure 2 near here]

NTM reported that at the beginning of her retraining effort, as she was playing in A415, the tone-color associations were covered in a black veil and that veil disappeared after months of training. She also reported that she can now easily switch, mentally, from one perceptual system (tone-color-pitch in A440) to the other (tone-color-pitch in A415), suggesting that the tone-color associations are well implemented in both systems. She described the two systems as visually distributed on each side of her mental blackboard, like the two different banks of a river, and that she could simply turn her mind's eye right or left to access the tone-color associations of each system. She reported that, in general, the colors elicited in the A415 system appear a little darker than the ones elicited in the A440 system. She explained that, for a given system, both the sight of the note alone and the auditory perception of a pitch alone will elicit the same color. For example, in A440 the vision of the C₅ on the score, without the physical sound associated to it, will elicit the color blue. Also, hearing the pitch corresponding to the C₅ in A440 (523,25Hz), without the visual note, will elicit the same color.

It is important to understand that the tone-color associations are activated only when NTM thinks about them or learns a new musical piece and not when she plays a mastered piece at full speed. More precisely, each note played, during a performance, does not trigger its own color. Rather, the whole musical excerpt tends to acquire a specific color. NTM is unable to identify why a particular excerpt is associated with a specific color, but she thinks that it could be linked to predominant notes or the “character” of the excerpt.

A few months after our interview, NTM reported, that she could easily learn new musical pieces and play in professional orchestras both in A415 and A440. This ability suggests an automaticity of the tone-color associations in both perceptual systems. Thus, the same tone-color association (e.g. C₅-blue) is automatically linked to two different pitches, depending of the tuning used (A440 or A415). She claimed that she sometimes still experiences some light interference between the two systems, but only when she does sight reading of a new musical piece that contains many sharp or flat notes, because it confers a different tonality to the whole musical piece which can be confusing.

NTM also claimed that she needed to “adapt” her absolute pitch as part of her baroque training, thus “enlarging” it and making it more “flexible” in order to accept other realities as part of it (the A415 tuning). She claims that her absolute pitch is now less automatic than before; she sometimes requires more concentration to identify a pitch. She also told us that sometimes, when she sings a song in her head, she has difficulty knowing if the song is tuned in A440 or in A415. However, she assured us that she has the capacity to think and play in A440 and in A415 at will, as if the two tuning standards are two different languages in her head. Despite this capacity, she claimed that it is still a little bit easier for her to think and play in A440 but she thinks that it could be explained by the fact that she has only played in A415 for a few years.

Second synesthesia evaluation

Since the on-line synesthesia battery is tuned in A440 and presents the physical sound (pitch) and the note on the score, it was impossible to use it to evaluate NTM’s performance in A415. To verify that NTM automatically links her tone-color associations to new pitches, we asked her to complete a homemade test in 2020, four years after the first battery. We showed her a score displaying the notes associated with the same thirteen tones used in the synesthesia battery (from C₄ to C₅ (High-C)). We

then asked her to tune her violon in A415, to play each note and to immediately draw the color she experienced on the score. She chose the colors using the color palette of Microsoft Word. Like the palette of the synesthesia battery, the one of Microsoft Word contains a slider allowing NTM to adjust the hue and the saturation level in order to find the exact color associated with each tone. We also asked her to redo the synesthesia battery in order to re-evaluate her other forms of synesthesia (grapheme-color, weekdays-color and month-color).

A comparison of the 2016 Piano Scale Color Picker Test and of the 2020 homemade synesthesia test confirmed that, although the tone-color associations remained similar, they are not linked to the same pitches. Thus, NTM adapted her tone concepts to the pitches of baroque tuning, acquiring the capacity to switch between the two perceptual systems at will (Figure 3). This suggests that, through her self-training, the tone concepts inducing her synesthetic colors had become flexibly attached to new pitches.

As mentioned before by NTM, the colors experienced in the A415 tuning appeared a little bit darker than the one experienced in the A440. It may seem intriguing to see that in A415, the A₄ elicits two different colors. However, NTM specified in the interview, that the A₄ in A440 could be associated with ochre or red.

[Figure 3 near here]

Effects of training on other synesthesia

NTM reported that her tone-color synesthetic training also altered her other forms of synesthesia. She claimed that color concurrents triggered by certain numbers, letters and months were less vivid since her intensive A415 training. She also reported that, when she now learns a new music repertoire,

musical excerpts are seldom associated with colors. However, color associations from pre-training musical excerpts are still present and did not vanish with her A415 training.

In the second synesthesia battery, NTM again scored as a synesthete on the Grapheme Color Picker Test, the Weekday Color Picker Test and the Month Color Picker Test (Table 1). However, when comparing her two batteries, we noticed changes on some inducer-concurrent associations. On the Grapheme Color Picker Test, some previously black letters and numbers gained color. Some previously colored letters, in contrast, lost their color and became black. Other letters simply changed color (Figure 4). The same phenomenon can be seen on the Month Color Picker Test. However, no alterations were reported on the Weekdays Color Picker Test. NTM was unable to explain why some particular graphemes and words changed colors between 2016 and 2020. We did not identify any clear pattern in the changes in these synesthetic associations either.

[Table 1 near here]

[Figure 4 near here]

Learning Mandarin

NTM claimed that learning to play baroque music was similar to learning a new language. It is interesting to note that during her training in baroque music, NTM also acquired a new language. She took Mandarin classes for three years at the university at a rate of five hours a week and reported finding it extremely easy to learn this language. Mandarin is a tonal language: a language in which pitch is essential to convey meaning. NTM believes that her absolute pitch helped her learn Mandarin easily and rapidly. From 2013 to 2015, she competed in a Chinese language contest for university students. For this contest, the participants must write a speech in Mandarin and present it orally in front of a jury. She won the contest at the first proficiency level after learning Mandarin for only a

few months and then went on to win first prize in two higher proficiency levels the two following years.

NTM claims that she now has Mandarin grapheme-color synesthesia. However, she specified that the colors are not triggered by the visual characteristics of Mandarin graphemes but rather by the dominant sound of this grapheme and corresponds to the color triggered by the letter in the latin alphabet corresponding to this sound in French (her native language). For example, NTM perceives the Mandarin grapheme for “woman” in a purple-blue color. This grapheme is pronounced “nü” and its dominant sound is the “u”. When looking at NTM’s first synesthesia battery, we can observe that the color triggered by the letter “u” is also purple-blue. NTM claims that a Mandarin grapheme only triggers color if she knows how it sounds.

Discussion

NTM represents a special case in many regards. Her absolute pitch and her synesthesia had helped her musical performance since childhood but both conditions led to a very difficult transition from standard to baroque tuning, in which pitches associated with different tone concepts are about a semitone lower. Since NTM has absolute pitch, her tone inducers (e.g.: C₅) were defined by two elements: the visual note on the score and the physical sound (pitch) associated with it. Before her baroque training, both elements were congruent, referring to the same tone concept. However, as she started to play baroque music, the pitches heard were incongruent with the visual representations of the notes on the scores leading to heavy interference in her tone-color synesthesia.

The intensive self-training that NTM underwent allowed her to pair novel pitches with her long-lasting tone-color associations, thus creating new congruencies and eliminating the strong interference she felt at first when trying to play in the baroque standard. The present case shows that

tone-color synesthetic associations acquired during childhood, although stable, can be flexibly attached to new pitches using explicit self-training strategies. Because of her training, her tone concepts underwent significant changes, their links to specific pitches becoming tuning-dependent. Tone concepts such as C₅ still evoke similar colors as the ones acquired in childhood, but pitches such as 415 Hz must now be understood as a tone concept in the context of a specific tuning standard to evoke a specific color. Thus, although the inducers remain stable, they are now linked to two different set of auditory stimuli, depending on the tuning used. The fact that NTM can now play professionally in both modern (A440) and baroque (A415) indicates that she developed two perceptual systems in which tone-color associations are linked to different pitches, and that those tone-color-pitch associations are automatic in both systems. They also remain stable over time and facilitate her musical performance.

There is evidence that in some synesthetes, the number of effective inducers can increase with experience or explicit learning even in adulthood (Mroczko et al., 2009; Richer et al., 2011). In word-taste synesthesia, words that are similar to effective inducers can become new effective inducers during adulthood (Richer et al., 2011). Also, Mroczko et al. (2009) showed that new synesthetic inducers can be acquired through training in adult synesthetes.

The experimental training of synesthesia-like associations has also been documented in non-synesthetes, mostly using grapheme-color associations (see Rothen & Meier, 2014 for a review). However, training effects have mainly been measured through indirect performance measures such as priming or interference rather than synesthesia batteries using test-retest procedures and after training, most participants do not generally report conscious synesthetic phenomena during perception as genuine synesthetes do. Color consistency measured by a synesthesia battery and synesthetic perceptual phenomena can develop in non-synesthetes following a really intensive

grapheme-color training session (30 min/day, 5 days/week during 9 weeks) including various tasks and homework to do outside the training sessions (Bor, Rothen, Schwartzman, Clayton & Seth, 2014). However, color consistency and perceptual synesthetic phenomena have been recorded immediately post training and no information concerning those two aspects is available in a later follow-up. Thus, it is impossible to know if the trained grapheme-color associations would be stable over years, as genuine synesthetic associations are.

NTM also reported that her A415 tone-color training modified her absolute pitch. Absolute pitch and tone-color synesthesia show phenotypic and genotypic overlap (Gregersen et al., 2013). The two conditions are associated with enhanced musical processing, early childhood acquisition and an increased connectivity in auditory cortex (Loui, Zamm & Schlaug, 2012). Also, both conditions can interfere with adaptation to a new tuning standard (Sacks, 2007). There is evidence that the generally stable perceptions of absolute pitch can be modified through musical experience detuned by a fraction of a semitone (Hedger, Heald & Nusbaum, 2013). Also, Gervain et al. (2013) showed that adults who took valproate learned to identify pitch significantly better than controls taking placebo, suggesting that pitch learning can be facilitated in the adult brain.

NTM rapidly mastered a tonal language as an adult, which also requires tonal plasticity. Absolute pitch is more prevalent in tonal language speakers (Deutsch, Dooley, Henthorn & Head, 2009), which suggests that it shows phenotypic overlap with tonal language proficiency as well as tone-color synesthesia. Altogether, changes in absolute pitch, adaptation to a new tuning standard, and rapid mastery of a tonal language suggest a high degree of plasticity in NTM's auditory system. This plasticity may have contributed to her adaptation to a new tuning standard despite her challenges. The links between exceptional auditory plasticity and musical performance deserve to be examined more systematically.

Conclusion

Both absolute pitch and tone-color synesthesia are early neurological gifts that can transform into curses when trying to learn a new tuning standard. This case indicates that synesthetic associations can be used as anchors to learn a new musical tuning standard when interference is high. It also suggests that tone concepts can undergo important perceptual modifications and still maintain their stability as inducers of synesthesia. Finally, this case shows that inducers can be used, at will, in two different perceptual systems and that synesthetic associations can be automatic and stable in both systems.

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Figures and tables

Figure 1

A440 tuning

Note on the score



do

Finger position

2

Tone heard

C₅

Associated color

Blue

A415 tuning

Note on the score



do

Finger position

2

Tone heard

B₄

Associated color

Yellow

Figure 2

VII Suonate à doi, op. 1 – Sonata IV – Violino



Figure 3

2016 (A440)

C	C	C	🔊
C-sharp	C-sharp	C-sharp	🔊
D	D	D	🔊
D-sharp	D-sharp	D-sharp	🔊
E	E	E	🔊
F	F	F	🔊
F-sharp	F-sharp	F-sharp	🔊
G	G	G	🔊
G-sharp	G-sharp	G-sharp	🔊
A	A	A	🔊
A-sharp	A-sharp	A-sharp	🔊
B	B	B	🔊
High C	High C	High C	🔊

Score: 0.376

2020 (A415)

C
C-Sharp
D
D-Sharp
E
F
F-Sharp
G
G-Sharp
A or A
A-Sharp
B
High C

Figure 4

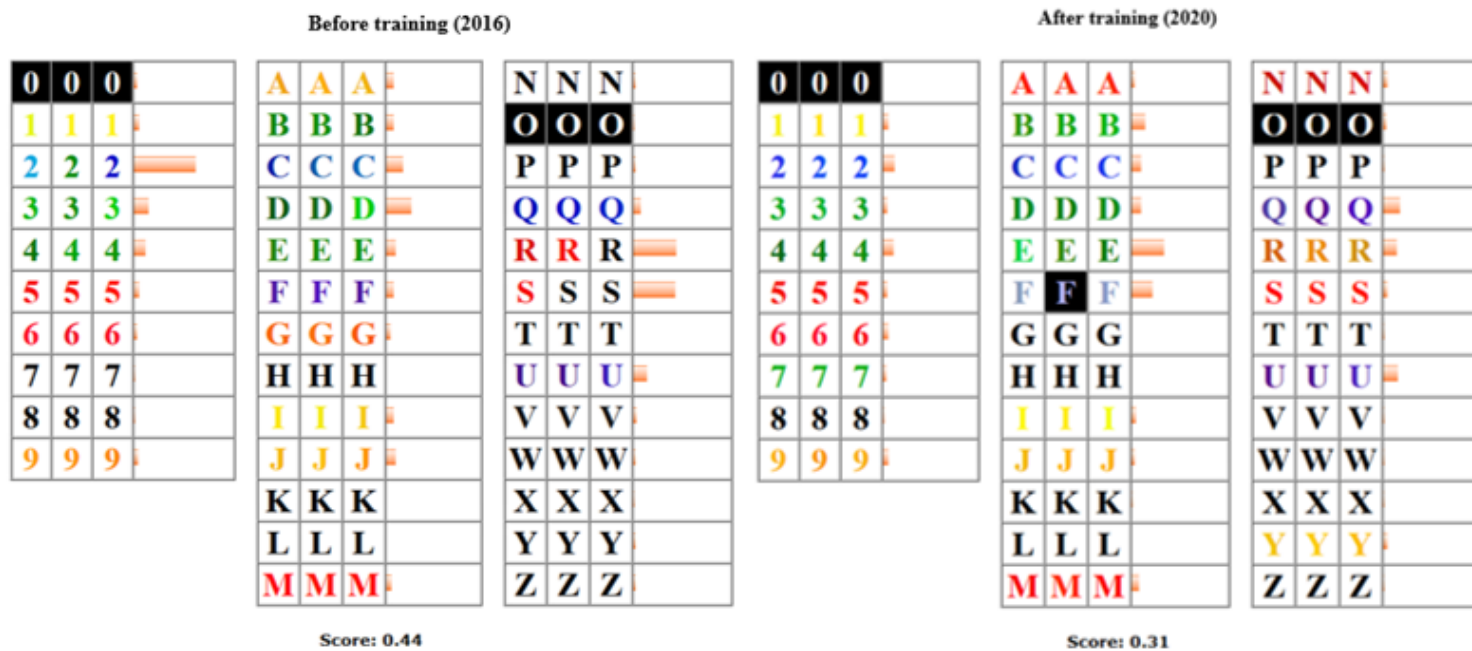


Table 1: Consistency scores for NTM's main types of synesthesia on two evaluations of the synesthesia battery before and after intensive training in the baroque A415 tuning standard. Consistency scores below 1.0 are considered synesthetic.

Type of synesthesia	Before training (2016)	After training (2020)
Tone-color	0.376	-
Grapheme-color	0.44	0.31
Weekday-color	0.21	0.14
Month-color	0.29	0.28

Figures captions (list)

Figure 1: An example of NTM's congruent (A440) and incongruent (A415) synesthetic associations when she started to learn baroque music

Figure 2: An example of NTM's color cues used to help her pair her synesthetic associations to new pitches in order to play baroque music

Figure 3: NTM's tone-color associations on the synesthesia battery (2016- A440 tuning) and on the home made synesthesia test (2020 – A415 tuning). The fact that the colors chosen for each tone are similar in A440 and in A415 shows that NTM's tone-color associations are linked to different pitches, depending of the perceptual system used.

Figure 4: Grapheme-color consistency test in NTM from her two synesthesia battery evaluations before and after intensive training in the baroque A415 tuning standard. Bars and score indicate color response variation over three trials within an evaluation session. Consistency scores below 1.0 are considered synesthetic (Eagleman et al., 2007).