STREAM SEGREGATION AND FORMANT AREAS

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ABSTRACT

For simultaneous playing of timbres characterized by their formants, the following principles could be observed:

1. blending: timbres with equivalent main formant areas are blending homogeneously.

2. partial masking: timbres with non-matching formant areas are perceived separately.

These two principles are corroborated by the instructions in many orchestration treatises.

The conclusion could be drawn that the position of formant areas would lead to similar results in the case of successive tones such as in stream segregation experiments: If that was the case, then a melody with alternating timbres would either be split in perception into two different melodies (if the formant areas were distinct) or would be heard as one sole melody (if the formant areas were equivalent).

In order to test this hypothesis, melodies were played, switching from one tone to the next between the timbres of two instruments. Additionally alternation of timbres was also employed using timbres whose formant areas had been purposely displaced using formantshifting software.

In an auditory experiment, 30 subjects were asked to judge whether the sound examples consisted in one sole, continuous melody or if they were hearing two separate melodies perceived as two latent, distinct parts.

In almost all cases featuring equivalent formant areas most of the subjects perceived one sole melody. Differing formant areas predominantly led to the perception of two different streams. Comparable results can be found in the literature on stream segregation.

1. Alternating timbres with equivalent main formant areas tend to produce one sole, continuous melody in perception.

2. Alternating timbres with non-matching formant areas tend to produce two distinct melodies in perception.

1. BACKGROUND

For a long time the prevailing opinion was that the timbres of musical instruments simultaneously playing in unison can be particularly well differentiated if their attacks are set apart by temporal delay and if they have different temporal envelopes (RASCH 1978, 21, 23 and 33). The longer the instruments‘ transient, the longer the possible temporal delay (asynchrony) between their onsets without losing the impression of a synchronous attack (GORDON 1987, 104). However, experiments featuring perfectly synchronous onsets as well as with removed initial and final transients showed that in such cases, as well, the simultaneous timbres can be differentiated similarly as well as those of the original timbres, and that the perception of mixed timbres is decisively influenced by the formant areas of the instruments involved (REUTER 1996, 259-275; similar results in: MARTIN 1999, 42). For simultaneous playing of timbres characterized by their formants, the following principles could be observed:

1. blending of timbre: if timbres with equivalent main formant areas are mixed, then the individual instruments cannot be differentiated from the total sound mixture; the timbre blends homogeneously.

2. partial masking (FRICKE 1986, 145): if timbres with non-matching formant areas are mixed, then the individual instruments can be very well differentiated amidst the total sound mixture; all timbre components can be perceived separately.

These two rules are fully corroborated by instructions for blending and mixing sounds in treatises of orchestration and instrumentation. For instance, WIDOR writes concerning the unison blending of French horn and bassoon (both instruments with main formants located between 300 and 500 Hz): “It [the bassoon] complements the harmony of the French horns in that it adjusts its own timbre so exactly to theirs that it ends up by fully blending in with them.” (WIDOR 1904, 46; similar statements in: MARX ^{2}1851, 145f. and 347; LOBE ^{3}1878, 30-31; KLING 1882a, 33; PROUT ^{2}1888, 47; JADASSOHN 1889, 242, 254, 346, 348; RIMSKY-KORSAKOV 1912, 57, 88, 90; PISTON 1955, 200, 427; KUNITZ 1956, Vol. 3, 78; KUNITZ 1961, 41,50; JACOB 1962, 162, 165; ROGERS 1970, 39 etc. similar results for other instruments in REUTER 2002).

Instruments whose main formant areas lie far apart one another such as the oboe (main formant at ca. 1000-1200 Hz) and the French horn are described as always clearly differentiable in unison and are only recommended for use as contrasting instruments (for ex. MARX ^{2}1851, 179f.; PROUT ^{2}1888, 71; JADASSOHN 1889, 346; KUNITZ 1957, Vol. 6, 463 etc.).

By using appropriate software (for ex. Steinberg‘s VoiceDesigner), the formant areas of the timbres involved in a total mixture can be displaced. Depending on the amount of displacement carried out, this permits one to purposely achieve either a blending of their timbres (by causing their main formant areas to overlap) or a partial masking of their timbres (if their formant areas are made to lie in different portions of the spectrum).

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2. AIMS

The conclusion could be drawn that the position of formant areas would lead to similar results in the case of successive tones such as in stream segregation experiments: If that was the case, then, depending on the formant areas of the instruments involved, a melody with alternating timbres would either be split in perception into two different melodies (if the formant areas were distinct) or would be heard as one sole melody (if the formant areas were equivalent).

3. METHOD

In order to test this hypothesis, the following melody was played, switching from one tone to the next between the timbres of two of the following instruments: oboe, bassoon, trumpet, French horn (for ex. c1= bassoon, g1= oboe, f1= bassoon, c1= oboe etc.) (The timbres used here originate from the recording described in REUTER 1996, 179-180):

Figure 1: melody for testing the hypothesis of formant based streaming

Additionally to the above described timbres, alternation of timbres was also employed using timbres whose formant areas had been purposely displaced using the VoiceDesigner (thus, bassoon with oboe formant (FG(ob)), oboe with bassoon formant (OB(fg)), French horn with trumpet formant (HN(tp)) and trumpet with French horn formant (TP(hn)). In an auditory experiment, 30 subjects were asked to judge whether the sound examples consisted in one sole, continuous melody or if they were hearing two separate melodies perceived as two latent, distinct parts (if two separate melodies were heard, the subjects were additionally asked to indicate which melody was in the foreground).

4. RESULTS

The result was that in almost all cases featuring concurrent formant areas most of the subjects did actually only perceive one sole melody (with the exception of oboe alternating with bassoon = (OB(ob)/FG(ob)).

Overlapping formant areas predominantly led to the perception of **one** sole stream:

	1	2	3		1	2	3
FG(fg)/HN(hn)	24	3	3	OB(ob)/TP(tp)	24	6	0
OB(fg)/FG(fg)	18	5	7	OB(ob)/FG(ob)	15	14	1
TP(hn)/HN(hn)	20	5	5	HN(tp)/TP(tp)	25	1	4

Figure 2: Column 1: Number of subjects who heard one continuous melody
Column 2: Number of subjects who heard two melodies (with the melody in the foreground starting on the first note)
Column 3: Number of subjects who heard two melodies (with the melody in the foreground starting on the second note)

Differing formant areas predominantly led to the perception of **two** different streams:

OB(ob)/FG(fg)	2	25	3	FG(fg)/FG(ob)	4	7	19
TP(tp)/HN(hn)	2	26	2	OB(fg)/OB(ob)	6	7	17
TP(tp)/FG(fg)	3	25	2	HN(tp)/HN(hn)	3	25	2
HN(hn)/OB(ob)	3	4	23	TP(tp)/TP(hn)	9	9	12

Figure 3: Column 1: Number of subjects who heard one continuous melody
Column 2: Number of subjects who heard two melodies (with the melody in the foreground starting on the first note)
Column 3: Number of subjects who heard two melodies (with the melody in the foreground starting on the second note)

The assumption that divergent formant locations of featured instruments would lead to hearing two melodies of which the one with the 'brighter' timbre (with the higher main formants) would be the one in the foreground was corroborated (there was some uncertainty concerning the sound example: trumpet alternates with trumpet (featuring French horn formant = TP(tp)/TP(hn)). Similar results can be found in the literature on stream segregation: already in 1975, Leon van Noorden showed that two alternating timbres with dissimilar distributions of partials tended to split in perception into two different streams The timbre-dependent streaming effect also appeared in 1979 in an experiment conducted by McAdams & Bregman when the authors added a third partial to one of two alternating sinus tones (McADAMS, BREGMAN 1979, 26-34). That same year, David L. Wessel was able to prove that, when hearing two alternating timbres, the probability of hearing the melody split into two increases with greater dissimilarity between the timbre spectrums (WESSEL 1979, in: WESSEL 1985, 640-657). On the other hand, Erickson (1982, 517-536) related the splitting of a melody played in two alternating timbres as an effect of focussing of attention. However, this could be attributed to the fact that, in my opinion, he used too many different alternating timbres in the same experiment (a six-tone melody was repeated many times, whereas five different instrument timbres were presented from note to note). In his experiment with stream segregation of residual tones in 1987, Punita Singh was able to show that, with alternating tones whose [virtual] frequency is identical, the melody splits into two as soon as their spectrum of partials becomes different (cf. the chart in Fig. 7 in SINGH 1987, 893).

With the synthetic instrumental sounds of a MIDI expander, Andrew Gregory (1994, 161-174) repeated an experiment which had already been carried out similarly by Tougas & Bregman in 1990. He presented two scales with divergent timbres and running in different directions, crossing one another in the middle. He asked 100 subjects to judge whether the location of the foreground melody after the crossing point was determined by timbre or by frequency. Here, as well, it was shown that it was easier to differentiate the two melodic lines with increasing dissimilarity between the featured respective timbres (cf. also TOUGAS, BREGMAN 1990, 123).

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5. CONCLUSIONS

Thus, to summarize, timbre-dependent streaming is a phenomenon which has been observed for quite some time. However, in all the experiments cited here it was manifestly difficult to elaborate a concept which would explain from what point on timbres would be different enough in order to produce the streaming effect. But by recurring to the formant areas discovered by Karl Erich Schumann (1929), it becomes easy to make a clear decision which applies to both simultaneous and successive notes played by formant-determined musical instrument sounds (i.e. wind instruments):

1. Musical instruments with equivalent main formant areas tend to be perceived as a homogenous blend when played in unison and, when played alternately in succession, tend to produce one sole, continuous melody in perception.

2. Musical instruments with divergent main formants are tend to be perceived as distinct when played in unison and, when played alternately in succession, tend to produce two distinct melodies in perception (two latent parts).

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