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Blend in Singing Ensemble Performance: Vibrato Production in a Vocal Quartet

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Abstract

Objective
'Blend' is a defining characteristic of good vocal ensemble performance, and in order to achieve this directors often identify vibrato as a feature to be controlled and consequently restrict its use. Analysis of individual voices in ensemble situations presents several challenges, including the isolation of voices for analysis from recordings. This study considers vibrato production as a feature that contributes to blend through an ecological study of a vocal quartet.

Method / Design
An SATB vocal quartet was recorded using head-worn DPAs (miniature microphones) and electrolaryngograph electrodes to enable fundamental frequency analysis of the individual voices. The same four-part material was recorded over several weeks of rehearsal to allow analysis of conscious and subconscious changes to vibrato production over time. Alongside the recording of their rehearsal discussions, singers were also asked for opinions of vibrato production in connection with blend.

Results / Conclusions
The results indicate that the singers in this study adjusted their vibrato to some extent to improve blend, with some instances of synchrony between voice parts. Some conscious alterations to vibrato were made to improve blend, however these are not always evident in the data, suggesting that these singers' own perceptions of their performance may have be influenced by other factors. These findings indicate a need for further studies of vibrato as a feature of blend, particularly in terms of the synergies between expectation and actual production, and potential synchronicity between singers: increased understanding of vibrato in an ensemble setting will lead to more efficient rehearsal techniques and vocal training, and could prevent vocal misuse leading to pathology in the future.

1. Introduction

Blend is a key objective in a cappella solo voice ensemble performance (one singer per voice-part), often being used as a main descriptor in the assessment of performance quality and is of particular importance in the performance of Renaissance and Baroque repertoire [1]. With the increased interest and understanding in the science of solo voice performance, research has begun to consider features of the singing voice that are representative of singing in a group, rather than as a soloist. Of particular interest is the concept of blend, whereby parts combine to create a merged sound rather than highlighting the individual voices in a texture. A number of factors are relevant to the topic of blend, including tone colour, sound level, intonation, unifying the vowel, and vibrato rate and extent (see [2,3]). This paper focuses on extent and synchronicity of vibrato, defined as 'a periodic undulation of the fundamental frequency' [4], in relation to blend in an SATB vocal quartet.

Analysis of multiple voices in ensembles poses a number of additional challenges to solo voice analysis. In the simultaneous recording of several voices, even using individual microphones situated close to the mouth, a certain amount of bleed from other voices is inevitable, and is likely to interfere with robust analysis of the individual voices. Various techniques have been employed to account for this issue and allow assessment of the ensemble singing voice, including polyphonic acoustic analysis toolkits such as AMPACT for MATLAB [5].

Studies are therefore often based on the perception of choral blend [6], rather than empirical analysis of the singing production, and include, for example, consideration of singer position [74,58]. In consideration of tuning in ensembles, electrolaryngographs have been used to allow analysis of the voice source, including fundamental frequency (F_0,), without interference from other singers [96,107].

Empirical studies concerning voice production in choral singing often involve experiments that control the environment, so that an individual is recorded in isolation, usually being tasked with blending their voice to a pre-recorded track of an ensemble which is delivered via headphones to the singer. The first significant study employing this type of protocol to investigate voice quality in choral blend is that undertaken by Goodwin [11], whose study analyzed sustained tones in solo and blend techniques and found differences in formant production, with stronger fundamental frequencies in the blended mode. Using binaural recordings from singer positions within a choir, Rossing *et al.* [12] analyzed formants alongside sound pressure level, as well as observing a wider vibrato in solo voice production compared to choir singing by the same singers. A later study employing the same method found increased relative energy in the spectrum between 2-4kHz when sopranos sang in a solo, rather than chorus, mode [13]. Ternström *et al*. [14] found clear differences in formant frequencies between singing and speech in choir singers, with agreement between the singers in the lower formants when singing.

With a particular focus on vibrato Mann [15] more recently studied undergraduate female singers, again singing with a pre-recorded track relayed via an earphone, and found a significant difference in the rate and extent of vibrato, alongside the duration of vibrato tones between choral and solo singing modes. However, Reid et al. [16]

found no difference between solo versus chorus modes in professional opera chorus singers when analysing vibrato rate and extent, long term average spectra, singing power ratio and energy ratio from close microphone recordings, concluding that opera chorus singers require a similar timbre to opera soloists. Close microphone recordings in a real choir situation were also used by Jers *et al*. [17], whose study analyzed long tones within a choral piece and found evidence of synchronization of vibrato between singers.

Whilst previous research into group singing has focused on blend in choirs, in practice, blend remains a key objective in the performance of solo-voice ensemble singing, although the context is somewhat different: the singers are blending different notes as the parts of a chord, rather than unison notes within their own part. This study investigates vibrato as a factor contributing to blend in a vocal quartet through an ecological experiment, whereby a newly formed vocal quartet rehearse and perform a piece live over a ten week period.

The main research questions are:

1. Do the singers employ a vibrato extent in keeping with expectations of Classical singing?
2. Do singers control their vibrato behavior when trying to achieve optimum blend?
3. Is there evidence that the singers synchronise their vibrato when singing together?

2. Method

A newly formed Soprano, Alto, Tenor, Bass (female, female, male, male, respectively) student vocal quartet at the University of York took part in the study. All participants were first study undergraduate singers aged between 19 and 21 and were undertaking a ten-week module in ensemble singing, which was assessed by recital as part of their final degree grade. As part of the module they had formal coached rehearsals twice a week with expected additional rehearsals (usually daily) throughout the ten weeks.

The singers were recorded during specific coaching rehearsals throughout the module, illustrated in table 1. These were chosen based on even distribution throughout the term whilst avoiding weekly disruption to their module. The same time slot was used for each session (Tuesdays, late morning circa. 11am after a rehearsal start time of 9:30am)

Week / Session number	Quality of Lx data	Number of takes	Take chosen
1 /1	Good	3	2
3 / 2	Good	2	2
5 /3	Poor (all parts not used)	2	Na
9 / 4	Good (poor Bass in places)	2	2

Table 1. The recording sessions of the vocal quartet during the ten-week module.

2.1 Recording setup

Singers wore a head-worn DPA 4090 omnidirectional microphone and Electrolaryngograph (Lx) electrodes held in place with an elastic strap. The DPA and Lx signals were recorded using two synced eight channel TASCAM DR680 recorders set to 16-bit 48.2Hz sampling frequency. A separate stereo recording was also made. The singers were positioned in their usual rehearsal and performance configuration, in a semi-circle in descending range order of voice part. All recording sessions took place in the same large rehearsal room in the Department of Music at the University of York. A reference pitch C4 was given on a piano before each take. The quartet set their own tempo.

2.2 Material

The singers performed two pieces from their recital repertoire as well as a bespoke piece (Exercise 3, see figure 1) written by Howard [9] primarily for the investigation of choral tuning. They were asked to focus on blending, but were given no further instruction when singing the exercise.

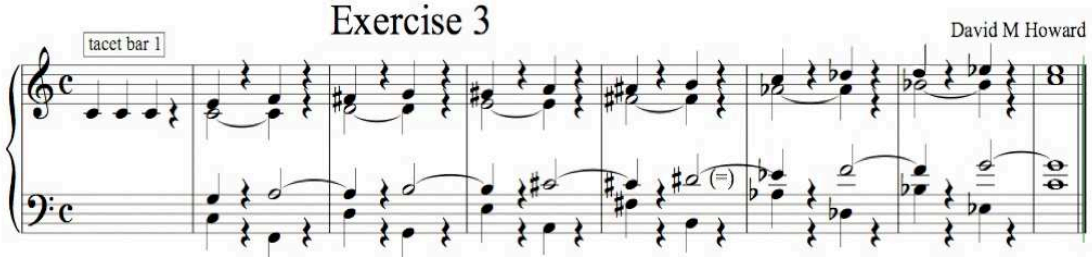


Figure 1. Musical score of the piece performed by the quartet from [9].

A minimum of two takes were obtained of Exercise 3 in each session, unless more were requested; the singers were asked which take they would 'use' (see table 1). The singers were also asked about their opinion of each take in view of their performance and perception of the blend. Prior ethical approval was obtained from the Physical Sciences Ethics Committee at the University of York.

3. Analysis

The best takes of Exercise 3, as determined by the participants, were extracted for analysis. F_0 values were obtained from the Lx signals using PRAAT [18]. When Lx data was not available due to poor contact of the electrodes, extraction of F_0 was obtained from the DPA recordings for the Bass. It was not possible to analyze two notes in session 4 which are noted in table 2 in the Results section. The data from session 3 was too poor for accurate analysis and was removed from the study.

F_0 data was exported to excel for analysis and plots were created for each beat of the piece. The onset of the next beat was determined by the introduction of any voice part after a rest. The vibrato tones were then extracted by eye from F_0 contours of each beat, ensuring complete vibrato cycles were selected and the average peak-to-peak

extent was calculated. Tones were classed as non-vibrato tones where no complete cycles of vibrato could be identified.

Distance from the mean F_0 was calculated in cents for each sample extracted in PRAAT. A Pearson correlation was performed on this data for the vibrato portion of the final note. The data for the Bass was not included in this analysis for sessions one and four as no vibrato was identified in these tones.

4. Results

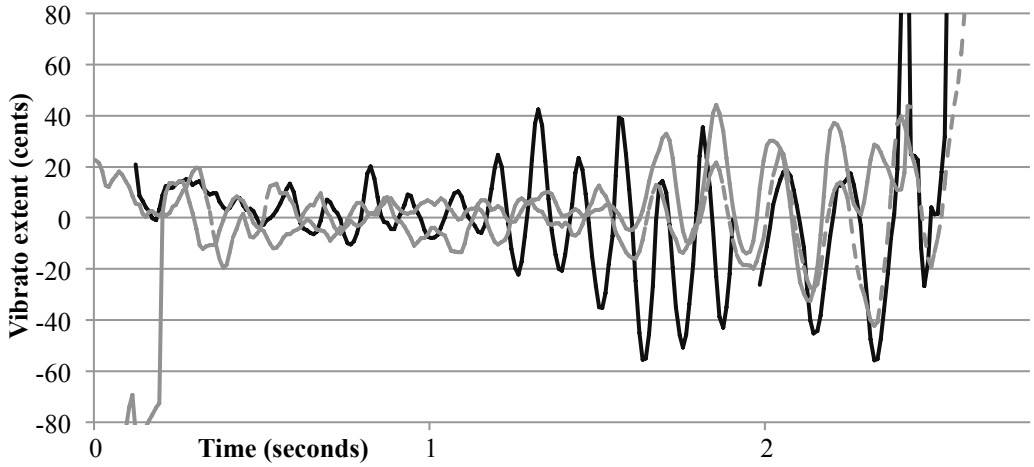
Table 2 shows the mean peak-to-peak vibrato extent of each beat sung by each singer in the 3 sessions that were analyzed. The mean vibrato extent of all four beats of the final bar are included in the final row.

	Session 1				**Session 2**				**Session 4**			
Beat number	S	A	T	B	S	A	T	B	S	A	T	B
B1	121		22	34	38				55			
B2						37				34		
B3	120	51	48		50		38		55			
B4			40				50					
B5	109		35		62	23	46		43		49	
B6												
B7	103	77			62	28	49		60	58		
B8			30				34				48	
B9	84		42		59	39	43				49	
B10												
B11	75	59	41		59	73	56		47	40	35	
B12			39								48	
B13	92		23		59		72		62		38	
B14						16				22		
B15	76	110			40	39			60	43		
B16			31				35				39	
B17	63		30		40	54	43		63		42	
B18												
B19	64	33			46				60			
B20			43				20				37	
B21	87		32		28		45		53	24	31	20
B22												
B23	61	26	47		50	45			42	54	34	NA
B24			46								59	
B25 - 28	56	46	36		46	47	47	18	42	59	50	NA
Mean of all sung tones	85	57	37	34	49	40	45	18	54	42	43	20
StDEV	22	28	8	Na	11	16	12	Na	8	14	8	Na

Table 2. Showing the mean peak-to-peak vibrato extent in cents of each note. White squares = no note was sung; striped squares = non-vibrato; grey scale light to dark = narrow to wide extent respectively.

Vibrato was present in most sung tones across all sessions in the Soprano, Alto and Tenor, although the notes lasting three beats sung by the alto and tenor often include one or two beats with no vibrato. Although random fluctuations in pitch occur, the Bass produced very few tones with a periodic phonation frequency modulation consistent with vibrato (see table 2).

The graphs in figure 2 show the F_0 contours for the Soprano, Alto and Tenor singing the final note of the exercise; this is the longest note of the piece with a written value of four beats, and as it is the final chord it is expected to be treated with particular care in terms of blend. In all three cases vibrato is introduced to the note after around one second, with the extent increasing to the end of the tone in most voices. A certain level of synchronicity also seems apparent once vibrato is established; Pearson correlation (see table 3) reveals that the Alto and Tenor are most similar in sessions one and two with the Soprano and Alto most correlated in session four. Closer inspection of the plots in figure 2 shows that for the first two sessions, the Soprano is the first to introduce vibrato. One possible conclusion could be that the other two singers are attempting to 'blend' to her vibrato pattern, however, especially considering the higher correlations between the Alto and Tenor for these sessions, there could be other explanations. The final note in session 2 was one of the few notes sung by the Bass with observable vibrato and so was included in the correlation analysis, where correlation was found with the Soprano for this session. However, as shown in figure 2, the vibrato is of very small extent and is highly irregular throughout the tone (see figure 2) making any speculation on synchronization with the other parts difficult. As vibrato was not observable in the other sessions the Bass was not included in the graphs or correlation analysis for these sessions.



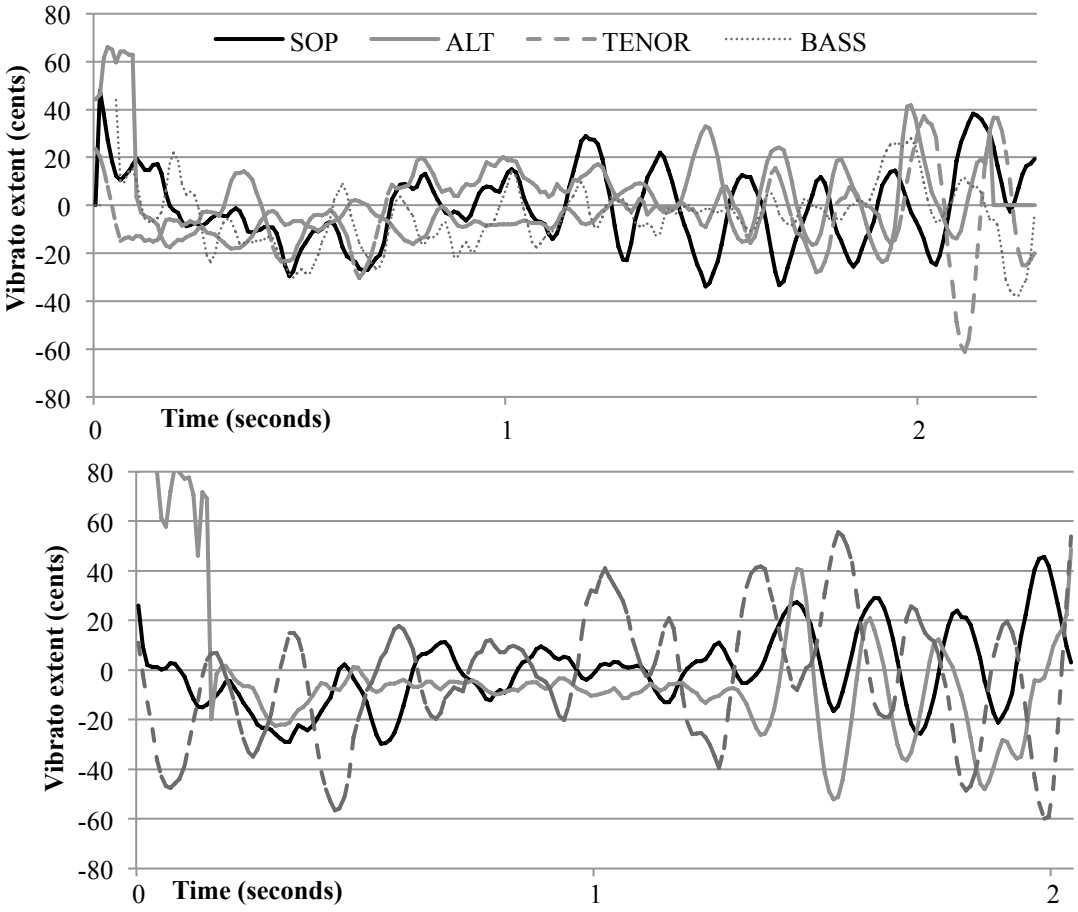


Figure 2. Graphs showing Soprano, Alto and Tenor vibrato curves for the final bar (four beats) of Exercise 3 in Session 1 (top) Session 2 (middle) and Session 4 (bottom)

Session	Soprano - Alto	Soprano - Tenor	Alto – Tenor	Soprano - Bass
1	0.454	0.614	0.72	NA
2	-0.523	-0.591	0.711	0.295
4	0.676	-0.561	-0.289	NA
All values significant at the $p<0.05$ level				

Table 3. Showing R values for Pearson correlations for the final note vibrato tone between the Soprano, Alto and Tenor in the three sessions.

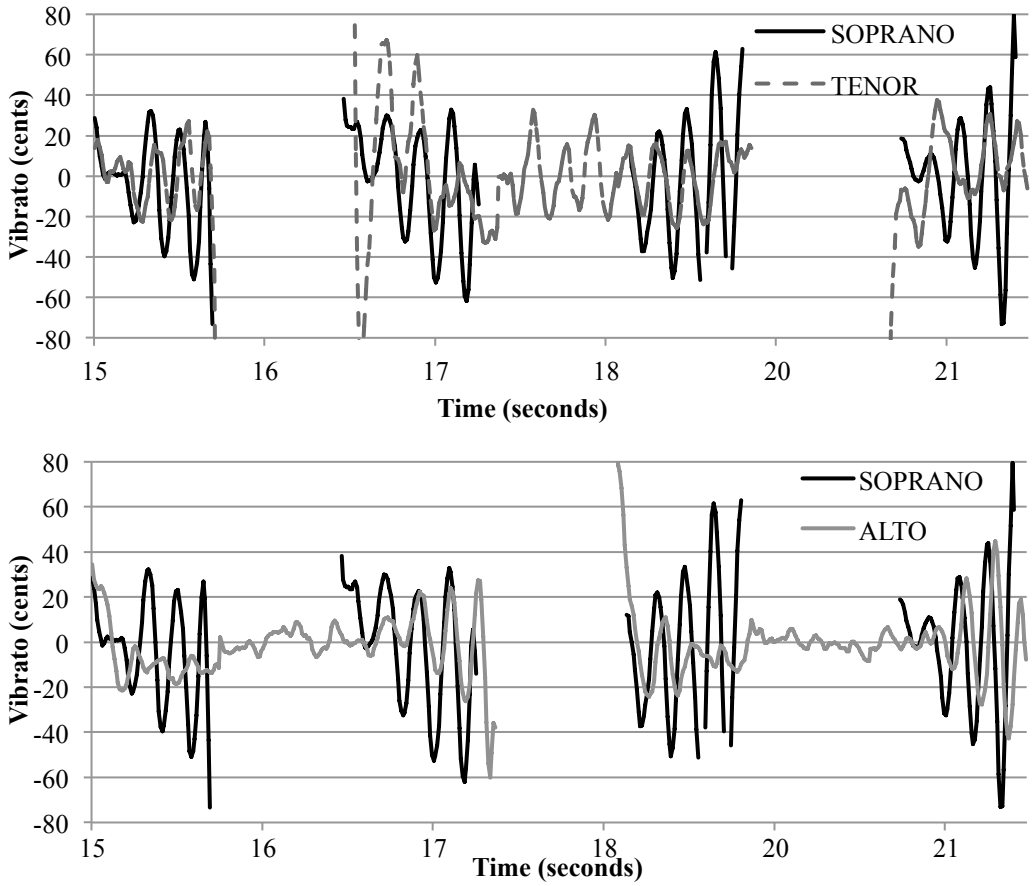


Figure 3. Showing the vibrato contours of the Soprano and Tenor (above) and Soprano and Alto (below) in beats 17 – 23 of Session 1.

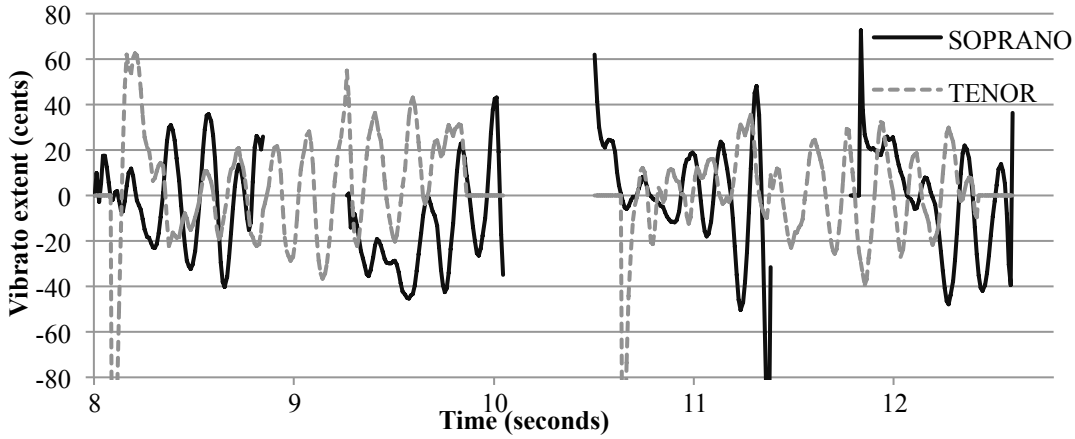


Figure 4. Showing vibrato contours of the Soprano and Tenor in Session 4 beats 8 – 14.

The crotchet beats (quarter note beats) sung by the Soprano prior to the final note all contain vibrato, from close to the onset of the tone. Each beat the Soprano sings coincides with the first or last beat or the Alto or Tenor notes, which are three beats long and carry over rests in the other three parts. The plots in figure 3 show the relationship between the vibrato of the Soprano, Alto and Tenor parts, and illustrate the tendency for the Alto and Tenor to create less consistent vibrato when singing

alone. In particular, the Alto tends to produce a relatively straight tone until the final crotchet of her notes, when she synchronizes with the Soprano. This behavior is evident in all sessions, although the vibrato of the Tenor voice is more consistent across his notes during the final session, with less evidence of synchronization (see figure 4. for an example).

5. Discussion

There is some evidence that this vocal quartet employ vibrato as a feature contributing to choral blend, in terms of the vibrato extent and the behavior of vibrato throughout tones. The objective given to the singers when performing this exercise was to concentrate on blending the sound, and over the period of these recordings they were being trained in good ensemble singing techniques. When commenting on their sessions after the recordings, they often noted vibrato as a key factor that they were trying to control. This included employing vibrato as a musical device, rather than a technical standard, and limiting its production to achieve optimum 'tuning and blend'.

The relatively small extent of vibrato employed by all the singers, with an overall mean peak-to-peak extent of 44 cents, compared with expectation for Classically trained singers (peak-to-peak of up to 200 cents) reflects the opinions of the singers and is consistent with the theory that ensemble singers should reduce vibrato extent, often at the request of the director. Vibrato in the soprano voice is often given particular attention, and so the notable reduction in vibrato extent by the Soprano across the sessions is in keeping with expectations of choral blend, as well as reflecting the singer's own perception and objective; all singers noted a reduction in vibrato as an objective in achieving improved performance. However, the pattern of vibrato use throughout long tones produced by the Alto and Tenor becomes less consistent, with increased presence of vibrato in long tones, particularly in the Tenor voice, with practice. The general absence of vibrato in the Bass voice is also unexpected and further studies are needed with more ensembles to confirm that this is a unique or unusual case.

Notable patterns of vibrato behavior within tones occur throughout the piece and sessions, with voices adapting vibrato production when other parts enter the piece. The final note is of particular interest, as it is the longest note in which all four parts are present, and as the final note could be given particular care in terms of blend.

In all three sessions the singers produce a non-vibrato tone for approximately one second before introducing vibrato. The introduction of vibrato half way through the tone, with vibrato increasing in extent once introduced, could suggest that vibrato is being used collectively for a musical effect. This hypothesis corroborates the conscious attempts of these singers to use vibrato to this end. The agreements of the singers on the timing of this onset may also be indicative of attempts to blend; once one singer begins a vibrato, the others quickly join in. Without further research, however, firm conclusions cannot be drawn.

The high R values of the Pearson correlation analysis (see table 3) confirm evidence of synchronization between the vibrato of the singers in the latter half of this final note; however, it is not possible to ascertain whether this is consciously being

controlled, is the result of a subconscious phenomenon connected to the blending of voices when singing together, or is due to the natural vibrato behavior of the individuals.

In the first two sessions the Soprano appears to 'lead' the onset of vibrato, the Alto and Tenor then introduce vibrato, syncing with each other (figure 2). It might be expected that, as the Tenor was maintaining phonation of his note beginning on the previous beat, he would provide a tone for the other voices to blend to, and therefore a vibrato to match to (if indeed this is possible). However, the tendency was for the Tenor and Alto to withhold vibrato until the final beat of their long tones (the point at which it becomes a chord) and wait for the soprano to initiate vibrato before introducing it to their tone (see figure 4).

In the case of the final session, whilst producing greater vibrato overall in terms of extent and use within tones, the Tenor still reduced his vibrato on the final chord before re-introducing it along with the other singers. This may suggest that the inclusion of the non-vibrato part of the final note is a feature of the desired blended sound. In the final note of session 4, the Tenor, rather than the soprano, introduces the first vibrato cycle once the chord is established. In this case the Soprano and Alto, rather than the Alto and Tenor sync with each other when they introduce vibrato to the note. In each of the three cases of the final note, therefore, the voices not involved in 'leading' vibrato production sync together. More data is needed to ascertain the extent to which vibrato synchronization occurs and if it is indeed a feature of blend and to understand the relationship between voice parts to this end.

The observed role of the Tenor and Alto parts within the exercise was to act as a pivot from which the other singers will tune their next note. This could be indicative of the tendency for the Alto and Tenor to reduce or remove vibrato from tones when singing alone and then increase vibrato once the other voices enter, often withholding vibrato for the first two-beats of the note: providing a non-vibrato tone for reference may be a conscious effort to provide stability for the other singers. Alternatively, it could correspond to insecurities in the singers being left to sing alone. The increased use of vibrato by the Tenor in the final session suggests that this may be the case and that the more familiar he became with the piece, the more vibrato he employed. However, the same effect was not observed in the Alto; more data is needed across more singers to draw meaningful conclusions.

The use of non-vibrato tones at the beginning of longer notes is also idiomatic of a classical singing style of early music [19,20] whereby vibrato is used as an ornament rather than a standard feature of singing; the quartet in this study were primarily performing Renaissance repertoire. This, combined with voice types being encouraged into both solo voice early music and choral / ensemble singing, indicates that the vibrato behavior observed here might be a stylistic feature of this quartet's performance. The synchronicity within the vibrato tones, however, suggests that this is worthy of further investigation.

The tendency of the Soprano to synchronize her single beat tones with the middle voice part's longer pivot notes, seen in figure 4, is consistent with preliminary findings of Jers *et al*. [17] when analysing the vibrato of choral singers. The vibrato tone of the Soprano also tends to be preceded by an under / overshoot, which

additionally supports their hypothesis that the vibrato synchronization is a by-product of the initial onset of the tone. However, as mentioned above, it appears that the Soprano initiates the vibrato, with the Alto and Tenor synchronizing to her. This, combined with the behavior observed in the final chord, suggests vibrato synchronization may be a controllable feature in achieving a blended sound.

Synchronization also seems to decrease across the sessions, which could suggest that this is not a key feature that they are considering when trying to achieve optimal blend, however the increased use of vibrato in the Tenor voice in the final session could have interfered with the synchronicity. Whilst all singers reported a reduction in vibrato use over the sessions, in practice this was only true of the Soprano and in connection with extent. The singers self-reported an overall improvement in their performance across sessions, suggesting that perception of vibrato is complex and may be influenced by other factors. Repeated measures are needed with more vocal quartets to explore the significance of tendencies that are emerging within this case study, especially considering the synchronization of vibrato, the impact of familiarization and practice over rehearsal sessions on vibrato production, and the agreement of findings with the perceptions of vibrato production by the performers themselves.

6. Limitations and future work

Whilst this study demonstrates great potential for investigating attributes of choral blend through protocols involving live ensemble performance, comparative data of the solo voices of the singers would be beneficial to confirm the causal relationship of the findings to ensemble singing, rather than solo voice attributes. Where possible, the addition of this data would be preferable in the future, however, when not available increased numbers of subjects and ensembles would further validate the findings. In addition, monitoring the private vocal study of the individuals to account for the variable of improved vocal technique and control/use of vibrato across the sessions would be valuable.

An additional study, which would complement this work and future work in the area, would be to include testing of the perception of blend changing over time using the recordings. This could be carried out utilizing a protocol similar to or adapted from Killian et al., whereby listeners used a digital interface to make continuous judgments of blend in choral groups [6].

7. Conclusions

This study uses a protocol suitable for measuring aspects of the voice source of individuals singing in an ensemble, in a relatively ecological setting, to assess characteristics of vibrato production as a feature contributing to blend in a vocal quartet. The singers in this study produced vibrato within tones at similar times, reduced mean vibrato extent over the sessions and, in certain cases, appeared to synchronize vibrato production within tones, perhaps indicating that vibrato production is playing a role in blend in this quartet. Perceptions of vibrato production amongst the singers did not always agree with the findings, suggesting that, in this

instance, the performer conceptions about vibrato production in ensemble singing could be misrepresenting practice.

These preliminary findings have important implications for the management of vibrato in an ensemble setting, which remains a controversial topic amongst singing teachers and directors, and illustrates that further studies are necessary to inform performance practice that promotes healthy and optimal voice production in group singing tasks.

8. Acknowledgements

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