SUBJECTIVE LISTENING STUDIES CONDUCTED BY ARUP AT A LEADING WESTERN OPERA HOUSE

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1 INTRODUCTION

This paper presents the outcome of subjective listening tests conducted in a modern western opera house ("The Opera"), for which Arup carried out the acoustic design around 20 years ago. The tests were aimed at establishing the effect of key variables in the orchestra pit arrangement: pit height, pit floor stepping, orchestra layout and upstage pit wall condition. The reasons for the exercise were primarily aimed at enabling The Opera to gain a better understanding of how these variables affect artistic outcomes. In particular, the understanding of a repertoire-sensitive balance between pit and stage to enable better casting.

2 BACKGROUND

2.1 Design and Post-Opening support

The Opera in question is a single volume horseshoe design with three seated balconies, opening over 15 years ago. Essential parameters are Volume=10,500m^3, T_{mf}=1.4s, Capacity=1,450. During design, the orchestra pit was carefully considered with loudness and balance issues in mind and is substantially open with surfaces around the proscenium zone optimised to support both singers and players. The minimum design target for G_{STAGE}:G_{PIT} ratio was 0dB, and this was verified by measurement. The pit includes three motorized lifts for height and area adjustment, a reversible (absorbing or reflecting) upstage panel system, and a demountable downstage pit rail system. Pit dimensions are shown below.

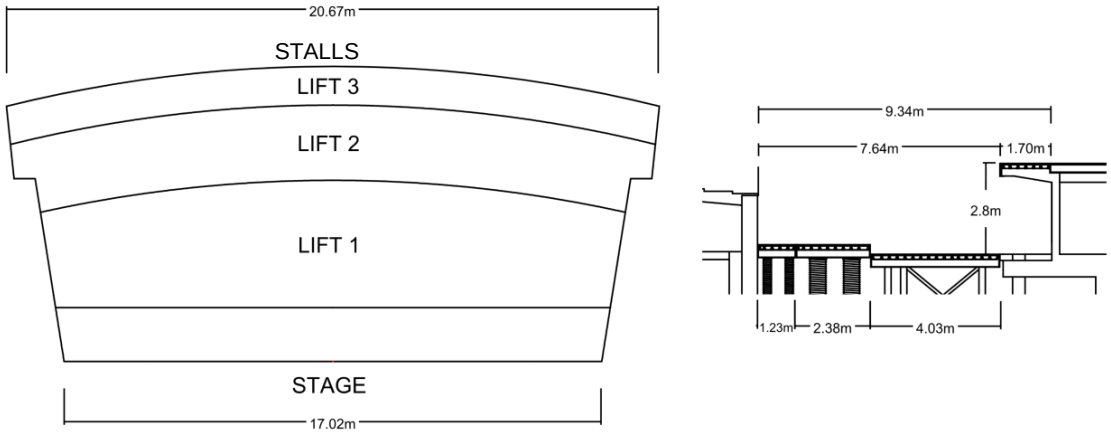

Figure 1: Layout and section of orchestra pit.

Since opening, The Opera has been favourably regarded acoustically, with a notably clear and refined orchestral sound. The resident company has a high reputation internationally and maintains elevated artistic standards.

The pit configuration commonly adopted for rehearsal and performance post-opening was between -1.9m and -2.2m relative to stage level, with a flat floor (lifts at same height). Post-completion, Arup

studied the stage-pit balance in some detail, as pit settings were adjusted. Tests were carried out with six source locations on stage and six in the pit, chosen to represent typical singing and playing positions. A reasonably supportive stage set was in place. Source heights were 1.6m above the stage and 1.3m above the pit floor. A total of 35 positions in the stalls seating area were measured.

Pit source measurements were made with the pit floor at -1.9m, -2.4m and -2.9m relative to stage level, to assess the effect of pit height on orchestra loudness. The overall results for the stage-to-pit balance with the pit floor at -1.9m relative stage level are approximately: first rows of stalls -1dB; central stalls areas 0.5 - 1dB; rising to 2.8dB at rear of stalls. The results showed that, assuming equal sound output from stage and pit, the stage-to-pit balance with the set on stage is in favour of the pit at audience locations very close to the pit, but after the first couple of rows becomes in favour of the stage, increasingly so towards the rear of the stalls. The design criterion for stage-to-pit balance of 0dB was achieved with the set except in the front rows adjacent to the pit. Comparison with the stage-to-pit balance measured by Arup during commissioning tests at another contemporary opera house show that, towards the rear of the stalls, the balance at The Opera is generally comparable, and more in favour of singers towards the rear of the stalls.

The table below summarises the measured effect of pit floor level together with modelled results of the effect of different set designs. All are with solid reflecting pit rail panels mounted.

Measure	**Expected change in stage-to-pit balance**
Set design	Up to 2.0dB
Lowering orchestra pit	Up to 0.8dB (1.5dB at 2kHz*)

* Noted as relevant wrt masking of vocal formants in 2kHz to 4kHz region
Table 1: Effect of pit floor level and set design on stage-to-pit balance.

Post-opening, a special exercise was conducted to assess subjectively the effect of different orchestra pit heights. For these subjective assessments, an acoustically-supportive set design was in place. There was general agreement of a positive balance and range of adjustment, with the following conclusions:

The singer to orchestra balance moves towards the singers as the pit is lowered. But as the pit becomes very deep (-2.9m re stage level), the orchestral quality is too compromised. The best compromise between singer-to-orchestra balance and orchestral quality was considered to be with the pit at -2.4m to -2.5m relative to stage level. The pit level should be adjusted according to the repertoire and the orchestration, with a default of around -2.4m and adjustment from there. So, for example (and very crudely for illustration): Handel, Mozart or Rossini might be performed with the pit at -2.1m; Bizet, Britten, Janacek, Puccini and Verdi at -2.4m; Stravinsky and Tchaikovsky at -2.4m or -2.5m; Wagner, perhaps also Richard Strauss, at -2.5m or -2.6m.

It was noted that The Opera would frequently set front-to back dimension (i.e. the number of lifts in use) of the pit deeper than required by the orchestra size within the pit, and certainly wider than anticipated by the design team in these circumstances, which does not help the stage-to-pit balance. It was recommended that the front-to back dimension of the pit should be minimised according to the size of the orchestra. Also, to ensure that the upper string sound is not adversely affected by the lower pit heights, portable rostra should be experimented with to increase the relative height of the upper string sections. Generally, the removable panels on the pit rail should be removed, at least on the upper strings side of the orchestra, but this should be reconsidered for each production.

2.2 Fast Forward to 2022

Following many successful years of operation, re-engagement between Arup and The Opera revealed an uncertainty within the current artistic leadership around how best to configure the pit and achieve good balance, with some instances of orchestral loudness, and corresponding limits on vocal casting. Overall, the conclusions reached in the post-opening exercises had not been fully translated into current operational use, in which the pit floor was normally high, flat and fully expanded, as

generally preferred by the orchestra. The Opera desired an artistic response centred around pit configuration and usage, and orchestral sound production informed by a better understanding of what would be most effective and within the bounds of reasonable demands on performers. Between Arup and The Opera there was a collective determination to gain a better understanding of the factors, especially around orchestral sound, that will be most beneficial in achieving this. There was also an agreement that this required a renewed qualitative evaluation in which key variables are systematically evaluated by a consistent cohort, comprising artistic staff from The Opera and Arup.

The post-opening exercises had suggested that, in terms of objective measures, lowering pit height improves balance with singers by reducing orchestral sound projection. There was a question, however, as to how this actually translates in performance. It had been noted that lower pit settings produced a more localised acoustic field within the pit itself, which is felt to reduce the quality of orchestral sound. Related to this are specific observations around effect of pit height and pit rail setting on violin sound, colour and ability to sustain a silky cushion from upper strings, as well as some sensitivity to bass register colouration noted by Arup when listening in the stalls. It is to be expected that when running lower pit settings orchestral textures may become less clear, and sound levels as experienced by pit musicians increase. This would tend to reduce the ability of pit musicians to hear singers and become aware they may overpower them. There is, therefore, a counter-intuitive suggestion that avoiding lower pit settings helps with balance. At the same time, the artistic approaches of different conductors, demanding different emphasis and control over sound production was noted as a very significant variable in terms of balance and overall artistic outcome.

Also, some production equipment noise had been noted by Arup in performance. Whereas the acoustic cues that pit players and singers utilise, and the harmonic content or colour conveyed to audiences, are very subtle, they can easily be obliterated by technical equipment which produces noise from moving elements, such as fans and theatrical lighting, even at modest levels.

3 TEST ARRANGEMENTS

All the above considerations fed into discussions between Arup and The Opera, which took account of the time available, availability of artists and other practical constraints. The result was agreement on a set of three questionnaires to be filled out by pit musicians, singers, and listeners, and a set of eight performance conditions in each of which the orchestra and singers (two female and two male) performed scenes from Verdi's Un ballo in maschera, and Puccini's Tosca and La Boheme.

The variables altered between conditions were the overall height of the pit; the front-to-back stepping between pit sections and lateral stepping of the violin section; the layout of the orchestra, with violins split antiphonally (1) or together (2); and the variation of upstage wall condition between absorbing and reflecting. Owing to time restrictions, altering the pit rail as an additional parameter was not possible and the pit rail was set to solid throughout the exercise.

Pit height Three heights, classified as low (-2.6m), medium (-2.35m) and high (-2.1m), were used. In the flat conditions each lift was at the same height.

Stepping Aside from overall pit level, the separate lift system allows for front to back stepped set-ups to be used. Lateral stepping (although not directly incorporated into the moveable lift system) can naturally also be created through the use of rostra. Stepping was considered an important variable to investigate alongside overall pit level, potentially as a means of mitigating loudness from brass instruments, as well as assisting string tone in relation to the barrier attenuation associated with proximity to the pit rail. So, for the stepped conditions, lift 1 (closest to the stage) was set 0.2m lower relative to the above pit height classifications. Additionally, independent to the overall pit level, the height of the first and second violins was varied using 0.4m and 0.2m height podiums for the front and side desks, respectively, to create additional front-to-back and lateral differentiation. Otherwise, the violins were in the "flat" position and were level with the rest of the orchestra. Table 2 below summarizes the various lift heights used in each condition.

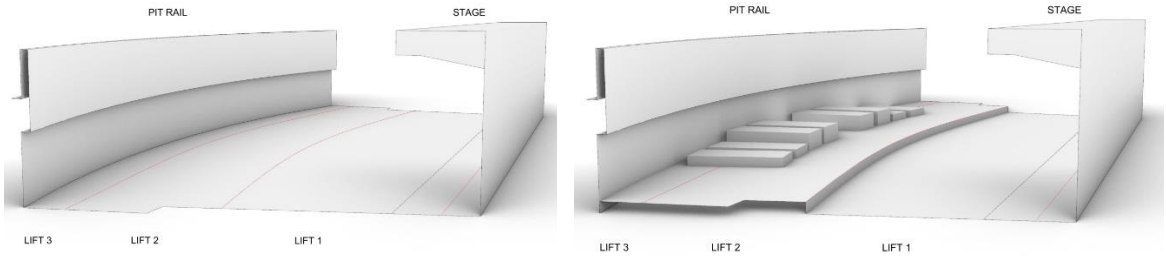

Figure 2: Orchestra pit in flat (left) and stepped (right) set up.

Layout Preferred orchestra layout within the pit is a complex function of performance practice, adaptation to particular pit characteristics, scoring, repertoire considerations and production-by-production artistic choices. For the session it was considered meaningful to explore the effect of two different layouts: one with first and second violin sections adjacent to each other, for a more homogenous quality considered appropriate for Puccini performance; and another layout with antiphonal violins (first violins on one side of the conductor and second violins on the other, along the pit rail). With this there is naturally an associated variation in the layout of the other orchestral sections, as in Figure 3.

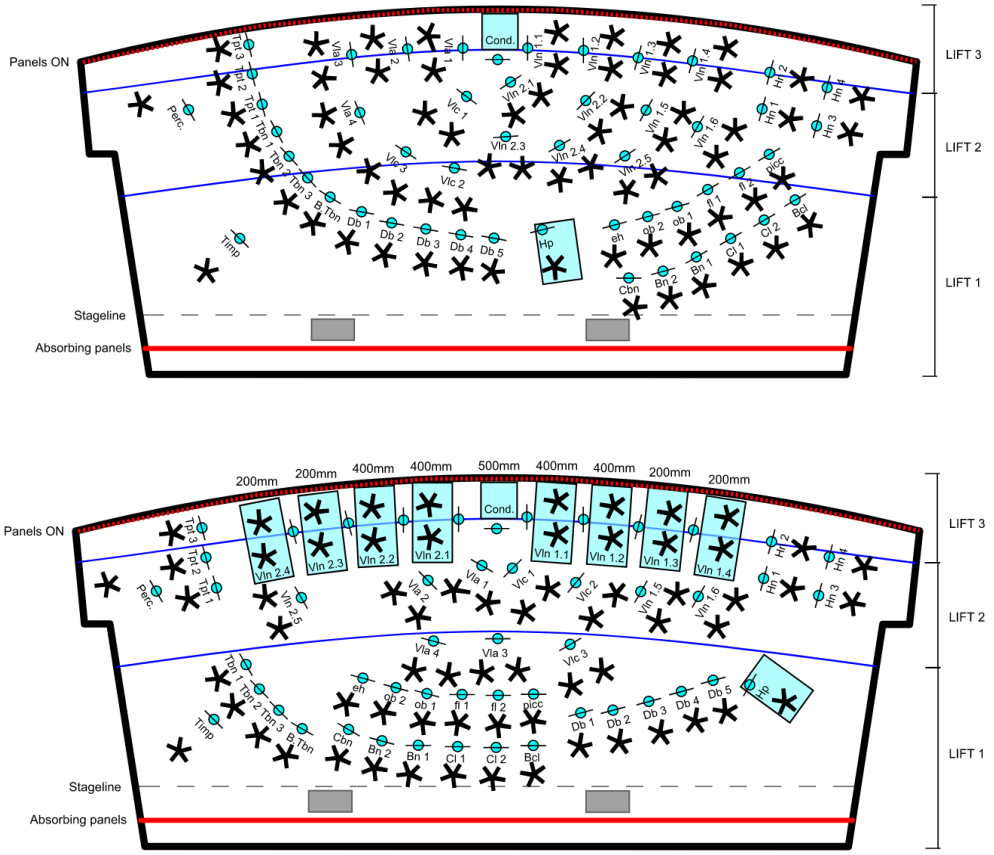

Figure 3: Orchestra pit in “violins together” (top) and “antiphonal violins (bottom) layout.

Upstage panels Generally, a reflective boundary would be expected to assist musicians in awareness of their own instruments. However, pit loudness may be increased with a reflective

boundary, alongside introducing the potential for comb filtering effects and congestion of texture, and so the upstage panel was considered an important parameter to vary. Throughout all the conditions, except for condition 8a, the pit wall panels were kept as absorbing panels. This parameter was only varied to use as a direct comparison of its effect between condition 8 (absorbing panels, medium pit level) and condition 8a (reflecting panels, medium pit level). A summary of all the performance conditions is given in Table 2.

Condition	Pit Set-up	Overall Pit level	Pit level heights relative to stage in metres				Layout	Upstage Panels
			Front Desk	Side Desk	Platform 1	Platform 2 & 3		
1	Stepped	high	-1.7	-1.9	-2.1	-2.3	1	Absorbing
2	Stepped	medium	-1.95	-2.15	-2.35	-2.55	1	Absorbing
3	Stepped	low	-2.2	-2.4	-2.6	-2.8	1	Absorbing
5	Flat	medium	-2.35	-2.35	-2.35	-2.35	1	Absorbing
6	Flat	high	-2.1	-2.1	-2.1	-2.1	1	Absorbing
7	Flat	high	-2.1	-2.1	-2.1	-2.1	2	Absorbing
8	Flat	medium	-2.35	-2.35	-2.35	-2.35	2	Absorbing
8a	Flat	medium	-2.35	-2.35	-2.35	-2.35	2	Reflecting

Table 2: Summary of performance conditions.

Questionnaires Separate questionnaires were developed for the three participant groups: listeners (n=5), singers and orchestral players. A large quantity of subjective ratings data were acquired, which for convenience in this paper have been treated as relating to “balance”, “loudness”, “clarity”, “orchestra tonal quality” and “overall impression”, as in Table 3.

Listener Questionnaire	**Category**
Balance – Orchestra relevant to each other	Balance
Balance – Singers relative to orchestra	Balance
Vocal clarity	Clarity
Orchestral loudness	Loudness
Orchestra tonal quality	Orchestra tonal quality
Overall impression	Overall impression
Singer Questionnaire	**Category**
Sense of own voice	Balance/Loudness
Clarity of orchestral accompaniment	Clarity
Balance with orchestra	Balance
Overall performance condition	Overall impression
Orchestral Performer Questionnaire	**Category**
Sound of own instrument	Balance/Loudness
Connection across orchestra	Balance
Connection with singers	Balance
Loudness level within pit	Loudness
Overall performance condition	Overall Impression

Table 3: Summary of questionnaire response categories.

4 RESULTS

4.1 Overall pit level

This section focuses primarily on the responses from conditions 1, 2 and 3 (with stepped arrangement), as the only variable altered was the pit level, changing from high, to medium, to low, respectively.

Balance For listeners, in the stepped conditions (1,2,3), lowering the pit height from high to medium produced slightly better balance ratings across the orchestra, most notably changing the basses and horns from “too strong” to “good”. Overall, this change resulted in a reduction in the balance of each orchestral section, though all were classified as having a “good” balance at medium height as well.

The change from medium to low pit height altered the balance of the violins, cellos and basses from “good” to “too weak”, whereas brass increased to louder levels at this height; changing from “good” to “too strong”. This change was noted by listeners as most significantly impacting the balance of the basses, who shifted from having a good presence in the overall orchestral balance at a medium pit height, to the lowest balance rating relative to other orchestral sections at low height.

A similar reduction in the balance of each orchestral section occurs between conditions 7 and 8 (flat set up) when lowering from high to medium pit height, with the exception of the brass and horns whose balance changed from “good” to “too strong”; similar to the effect of changing from medium to low pit height between conditions 2 and 3 (stepped set up). Overall listener comments and ratings support that the middle heights provided a more equal balance between members of the orchestra and the low height, whilst reducing the overall orchestral balance, allows more space for the singers.

For the orchestra, the connection to singers decreased for all instrumental sections as the pit height was lowered, with the exception of the cello, clarinet and trumpet sections showing a preference for the middle height. For singers, ease of balance with the orchestra was greatest in the medium height setting, and lowest at high height setting.

Loudness Listener ratings show a clear correlation with orchestral loudness increasing with pit height, with conditions 1, 6 and 7 (high height) rated as loudest across the conditions assessed, with the exception of when upstage panels were altered to reflecting in condition 8a (medium height). This is inversely related to the balance of the singers relative to the orchestra, whereby singer balance increases as height is lowered, particularly so in the case of the soprano voice, rated between “good” and “too quiet or weak” at the highest pit setting, and “good” and “too loud or strong” at low height. It is worth noting that orchestral loudness of high pit height conditions was still rated as “moderate” by listeners, save for condition 7 (flat set up, violins together) which was rated as “loud”, particularly during the musical climaxes.

Player ratings point in some cases, but not all, to a contrary pattern, with loudness increasing as the pit height is lowered. Exceptions to this are the trumpet and horn sections, which noted a direct decrease in loudness with the lowering of pit height. For instruments towards the centre of the pit, condition 2 (medium height) was loudest. Overall, between medium height and low height, the averaged responses of the orchestra are the same, although 50% of musicians found the medium setting to be loudest, and 43% found the low setting to be loudest. At low height, the members across the woodwind section noted that their own sounds felt drowned out, forcing them to play louder.

Orchestral tonal quality At low pit height listeners noted that some articulation and quality of orchestral sound was lost. A greater presence to the violins was noted at high pit levels, to some extent mitigating the perceived vulnerability of the upper harmonics to pit rail screening. Generally orchestral quality was rated better for the high setting.

Clarity Overall clarity for listeners appears to be less affected by pit height than by other parameters such as pit set-up (stepped or flat).

For singers, the clarity of the orchestral accompaniment rated consistently highest at a high pit setting, the high and flat set-up of condition 6 showing the highest clarity results.

4.2 Stepped or flat

This section focuses primarily on comparing the responses from conditions 1 and 6 (high pit height), and conditions 2 and 5 (medium pit height) as the only independent variable altered was the pit set up changing from stepped to flat, respectively.

Balance
For listeners, at the high pit setting, the flat set up was preferred in terms of balance; whereas for the medium height, the stepped arrangement was preferred. At high pit height, looking in particular at conditions 1 and 6 in which only the stepping changes, the listeners noted that the balance of violins, basses and horns reduced most dramatically, moving from “too strong” to “good”. The balance of all other instruments reduces proportionally to each other when moving to stepped, though remaining at “good” level of balance throughout.

From the orchestra’s perspective, we see an overall increase in connection with the singers in the flat setting, particularly at high pit height, improving from “average” to “good”. The exceptions to this are the violins, horn and percussion, all of which are downstage of the pit and sitting side-on to the stage, who noted a slight decrease in connection; though still “good”. The same is true for the orchestra’s sense of their own instruments’ sound, showing an improvement in the flat setting at high pit height, except for violins and horns again. In terms of connection across the orchestra, a more complex relationship arises, with some instrumental groups (violin I, cello, basses, flute, trumpet) reflecting a higher connection in the flat setting at any pit height; some reflecting a higher connection in the stepped setting at any pit height (violin II, oboe, bassoon, percussion), and the remaining instruments reflecting no change at high pit height and a negative affect on balance when moving to stepped setting at medium height (viola, clarinet, horn, trombone, timpani).

The singers’ sense of balance with the orchestra was highest in condition 6 (flat, high), which aligns with the responses of the orchestra. For singers the change from stepped to flat was most impactful at the high pit setting, with little change being observed from such a change at medium pit height.

Loudness Overall, listeners considered the flat pit set-up resulted in greater orchestral loudness, with listeners noting it resulted in “less detail in the soprano voice”. Relating this to the effect on balance, this may be why the overall balance of the basses was reduced in the flat set up for listeners, as the overall loudness levels of the orchestra have increased.

For players, the pit-set-up does not appear to have a significant impact on the loudness ratings, as the overall averaged loudness ratings do not differ greatly when comparing flat and stepped at different heights. However, the flat set up shows a slight increase in overall loudness at a high pit-height, whereas a slight decrease in loudness was observed when changing at medium height. Exceptions to this trend are Violin I and Clarinets, who felt the “flat” set-up was louder, making it “difficult to hear others”.

The oboes noted “excessive” levels for the stepped set up at both high and medium pit-height. Looking across all conditions, a marked change between “stepped” pit set-up (conditions 1, 2 and 3) and “flat” is observed for the oboes; implying it plays a significant impact on their experience in the pit.

Singer responses showed that the sound of their own voice was “excellent” in the flat set-up at both high and medium pit heights

Orchestral tonal quality Listeners' ratings of orchestral tonal quality does not seem impacted by pit set up, when comparing conditions in which pit set up was the only variable. However, written observations noted a reduction in 'transparency' of the sound when moving to flat set up, notably at medium pit height in which there was a relatively "undifferentiated" sound that can get too loud. In comparison, condition 6 (flat, high) was noted as being "a little too present".

Clarity Listener feedback shows that the stepped set-up positively impacted the vocal clarity, reflecting a "good" clarity at high pit-height and "excellent" clarity at medium pit-height. Although both flat set-up conditions offered lower vocal clarity relative to stepped, highlighting a clear inverse relationship with vocal clarity and orchestral loudness, they still classified as "good" levels of clarity.

Vocal clarity was at its greatest at the medium pit height, followed by low pit height. Whilst the low pit-height was only used in stepped set-up, the condition was still rated higher to the flat set up at medium and high pit heights, showing the reduction in vocal clarity in the flat set up, particularly for female voices. The clarity of the male voices remained consistent throughout the flat set-up conditions, despite other physical parameters changing.

For singers, the pit set up has a more obvious effect on the clarity and balance when the pit is set at a high level, noting an increase in both. Comparatively, at medium height the pit set up does not affect their experience of orchestral clarity.

4.3 Orchestral layout

This section focuses primarily on comparing the effects of orchestral layout at a medium pit-height between conditions 5 (antiphonal violins) and 8 (violins together), and at a high pit height between conditions 6 (antiphonal) and 7 (together).

Balance With "violins together", listeners perceived an increase in overall loudness, particularly so for percussion. At the high pit height in particular, the "violins together" layout appears to bring out the basses more strongly, with listeners noting their presence in the balance of the orchestra. Ratings also indicated a marginal increase to the overall strength of the violins in the "violins together" layout in relation to the rest of the orchestra, noting a more "solid and homogenous" sound. For listeners, the perceived increase in loudness may also have an affect on a reduction in the singer balance, demonstrating a decline in balance and clarity in this layout. It is interesting to note that both cases of the "violins together" layout, conditions 5 and 6, yielded the lowest level of variation for listener responses for orchestral loudness. This is seemingly reflected in their commentary, which noted less differentiation of sound for these conditions, offering less transparency of tone.

Woodwinds, particularly oboe, noted the significance of playing in the centre of the pit in the "antiphonal" set-up to their connection across the orchestra. In the "violins together" layout, all instrumental groupings generally have closer proximity to their own section (see cellos, double basses, brass section layouts).

For singers, the balance with the orchestra reduces as the violins are positioned together. This is perhaps related to the overall increase in loudness levels, particularly in the violins, that listeners noted.

Loudness For listeners, the "violins together" layout showed a slightly louder overall orchestral level, when compared to the same height with the "antiphonal" layout". At high pit heights, the change to violins together raised the loudness levels from "moderate" to "loud", whereas at medium height the increase was still considered "moderate". This slight increase may be related to the increased prominence of the double basses in this setup.

As an overall average over the orchestra, the loudness rating from players does not change greatly across all conditions tested. However, it is interesting to note that four out of the five players that did

note an increase in loudness (trumpet, flute, clarinet, horn) when moving to “violins together” have all been moved closer to each other within the pit, and also indicated a reduced sound of their own instrument. Overall condition ratings slightly increase in “violins together”, but again it is those instruments that have been moved closer to each other that have noted a reduced overall quality.

Spatial factors seem to be influencing an increase in certain groups’ sound of their own instrument. Trombones now have more space from percussion; both cellos and violas are now positioned closer together as a group, the woodwind section are moved away from the centre, giving them more of their own space in the pit. Equally, decreases in the sense of own instrument appear to be influenced by a reduction in space. In the “violins together” layout , trumpets are now positioned directly next to the basses, and the horns now have the woodwind section positioned closer to them.

Clarity For listeners, moving to “violins together” in conditions 7 and 8 appears to have a negative impact on the vocal clarity of female voices. The clarity of male voices, however, does not seem impacted both other physical variables when in the “flat” pit set-up, moving to the “violins together” layout negatively impacts the female voice clarity at both medium and high pit heights. Condition 7 (high pit height, flat set up, “violins together”) reflects both the lowest vocal clarity responses and vocal balance to the orchestra, though they are still remarked as “good”.

For the singers, the change in layout did not reflect any change in orchestral clarity at medium pit-height. However, the effect of layout change was more impactful at high pit-height, reflecting a similar trend to the listeners’ experiences, suggesting that the “antiphonal violins” of condition 6 aided clarity of the orchestra, as well as ease of balance.

Orchestral tonal quality Though pit height appears to be the main driver of orchestral tonal quality for listeners, with high pit heights being favoured, the combination of the “violins together” layout with a high pit height in condition 7 proved to have a negative impact on tonal quality; potentially due to the overall loudness increasing to “excessive” in this condition. This is supported by written notes on condition 7, which noted that the overall balance was too loud, particularly in climaxes, and that the horn section risked “overplaying” in the scenes from Boheme.

However, at the medium pit-height and “violins together” layout of condition 8, listeners responded positively to the tonal quality of the orchestra and loudness levels. The balance was noted to be improved in this layout, giving more “space for the singer to sing into”. It is noted also that the upper strings are slightly attenuated in this layout and height, as mentioned above, though the lower strings and brass are more present with a sense of “bounce” and sense of “emotional connection”. In light of this, it is worth noting that written feedback from listeners on moving to “violins together” highlights a need for sensitivity to repertoire, with the layout felt by listeners to be more idiomatic during the Puccini excerpts, compared to the sections of “overplaying” in Boheme.

4.4 Upstage Panels

Balance For listeners, the overall balance of the orchestra reduced when moving from an absorbing up stage panel to reflecting. It was felt, in particular, that the violins in particular became “too quiet” and “distant”. In contrast to this, the basses became “too loud” and overpowered the sound of the other instruments.

Pit musician ratings indicate that the reflecting panels either made a positive impact on connection across the orchestra, or no change at all. Cellos felt that the reflecting panels aided their connection to the double bass section, which improved their overall connection with the strings. Trumpets also noted a “good” connection, both across the orchestra and with the singers, with reflecting panel. The bassoons noted no difference when the reflecting panels were set, most likely due to them being near the panels; indicating that the effect of the panels on the connection across the orchestra is greatest for players downstage. It was also observed from the orchestra ratings that the reflecting panels made

little difference to their connection to the singers. In contrast, singers' responses showed an increase in both clarity and balance with orchestra with the reflecting panels.

Loudness For the listeners, the overall trend is that the use of reflecting panels increased the overall loudness of the orchestra to "excessive" levels, particularly an increase in presence of the double basses. The flat set-up and "violins together" layout have also shown an increase in orchestral loudness, so the three parameters of condition 8a in combination may prove overpowering at medium pit-height. A blending of the orchestral sound was also noted, leading to a reduction in a sense of "distinction" between instrumental groups. Written observations by listeners noted less presence and a sense of distance of the upper strings with reflected surfaces.

Clarity The reflective upstage panels of condition 8a improved the singers' sense of balance and clarity of the orchestra, when compared to absorptive panels in condition 8, although with the absorbent panels the rating is still "good".

Orchestral Tonal Quality The previously mentioned increase in overall orchestral loudness for listeners, due to the reflective panels, seems to result in a lowering of tonal quality. Listeners noted a less differentiated and more congested sound quality with reflective panels, with relative over presence of double bass in the orchestra, and weakness of violin sound. For listeners the absorbent panels "cleaned" the orchestral sound, clarifying textures and revealing more detail and beauty of tone.

5 CONCLUSIONS

The listening session convincingly demonstrates the power of the physical variables built into the design of the Opera to be an essential part of the artistic thinking for each production and cast. The magnitude of the subjective effects and their artistic correlates were hugely significant. At the right balance point, the artistic outcome can be greatly magnified, making all the difference between a merely good performance and a truly emotionally captivating, unforgettable one.

There is a clearly observable tension between conditions for pit musicians, and quality of listening experience and conditions for singers in terms of balance. Although it was interesting to find that singers did themselves generally prefer balance with a high pit setting, there is good evidence for use of a generally lower pit height setting than has commonly been adopted at The Opera, although clearly this should be a response to repertoire. Generally speaking, lower settings for larger repertoire are more likely to be optimal. But conductor personality and artistic approach is a very significant variable – a focus on sound production and controlled playing can enable use of high pit settings. Such settings without care are very difficult for singers in some repertoire.

There is also good evidence for stepping to be explored further as a valuable means of adjusting orchestral balance and colour, and assisting in enabling a lower pit height and improved balance, though this of course requires care in terms of sightlines and the effect on individual sections of the orchestra. Space for the players is highly appreciated and aids their awareness of their own sound. This again is potentially in tension with the degree of open pit presented to the room.

There is also good evidence for a significant improvement in tonal quality with an absorbing upstage wall condition. This clearly has some implications for support to musicians, but a totally reflective boundary was certainly less conducive to good sound for the audience, and this variable should certainly be explored further in conjunction with careful / selective use of reflective supporting elements in the pit.