# LOOKING AT SINGING: DOES REAL-TIME VISUAL FEEDBACK IMPROVE THE WAY WE LEARN TO SING?

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## ABSTRACT

Fifty-six participants (age range = 18-60 years), with skills ranging from confident trained singer to untrained non-singer, were assessed for pitch accuracy while singing a sequence of interval patterns of difficulty appropriate to their experience. Two-thirds of the participants were offered one of two different displays showing real-time visual feedback (VFB) on a computer screen, enabling them to monitor the accuracy of their pitch; the other third (Control group) received no visual feedback. Both VFB displays offered knowledge of results (KR), but in different modes. Pitch accuracy was assessed before, during, and after the intervention by acoustic measurement. All participants performed less accurately when assessed while real-time VFB was being provided, compared to the pre- or post-intervention assessments. This reinforces earlier research showing that KR offered during task performance may interfere with skill acquisition and application. However, significant improvement in accuracy was shown post-intervention when compared with the baseline performances. Comparison between the two displays showed that fully-contextualised pitch information was significantly more useful to participants with no previous singing training than a simpler right/wrong VFB display. For participants who had some prior singing training, the less complex display was more helpful. We conclude therefore that VFB eventually enhances singing training despite its initial negative impact. In addition, the results indicate that optimal VFB for beginners offers richer, contextualised information, while optimal VFB for singers with some prior training should contain fewer information elements, thus easing their cognitive load.

[Keywords] Cognitive load; Feedback; Human-computer interaction (HCI); Knowledge of results; Motor skills learning; Music education; Singing pedagogy; Visual feedback; Voice – Acoustic analysis

## 1. INTRODUCTION

In late 16th Century England, composer William Byrd wrote a set of pithy observations as Preface to his *Psalmes, Sonets & Songs of Sadnes and Pietie*. It's that frequently-quoted set of epigrams which includes

> 'Since singing is so good a thing,
> I wish all men would learn to sing.'

The Preface is entitled 'Reasons, briefly set down by the author, to persuade everyone to learn to sing'. His sixth reason is pertinent here:

'It is the onely way to know where Nature hath bestowed the benefit of a good voice: which guift is so rare, as there is not one among a thousand, that hath it: and in many, that excellent guift is lost because they want art to expresse Nature.' (Byrd, 1588).

It is instructive to note Byrd's opinion; a good voice is a gift of nature, but the full realisation of its worth can only be made once the possessor of that voice is *taught* singing. Nature alone is not enough; it needs art. It is the art (and science) of singing pedagogy that effects optimal use of that innate gift of a voice.

Learning to sing involves a complex web of inter-related tasks, engaging the body, the mind and the spirit. Both singing teachers and their students have traditionally sought improved means of defining and assessing these tasks. Research across cognate areas of interest to singing teaching includes investigations into educational psychology, neuromuscular skill acquisition, cognitive load and feedback. It is no new thing to offer singers feedback; it has formed the basis of much of the traditional approach to music teaching, and is especially embedded in singing teaching practices. Giving verbal feedback after a performance is the norm. Singing teachers often employ a full-length mirror to assist students with postural difficulties; this could be seen as a real-time visual feedback device, requiring students to monitor a continuous picture while undertaking a learning task (singing). Twentieth-century technologies brought audio recording and then video recording to the singing studio, enabling students to review work at the conclusion of performance; in some studios, a video camera is connected to a wall screen, giving singers immediate visual feedback of body alignment and use.

But is feedback always a blessing? In a review article discussing the effects of feedback on motor skills learning, Wulf and Prinz (2001) summarise the findings of numerous researchers by stating that the effectiveness with which motor skills are acquired may be adversely affected if the learner pays too much attention to her/his performance. In sports science experiments (including tennis and golf training and ski simulation tasks), results indicated that instructing the learner to maintain an external focus, rather than think about their own performance and maintain self-awareness of their movements, yielded optimal skills acquisition. In essence: 'Keep your eye on the trajectory of the tennis ball and where you want it to land – don't think about your backswing.' Wulf and Prinz add that a consequence of this observation is that motor skills learning is further enhanced when there is a greater physical distance between the body and the effect produced by its task.

It is therefore worth considering whether the amount of 'helpful' information offered a student during their learning process can be too much. Cognitive load theory (CLT), which emerged in the 1980s based on such work as Schmidt's (1975) schema theory for discrete motor skill learning, and subsequently expanded by further research, is useful here. Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time. CLT (Sweller, 1988; 1994) describes learning as a form of information processing which utilises both long term memory (where skills and knowledge are permanently housed) and working memory (the area which works with the conscious intellect). Information can only be stored in the long-term memory once it has been processed through the working memory. However, the capacity of working memory alone is very limited in both quantity and duration; Paas, Renkl and Sweller (2003) suggest that no more than two or three novel interacting elements may be handled effectively at any one instant. Because these limitations can hamper learning, CLT proposes that effective instructional design should take into consideration the number of elements

which the learner needs to manage at a given time, and adjust the rate of instruction information to conform to the capacity of the working memory.
Training singers in the art with which they may best 'expresse' Nature involves their singing teachers in a range of tasks. These include musical, literary, aesthetic and neuromuscular skills instruction. It is with the first and last of these four areas of endeavour that this investigation is concerned. Recent sports science has investigated the acquisition of motor skills with such thoroughness that singing teachers are indebted to the richness of these research resources. Singing is, after all, a kind of sport. It certainly is 'a human activity capable of achieving a result requiring physical exertion and/or physical skill,' which is how the Australian Institute of Sport begins to define 'sport'; a dictionary definition, 'An activity involving physical exertion and skill that is governed by a set of rules or customs and often undertaken competitively,' is equally accurate. Anyone questioning the competitive nature of singing has had no contact with the world of opera.

There has already been a range of investigations into the use of cognitive feedback (for instance, Juslin and Laukka, 2000), and computer-aided practice systems (for instance, Banton, 1995; Weidenbach, 1997) in music training. The field of singing has been slower in utilising and assessing these pedagogic developments. Developing his schema theory relating to the way in which children learn to sing in tune, Welch (1985) examined the interaction between learning to sing and KR in the form of visual feedback. His results indicated that schema generation was deficient in child learner singers when KR via VFB was not offered during the learning process; however, the presence of this KR during trials enabled subjects to maintain performance subsequent to the withdrawal of KR. More recently, Verdolini (1997) has researched connections between singing pedagogy and skills acquisition.

The development of a range of music- and voice-based real-time visual feedback applications over the last two decades (Callaghan, 2004; Davis, 1999; Garner & Howard, 1999; Howard, 1993; Nair, 1999; Nisbet, 1995; Thorpe, Callaghan, & van Doorn, 1999; Welch, Howard, & Rush, 1989) makes it timely to investigate ways in which real-time visual feedback may enhance singing training. Research into the use of visual feedback in singing pedagogy should help to derive, test and perfect a coherent visual language for a process which traditionally has been predominantly auditory, linguistic and kinaesthetic.

## 2. AIM

The aim of this investigation was to examine a novel form of VFB for singers, consider its integration into singing pedagogy, and evaluate its impact on pitch matching.

Research questions addressed during this study included:

- How do singers of all skill levels process visual information whilst singing? Does the design of the visual display affect processing?
- Is there an interference effect associated with simultaneous processing of aural, visual and other sensory information by singers?
- Do singers benefit from knowledge of results (KR)?
- Do singers prefer more information or less information about their pitch accuracy when they are learning to sing?
- Do they work better within literal constructs of pitch (Screen B – keyboard design) or are they able to abstract the

concept of pitch to a diagrammatic representation (Screen A – pitch grid design)?

# 3. METHOD

Using two different modes of presentation of visual information of the singer's voice, as well as a non-interactive control mode, this investigation analysed both acoustic and demographic data, following the single case three-group pre-test post-test between subjects (nested) experimental design.

## Participants

Volunteers were sought from staff, students and administrative personnel at the Faculty of Health Sciences campus of the University of Sydney, by advertising a free one-hour singing lesson. Fifty-six participants ranging in age from 18 to 60 years responded; their skills ranged from confident trained singer to untrained non-singer. They were divided randomly into three groups: Group A and Group B were chosen to receive real-time visual feedback, while Group C, the Control group, was offered no VFB. Table 1 gives an analysis of the participants in the study, by gender, visual feedback mode and level of difficulty of the interval pattern sung.

| **VFB mode** | **Skill Level 01** | **Skill Level 02** | **Skill Level 03** | **Totals** |
|---|---|---|---|---|
| Screen A *Males* | - | 2 | 1 | **3** |
| Screen A *Females* | 6 | 6 | 4 | **16** |
| **Screen A Totals** | **6** | **8** | **5** | **19** |
| | | | | |
| Screen B *Males* | 2 | 2 | - | **4** |
| Screen B *Females* | 6 | 6 | 3 | **15** |
| **Screen B Totals** | **8** | **8** | **3** | **19** |
| | | | | |
| Screen C *Males* | 2 | 1 | 1 | **4** |
| Screen C *Females* | 4 | 6 | 4 | **14** |
| **Screen C Totals** | **6** | **7** | **5** | **18** |
| | | | | |
| **TOTALS** | **20** | **23** | **13** | **56** |

**Table 1**: Participants, feedback mode and skill levels.

## Procedure

The overall procedure consisted of a pre-session questionnaire, a singing lesson (including pre-test, intervention and post-test), and a post-session questionnaire. All participants provided written informed consent before participating in the experiment. All sessions were scripted. Each session began with a pre-session questionnaire, to be filled in (hand-written) by the participant, with no coaching from the researcher. Data sought included simple demographic information, singing training, spoken-voice training, musical training, and number of musical instruments played. Each participant was given a single one-hour session conducted by the same investigator, a highly-trained and experienced singing teacher. These sessions took place over a period of fourteen weeks.

The practical work commenced with physical then vocal warm-ups, from which the researcher was able to assess the approximate vocal range, level of singing skill and musicianship of the participant. The researcher then chose an appropriate exercise pattern and began practising it with the participant. This enabled the researcher to determine the participant's optimum pitch range for this activity. Once this was established by agreement, and the participant indicated readiness, the first test pattern (five interval sequences in upward semitone increments) was performed. Patterns were sung on the vowel sound of the participant's choice: either /u/ (as in 'pool') or /a/ (as in 'part'); the vowel remained the same for all that session's tests.

Because of the wide range of prior musical experience in the groups, the exercises used during the study were divided into three skill levels. As far as was possible the distribution of skill level between the three study groups was kept equal.

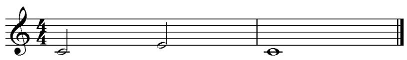


**Figure 1**: Skill Level 1 - Simplest [1-3-1]

**Figure 2**: Skill Level 2 - Medium difficulty [1-4-6-4-1]

**Figure 3**: Skill Level 3 - Most complex [1-flat7-2-3-4].

After working with or without VFB, using scales, single notes or songs, all participants were again tested with the same five patterns originally used. Subsequent to this, they completed a short post-session questionnaire; it contained five diagnostic questions designed to indicate bias towards preferred learning styles as exemplified in Howard Gardner's Multiple Intelligences Theory (Gardner, 1983). Although broad in nature, these general indicators of learning style preference can signpost the profile of singing students most likely to gain benefit from interactive, visually-based instructional feedback systems. The questionnaire also covered questions of health and physical capabilities (handedness, colour blindness, history of vocal problems, history of ear/hearing problems, nicotine and caffeine intake, current medication). For Groups A and B only, there were also four open-ended questions asking the participant how they perceived their interactions with the real-time VFB. Once this questionnaire was completed, the participants again repeated the test sequence of exercise patterns; this ended the session.

## Screen Displays

Three different screen displays were used to collect data relevant to the research questions. Groups A and B were offered different forms of real-time visual feedback (Screen A or Screen B), while Group C had their interval patterns played by the computer instead of the keyboard, but received no visual feedback on their voice. The sham 'intervention' segment was conducted via computer screen similar to that used for Group B. For Groups A and B, two different visual representations of the voice were chosen. Although both offer visual feedback to the learner, the style and nature of that feedback information differs between the two. It would be useful to determine which of these two feedback styles is better for assisting learner singers.

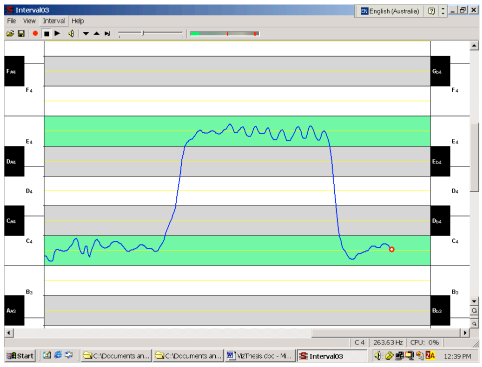


**Figure 4:** VFB mode - Screen A

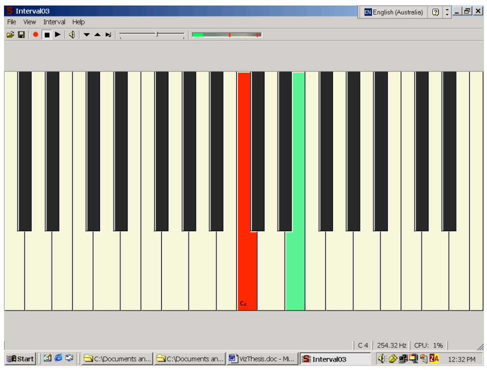


**Figure 5**: VFB mode - Screen B

The two screenshots are of the same sung sequence. At the end of a simple 1 –3 –1 interval, the singer has sung $C_4$, $E_4$, and $C_4$. In Screen A, the sequence can be followed by the pitch trace (blue line) traversing the two green target pitch areas. The learner thus has targets to aim for, validation when these targets are met, a sound and space context within which to place the targeted pitches, and a means of seeing where their voice pitch has been, to help them in targeting future pitches. The design of Screen A is based on a prototype for the pitch display of Sing&See™, specialised software which displays a visualisation of acoustic information about a singer's voice in (near) real- time on a computer screen. This software was developed at the University of Sydney (Callaghan, Thorpe & van Doorn, 2004; Callaghan & Wilson, 2003, Thorpe, Wilson, Crane, van Doorn & Callaghan, 2003) and is now available commercially (http://www.singandsee.com).

In Screen B, only the last note's key (the $C_4$) has changed colour to show its accuracy. The fact that the $E_4$ was sung previously has disappeared; the current pitch is the only one reflected in the display. The design of Screen B is based on a piano, and shows real-time visual feedback for pitch accuracy in a keyboard display. Any sung note colours the appropriate piano key pale red, but only while it is being sung. Targeted pitches are green-coloured keys which, when sung correctly, turn bright red. The display indicates immediately what pitch is currently being sung, but gives the singer no history of what has just been sung previously.

Screen C (control) is the same as Screen B, but with the pitch response deactivated. It therefore merely acts as a substitute for a piano, playing the appropriate exercise pattern for the participant to sing, but offering no visual feedback.

## Equipment

All sessions were undertaken in a soundproof room (Speech Laboratory, School of Communication Sciences and Disorders, University of Sydney). Equipment used in this investigation included: computer (DELL Optiplex GX150 Celeron processor with DELL flat screen monitor and a pair of JUSTER SP-691 speakers), external USB Audio Interface (ROLAND UA-30), head-mounted condenser microphone (AKG MicroMic C 420), DAT Tape machine (SONY ZA5ES), mixing console (BEHRINGER Eurorack MX 602A 6-Channel, 2-Bus), and synthesiser (ROLAND E-36 Intelligent Keyboard; used only on 'Grand Piano' setting).

All test sequences were recorded with the participant standing, with the computer screen at a height of 120cm from the floor, and therefore easily seen by standing adults of average height..

## Analysis

Each of the three test sequences (baseline, intervention and follow-up) was recorded on digital audio tape (DAT) and then transferred to computer memory via a digital SP/DIF link. Cool Edit was used to isolate the individual test sequences and save them into individual WAV sound files. These data were then tagged using the EMU Speech Database System program, to precisely label each note sung. Fundamental frequency was analysed within EMU and the values at the instants identified for each note were transferred to a spreadsheet (Microsoft Excel). The pitch error between what was sung and the specified note was calculated in cents (100 cents equals one semitone) and the average error over the 3 or 5 notes in each sequence was obtained. These values were transferred to a statistical analysis package (SPSS) for subsequent analysis. Demographic, training, learning styles, and health information were also collated and analysed.

In case the study only examined the ability of participants to replicate set pitches, an extra measure of capability was added to the tests; the accuracy with which intervals were sung. It could be argued that a singer who sings two wrong notes but observes an accurate interval between them shows pitching capability.

## 5. RESULTS

Figure 6 shows the average pitch error ($F_o$ error) displayed by all participants. Only the absolute value of the error (i.e. negative errors converted to positive numbers) is shown in order to simplify graphical representation - so on the y axis, the lowest number is the most accurate. The results are segregated into Screen A, Screen B and Screen C (control), and show the average accuracy for the tests at (1) baseline, (2) during intervention, and (3) post-intervention. The tendency for all participants' pitch accuracy to worsen during the intervention part of the session is evident, as is the general improvement following intervention.

**Figure 6**: All participants grouped by feedback (A-B-C); pitch accuracy in Tests 1 to 3.

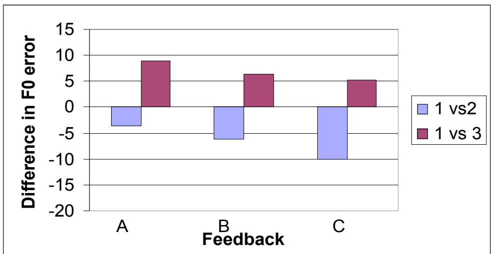
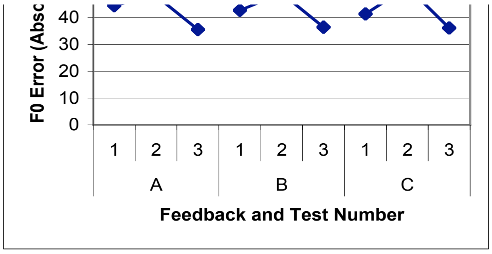



**Figure 7**: All participants grouped by feedback (A-B-C); 1 Vs 2 = effect of intervention; 1 Vs 3 = difference between pre-test and post-test pitch accuracy.

Using the data of Figure 6, two useful comparisons can be made. By subtracting the Test 1 number from the (generally) worse score for Test 2, an average view of the impact that VFB intervention had on pitch accuracy can be gained. These are the blue graphic bars (*1 Vs 2*) which fall below the 0 value in Figure 7. Again, by subtracting the




(generally) improved figure for Test 3 (post-test) from Test 1 (pre-test), a relative measure of overall improvement may be derived. This result is shown in the red graph bars (*1 Vs 3*) which appear above the 0 line in Figure 7.

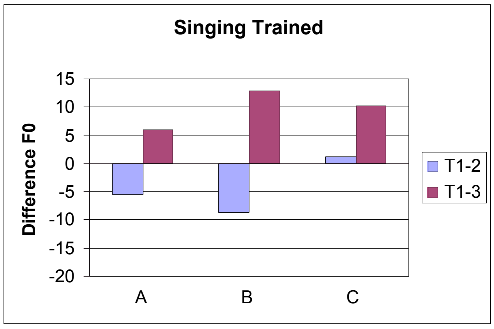



**Figure 8**: Participants who had received singing training: T1-2 = effect of intervention; T1-3 = difference between pre-test and post-test pitch accuracy.

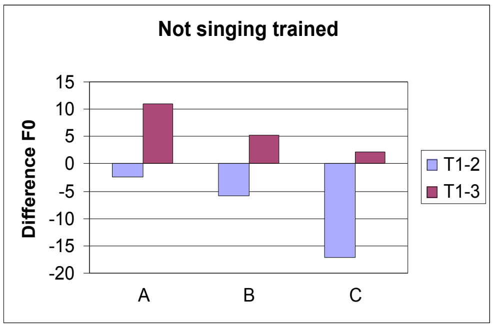



**Figure 9**: Participants who had not received singing training: T1-2 = effect of intervention; T1-3 = difference between pre-test and post-test pitch accuracy

Another consideration was whether the amount of singing training previously experienced by the participants affected their responses to the different feedback modes. For this purpose, participants who reported having had individual singing training (n = 14) were compared to participants who had not (n = 42); Figures 8 and 9 (above) show pitch accuracy results for these two cohorts. The T1-2 result averages the impact that VFB intervention had on pitch accuracy; it is the result of subtracting the Test

1 number from that of Test 2. The T1-3 result gives a relative measure of overall improvement; it is derived by subtracting the (generally) improved figure for Test 3 (post-test) from Test 1 (pre-test).

In Figures 8 and 9, intervention (T1-2) using the pitch grid display (Screen A) had the least adverse impact upon both singing-trained and untrained participants. However, comparing pre-test to post-test results showed that trained singers using Screen B made the best improvement in pitch accuracy (Figure 8). Non-singing-trained participants gained best overall accuracy when using Screen A (Figure 9). The increase in inaccuracy during intervention for the non-singing-trained Control group (Figure 9) may be explained by the way in which their non-VFB second test was administered; their sequence of intervals was played by the computer instead of the keyboard. They were being tested in an unfamiliar set of circumstances, including a different quality of tone, without any feedback.

A likely interference effect on these results was the influence which the use of a keyboard design might have upon people who had undertaken some level of keyboard instrument training. It was therefore decided to select all participants who had this training (n = 32) and contrast their results with the remainder of the participants (n = 24).

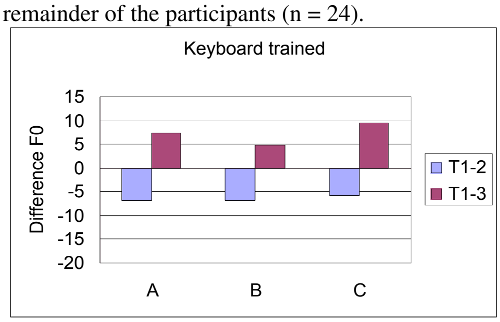



**Figure 10**: Participants who had received keyboard training: T1-2 = effect of intervention; T1-3 = difference between pre-test and post-test pitch accuracy

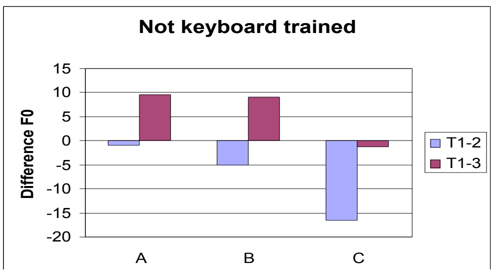



**Figure 11**: Participants who had not received keyboard training: T1-2 = effect of intervention; T1-3 = difference between pre-test and post-test pitch accuracy.

It was expected that keyboard-trained participants would respond better to the visual display of Screen B; as can be seen from Figure 10, this is not the case. Intervention (T1-2) had a similar effect on all groups of keyboard-trained participants in Figure 10, and the best overall improvement in pitch accuracy (T1-3) was shown in the Control group, with VFB from Screen A (the pitch grid) producing better results that Screen B (keyboard design). The results shown in Figure 11 (the non-keyboard trained cohort) reflect the general result of Figure 7, with the Screen A group showing a little more improvement in pitch accuracy than the Screen B group.

On average, all participants improved in pitch accuracy from their baseline performances. The intervention phase was particularly interesting across all groups; there was significant loss of pitch accuracy when interacting with the VFB display. This underpins findings by Welch (1985), Swinnen et. al. (1990), and Steinhauer and Grayhack (2000). However, the Control group also showed a marked lessening of pitch accuracy in this segment of the experimental session.

## Discussion

These early results indicate that providing KR during the learning of pitch matching in singing has the initial result of worsened performance: providing real-time VFB during execution of the task generally resulted in decreased pitch accuracy. In the follow-up phase of the investigation, however, marked performance improvement was shown. This level of improvement was not commensurate with the mere continuance of practice as in the Control group. For singers with some training, Screen B was the more effective visual display, giving the learner specific right/wrong feedback. Untrained singers appeared to respond better to feedback with more detailed, contextualised information. Likely conclusions to draw from these results are that beginners benefit from richer, contextualised feedback because of the unfamiliarity of the task, while participants with some singing training need feedback that gives clear right/wrong information, perhaps because their prior training affects them in the form of added cognitive load.

More analysis work remains to be done with the results of this investigation; these findings are simply the earliest analyses completed. The body of research into self-controlled feedback is important in view of both current and future applications of the kind of real-time visual feedback technology used in this investigation. Studies such as Chiviacowsky and Wulf (2002) are a reminder that, when used either in a singing studio with a teacher, or at home by the student singer alone in practice mode, provision of KR *on request* can optimise motor skills learning.

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