

Balanced imitation sustains song culture in zebra finches

Ofer Tchernichovski, Sophie Eisenberg-Edidin & Erich D. Jarvis

Supplementary Information

Supplementary Note 1. Testing for imitation from neighbor tutor songs

We tested if pupil's who imitated their tutor's song poorly were influenced by the song of other tutors in their room, whom they could hear. We did not record the entire acoustic environments that existed in each room in each developmental period. However, we found 22 clutches with pupils who imitated poorly (lowest quartile), where we have recordings from at least one neighboring tutor that raised chicks in the same room at the same time. In cases of more than a single neighbor tutor, we selected the tutor that was imitated most accurately by his sons. We then measured the similarity between the song of pupils who imitated their tutor poorly, and the song of that 'popular' neighbor tutor. We performed this analysis in four different colony rooms. We compared these similarities to shuffled data: pairing each pupil with a non-neighbor tutor from a different room. We found that the mean similarity within a room was not higher than that across rooms (within a room: $38.7 \pm 2.6\%$; across rooms: $40.1 \pm 3.6\%$). Although we cannot exclude the possibility that these pupils might have copied song elements from tutors that we did not record, results are consistent with earlier observations, suggesting that zebra finches mainly imitate tutors that live with them and, in those conditions, ignore songs from birds they cannot interact with.

Supplementary Note 2. Mixed effects statistical models

2.1 Linear mixed-effects model for syllable diversity

Linear mixed-effects model fit by ML

Model information:

| | |
|-----------------------------|-----|
| Number of observations | 81 |
| Fixed effects coefficients | 2 |
| Random effects coefficients | 116 |
| Covariance parameters | 3 |

Formula: Influence ~ 1 + DivTutor + (1 | tutorID) + (1 | pupilID)

Model fit statistics:

| AIC | BIC | LogLikelihood | Deviance |
|--------|--------|---------------|----------|
| 703.18 | 715.15 | -346.59 | 693.18 |

Fixed effects coefficients (95% CIs):

| Name | Estimate | SE | tStat | DF | pValue | Lower | Upper |
|----------------------------------|----------|--------|---------|----|----------|---------|--------|
| {'(Intercept)'} {'DivTutor' } | 44.968 | 25.974 | 1.7313 | 79 | 0.087302 | -6.7311 | 96.668 |
| | 8.8155 | 9.9074 | 0.88979 | 79 | 0.37628 | -10.905 | 28.536 |

2.2 Linear mixed-effects model for song similarity (tutor->pupil):

Model information:

| | |
|-----------------------------|-----|
| Number of observations | 160 |
| Fixed effects coefficients | 2 |
| Random effects coefficients | 228 |
| Covariance parameters | 3 |

Formula:

Similarity ~ 1 + tutorinfo + (1 | TutorID) + (1 | PupillID)

Model fit statistics:

| | | | |
|--------|--------|---------------|----------|
| AIC | BIC | LogLikelihood | Deviance |
| 1368.9 | 1384.2 | -679.44 | 1358.9 |

Fixed effects coefficients (95% CIs):

| Name | Estimate | SE | tStat | DF | pValue | Lower | Upper |
|-----------------|----------|--------|--------|-----|----------|---------|--------|
| {'(Intercept')} | 4.5151 | 34.44 | 0.1311 | 158 | 0.89586 | -63.506 | 72.537 |
| {'tutorinfo' } | 21.614 | 11.077 | 1.9512 | 158 | 0.052801 | -0.2646 | 43.492 |

Random effects covariance parameters (95% CIs):

Group: TutorID (68 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|--------|-------|
| {'(Intercept')} | {'(Intercept')} | {'std'} | 11.765 | 8.5868 | 16.12 |

Group: PupillID (160 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|------------|-------------|
| {'(Intercept')} | {'(Intercept')} | {'std'} | 9.5709 | 3.432e-225 | 2.6691e+226 |

Group: Error

| Name | Estimate | Lower | Upper |
|-------------|----------|-------------|-------------|
| {'Res Std'} | 10.301 | 2.5171e-194 | 4.2158e+195 |

2.3 Linear mixed-effects model for song influence (pupil->tutor):

Linear mixed-effects model fit by ML

Model information:

| | |
|-----------------------------|-----|
| Number of observations | 160 |
| Fixed effects coefficients | 2 |
| Random effects coefficients | 228 |
| Covariance parameters | 3 |

Formula:

Influence ~ 1 + tutorSongDiversiy + (1 | TutorID) + (1 | PupillID)

Model fit statistics:

| | | | |
|--------|--------|---------------|----------|
| AIC | BIC | LogLikelihood | Deviance |
| 1378.7 | 1394.1 | -684.34 | 1368.7 |

Fixed effects coefficients (95% CIs):

| Name | Estimate | SE | tStat | DF | pValue | Lower | Upper |
|-----------------|----------|--------|---------|-----|-----------|---------|---------|
| {'(Intercept')} | -87.206 | 33.012 | -2.6417 | 158 | 0.0090794 | -152.41 | -22.005 |

{ tutorSongDiversiy } 50.645 10.623 4.7672 158 4.2092e-06 29.662 71.627

Random effects covariance parameters (95% CIs):

Group: TutorID (68 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|--------|--------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 10.52 | 7.3672 | 15.021 |

Group: PupilID (160 Levels)

| Name1 | Name2 | Type | Estimate | Lower |
|-----------------|-----------------|---------|----------|-------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 10.687 | NaN |

2.4.2 Linear mixed-effects model for pupil vs tutor song diversity

Model information:

| | |
|-----------------------------|-----|
| Number of observations | 160 |
| Fixed effects coefficients | 2 |
| Random effects coefficients | 228 |
| Covariance parameters | 3 |

Formula:

PupilInfo ~ 1 + tutorinfo + (1 | TutorID) + (1 | PupilID)

Model fit statistics:

| AIC | BIC | LogLikelihood | Deviance |
|--------|---------|---------------|----------|
| -148.1 | -132.72 | 79.05 | -158.1 |

Fixed effects coefficients (95% CIs):

| Name | Estimate | SE | tStat | DF | pValue | Lower | Upper |
|-----------------|----------|----------|--------|-----|------------|---------|---------|
| {'(Intercept)'} | 1.8714 | 0.21987 | 8.5116 | 158 | 1.2535e-14 | 1.4372 | 2.3057 |
| {'tutorinfo' } | 0.39667 | 0.070882 | 5.5961 | 158 | 9.4591e-08 | 0.25667 | 0.53666 |

Random effects covariance parameters (95% CIs):

Group: TutorID (68 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|----------|----------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 0.043436 | 0.019049 | 0.099045 |

Group: PupilID (160 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|-------|-------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 0.11119 | NaN | NaN |

Group: Error

| Name | Estimate | Lower | Upper |
|-------------|----------|-------|-------|
| {'Res Std'} | 0.088047 | NaN | NaN |

2.4.3 Linear mixed-effects model for pupil song diversity (all factors combined):

Formula:

PupilSongDiversity ~ 1 + Similarity + Influence + TutorSongDiversity + (1 | TutorID) + (1 | PupilID)

Model fit statistics:

| | | | |
|---------|---------|---------------|----------|
| AIC | BIC | LogLikelihood | Deviance |
| -167.68 | -146.15 | 90.839 | -181.68 |

Fixed effects coefficients (95% CIs):

| Name | Estimate | SE | tStat | DF | pValue | Lower | Upper |
|------------------------|-------------|------------|----------|-----|------------|------------|------------|
| {'(Intercept)'} | 1.8762 | 0.21598 | 8.687 | 156 | 4.7489e-15 | 1.4496 | 2.3028 |
| {'Similarity' } | 0.0032593 | 0.00069207 | 4.7095 | 156 | 5.4504e-06 | 0.0018923 | 0.0046263 |
| {'Influence' } | -0.00034424 | 0.00068015 | -0.50613 | 156 | 0.61348 | 0.18298 | 0.47618 |
| { TutorSongDiversity } | 0.32958 | 0.074217 | 4.4408 | 156 | 1.6891e-05 | -0.0016877 | 0.00099925 |

Random effects covariance parameters (95% CIs):

Group: TutorID (68 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|----------|----------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 0.041927 | 0.018252 | 0.096313 |

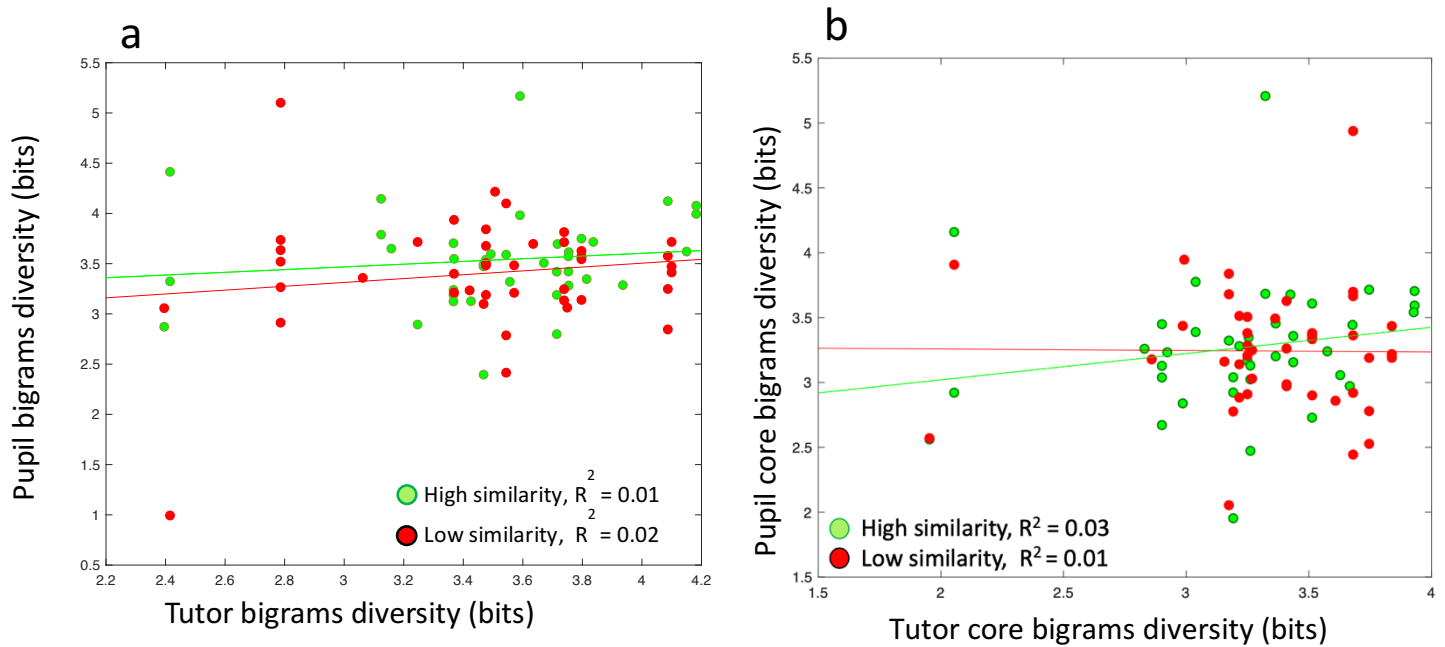
Group: PupilID (160 Levels)

| Name1 | Name2 | Type | Estimate | Lower | Upper |
|-----------------|-----------------|---------|----------|-------|-------|
| {'(Intercept)'} | {'(Intercept)'} | {'std'} | 0.10243 | NaN | NaN |

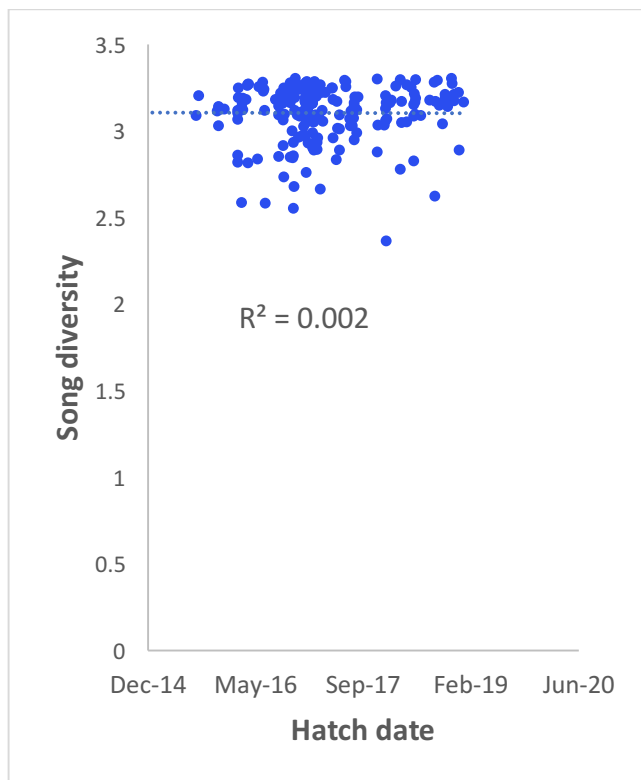
Group: Error

| Name | Estimate | Lower | Upper |
|-------------|----------|-------|-------|
| {'Res Std'} | 0.082244 | NaN | NaN |

Supplementary figures



Supplementary Fig. 1: **a** Tutor vs. pupil diversities of syllable type transitions (bigrams). **b** same as (a) for core-motif syllable types transitions are uncorrelated. Core motif syllables were identified as syllable types that repeat in a persistent serial order in each song motif, excluding introductory notes and repeated calls. Source data for this figure is in Supplementary Data File 1.



Supplementary Fig. 2: Time course of song diversity during the lifetime of the colony. Source data for this figure is in Supplementary Data File 1