Adolescent Social Environment Shapes Sexual and Aggressive Behaviour of Adult Male Zebra Finches (*Taeniopygia guttata*)

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ABSTRACT

Adolescence is the pivotal transitional phase during which animals become sexually and socially mature and acquire the skills to cope with a variety of environmental challenges on their own. We investigated in a bird species, the zebra finch, how the social environment experienced during this period influences their behaviour in a sexual context. Zebra finches were kept in pairs (male-female or male-male) or larger mixed-sex groups (3 males and 3 females) during adolescence and the long-term consequences were studied on courtship behaviour, aggressiveness and attractiveness in 42 males. To investigate the stability of the observed effects over time, all behavioural tests were repeated approximately four months after the initial recordings. Males that grew up with a single female showed the most intense courtship and highest aggressiveness and were most attractive to females, while group-reared males had lowest courtship and aggressiveness and were the least attractive. The observed differences in courtship and aggressiveness were stable, while the differences in attractiveness disappeared over time. These findings are very similar to earlier studies on guinea pigs, indicating that the observed effects represent a general phenomenon, not restricted to mammals with a similar function and presumably also similar underlying mechanisms.
KEYWORDS
adolescence, social experience, phenotypic plasticity, aggressiveness, courtship, attractiveness, zebra finch

INTRODUCTION
The social environment experienced early in life can strongly affect how an individual deals with social challenges in adulthood, such as aggression towards conspecifics (Benus and Henkelmann 1998; Delville et al. 2003; Arnold and Taborsky 2010), courtship behaviour (Siegeler et al. 2011) mate-choice behaviour (Adkins-Regan and Krakauer 2000; Field and Waite 2004), territoriality (Sundström et al. 2003) and grouping behaviour (Chapman et al. 2008). Most research about social influences on behavioural development has concentrated on the early postnatal phase when the first social experiences have important long-term effects on social and sexual behaviour (Lorenz 1935; Immelmann and Suomi 1981). Only very recently research has started to emphasize and investigate the importance of the social conditions during adolescence (Sachser and Lick 1991; Ferris et al. 2005; Kaiser et al. 2007; Sachser et al. 2011). During this transitional period, when juveniles mature to independent adults, they typically leave the familiar environment of their early development and encounter a range of novel environments, situations and conspecifics. Maturation of morphology and behaviour during adolescence is accompanied and regulated by changes in endocrinological and neuronal systems (Bischof and Rollenhagen 1999; Bischof et al. 2002; Bischof 2003; Sisk and Zehr 2005; Blakemore 2008; Blakemore 2010; Lürzel et al. 2010; Buwalda et al. 2011; Lürzel et al. 2011). Yet, we know very little about the consequences of the social environment during this phase for adult behaviour.
Evidence of phenotypic modifications caused by social influences during adolescence originates mainly from research on mammals (Sachser and Kaiser 2010), including humans (Dishion et al. 1997; Carlo et al. 2007), although social experience during the transition to adulthood can have long-lasting influences on adult behavioural traits in birds as well (Bischof and Clayton 1991, Groothuis and Mulekom 1991; Bischof 1994). Given that such phenotypic changes are potentially adaptive processes enhancing survival and reproductive success, the consequences of the social environment experienced during the transition to adulthood merit study on a broader scale than the previous narrow focus in birds which has mainly concentrated on the influence of the social environment on imprinting or song learning (Eales 1985; Bischof 1994; Bischof 1997). Hence, the aim of this study is to investigate the potential importance of variation in social experience during adolescence on behavioural interactions with conspecifics during adulthood in an avian species, the zebra finch (Taeniopygia guttata).

Zebra finches are highly social animals that roost and breed together in colonies. During adolescence (day 40 to 100), individuals experience fundamental changes in the social environment since they are no longer primarily surrounded by the familiar parents and siblings, but start to interact with a range of unfamiliar conspecifics in their colony that may become partners or competitors (Zann 1996). As in other species, sexual dimorphism in plumage and behaviour appears (Sossinka 1980) during this phase, and sexual preferences and adult song performance stabilizes (Bischof 1997). These morphological and behavioural changes are accompanied by hormonal and neuronal reorganisation (Pröve 1983; Adkins-Regan et al. 1990) which can be influenced by the social context experienced during this phase (Pröve 1981; Rollenhagen and Bischof 1994; Bischof et al. 2002; Bischof 2003).

We studied how the number and sex of conspecifics encountered during adolescence influences the behaviour of adult male zebra finches (Taeniopygia guttata) in a sexual context, by keeping them in pairs (male-male or male-female) or in groups (3 males and 3...
females) during this period. When they were adult, we examined courtship and aggressive
behaviour in the males. Since we found behavioural differences between males from different
social backgrounds, we also tested the males’ relative attractiveness to females. To investigate
the stability of the observed effects over time, all behavioural tests were repeated about 4
months later.

METHODS

Subjects

The 42 male zebra finches (Taeniopygia guttata) used for this study were bred in five aviaries
(6m*2m*3m), each containing 10 to 15 domesticated adult breeding pairs at the University of
Bielefeld (for further housing details see below). We tried to avoid the use of siblings
throughout the study. The actual subjects used in the study were sired by 24 different breeding
pairs in 26 broods and in no case siblings were assigned to the same treatment group. During
their first 40 ± 2 days of life, they were reared in the breeding aviaries with their parents,
siblings and other zebra finches of different ages and both sexes. Throughout the whole
experiment, a commercial zebra finch diet (Elles, Mischfutter für Exoten, L. Stroetmann Saat,
48163 Münster, Germany) and water were available ad libitum. Twice a week this diet was
supplemented with egg food (Cédé N.V., 9940 Evergem, Belgium) and germinated seeds.

Treatment

At day 40 ± 2 after hatching, birds (males and females) were assigned to one of the three
treatment groups: one male and one female (1m/1f), 2 males without a female (2m/0f), or 3
males and 3 females (3m/3f). These birds were reared together until adulthood (day 110 ± 2).
Siblings were never assigned to the same group, and birds within one group did not differ in age by more than 4 days. During the treatment phase, the different treatment groups had auditory but no visual contact. All groups had access to at least 2 big feeding stations (automatic circular feeders with a central food depot (diameter: 16 cm, height: 20 cm)) during this phase, to ensure that the easy access to food was warranted for each bird and a potential difference in food competition between the groups of different sizes was minimized.

After 70 ± 2 days in the treatment groups, the males were transferred into individual cages (0.3m*0.4m*0.4m) located in two rooms in our main building where they experienced a constant temperature of 25°C and a light-dark cycle of 14:10 h. Again, birds had auditory but no visual contact with each other. Three weeks later, we began testing the birds’ courtship behaviour, aggression and attractiveness (Table 1). The stimulus females used in these tests were colony reared and thus had experience with both male and female conspecifics of different ages.

The study was performed in two batches. Males from batch 1 (N=8 for each treatment) were hatched and kept in outdoor aviaries (6m*2m*3m) during their treatment phase (June - December 2010), thus temperature and light conditions were determined by the local weather and the local natural photoperiod. However, all aviaries were roofed and featured with infrared heat lamps to ensure that birds were not directly exposed to rain and cold. Males from batch 2 (N=6 for each treatment) were hatched and kept indoors (October 2010 - February 2011) in standard double cages (0.3m*0.8m*0.4m) (1m/1f and 2m/0f) or in small indoor aviaries (1m*2m*2m) (3m/3f) at a constant temperature of 25°C and a light-dark cycle of 14:10h.
Male Behaviour and Attractiveness

Courtship Song

Directed song, which is defined as song that a male produces facing a female in his proximity (Sossinka and Böhner 1980) was quantified as an important component of male courtship behaviour. Each male was individually exposed to an unfamiliar female sitting in a cage attached to the front of the male’s cage. Three different females were used; each served equally often as a stimulus for the males of the different treatment groups. The experiment took place in the room where males were individually housed between different tests. Thus, background noise produced by conspecifics was always present. The latency to present the first courtship song and the number of directed motifs sung within the first 10 minutes were recorded. Males that did not sing at all received a latency value of 600 seconds. Recordings took place between 9:00 am and 11:00 am.

Aggression Towards Other Males

One male from each treatment group and an unfamiliar female were housed together in a standard double cage (0.3m*0.8m*0.4m; four perches: two in the upper half and two in the lower half of the cage). Males were identified by using differently coloured rings (violet, light blue and yellow) with care taken that each colour was assigned with equal frequency to each treatment group throughout all replicates. We recorded the number of times one male chased another as a measure of aggressiveness towards other males. Chasing was defined as a flight at another male followed by his immediate displacement. A chase was finished when the chased bird landed. Tests always lasted 3 hours and started between 8:00 and 9:00 am by introducing the female into the cage. Every five minutes the behaviour of a focal male from a different treatment was recorded, resulting in 12 observation periods (a total sample time of 1 hour) for each male.
To prevent physical harm to the experimental males, they were continuously observed during the tests and these would have been interrupted if the males showed sustained high intensity aggression or actual fighting which could result in injuries. However, this was not necessary since the males showed only low-intensity aggressive behaviour such as threats and chases, which is typical for zebra finches, who are highly social and generally tolerant of conspecifics.

**Male Attractiveness**

One male from each treatment group was kept individually in a cage (0.4x0.3x0.2m) with metal bars allowing visual contact from all sides (Figure 1 inset). The three cages containing the experimental males and a fourth, empty cage, representing a neutral location were affixed in the four upper corners of a cubic aviary made of wire mesh (2x2x2m) (Figure 1). The empty cage was included in the setup because a pilot experiment showed that this neutral position prevents females from developing a place preference. A female, unfamiliar to all males was brought into the aviary where she could perch in front of each of the four cages. A light-barrier on the perch automatically recorded the time the female spent in front of each cage. Recordings took place over a period of eight hours from 8:00 am to 5:00 pm. After each hour, the position of males within the setup was changed by moving each cage one position clockwise to ensure that the measured time reflected a true male-preference rather than a place preference. For acclimatisation, the female was placed into the aviary and the males into their cages 15 hours before the test started. The female and each male had mutual visual contact, but the males could not see one another.

The same three males remained together in the aggressive behaviour test and the attractiveness test and thus got to know each other as the study progressed.
Temporal Stability of male courtship rate, aggressiveness and attractiveness

Each of the behavioural tests was repeated 4 months after the first measurements. Between the first recordings and the repetitions, all males were kept in visual but not acoustic isolation. In the repetitions, males were tested in new combinations and thus were not familiar with each other beforehand. However, as in the first experiments, the three males that built a triad in the aggressiveness test were later tested together in the attractiveness test. As stimulus birds, new unfamiliar females were used. One 3m/3f male died, resulting in a sample size of N = 41 for the directed song measurement. The aggression and attractiveness tests were not repeated for this male nor for the males from the 1m/1f and the 2m/0f treatment partnered with him during the first testing phase, thus reducing the sample size to N=39 for these tests.

Data Analysis

Data Transformations

Some data was transformed because variances were significantly different between treatments (Levene’s Test) or residuals were not normally distributed (Kolmogorov-Smirnov-Test). The numbers of motifs sung in the directed song test were log transformed (a value of 1 had to be added to each measure because several birds did not sing at all).

For the analysis of aggressiveness, the number of chasings was summed up for each male over all 12 observations and a rank of aggressiveness was assigned to each bird, giving the highest rank to the male with the highest total number of chasings.

We calculated an attractiveness score as the relative duration of stay in front of each male for each female tested to correct for the variation between females in overall perching time. Time spent at the empty cage was not included in this calculation. Since fractions can only vary...
between 0 and 1, we used the logit of the attractiveness score to ensure normality and variance homogeneity. All other measured data did not have to be transformed and were analysed using the raw values for the ANOVA.

Statistics

Data from both batches were analysed in a single statistical model, using an ANOVA with “treatment” and “batch” as fixed factors. Unless specifically mentioned in the results, the effect of the interaction between batch and treatment and the effect of batch on their own were negligible (p > 0.2) and were excluded from the final model. When the ANOVA showed a significant treatment effect, pair-wise post-hoc comparisons were done using two-sample t-tests with Sidak adjustment to correct for multiple testing.

To test for a relationship between the males’ relative attractiveness and all other behavioural measures, we performed correlation analyses. In case the respective data sets did not differ from a normal distribution (Kolmogorov-Smirnov-Test) we calculated a Pearson-Correlation; otherwise we used a non-parametric Spearman-Rank-Correlation.

The change in male attractiveness over time was calculated by subtracting the value from the first recording from his value from the second recording (four months later) for each male. These values were tested against a test-value of zero using a one-sample t-test.

Results are always presented as means ± standard errors. All analyses were performed in SPSSv19 and the significance level α was set at p < 0.05.
RESULTS

Male Behaviour and Attractiveness

Courtship Song

Male zebra finches that grew up in different social environments during adolescence differed significantly in their latency to court an unfamiliar female (ANOVA: $F_{2,39} = 9.27, P = 0.001$, Figure 2A) and in their motif rate (ANOVA: $F_{2,39} = 9.98, P < 0.001$, Figure 3A). Post-hoc comparisons revealed that males reared in a mixed-sex group (3m/3f) started to court significantly later than males raised with a single female (1m/1f) or a single male (2m/0f) (two-sample t-test with Sidak adjustment: 3m/3f vs. 1m/1f: $t_{26} = 3.92, P = 0.001$, 3m/3f vs. 2m/0f: $t_{26} = 3.51, P = 0.003$) The latter two groups did not differ in their latency to court an unfamiliar female (two sample t-test with Sidak adjustment: $t_{26} = 0.41, P = 0.97$). A similar pattern was observed for the motif rate: 3m/3f males had a significantly lower rate of singing than 1m/1f and 2m/0f males (two-sample t-test with Sidak adjustment: 3m/3f vs. 1m/1f: $t_{26} = 4.72, P < 0.001$, 3m/3f vs. 2m/0f: $t_{26} = 3.12, P = 0.008$), while the latter ones did not differ in their motif rate (two-sample t-test with Sidak adjustment: $t_{26} = 1.60, P = 0.62$).

Aggression Towards Other Males

The social environment experienced during adolescence significantly influenced male zebra finches’ aggressiveness towards other males when competing for a female (ANOVA: $F_{2,39} = 3.82, P = 0.03$, Figure 4A). Post-hoc comparisons showed that 3m/3f males were significantly less aggressive compared to 1m/1f males (two-sample t-test with Sidak adjustment: $t_{26} = 2.69, P = 0.03$). Compared to 2m/0f males, both 3m/3f males (two-sample t-test with Sidak adjustment: $t_{26} = 0.82, P = 0.80$) and 1m/1f males (two-sample t-test with Sidak adjustment: $t_{26} = 1.88, P = 0.19$) did not differ in aggressiveness. Batch was excluded from the final model.
since the effect of the interaction between treatment and batch (ANOVA: $F_{2, 36} = 2.45, P = 0.10$) and of batch (ANOVA: $F_{2,38} = 3.47, P = 0.07$) were not statistically significant and their inclusion did not change the significance of the treatment effect.

Male Attractiveness

The time female zebra finches spent with a male depended significantly upon the male’s social rearing conditions (ANOVA: $F_{2,39} = 7.08, P = 0.002$, Figure 5A). Females spent significantly more time near 1m/1f males compared to 3m/3f males (two-sample t-test with Sidak adjustment: $t_{26} = 3.71, P = 0.002$). Furthermore, there was a strong tendency for the females to sit longer near 1m/1f males compared to 2m/0f males (two-sample t-test with Sidak adjustment: $t_{26} = 2.41, P = 0.06$). The time females spent in front of 2m/0f and 3m/3f males did not differ significantly (two-sample t-test with Sidak adjustment: $t_{26} = 1.29, P = 0.50$). The males’ relative attractiveness was positively correlated with male courtship motif rate (Pearson: $N = 42, r_p = 0.354, P = 0.02$) and the absolute number of chasings (Spearman: $N = 42, r_s = 0.466, P = 0.002$). Furthermore, a negative relationship between the males’ relative attractiveness and their latency to court a female was observed by trend (Spearman: $N = 42, r_s = -0.254, P = 0.11$).

Temporal Stability of male courtship rate, aggressiveness and attractiveness

Four months after the first recordings, treatment effects on latencies to court an unfamiliar female (ANOVA: $F_{2,38} = 3.97, P = 0.03$, Figure 2B), on motif rate (ANOVA: $F_{2,38} = 4.63, P = 0.02$, Figure 3B), and on the level of aggressiveness towards other males (ANOVA: $F_{2,35} = 4.8, P = 0.01$, Figure 4B) remained stable. Group-reared males still started to court an
unfamiliar female significantly later than males reared with a single female (two-sample t-test with Sidak adjustment: $t_{24} = 2.52, P = 0.048$), and they still started to court later than males reared with a single male, although the significance of this difference was borderline (two-sample t-test with Sidak adjustment: $t_{24} = 2.39, P = 0.07$). As during the initial recording, 2m/0f and 1m/1f males did not differ in their latency to court (two-sample t-test with Sidak adjustment: $t_{24} = 0.13, P = 0.99$). The motif rate of 3m/3f was still significantly lower than the motif rate of 2m/0f males (two-sample t-test with Sidak adjustment: $t_{24} = 2.83, P = 0.022$), and tended to be lower than that of 1m/1f males (two-sample t-test with Sidak adjustment: $t_{24} = 2.25, P = 0.09$). Males reared with a single male or female still did not differ in their motif rate (two-sample t-test with Sidak adjustment: $t_{24} = 0.59, P = 0.91$). Also, as in the first measurement, group-reared males were still significantly less aggressive compared with those reared with a single female (two-sample t-test with Sidak adjustment: $t_{24} = 2.89, P = 0.02$), and still did not differ in aggressiveness from those reared with a single male (two-sample t-test with Sidak adjustment: $t_{24} = 0.47, P = 0.95$). Males reared with a single female continued to show on average the highest level of aggression, which this time was almost significantly higher than that of males reared with a single male (two-sample t-test with Sidak adjustment: $t_{24} = 2.41, P = 0.06$).

In contrast to the stable treatment differences in courtship and aggression, females no longer spent different amounts of time in front of the males when the attractiveness test was repeated (ANOVA: $F_{2,36} = 0.84, P = 0.44$, Figure 5B). This was due to a significant increase in the relative time females spent in the proximity of the 3m/3f males (one-sample t-test: $t_{12} = 2.19, P = 0.049$), and in a significant reduction in the relative time spent in front of the 1m/1f males (one-sample t-test: $t_{12} = -3.60, P = 0.004$). The relative time females spent in front of the 2m/0f males did not change (one-sample t-test: $t_{12} = 0.21, P = 0.84$). Males’ relative attractiveness was no longer correlated with courtship motif rate (Pearson, N = 39, $r_p = 0.016$, ...
P = 0.92), latency to court a female (Spearman: N = 39, r_s = -0.09, P = 0.59) and the males’ absolute number of chasings (Spearman: N = 39, r_s = -0.011, P = 0.946).

**DISCUSSION**

Our experiments clearly show that the behavioural responses of zebra finch males to social stimuli (potential mate/competitor) strongly depended on the social environment which they experienced during adolescence. Males that grew up with a single female during adolescence showed the most intense courtship and highest aggressiveness towards mates or competitors and were the most attractive to female conspecifics, while group-reared males had lowest courtship and aggressiveness rates and were also the least attractive.

When we repeated the tests four months later, the significant differences in courtship (albeit slightly diminished) and aggressiveness persisted. In contrast, the attractiveness of the males, as rated by female zebra finches, no longer differed significantly between treatments. The strength of the social environment’s impact during adolescence on the development of these behavioural traits is further corroborated by the fact that males were affected equally in almost all cases in both batches, although these differed in temperature, photoperiod, housing and background noise (see Methods). The only difference between the batches that one might see by trend is that males that were reared in cages/small aviaries (batch 2) tend to be more aggressive than males reared in big aviaries (batch 1) (Figure 4). It could be speculated that this results from the difference in space the birds had during their treatment phases. While the males in big aviaries had some space to escape from aggression, birds reared in small aviaries might not have been easily able to avoid aggressive interactions and thus became more aggressive on their own. However, since the differences between batches are so small, even
the small aviaries might have been big enough to allow the avoidance of aggressive
encounters.

The outcome of our experiment strongly resembles very similar studies in guinea pigs reared
pair-wise or in colonies during adolescence: when two pair-wise reared males were housed
with a single unfamiliar female, they started to court earlier and showed higher rates of
aggression than two colony-reared males in the same situation (Sachser and Lick 1993, Kaiser
et al. 2007). The consistency of these effects across an avian and a mammalian species
indicates that the observed influence of social experience during adolescence may represent a
general phenomenon.

**Function of the Behavioural Modifications**

A possible function of the observed behavioural modifications may be that the social
environment during adolescence prepares individuals for the demands of the social conditions
during adulthood. Living in a group requires that individuals get along with other members of
their group to minimize costs originating from competition and to benefit from the advantages
of living in a social group. The low levels of aggression in our group-reared male zebra
finches may directly decrease costs of physical conflicts and their more cautious courtship
behaviour may reduce costs indirectly by decreasing the likelihood of courting a female that is
already paired, which in zebra finches results in a physical conflict with the female’s mate and
the female itself (Silcox and Evans 1982; Zann 1996). Indeed, studies on guinea pigs indicate
that individuals benefit from such behavioural modifications: guinea pig males reared in a
colony during adolescence easily integrated into a new social group without showing signs of
stress, whereas males that spent their adolescence in isolation or together with a single female,
were involved in a high amount of socio-negative interactions, lost a substantial amount of
weight and showed increased cortisol levels when exposed to a group of unfamiliar
conspecifics during adulthood (Sachser 1993; Sachser and Renninger 1993). Whether social experience in a group during adolescence is indeed beneficial for male zebra finches when they have to interact with other individuals later in life is under investigation at present. The behavioural profile shown by zebra finch males reared with a single female could be interpreted as pathological in terms of not being well adapted to a group-living life-style. Alternatively, their behaviour may be adapted to a social environment where it is not necessary to adjust the behaviour to the continuous presence of other individuals, as suggested by Sachser et al. (2011). In nature, such a situation may occur under low population densities, when the chance to meet a potential mate may be quite small so that the best strategy to maximize reproductive success may be to court each female immediately and with high intensity and to attack every potential competitor. In the ancestor of the wild guinea pig, the wild cavy, a comparable situation exists in the natural habitat at low population densities (Asher et al. 2004). In contrast, under high densities male cavies are less aggressive towards same-sex conspecifics and pursue a queuing strategy to increase reproductive success (Asher et al. 2008). According to the guinea pig /cavy studies the distinct behavioural modifications observed in male zebra finches grown up with a single female or in a group of conspecifics during adolescence can therefore also be interpreted as adaptations to different social environments, for example to local or seasonal differences in population densities.

Temporal Stability of male courtship rate, aggressiveness and attractiveness

The experimental treatment affected courtship and aggressive behaviour 3 weeks after animals had been removed from the different social environments and kept under identical conditions. Moreover, the repetitions of the directed song and the aggression measurements four months after the first test clearly demonstrated that the differences between males grown
up under distinct social conditions during adolescence are not temporary, but persist at least for several months, even though the males from all treatments made the same novel experiences between the test repetitions. They were kept either isolated between the tests or spent time with unfamiliar females and males from the other treatments during the tests, but these experiences were not sufficient to override the influence of the social conditions during adolescence, indicating a reduced behavioural plasticity for courtship and aggression in adulthood.

The high courtship rate of pair-wise reared males may have directly increased their attractiveness in the first preference tests as has been shown in many species (Gottlander 1987; Radesäter et al. 1987; Collins et al. 1994; but see also: Forstmeier and Birkhead 2004). This assumption gets even directly supported by the positive correlation between motif rate and the males’ relative attractiveness. Such enhancement of courtship rate may originate from a lack of experience with comparing receptivity, rejection and solicitation behaviour of different females leading to an indiscriminate courting of all presented females, as has been shown for females who are less choosy when they have little experience with male courtship song (Riebel 2000, Lauay et al. 2004). Also, the attractiveness of group-reared males may be reduced because the presence of juvenile males may have inhibited a faithful representation of their father’s song, (Tchernichovski and Nottebohm 1998) possibly because they copied song syllables from each other (Jones et al. 1996). Furthermore, courtship activity of a male can be reduced by the presence of another male (Ikebuchi et al. 2009). Since males already knew each other from the aggressiveness test and were able to see each other in the attractiveness tests, the most aggressive male may have suppressed courtship activity of the other males and thereby influenced the choice of the female indirectly. The strong positive correlation between male’s relative attractiveness and their level of aggressiveness may underline this idea.

Although there is already some evidence that a female zebra finch’s preference in a choice test reflects a true sexual preference (Clayton 1990), it seems important to note that an
observed preference in a choice test like the one performed in this study (which did not allow
the different birds to interact physically with each other) does not necessarily mean that the
females would actually pair with the male they preferred in this test when they can interact
physically with him (Rutstein et al. 2007).

The attractiveness of the males for females was not stable over time. Four months after the
initial assessment, 3m/3f males had become more attractive while the attractiveness of the
1m/1f males had decreased, so that male attractiveness no longer depended on their social
rearing conditions. This indicates that some aspects of male behaviour or appearance that we
did not measure must have changed from the first to the second measurement. Alternatively,
the slight reduction in the differences in courtship rate may have been sufficient to prevent
females from differentiating between the different phenotypes.

In summary, further approaches are needed to shed more light on the impact of social
experience during adolescence on the development of zebra finch males’ attractiveness.

Adolescence - A Sensitive Period for the Modification of Socially
Relevant Behaviour?

Our study clearly shows that the development of male zebra finches’ courtship and aggressive
behaviour is influenced by the social environment they experience during adolescence. It is
not possible to decide from our experiments whether this long-lasting influence of the social
environment is restricted to the time of adolescence (a sensitive period) or can be observed
over the entire lifespan of an animal. Sensitive periods at the time of adolescence have been
described for two aspects of social behaviour in birds: for sexual imprinting where the final
sexual preference of a zebra finch male is established during adolescence (Bischof 1994;
Bischof 2007), and for song learning, where the permanent song of a young male becomes
stabilized in its adult appearance (Bischof 1997). In agreement with these studies the
behavioural changes (aggressiveness and courtship rate) observed in our study are stable and modifications occur at the same developmental period, namely adolescence. It could therefore be speculated that the development of social behaviour shown here may just be another aspect of social learning during adolescence and that the endocrinological and neural mechanisms regulating imprinting and song learning may also underlie the behavioural changes observed here.

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Ethical standards

All experimental procedures applied in this study are not regulated by the German animal protection law and do not need a special approval.

Animal facilities were approved (dated 18 April 2002) for keeping and breeding zebra finches for research purposes by the local government authority responsible for health, veterinary and food monitoring (Gesundheits-, Veterinär- und Lebensmittelüberwachungsamt). Details of breeding and housing conditions are described in the respective method sections.
References


Figure Captions

Figure 1 Experimental setup of the attractiveness test.
Males from different treatments were placed in small cages in the corners of the experimental aviary. A female was brought into the aviary and could perch in front of the male cages. Male attractiveness was assessed by recording the time females spent in front of each male using light-barrier bordered perches attached to the front of each cage (see inset). Arrows indicate positions of the light-barrier bordered perches within the setup, F/W = food & water dispensers.

Figure 2 Courtship song: latency.
Latency until first directed motif sung [s]
(a) Results of the first measurement
(b) Results of the repetition around 4 month later
Data are shown separately for batch 1 (triangles, N = 8 for each group) and batch 2 (circles, N = 6 for 1m/1f and 2m/0f; N = 5 for 3m/3f). Shown are means ± SEM; ** p < 0.01, * p < 0.05, (p) p = 0.07.

Figure 3 Courtship song: motif rate.
Average number of directed motifs sung within each minute.
(a) Results of the first measurement
(b) Results of the repetition around 4 month later
Data are shown separately for batch 1 (triangles, \( N = 8 \) for each group) and batch 2 (circles, \( N = 6 \) for 1m/1f and 2m/0f; \( N = 5 \) for 3m/3f). Shown are means ± SEM; *** \( p < 0.001 \), ** \( p < 0.01 \), * \( p < 0.05 \), \((*)\) \( p = 0.09 \).

**Figure 4**  
Aggression towards other males.

Ranks of chasing, for calculation of ranks see “data transformation”.

(a) Results of the first measurement

(b) Results of the repetition around 4 month later

Data are shown separately for batch 1 (triangles, \( N = 8 \) for each group) and batch 2 (circles, \( N = 5 \) for each group). Shown are means ± SEM; * \( p < 0.05 \), \((*)\) \( p = 0.06 \).

**Figure 5**  
Male attractiveness.

Females’ relative duration of stay at the different treatment birds [%]

(a) Results of the first measurement

(b) Results of the repetition around 4 month later

Data are shown separately for batch 1 (triangles, \( N = 8 \) for each group) and batch 2 (circles, \( N = 5 \) for each group). Shown are means ± SEM; ** \( p < 0.01 \), \((*)\) \( p = 0.06 \).

**Table Captions**

**Table 1**  
Time table of experimental procedures.

For more details see text.
Figure 2

(a) (b)
Figure 3
Figure 4

(a) (b)

* *
Figure 5
<table>
<thead>
<tr>
<th>Subjects‘ Age</th>
<th>Action/ behavioural test type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>hatching of subjects in breeding aviaries</td>
</tr>
<tr>
<td>40 ± 2</td>
<td>subjects transferred to treatment groups</td>
</tr>
<tr>
<td>110 ± 2</td>
<td>subjects isolated from treatment groups</td>
</tr>
<tr>
<td>131 ± 1</td>
<td>courtship song test</td>
</tr>
<tr>
<td>135 ± 5</td>
<td>aggressiveness test</td>
</tr>
<tr>
<td>145 ± 6</td>
<td>attractiveness test</td>
</tr>
<tr>
<td>253 ± 1</td>
<td>repetition courtship song test</td>
</tr>
<tr>
<td>258 ± 4</td>
<td>repetition aggressiveness test</td>
</tr>
<tr>
<td>270 ± 6</td>
<td>repetition attractiveness test</td>
</tr>
</tbody>
</table>