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Early learning and speciation : the effects of early experience on sexual and aggressive behaviour in Lake Victoria cichlid fish

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Chapter 5

Females learn from mothers, and males learn from others. The effect of mother and siblings on the development of female mate preferences and male aggression biases in Lake Victoria cichlids, genus *Mbipia*.

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Abstract

While species assortative behaviour is often observed in sympatrically occurring species, there are few examples where we understand the extent to which development of assortative behaviour is genetically or environmentally determined, for instance through learning. However, the majority of mate choice theory assumes genetic recognition mechanisms. Knowledge about the development of species recognition is important for our understanding of how closely related species can coexist, and how this coexistence may have arisen. The ontogeny of female mate choice, for instance, may critically influence the degree of assortative mating under many circumstances. Also, male assortative aggression behaviour may affect fitness, and the possibility for coexistence of two closely related species. Here we test whether male aggression biases and female mate preferences of two Lake Victoria rock cichlid species, *Mbipia mbipi* and *Mbipia lutea*, are affected by experience. With an interspecific cross-fostering experiment, we test the effect of experience with the phenotype of the mother and that of the siblings on species assortative mate preferences and aggression biases. We demonstrate that female mate preferences are strongly influenced by learning about their mothers' phenotype, but not by experience with their siblings, despite ample opportunity for interactions. Male aggression biases, in contrast, are affected by experience with siblings but not by learning about their mothers' phenotype. We suggest that the development of assortative behaviour of females, but not of males, creates favourable conditions for sympatric speciation in Lake Victoria cichlids.

Key words: sexual imprinting, rival imprinting, speciation, East African cichlids.

Introduction

Stable coexistence of closely related species is possible with reproductive isolation to prevent hybridization and a source of negative frequency dependent selection to maintain both species (e.g. van Doorn et al. 2004; Rueffler et al. 2006; Dieckmann & Doebeli 1999). Reproductive isolation is mediated by preferences for conspecifics as potential mates. However, individuals of species that share their habitat with closely related species face the every day problem of deciding whom to interact with. How do individuals develop the selectivity to interact preferentially with conspecifics? Several developmental mechanisms can produce such assortative preferences, ranging from a fully genetically controlled development to fully environmentally determined preferences (Riebel 2003b; Shaw 2000). Some of these mechanisms, however, will not produce assortative behaviour in all circumstances, while other mechanisms may particularly easily produce species assortative interactions under many circumstances (Dieckmann & Doebeli 1999; Servedio 2000; van Doorn et al. 2004; Arnegard & Kondrashov 2004; Beltman & Metz 2005, this thesis chapter 2). The developmental mechanism behind preferences and biases in social interactions may therefore play a pivotal role in the evolution of species assortative behaviour and therefore speciation. The study of its development may help us understand these processes.

To keep one species from out competing the other species, or to prevent chance fluctuations in population size to eliminate one of the species, a source of negative frequency dependent selection is needed (reviews in Kirkpatrick & Ravigne 2002; Rueffler et al. 2006), which may maintain both phenotypes, and also drive the evolution of new species. Natural selection through competition over resources may be one such source. An alternative or an additional source for frequency dependent selection has been indicated in male-male competition (Seehausen & Schluter 2004; Mikami et al. 2004; van Doorn et al. 2004). Males may be better off by selectively fighting only with males that compete for the same females or resources, and assortative male-male aggression would be adaptive in many cases. Male aggressive behaviour could therefore also exert selection on species specific phenotypes (e.g. Alatalo et al. 1994; Seehausen & Schluter 2004; Tynkkynen et al. 2005). When males compete selectively with other males that are of a similar phenotype as themselves, rare phenotypes would have fewer aggressive encounters than the common phenotype and therefore incur lower costs to obtain and maintain a territory (Seehausen & Schluter 2004). The reduced male-male competition for rare phenotypes should then result in increased mating opportunities. Speculating on how this may be achieved; males may be able to invest more in courtship, or may be preferred by females, for instance because they are in better condition after less fighting (Wong & Candolin 2005). A rare-male advantage arises from strictly assortative male-male interactions, thus proximately mediated by the development of selective male aggression. When the development of species recognition is particularly geared towards producing assortative male-male

interactions, i.e. it is not susceptible to fluctuations in the distribution of phenotypes in the population, frequency dependence effects could occur.

Although the occurrence of species assortative behaviour is relatively common, in comparison only a few studies have looked at what developmental mechanism mediates it, and often only in one of the sexes (fish: Engeszer et al. 2004; this thesis chapter 3; songbirds: ten Cate & Vos 1999; Slagsvold et al. 2002; Hansen & Slagsvold 2003; Riebel 2003b; corn borer moths: Roelofs et al. 1987; crickets: Shaw 2000; Ritchie 2000; fruit flies: overview in Coyne & Orr 2004). As a consequence, our understanding of the possible evolutionary trajectories leading to assortative behaviour and reproductive isolation is limited. One developmental mechanism mediating mate preferences that is found in several species is early learning by young about a parental phenotype as a model for their later preferences for mates (Kendrick et al. 1998; ten Cate & Vos 1999; Bereczkei et al. 2004, this thesis chapter 3). This mechanism, also known as sexual imprinting, matches an individual's preference to the parental phenotype. High genetic, and therefore phenotypic, similarity between parent and offspring appearance will ensure a relatively good match of social preferences and own phenotype. While often studied in the context of mate preferences, male-male interactions may be mediated by imprinting also, called rival imprinting (Vos 1994; Hansen & Slagsvold 2003). Alternatively, a genetic predisposition for 'own type' bias may also provide assortative social interaction patterns. In contrast, influence from encounters with less related individuals would clearly not produce assortative behaviour. In many animal species this includes virtually all learning after independence, due to dispersal from their natal area.

A particular group of species where coexistence of closely related species occurs regularly are the haplochromine rock cichlids from East Africa, with about 1100 species in the three great lakes (Seehausen 2000; Turner et al. 2001). They are especially interesting to study assortative behaviour because this seems to mediate their reproductive isolation. The large number of species suggests that haplochromine cichlids have properties that make them coexist with many closely related species (Salzburger et al. 2005; Seehausen 2006a). Moreover, the ecological differentiation between sympatric species pairs seems limited (Seehausen & Bouton 1997; Genner et al. 1999a), thereby minimizing the role for ecological competition in frequency dependent selection. In the laboratory, haplochromine cichlid species can interbreed, and hybrid infertility has not yet been observed (Van der Sluijs et al. *in press.*; Seehausen 2004). Thus, haplochromine cichlids do not appear to have built up genetic incompatibilities between species which would prevent them from interbreeding, suggesting that reproductive isolation is almost entirely mediated by mate choice. It has been hypothesized that male-male interactions yield negative frequency dependent selection in cichlids (Seehausen & Schluter 2004). In males, territorial ownership is a requirement for mating, and males will defend their territories vigorously against competing

males. Such territories are in general for mating purposes only and are not or very rarely used for feeding (Seehausen & Schluter 2004). Also, males more often have neighbouring territory owners of another species than their own species, a pattern predicted when male-male aggression indeed yields negative frequency dependent selection (Seehausen & Schluter 2004). Moreover, male-male aggression is biased towards males that are likely to compete for the same females (Lake Victoria: Dijkstra et al. 2006b; Dijkstra et al. 2007; Lake Malawi: Genner et al. 1999b).

How might assortative behaviour in these cichlids be achieved? The exclusive and prolonged maternal care in haplochromine cichlids provides the young with the opportunity for learning about their mothers' phenotype. Such learning may produce assortative social preferences. We showed in an interspecific cross-fostering experiment that females of a closely related species pair (species *Pundamilia pundamilia* and *P. nyererei*) from Lake Victoria indeed imprint on their mothers' phenotype (chapter 3). However, the males from the same cross-fostering experiment did not show any difference in their aggression bias when fostered by a female of a sister species or of their own species; all males selectively direct their aggression to conspecific males (chapter 4). However, there are indications that experience with conspecifics at a later age may affect the direction of male aggression (Dijkstra et al. 2006a, this thesis chapter 4). There is some indication from a study on *Astotilapia burtoni* that young individuals may learn from their siblings (Crapon de Caprona 1982). Since in our earlier cross-fostering experiment males had exposure to their male siblings, they also may have learnt about their phenotypic characteristics. The females in that experiment, on the other hand, were not allowed interaction with males from the age of onset of sexual dimorphism onwards. However, interactions among sub adults may occur frequently in nature, and such experience could potentially diminish the consequences of imprinting for assortative mating.

In this paper we address the relative influence of experience with the maternal phenotype and the phenotypes of siblings on female mate choice and male rival recognition. We present a cross-fostering study in the closely related, ecologically similar and sympatrically occurring species from Lake Victoria: *Mbipia mbipi* and *M. lutea*. They show overlap in morphology, feeding ecology and time and place of breeding, while male nuptial coloration is distinctly different, which is typical for such closely related species pairs (Seehausen et al. 1998). We obtained cross-fostered individuals by swapping full broods between brooding females, as well as swapping almost the full brood or only a few eggs. This way we test the effect of both learning from mothers' phenotype as well as learning from their siblings' phenotype. By allowing the broods to grow up as either pure species groups or as mixed species groups we mimicked possible skewed social experience individuals may encounter while maturing. We tested females for their mate preference and males for their aggression bias. In this study we did not test for male mate preferences, although they would be interesting to address in future studies.

Methods

Reproductive behaviour

Adult males will defend territories in order to attract females. The various aggressive and courtship displays of males and females are extensively described in Baerends & Baerends-van Rhoon (1950). Territories in these limnetic species are only for reproductive means, feeding occurs outside the territories (Seehausen & Schluter 2004). Aggressive interactions usually will take place at the border of the territories, to repel intruders. There are two categories of behavioural display that we scored during observations of the aggressive interaction observations. The first category is formed by attack-like displays, called frontal displays, which precedes the biting of each others mouth, used at the border of a territory. Both these behaviours (frontal displays and biting) were taken together in one frontal behaviour measure by adding up the instances of each behaviour. The other category is formed by lateral displays, which may be followed by quivers. These behavioural elements are often used in within-territory fights. Like for the frontal behaviour, we took these two displays in one lateral display measure.

Courtship interaction often starts at the boundary of a territory, and consists of a sequence of displays. During courtship the male will approach a female when she enters the territory and the male will show a lateral display, followed by a quiver and a lead swim towards the center of his territory. The female can respond to these behaviours by approaching the male and by following his lead swim. The male will lead the female to the center of its territory, where spawning may take place. We scored the type of displays a male gave in a mate choice test, and the subsequent approach behaviour of the female.

Raising of the treatment clutches

We raised clutches in 4 different treatment groups, in which mother, siblings or both could be either a conspecific or heterospecific of the focal individual. We refer to them by abbreviations: the first letter indicates a con- or heterospecific mother, the second letter indicates the siblings: $C_{mo}C_{sib}$: conspecific mother, conspecific siblings; $C_{mo}H_{sib}$: conspecific mother, heterospecific siblings; $H_{mo}C_{sib}$: heterospecific mother, conspecific siblings and $H_{mo}H_{sib}$: heterospecific mother and heterospecific siblings (Figs. 1 and 2).

Each of the four treatments consisted of exchanging eggs between brooding females. Broods contained on average 22.6 eggs, minimal 15, maximal 41. In the $C_{mo}C_{sib}$ treatment we exchanged the full clutch between two females of the same species. In the $C_{mo}H_{sib}$ group we exchanged all but 3 to 6 focal eggs between two females of the different species. In the $H_{mo}C_{sib}$ group we exchanged full clutches between females of the different species and in the $H_{mo}H_{sib}$ group we exchanged 3 to 6 focal eggs, between two females of the different species. Mouth brooding takes 3-4 weeks, then the female releases the fry from her mouth. Fry start foraging independently from that moment on. Females of these species display fry guarding behavior during up to 3 weeks. The brooding females were allowed to show their normal brood care

behaviour. After the extended brood care period, the foster mother was removed from the experimental clutch and returned to the stock tank. The clutch was moved to a larger tank when they were between two to three months old, and remained there until they were sexually mature (approximately 8 months). In nature sibling groups may not stay together this long, but we decided for this treatment to maximize any possible effect of experience with siblings. After both sexes had fully developed, as judged from their nuptial coloration, but before any breeding had occurred in the tank, the focal females and males were removed from the tank and isolated approximately two weeks before testing.

We were able to raise 4 $C_{mo}C_{sib}$ clutches, two of each species; 4 $C_{mo}H_{sib}$ clutches, only *M.lutea*; 7 $H_{mo}C_{sib}$ clutches, 2 *M.mbipi* and 5 *M.lutea*; and 6 $H_{mo}H_{sib}$ clutches, 3 of each species. Because the $C_{mo}H_{sib}$ and $H_{mo}H_{sib}$ groups each yielded only a few individuals per clutch (due to the design of the treatment, average ratio of individuals of the focal species to heterospecific individuals was 1:8), and a few clutches contained either experimental males or females, our sample size was too small to analyze the data on a per species and per treatment basis. We therefore merged the data of both species in this experiment.

Female mate choice tests

We performed 38 successful preference tests on 20 females (4 $C_{mo}C_{sib}$, 3 $C_{mo}H_{sib}$, 5 $H_{mo}C_{sib}$, 8 $H_{mo}H_{sib}$), from in total 13 broods. Each female was tested twice, except for two females, who did not become gravid again after their first trial. The test setup and the scoring method was the same as described in chapter 3. The experimental tank (2 x 0.5 x 0.5m) was divided into 3 equal compartments by two grids with mesh-size 160 x 160 mm. In the outer compartments a *M. mbipi* and *M. lutea* male were placed and bricks were provided as territorial 'rocks'. The mesh size prevented the males from going through the grid, but the females were smaller than the males and were able to swim freely through the tank. In the middle compartment shelter for the female, in the form of a PVC tube, was provided. Males were matched for standard length as much as possible (average standard length difference was 0.6 mm +/- 0.09 SE, average 0.75 % difference relative to the largest male). Males were placed into the experimental tank one day before testing. Twenty stimulus males of each species were (re)combined to 22 stimulus pairs. The average number of times each stimulus pair was used was 1.73 +/- 0.18 SE. A gravid female (i.e ready to lay eggs, as judged by the swelling of the abdomen) was placed in the middle compartment 30-60 minutes prior to testing while opaque sheets hid the males from her. Then the sheets were removed, and the female could reach and see the whole tank. A trial lasted 30 minutes. Courtship behavior was scored as described in Seehausen and van Alphen 1998 and this thesis chapter 3. In a successful trial both males displayed at least two quivers and the female responded positively to a quiver twice. If these criteria were not met, testing was later repeated. We tested until each female had two successful trials, with different male pairs and with

species and tank side fully counterbalanced. Preference scores used in statistical analysis are the approach ratio to the displays of the conspecific male minus that to the heterospecific male. For instance for quiver displays: ($\#$ approaches to conspecific male / $\#$ quiver displays conspecific male) – ($\#$ approaches to heterospecific male / $\#$ quiver displays heterospecific male). The resulting scores were therefore on a scale between 1 and -1, which we used as a measure for preference for conspecific males and heterospecific males respectively.

Male aggression bias tests

We tested 11 $C_{mo}C_{sib}$ males, 4 $C_{mo}H_{sib}$ males, 8 $H_{mo}C_{sib}$ males and 8 $H_{mo}H_{sib}$ males, from a total of 19 broods. Each male was tested twice, except for two males, one in the $H_{mo}C_{sib}$ group and one in the $C_{mo}H_{sib}$ group, who died before the end of the experiment. The focal male was placed 48 hours prior to testing in the experimental tank (2 x 0.5 x 0.5m), which was divided in half with the use of 2 opaque PVC sheets. Each male also had a 'neighbour male': a smaller male cichlid of a different genus placed at the end of the tank behind a Plexiglas sheet. We placed this male in the experimental tank to enhance territoriality (Dijkstra et al. 2006b). At the time of testing, two cylinders were placed in the experimental space of the focal male. In these cylinders we placed a male of each species, matched for standard length to each other (mean difference in standard length was 0.4 mm +/- 0.06 SE, average 0.8 % difference relative to the largest male). Thirty two *M. mbipi* and 34 *M. lutea* males were (re)combined to 44 stimuli pairs. The average number of times each stimulus pair was used was 1.59 +/- 0.13 SE. Observations started right after placement of the cylinders, and lasted 20 minutes after the start of aggressive interactions. Behaviours scored were: frontal displays, bites, lateral displays and quivers. Aggression bias as analysed in the statistical analysis was the proportion behaviour directed at the conspecific male, which therefore yields a score between 0 and 1, with a score above 0.5 indicating an aggression bias to males of their own species.

Statistical analysis

All statistical analyses were conducted using R statistical software (R Development Core Team 2005). We fitted Generalised Linear Mixed Effect Models (GLMMs). All models were hierarchically nested, correcting for any pseudoreplication: broods within treatment, and individuals (two trials) within broods. We had two fixed effects which each had two levels: foster mother (conspecific or heterospecific) and siblings (conspecific or heterospecific). If the fixed effect of foster mother is significant in the model, the behaviour of the males or females is affected by the phenotype of the (foster) mother that raised them. If the fixed effect of siblings is significant in the model, the behaviour of the males or females is influenced by the phenotypes of their (foster) siblings. An interaction would indicate that each of the treatments had a different effect in each combination. We stepwise deleted factors from a fully saturated model until the minimal adequate GLMM was found, but always

keeping repeated measures for each individual as a random factor. Depending on the nature of the data, we used the Gaussian (standard normal) or the binomial distribution to fit our models. For data analysed with Gaussian distribution we report F-tests on the variance, while we report a X^2 test on the deviance, as appropriate for binomial data. At each step in the model simplification, we verified that the assumptions of normal distribution of the errors and heteroscedastity were met, by visual inspection of the concerned plots, and for overdispersion when the binomial distribution was used. We did not test for significant female mate preferences or male aggression biases per treatment group, due to the limited sample size in each separate group.

Results

Although we cannot statistically test for species differences, inspection of the data obtained from the two types of tests in males and females showed that *M.mbipi* fell safely within the range of *M.lutea*, for which we obtained more data.

Female mate choice tests

We found a significant effect of the species of the (foster) mother on the mate choice behaviour of the females (figure 1). Females were more likely to

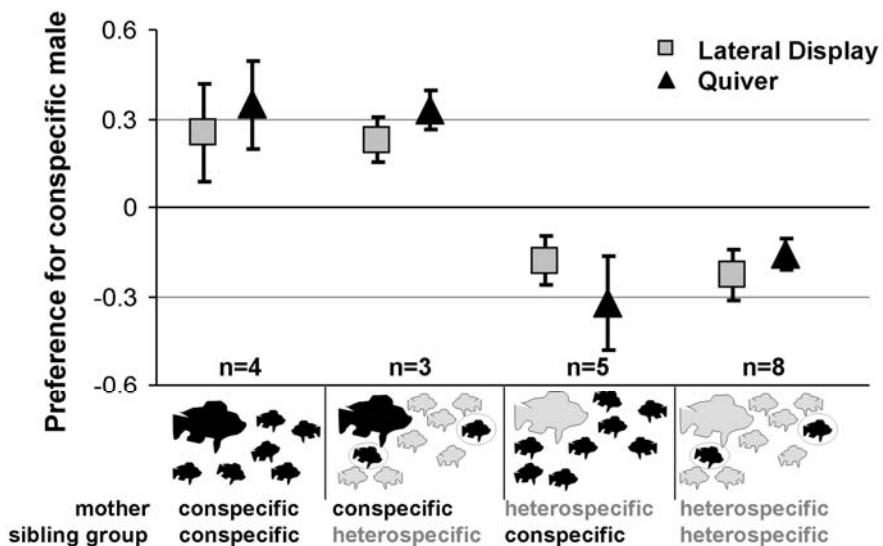


Figure 1 Female preferences in the different treatment groups. Grey squares are lateral displays, black triangles are quivers; means +/- SE. Scores above zero reflect a preference for conspecific males, scores below zero reflect a preference for heterospecific males.

Response variable	Explanatory variable		df	<i>P</i>
Lateral Display	distribution: Gaussian	<i>F</i>		
	Fixed effects:			
	<i>mother</i>	18.11	1,18	<0.001
	siblings	0.34	1,17	0.57
	mother x siblings	0.01	1,16	0.94
	Random effect:			
Quiver Display	<i>Individual</i>	Lh. ratio = 0.1301		0.717
	brood	Lh. ratio<.0001	1	
	distribution: Gaussian	<i>F</i>		
	Fixed effects:			
	<i>mother</i>	29.63	1,18	<0.001
	siblings	0.80	1,17	0.38
First visit	mother x siblings	0.005	1,16	0.94
	Random effect:			
	<i>Individual</i>	Lh. ratio < 0.0001		1
	brood	Lh. ratio<.0001	1	
	distribution: binomial	X²		
	Fixed effects:			
Time spent	<i>mother</i>	6.32	1	0.01
	siblings	0.15	1	0.67
	mother x siblings	0.02	1	0.99
	Random effect:			
	<i>Individual</i>	0.1677	1	0.6821
	brood	0	1	1
Time spent	distribution: binomial	X²		
	Fixed effects:			
	<i>mother</i>	2.81	1	0.09
	siblings	1.02	1	0.31
	mother x siblings	0.06	1	0.81
	Random effect:			
Time spent	<i>Individual</i>	<0.001	1	0.999
	brood	0	1	1

Table 1 Results of the GLMM's of analysis of the female preference tests. The effects are listed in reverse order of deletion from the model. The final model is in *italic*.

approach a displaying male if he was of the same species as their foster mother. This was true on both the level of lateral displays ($F(1,18)= 18.11$, $P<0.001$) and on the quiver displays ($F(1,18)= 29.63$, $P<0.001$). Females showed a trend to spending more time with the male of the same species of their foster mother ($X^2=2.81$, $df=1$, $P=0.09$). There was no effect of siblings in either measure (figure 1, table 1).

We tested for an effect of treatment on which male a female visited first in a trial. This first visit was more often than random to the male of the foster

species ($X^2=6.32$, $df=1$, $P=0.012$) (table1). Again, siblings had no effect on the choice of first visit. Additionally, we tested if the male a female visited first in a trial was predictive of her approach rate to either lateral display or quiver display. There was a significant relation between first visit and differential approach rate to the quiver display ($X^2=5.7$, $df=1$, $P=0.017$), and a trend with lateral display ($X^2=2.75$, $df=1$, $P=0.09$).

Male aggression bias tests

We found an effect of sibling group, but not mother, on the direction of aggression by the males (figure 2) This was significant in all three parameters: the proportion frontal behaviour directed to the conspecific intruder ($X^2=13.17$, $df=1$, $P<0.001$), the proportion lateral behaviour ($X^2=17.59$, $df=1$, $P<0.001$) and the proportion of time spent interacting with the conspecific intruder ($X^2=10.77$, $df=1$, $P=0.001$). Males with conspecific siblings showed more displays towards and spent more time interacting with the conspecific intruder, than males raised with heterospecific siblings. Males displayed more often with frontal behaviour than with lateral behaviour (paired t test: $t_{36} = 5.39$, $P< 0.001$, mean of the differences: 48.2). The random effect 'individual' was significant in both the frontal behaviour and lateral behaviour, we therefore subsequently tested if this was due to a difference in the behaviour between the first trial and the second trial. We also tested if such a 'trial effect' was

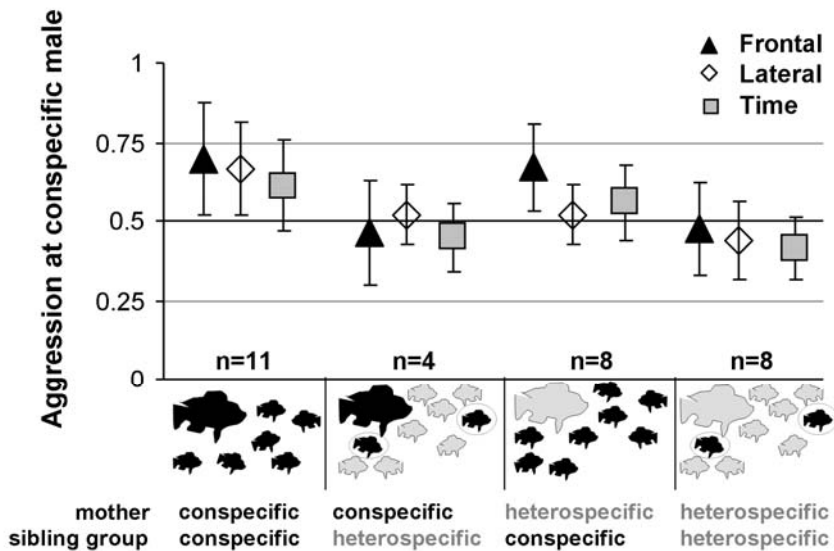


Figure 2 Male aggression direction of the different treatment groups. Black triangles are frontal behaviour, open diamonds are lateral behaviour, grey squares are time spent interacting; means \pm SE. Scores above 0.5 reflect more aggression to conspecific intruders, scores below 0.5 reflect more aggression to heterospecific intruders.

Response variable	Explanatory variable	X ²	df	P	
Frontal behaviour	Fixed effects:				
	<i>siblings</i>	13.17	1	<0.001	
	mother	0.07	1	0.80	
	mother x siblings	0.0003	1	0.99	
	Random effect:				
	<i>Individual</i>	8.91	1	0.0028	
Lateral behaviour	Fixed effects:				
	<i>siblings</i>	17.59	1	<0.001	
	mother	0	1	1	
	mother x siblings	0	1	1	
	Random effect:				
	<i>Individual</i>	32.41	1	<0.001	
Time spent	Fixed effects:				
	<i>siblings</i>	10.767	1	0.001	
	mother	1.5044	1	0.22	
	mother x siblings	0.076	1	0.78	
	Random effect:				
	<i>Individual</i>	0	1	1	
Effect of trial:	brood				
	brood				
	FD-B	trial	2.06	1	0.11
		siblings	15.52	1	<0.001
		trial x siblings	0.01	1	0.94
	LDQ	trial	0.15	1	0.67
siblings		7.95	1	0.004	
trial x siblings		0.01	1	0.90	

Table 2 Results of the GLMM's of analysis of the male aggression tests. The effects are listed in reverse order of deletion from the model. The final model is in *Italic*. The final models testing for the effect of trial also show non significant interaction effects, but the deletion of the interaction effect did not make the trial effect significant. We therefore kept the full model as final, showing no effects of trial

different between the treatments. We did not find such effects (table 2).

Discussion

Our data show effects of experience on both female choice and male-male aggression in these cichlid species. The females raised in our experiment developed a sexual preference for males of their mothers' phenotype. We tested females when they were sexually mature, at which time their (foster)

siblings were also fully developed and their brothers thus showed nuptial coloration. In two of the four treatment groups: $C_{mo}H_{sib}$ and $H_{mo}H_{sib}$, females therefore had the opportunity to interact with males of a different species than that of their foster mother, but this caused no shift in preference towards the species of their siblings. So, despite ample opportunity for interaction with their (foster) siblings, this did not affect their mate preference. Our results thus show that imprinted preferences can be robust against later social experiences. In a previous cross-fostering study on another species pair, females of *P. pundamilia* and *P. nyererei* showed the same effect of foster mother on their mate preferences (chapter 3). The high similarity between the results of both studies supports the idea that the closely related haplochromine cichlid species of Lake Victoria share this imprinting behaviour. Because females imprint on their mothers' phenotype, rather than on other individuals, there is a strong link between the phenotype of the female and her preference for males with a similar phenotype (chapter 2). This is a condition for strong assortative mating patterns, critical for both a sympatric speciation scenario and reinforcement after secondary contact (e.g. Felsenstein 1981; Servedio 2000).

In contrast to the females, males adjusted the direction of their territorial defence depending on the composition of the brood they grew up in. Males showed more aggression to heterospecific males if they had been raised with heterospecific sibling males, while the species of foster mother had no significant effect on the parameters we measured. The males' aggression thus was not directed at their own phenotype at all times, but instead at males similar to the males they were raised with. Under normal conditions (i.e. not when cross fostered) siblings would resemble a males' phenotype more than in our mixed broods cross fostering. However, offspring shares on average more of the genotype, and phenotype, with their mother than with their siblings. Even though some aspects of the female's phenotype are different from the male's phenotype, there are apparently cues available to generalise from the mother's phenotype to the male's phenotype as shown by the females in this study and in chapter 3. Rival imprinting on the mothers' phenotype would thus more likely lead to species assortative aggression than when males imprint on their siblings.

Species differences in the effects of imprinting could not be tested for with the data obtained in this study. Although we did not find any species differences in our previous cross fostering study, a difference in early learning between closely related species was shown in studies on birds (Slagsvold et al. 2002; Hansen & Slagsvold 2003).

Sexually mature males are brightly colored, while females are mostly yellow or brown-grey. However, there is some difference in the coloration of females between the two species, and this difference is also enhanced during mouth brooding (Seehausen et al. 1998). The young females may thus possibly have learnt about their mothers' colour, but it is equally possible that olfactory cues have been imprinted on. As both colour and chemical cues could be used at all stages of the experiment, we cannot conclude which cue served as imprinting stimulus.

While we can conclude that females learnt about their mother in the first few weeks of their lives, either during mouth brooding or while the mother guards the fry, when the males learnt cannot be assessed from this experiment.

If under natural conditions males learnt while hatching, or shortly thereafter, they are likely to imprint on closely related individuals, because the other hatchlings are at least half-siblings. But although they shared the time in the mouth of their (foster) mother with their foster siblings, it is not very likely that they learnt about them at that time. During this stage, there are no discernable visual differences between fry (Fernald & Hirata 1979), and the available light in the mouth of the mother is likely to be quite limited. This implies that if the fry learn about their siblings at this stage, they probably would have to rely on olfactory cues. However, the olfactory cues in the mothers' mouth are also likely to be largely influenced by the mother herself. Since we found no influence of species of foster mother on the males' behaviour, it seems unlikely that males use this experience while hatching. At a later stage, the females of these cichlids also provide care for their offspring after hatching by taking them back into their mouth with approaching danger (another fish, or in our experiment, an animal care taker). Fry then rely on visual cues, in order to approach the mouth of the female (Baerends 1993; Russock 1999). The interaction with their siblings at this time may provide them with the opportunity to learn about their fellow siblings, which would ensure that they learn about closely related individuals. While in our experiment the brood stayed in one tank exclusively, in nature it is largely unknown how and if young cichlids aggregate from the time their mother leaves them alone until the time they become territorial. However, schools of same size fry can often be seen in shallow water at the rocky shores (pers obs MNV), and mixed species shoals of non-breeding males have been observed (Seehausen et al. 1998 & pers com M.E. Maan). If males establish their aggression biases at that stage, those biases are not likely to be assortative, because the individuals they encounter at that time are likely to be from different species. However, this scenario would not explain the species assortative behaviour found in wild males of several reproductively isolated populations (Dijkstra et al. 2006b; Dijkstra et al. 2007). Interestingly, interactions with males of a different species do not necessarily result in a lack of an aggression bias for their own phenotype, and may even bias aggression towards their own phenotype (Dijkstra et al. 2006a). This suggests that the development of aggression biases is sensitive to the context of the interactions between males, and that males do not learn the same way from their encounters with various males. However this is at the moment speculative and more experiments are needed.

Lake Victoria rock cichlids have been proposed as a possible case of sympatric speciation. This was postulated on the basis of distribution patterns of many species pairs, where one of the two species is nested within the distribution of the other (Seehausen & van Alphen 1999). The species pair in this study also shows such nested distribution (Seehausen et al. 1998). Conditions allowing sympatric speciation are quite strict, calling for strong assortative mating mediating reproductive isolation at a very early stage of divergence, and a

source of negative frequency dependent selection driving the divergence. The alternative scenario leading to the observed distribution pattern of related species is secondary contact after allopatric divergence (Bouton 2000). This still requires reproductive isolation, but frequency dependent selection does not need to drive the divergence. While the imprinting behaviour of the females could cause strong assortative mating patterns in both scenarios of speciation (Servedio et al. in press and this thesis chapter 2), the male-male interactions are not assortative at all times. The cross-fostering experiment may be an unlikely situation in nature; however at an incipient speciation stage hybridization may be more common, and mixed broods resembling our experiment can easily occur. We therefore propose that the developmental mechanism for male aggressive behaviour is unlikely to produce enough frequency dependent selection at the earlier stages of speciation to help drive sympatric speciation, although it needn't hamper speciation either.

In summary, the results of our experiment indicate that females of the species pair *M.mbipi* and *M.lutea* sexually imprint on their mothers' phenotype, while the males do not. Male behaviour was affected by experience with siblings. This is consistent with the findings in a previous cross-fostering study with the other species pair *P. pundamilia* and *P. nyererei* (chapter 3 and chapter 4). The similarity of the results indicates that the developmental mechanisms of assortative behaviour may be shared between the highly related cichlid species of Lake Victoria. Secondly, the development of assortative male-male aggressive behaviour is partly mediated by experience with other individuals than their mother, possibly their siblings in nature. Learning about siblings would provide males in reproductively isolated species with an aggression bias for their own phenotype, but in hybridizing populations this may most likely result in a lack of an aggression bias. The development of assortative behaviour of females, but not of males, therefore, creates favourable conditions for sympatric speciation. However, in a scenario involving secondary contact after allopatric divergence the behaviour of both sexes contributes to species coexistence.

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Fishing for rock cichlids.
Mhoja Kayeba (left) and three young fishermen on Makobe Island.

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