

Testing the relationship between social competence and cognition in the daffodil cichlid



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Abstract

Differences in social competence can be observed in the highly social daffodil cichlid (*Neolamprologus pulcher*). It is unclear what underlies these differences; however, cognition might be related to social competence. The aim of this research is to study the relationship between social competence and cognition and to find evidence for general intelligence in the daffodil cichlid. With a split-brood design with two rearing conditions, individuals were raised either with or without their parents resulting in individuals with high and low social competence. These individuals underwent a series of cognitive tests (innovation, associative learning, reversal learning, and impulse control). There was no relation found between social competence and any of the cognitive tests. A separation in social and non-social learning processing could be the reason for this or the difference in social competence could be less present than expected. Additionally, no correlation between any of the cognitive tests was found, suggesting there is no general intelligence in this species.

Cognition, general intelligence, Neolamprologus pulcher, social competence

Introduction

For social animals, life can depend on their ability to handle social situations. Survival can be related to being part of a social group when foraging, predator protection, and reproduction are social activities. The ability to effectively navigate social situations is referred to as social competence. Broadly defined social competence refers to the ability of an animal to optimise the expression of its social behaviour as a function of the available social information (Taborsky & Oliveira, 2012). Within species differences in social competence can be observed. However, it is unclear what underlies these differences. While a genetic disposition for social competence has only been showed in human twin-studies (McGuire et al., 1999), a relationship between cognitive ability and social competence remains a possible explanation in non-human animals. For instance, when an individual is better at learning, learning and remembering social cues could be easier. Perceiving social cues, learning from social situations, and making decisions based on social cues are all examples of using cognitive functions in social situations. Even though cognition and social behaviour are linked in many ways, there is still much unknown about their relationship. In rats (*Rattus norvegicus*) an expected relationship between social competence and social learning was found, however, non-social learning was unaffected (Levy et al., 2003). Studies in humans show contradictory results regarding the relationship between IQ and social intelligence. Both a positive relation (Almat et al., 2023) and a clear distinction (Marlowe, 1986) are found. This topic remains questionable and is suggested to be dependent on the use of different diagnostic tools to assess social intelligence.

A related and argued topic in animal studies is general intelligence, which describes general cognitive ability. When an individual's scores on multiple cognitive tests are highly correlated there must be something influencing the performance, a general factor (g factor). Although the validity of this factor is debated, many studies have found strong correlations between test performances in humans and some non-human animals. However, the evidence on general intelligence in animals is weak (Poirier, 2020). The majority of studies are on mice (*Mus musculus*) which is the species with the highest correlations. Nevertheless, there are critiques that the cognitive tests used in these studies would be too similar (Shaw & Schmelz, 2017). Often mentioned points of critique in studies on general intelligence are the similarity of tests and the limited inclusion of social cognition or social competence tests. Furthermore, research on cognition and general intelligence has mainly been focused on mammals and birds. Moreover, fish species are especially understudied in research related to cognition and (social) intelligence.

Regarding general intelligence, there have been limited studies yielding no evidence supporting the existence of general intelligence in fish. Aellen, Burkart, and Bshary (2022) argued the lack of general intelligence found in wild-caught cleaner fish (*Labroides dimidiatus*) could be an indication of different cognitive processing between endo- and ectotherm vertebrates due to their differences in brain organisation. Furthermore, in guppies (*Poecilia reticulata*) two measures of inhibitory control were found to be related but did not correlate with performance in problem-solving, a different cognitive

domain (Montalbano, Bertolucci & Lucon-Xiccato, 2020). Studies linking cognitive performance to social competence in fish have not resulted in conclusive positive or negative relations. Based on the notion that animals from a more diverse social environment show higher social competence, cognitive results from two cichlid species reared in heterogenous broods were compared with individuals reared with conspecifics. Fischer et al. (2021) found that individuals growing up in a diverse social environment are faster and more accurate learners in discrimination tasks but not in reversal learning. Temporary social environment has also been known to influence learning in cichlids (*Cichlasoma paranaense*). Isolating individuals for as short as ten days impacted learning skills in a spatial learning task in a highly social species (Brandão et al., 2015).

To better understand the relation between social competence and cognition and investigate general intelligence in fish this research will study the cooperatively breeding daffodil cichlid. Previous research has shown that social competence in this cichlid is affected by early social environment (Arnold and Taborsky, 2010). Raising offspring with parents and (adult) helpers results in individuals with higher social competence compared to raising offspring with siblings only. The reason for these differences is still unclear. It could be due to more social learning opportunities with peers as a result of a safe environment provided by the adults. Or it could be the result of eavesdropping, which was in this case learning through observing interactions of the adults with each other, as there were no direct interactions between adults and offspring. This study aims to test whether cognitive performance is related to social competence and whether there is general intelligence in the study species. By manipulating rearing conditions, we will bring up individuals with varying social competence levels. These will undergo a series of cognitive tests after which we will test the differences in performance between individuals with high and low social competence. Additionally, we will compare the test performances on cognitive tests within subjects to find evidence for general intelligence.

Apart from the unanswered questions on animal cognition, an additional motive for this research is to shine some light on the mystery that is still surrounding fish. By being underrepresented in animal cognition research there is a misconception that fish are not intelligent animals and are not able to learn. By studying the social and cognitive complexities of fish we hope to contribute to a change in this misconception which could have a positive effect on fish welfare (Brown, 2015).

Methods

This study was conducted between April 2022 and April 2023 in the Carus fish lab facilities in Wageningen. The studied species was the daffodil cichlid, endemic to Lake Tanganyika. Lake Tanganyika borders four countries in southeast Africa and is home to at least 250 cichlid species. The cichlid is a cooperative hole breeder that forms monogamous pairs to breed. Around this pair a group is formed with helpers, these can be related or unrelated individuals. In exchange for brood care and offspring protection, the helpers are part of a group which can be beneficial for their survival. There is a size and sex hierarchy with males and larger individuals being on top.

Study design

The study by Arnold and Taborsky (2010) showed that keeping offspring with or without parents and helpers results in differences in social competence. In this study, we were interested in the difference in cognition between groups that differ in social competence. To create groups with a difference in social competence we split offspring from eight breeding pairs. Half of the offspring were reared with their parents and the other half without. Clutch sizes varied between twenty and fifty. A total of fifty individuals were used for cognitive experiments.

Breeding pairs

Eight breeding pairs were established by first putting the female in the breeding tank and giving her some time to get used to the tank. The same day the male was put into the tank inside an isolation box. This way the pair could get used to each other without the risk of aggression. The male was left

in the isolation box overnight and freed the next day. On the same day, the pair would be observed a couple of times to check if there was no aggression.

Treatments

When a breeding pair was established, there were daily egg checks. When eggs were found or when eggs hatched this was noted. Ten days after eggs had first been spotted all offspring was removed and put in a separate tank. Half of the offspring was assigned to the low social competence treatment (LSC) and put into a new tank separated from parents and other individuals. All sides were blocked to prevent any contact with adults. The other half was assigned to the high social competence treatment group (HSC) and returned to their parents. The offspring from both groups stayed in their assigned rearing conditions for 60 days. After 60 days, offspring from the HSC group were transferred to their tank. The low social competence group was also transferred to a different tank to reduce the effect of stress on experimental results. All groups were in this condition of no parents and semi-open sides for at least 30 days.

Housing individuals

When used for the cognitive assays, fish would be at least 2 cm standard length (SL) (90 days old). The assays were performed in assay tanks consisting of three compartments. The front compartment, with on the bottom a white flat plate containing holes for food rewards, was separated from the middle compartment by two sliding doors, an opaque and a transparent door. The mid-compartment was the home compartment of the focal fish. The back compartment was separated by a transparent wall from the middle compartment and was home to one or two companion fish. As there is no experimental permit but only a license, individuals cannot be isolated as that would cause too much stress. The focal fish must always be able to see their companion fish, however, they are separated at all times by the transparent wall. Olfactory cues are important for communication for the cichlids, these were possible as the focal and companion fish shared the same water. The home departments of the focal fish and the companions both had a shelter floating on top and sand on the bottom. The companion fish was at least 0.5 centimeters smaller in SL than the focal fish to ensure the dominancy of the focal fish. The companion fish were first put into their compartment and left overnight to establish ownership of the territory. The next day the focal fish was introduced and left overnight before starting testing. The companion fish were fed every weekday with baby fish food (powdered fish flakes). Focal fish that were doing experiments were only fed flakes every Friday. If no experiments were performed the next day, they were also fed during the week.

Cognition

Pre-training

Before being able to execute the cognitive experiments, the fish were taught to eat from a hole in the plate during the pre-training phase. The first step was putting a piece of krill in the middle hole closest to the home compartment of the fish. Three trials, an hour each, per day for each individual. After this step, the reward moved one row further from the home compartment. The last step was reducing the time from one hour to five minutes. An individual moved to the next step or was finished with pre-training after successfully eating from the hole five out of the last six trials.

Innovation

The innovation assay was used to test problem-solving/neophobia. The test started with four trials (five minutes each) on the first day. In the first and third trials, a piece of krill was placed in the middle hole of the second row and covered with a black disk. The individual was given five minutes to move the disk and eat the reward. The second and fourth trials were 'reminder trials' in which the disk was removed to remind them of the food being there. As soon as an individual ate during a 'disk trial' they were done with innovation. If an individual did not eat during the first or third trial, they did a full day of innovation the next day. The full day had to directly follow the first trial day. On the full day, the black disk was placed over the reward and after the trial started there were multiple checks over the

following six hours to see if the disk was moved. If the individual did not eat after six hours the doors stayed open overnight. The next morning (± 24 hours after starting the trial) was the final check after which the doors closed.

Disk pretraining

In between innovation and associative learning, another round of pretraining took place. The aim of this pretraining was for the fish to learn how to move a disk covering the food reward. Yellow disks were used, and food was placed in the middle hole, the second row from the home compartment. Step by step the disk moved from being next to the hole to fully covering the hole. The steps were disk next to the hole (not covering), $\frac{1}{2}$ covering, $\frac{3}{4}$ covering, and fully covering. An individual moved to the next step when successfully eating five out of the last six trials. Each individual went through three trials every day, an hour for each trial. After hitting the criteria in the fully covered step, the next step was doing this within five minutes. After hitting the criteria in the five-minute step, the last step was doing this with a camera in front. We noticed during pre-training that most fish were easily scared and did not come to the front compartment when we were there watching. By putting a camera in front and looking inside the tank through the camera screen we could shield ourselves and most fish were more comfortable coming to the front. We used a camera in the associative and reversal learning and impulsivity assay as well. After hitting the criteria in this step, the individual could move on to associative learning.

Associative learning

For the associative learning experiment, two yellow disks were used. This colour was used in pre-training and the individuals associated this with food already. One of the disks was movable and the other disk had a weight glued to it making it too heavy to be moved by the cichlids. Both disks had a reward in the form of a piece of krill underneath to provide the same olfactory cue for each disk. The disk that could be moved was the reward disk and was consistently placed at either the right or left side of the plate for each individual. The rewarded side was randomized at the beginning and stayed the same during all trials in this experiment. The fish had to associate the side to the reward and not try to open both disks.

The trial is started by first opening the opaque door and shortly after the transparent door to allow the fish to enter the experimental compartment of the tank. When a fish chose the correct disk first, the trial was marked as successful. When a fish chose the incorrect disk, the trial was marked as unsuccessful. The observers counted it as a choice when the individual clearly tried to move the disk. This could be by biting the disk or trying to push or nudge the disk. The individual was given 3 minutes to make a choice, when no choice was made within 3 minutes the trial is marked as NC (No Choice), and the disk was moved by the observer to reveal the reward. We reset the trial when the individual had eaten the reward or two minutes after revealing the reward. Each individual went through three trials a day until they hit the learning criteria which was five out of six consecutive correct trials.

Reversal learning

In the reversal learning experiment, the side of the rewarded disk was switched for every individual. This experiment followed the same protocol as the associative learning experiment. The individual had to learn the new reward association and hit the learning criteria (five out of six consecutive).

Impulsivity

We tested impulsivity by putting food on the plate under a weighted disk (middle hole, second row). The individual was not able to move the disk. For ten minutes we counted the number of times an individual would peck the disk with a hand tally counter. We used a camera to shield ourselves and film the trial. Remarks were also noted, for example when most pecks took place during the first or last part of the trial. This experiment always took place the day after a fish had been fed flakes to prevent differences based on hunger.

Results

The data was analysed using RStudio (2021.09.0).

Innovation

The innovation assay was completed by fifty individuals with twenty-six individuals that did innovate. We found no significant effect of treatment on innovation ($\chi^2 = 0.32$, $F_{1,45} = 0.03$, $p = 0.87$). Sex and length were removed from the model as they did not have a significant result and did not improve the fit of the model.

Associative learning

We used data from forty-seven individuals. There was no difference in the learning rate based on the side of the rewarded disk. There were also no effects of sex or length on learning rate. These factors were therefore excluded from the model as they did not improve the fit of the model. We found no significant effect of treatment on associative learning ($R^2 < 0.01$, $F_{1,45} = 0.03$, $p = 0.87$). Used ANOVA to compare models)

Reversal learning

The reversal learning assay was completed by 39 individuals. We found no significant effect of treatment on reversal learning ($R^2 = 0.02$, $F_{1,37} = 0.71$, $p = 0.40$). Side of the rewarded disk, sex, and length were removed from the model as they did not have a significant result and did not improve the fit of the model.

Impulsivity

The impulsivity assay was completed by 38 individuals. We found no significant effect of treatment on impulsivity ($R^2 = 0.02$, $F_{1,36} = 0.77$, $p = 0.39$). Sex and length were removed from the model as they did not have a significant result and did not improve the fit of the model.

Correlations between tests

We found no correlations between any of the cognitive tests (Figures 1 & 2 and Tables 1 & 2).

Table 1 Pearson correlation with *p*-value between the cognitive tests

Test 1	Test 2	Pearson's correlation	<i>p</i> -value
Associative	Reversal	-0.10	0.55
	Innovation	-0.02	0.91
	Impulsivity	0.14	0.41
Reversal	Innovation	0.06	0.72
	Impulsivity	-0.03	0.84
Innovation	Impulsivity	0.03	0.87

Table 2 Results linear models between tests, treatments, and interactions

Dependent	Independent	Factors	t-value	<i>p</i> -value
Associative	Reversal		0.40	0.69
		Treatment	1.34	0.19
		Treatment x Reversal	-1.44	0.16
	Innovation		0.06	0.94
		Treatment	0.26	0.80
		Treatment x Innovation	-0.16	0.87
	Impulsivity		0.43	0.67
		Treatment	-0.09	0.93
		Treatment x Impulsivity	0.13	0.90
Reversal	Associative		0.47	0.64
		Treatment	1.08	0.29
		Treatment x Associative	-1.16	0.25
	Innovation		-0.78	0.44
		Treatment	-0.95	0.35
		Treatment x Innovation	1.44	0.16
	Impulsivity		0.59	0.56
		Treatment	1.01	0.32
		Treatment x Impulsivity	-1.00	0.33
Innovation	Associative		0.06	0.95
		Treatment	-0.46	0.65
		Treatment x Associative	-0.17	0.87
	Reversal		-0.69	0.49
		Treatment	-1.80	0.08
		Treatment x Reversal	1.60	0.12
	Impulsivity		0.64	0.53
		Treatment	-0.02	0.99
		Treatment x Impulsivity	-0.61	0.54
Impulsivity	Associative		0.42	0.68
		Treatment	0.40	0.69
		Treatment x Associative	0.17	0.86
	Reversal		0.49	0.63
		Treatment	1.39	0.17
		Treatment x Reversal	-1.13	0.27
	Innovation		0.60	0.55
		Treatment	0.97	0.34
		Treatment x Innovation	-0.58	0.57

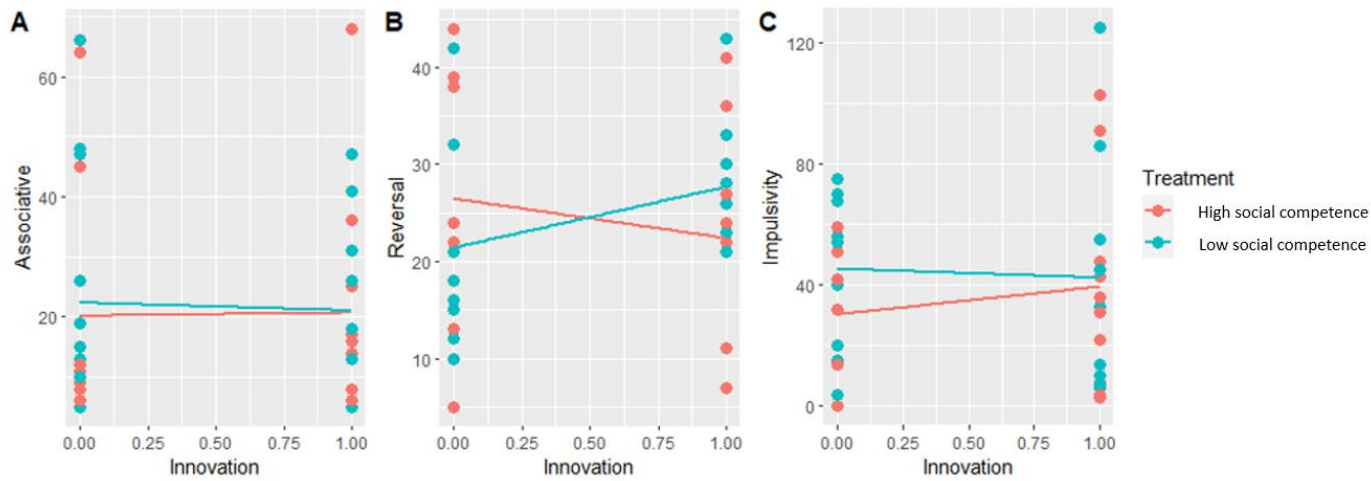


Figure 1. The effect of social competence on innovation in the daffodil cichlid. There is no effect of treatment on cognitive performance. There are no correlations between performance on innovation and associative learning, reversal learning and impulsivity. Red dots represent high social competence treatment, blue dots represent low social competence treatment.

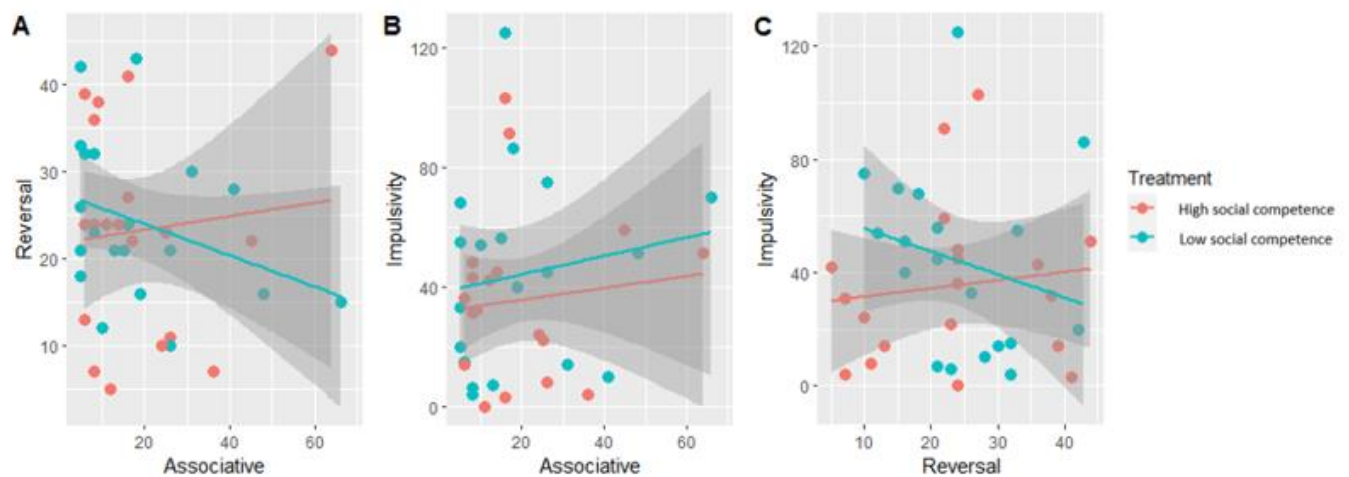


Figure 2. The effect of social competence on associative learning, reversal learning and impulsivity in daffodil cichlid. There is no effect of treatment on cognitive performance. There are no correlations between reversal learning, associative learning, and impulsivity. Red represents high social competence treatment; blue represents low social competence treatment.

Discussion

This study investigated the relationship between social competence and cognition and tried to find evidence for general intelligence in the daffodil cichlid. By manipulating rearing conditions, we created two groups of individuals, one with high social competence and one with low social competence. These individuals were subjected to four cognitive tests and the results were compared between the high and low social competence groups. The cognitive tests were also compared to find correlations.

We did not find a relation between social competence and performance in any of the cognitive tests. This could mean there is a separation between social learning and non-social learning in this species or fish in general. This can be due to the different processing of social information versus non-social information. It would be interesting to test this by performing additional social learning tasks. A different explanation for the lack of relation between social competence and cognition could be that social competence was not affected by the rearing conditions in our individuals. The treatment design in this study was based on the methods by Arnold & Taborsky (2010) where they did find a difference in social competence. Their study had one difference which was an additional treatment group with

parents and helpers. However, they did not find any difference in social performance between the groups with or without helpers. The asymmetric competitive situation task to determine social performance has been performed by the individuals in this study, however, the videos have not been scored yet. For future reference, the social performance test results should be analysed to ensure the social competence difference and the groups might need to be rearranged and reanalysed.

Our second aim was to find evidence for general intelligence in the daffodil cichlid. We did not find any relation between the results of the cognitive tests thus there is no evidence for general intelligence. This is in line with the previously mentioned study on cleaner fish in which there was also no evidence of general intelligence. There could be a difference in brain structure between endo- and ectotherm animals as there has been some evidence for general intelligence in endotherm animals. The authors mention the hypothesis that the difference in brain size between ectotherm and endotherm animals is driven by endotherm brains being more specialized learning machines versus the endotherm being general-purpose learning machines. Support for this hypothesis and the subject of general intelligence in ectotherm animals lacks sufficient research at this moment and should be a focus point in the future. However, finding evidence for general intelligence in non-human animals is highly debated. An important aspect of this debate is the combination of cognitive tests or test battery. To indicate general intelligence, a wide selection of domains must be evaluated. In this study, we used a problem-solving task (innovation), associative learning, reversal learning, and impulsivity task. The impulsivity task is a form of an unsolvable test. We measured the number of times an individual would try and open a weighted disk even though it was impossible to move it. The domain that is measured with this is a bit questionable. A high number of tries could mean the individual does not understand the disk is unmovable and could be perceived as less intelligent or as unable to control their impulse. However, it could also mean the individual is very persistent which can be seen as a positive quality. Therefore, a paper from Rowe and Healy (2014) describes the difficulty of knowing what you are measuring in animal cognitive testing. Besides, as mentioned before speed differences in reaching criteria could also reflect differences in learning strategy. Many factors can influence cognitive performance. Motivation also plays a big part in cognitive tests and some studies use the term effort when talking about motivation. Some argue that body-to-task contacts that can be seen as one learning opportunity should be included in the measurement of performance in certain tasks (Griffin & Guez, 2016). For example, if an individual in the innovation trial opens the disk in fifteen tries after five minutes and a second individual opens the disk in one try after ten minutes, one could argue that only reporting time does not cover the full performance measurement. And for individuals that did not open the disk at all should be reported whether they tried and failed or did not try at all. We tried to control for this in the associative and reversal learning tasks by basing their choice only on the first peck or attempt at moving a disk instead of waiting for them to completely move one of the disks. However, personality can still affect performance. When a fish is too shy to show itself, there will be no attempts at solving the tests and bold exploring fish might have better chances. For instance, in zebrafish and guppies boldness relates positively to inhibition (Lucon-Xiccato, Montalbano & Bertolucci, 2020), and in three-spined sticklebacks, boldness was related to time-to-making a decision but not to decision-making accuracy (Mamuneas, 2015). A meta-analysis by Dougherty and Guillette (2018) found evidence for a small significant relationship between personality and learning across species, however, the direction is highly variable.

Additionally, there were a few methodological points that should be considered in further research. First of all, because of the set-up of our tanks and the shyness of the cichlids, working with two observers was a challenge. We used a screen and video camera to block ourselves from the view of the fish, yet the other observer was not always blocked and at times spooked the individual in a trial. Secondly, pre-training took longer than expected and this could have to do with the age of the individual. We noticed that after replacing some individuals halfway during the experiments because of stagnation, the replacements, which were bigger when starting, seemed to go through pre-training quicker than the initial individuals we started with. The smaller individuals also had more trouble opening the disks. Starting with pre-training at an older age might be beneficial for the learning process.

In conclusion, no relation between social competence and cognition was found in this study which can be due to a separation between social and non-social learning or a lack of difference in social competence in the studied individuals. Additionally, there was no evidence for general intelligence in the daffodil cichlids which is in line with previous research in fish that suggests a difference in brain structure between endo- and ectotherm animals. To support this theory more research on general intelligence in fish and other ectotherm animals is needed.

Literature

- Aellen, M., Burkart, J. M., & Bshary, R. (2022). No evidence for general intelligence in a fish. *Ethology*, *128*(5), 424-436.
- Almat, N. S., Aliya, M. S., Zhanna, U. T., & Gulmira, D. S. (2023). The Relationship Between Social Intelligence And IQ: A Psychometric Analysis. *The Open Psychology Journal*, *16*(1).
- Arnold, C., & Taborsky, B. (2010). Social experience in early ontogeny has lasting effects on social skills in cooperatively breeding cichlids. *Animal Behaviour*, *79*(3), 621-630.
- Brandão, M. L., Braithwaite, V. A., & Gonçalves-de-Freitas, E. (2015). Isolation impairs cognition in a social fish. *Applied Animal Behaviour Science*, *171*, 204-210.
- Brown, C. (2015). Fish intelligence, sentience and ethics. *Animal cognition*, *18*(1), 1-17.
- Dougherty, L. R., & Guillette, L. M. (2018). Linking personality and cognition: a meta-analysis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1756), 20170282.
- Fischer, S., Balshine, S., Hadolt, M. C., & Schaedelin, F. C. (2021). Siblings matter: Family heterogeneity improves associative learning later in life. *Ethology*, *127*(10), 897-907.
- Griffin, A. S., & Guez, D. (2016). Bridging the gap between cross-taxon and within-species analyses of behavioral innovations in birds-making sense of discrepant cognition: innovation relationships and the role of motor diversity. In *Advances in the Study of Behavior* (Vol. 48, pp. 1-40). Academic Press.
- Lévy, F., Melo, A. I., Galef Jr, B. G., Madden, M., & Fleming, A. S. (2003). Complete maternal deprivation affects social, but not spatial, learning in adult rats. *Developmental Psychobiology: The Journal of the International Society for Developmental Psychobiology*, *43*(3), 177-191., ISO 690,
- Lucon-Xiccato, T., Montalbano, G., & Bertolucci, C. (2020). Personality traits covary with individual differences in inhibitory abilities in two species of fish. *Current Zoology*, *66*(2), 187-195.
- Mamuneas, D., Spence, A. J., Manica, A., & King, A. J. (2015). Bolder stickleback fish make faster decisions, but they are not less accurate. *Behavioral Ecology*, *26*(1), 91-96.
- Marlowe, H. A. (1986). Social intelligence: Evidence for multidimensionality and construct independence. *Journal of educational psychology*, *78*(1), 52.
- McGuire, S., Manke, B., Saudino, K. J., Reiss, D., Hetherington, E. M., & Plomin, R. (1999). Perceived competence and self-worth during adolescence: A longitudinal behavioral genetic study. *Child Development*, *70*(6), 1283- 1296.
- Montalbano, G., Bertolucci, C., & Lucon-Xiccato, T. (2020). Measures of inhibitory control correlate between different tasks but do not predict problem-solving success in a fish, *Poecilia reticulata*. *Intelligence*, *82*, 101486.
- Poirier, M. A., Kozlovsky, D. Y., Morand-Ferron, J., & Careau, V. (2020). How general is cognitive ability in non-human animals? A meta-analytical and multi-level reanalysis approach. *Proceedings of the Royal Society B*, *287*(1940), 20201853.
- Rowe, C., & Healy, S. D. (2014). Measuring variation in cognition. *Behavioral Ecology*, *25*(6), 1287-1292.
- Shaw, R. C., & Schmelz, M. (2017). Cognitive test batteries in animal cognition research: evaluating the past, present and future of comparative psychometrics. *Animal cognition*, *20*(6), 1003-1018.
- Taborsky, B., Arnold, C., Junker, J., & Tschopp, A. (2012). The early social environment affects social competence in a cooperative breeder. *Animal Behaviour*, *83*(4), 1067-1074.
- Taborsky, B., & Oliveira, R. F. (2012). Social competence: an evolutionary approach. *Trends in ecology & evolution*, *27*(12), 679-688.
- Wallace, K. J., Choudhary, K. D., Kutty, L. A., Le, D. H., Lee, M. T., Wu, K., & Hofmann, H. A. (2022). Social ascent changes cognition, behaviour and physiology in a highly social cichlid fish. *Philosophical Transactions of the Royal Society B*, *377*(1845), 20200448.