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RESEARCH

Too young to be bold: Lack of personality in juvenile goby

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Abstract
Animal personality, defined as consistent individual differences in behaviour across time and contexts, can significantly influence fitness and survival. However, the expression and stability of personality traits across ontogeny remain poorly understood, particularly in species undergoing complex life history transitions. Here, we examined behavioural consistency in juvenile two-spotted goby (*Pomatoschistus flavescens*) during the critical shift from a pelagic to a benthic lifestyle. Using two standardised assays—the emergence test (boldness) and open field test (exploration)—we assessed behavioural repeatability across repeated trials in a laboratory setting. Across most behavioural measures, we found low repeatability, with within-individual variance exceeding among-individual variance. Correlation analyses revealed consistent behavioural responses within contexts (e.g., among boldness measures), but no significant cross-context correlations, indicating that boldness and exploration do not form a behavioural syndrome in juveniles. These results contrast with findings in adult gobies and suggest that stable personality traits may not be present at this developmental stage. We propose that the observed behavioural flexibility may be adaptive, allowing juveniles to respond rapidly to the variable environmental and social conditions encountered during post-settlement. This ontogenetic plasticity may confer survival advantages in dynamic reef environments. Our findings underscore the importance of incorporating life stage and developmental context when investigating animal personality and behavioural organisation.

Keywords Boldness · Exploration · Two-spotted goby · Plasticity · Juvenile

Introduction

Many reef fish species exhibit complex life histories, comprising a pelagic larval stage followed by benthic, site-attached juvenile and adult phases. In these species, settlement from the plankton represents a critical transition in their life cycle, characterized by rapid changes in behaviour, morphology, and ecology (Leis and Mccormick 2002). Adapting to new surroundings poses significant challenges – new predators, unfamiliar habitats, intense competition – all contributing to high mortality rates (Almany and Webster 2006; Doherty et al. 2004). Yet, as recruits settle and gain experience, their survival chances improve significantly (Doherty and Sale 1986). Throughout this critical period, individuals face the challenge of learning to identify novel predators while optimizing their escape responses and foraging success. Those fish that can successfully adapt these behaviors will have better survival outcomes (Ferrari et al. 2015; Lönnstedt et al. 2012), making inter-individual variation in escape responses a potentially crucial factor in determining survival (Marras et al. 2011).

Juvenile reef fish are expected to rapidly develop consistent behaviours, such as boldness and aggression, which are likely to enhance survival during this life stage (Fuiman et al. 2010). However, behavioural flexibility remains equally important, allowing individuals to respond to changing

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environments (Ramasamy et al. 2015). Indeed, if only one optimal behavioural phenotype existed, natural selection would presumably eliminate genetic variation over successive generations (Réale et al. 2007). Yet, behavioural traits remain variable and heritable (Penke et al. 2007; Réale et al. 2007), suggesting that different behavioural strategies carry distinct trade-offs (Kelley et al. 2013).

The concept of animal personality—defined as consistent individual differences in behavior across time and contexts (Réale et al. 2007)—has profound ecological and evolutionary implications(Sih et al. 2012). Biro and Stamps 2015 argued that personality traits may be more plastic early in life, especially in unpredictable environments, where selection pressures are less stable (Fischer et al. 2014; Polverino et al. 2016). At the same time, behavioural traits and physiological processes may interact to produce consistent life-history strategies (Biro and Stamps 2008).

This variability can be advantageous at the species level. For example, a species comprising both bold individuals (or populations) that thrive in risk-free environments, and cautious individuals (or populations) that cope effectively with high-risk conditions, can potentially succeed across diverse ecological contexts (Sih et al. 2004). The species' overall success is subsequently constrained by mechanisms that reduce variation within populations (e.g., strong selection) or amongst populations (e.g., gene flow). Another example involves density-dependent fitness variation. In certain systems, more aggressive individuals outcompete others at high densities, whilst at low densities, aggressiveness represents a costly, unnecessary expenditure of energy (Duckworth 2006).Exploring how such behavioural variation develops and functions during key life stages can reveal much about the dynamics of animal personality (Dingemanse and Wright 2020; Duckworth 2015).

In this study, we investigated whether wild juveniles of a common goby displayed evidence of personality traits. Specifically, we focused on two personality dimensions: (1) boldness-shyness, arguably the most frequently studied personality dimension, reflecting responses to perceived risk; and (2) exploration-avoidance, indicating willingness to explore novel environments, food sources, or objects in the absence of predators or other threatening stimuli.

In this study, we used as a model species the two-spotted goby, *Pomatoschistus flavescens*, a small (adult length: 35–55 mm), sexually dimorphic marine fish distributed along European coasts from Portugal to northern Norway (Miller, 1986). This short-lived species typically survives only one year (Johnsen 1945) but reproduces multiple times during an extended breeding season lasting from February to July in our study region (A.M.F. pers. observation). Juveniles are often found in nearshore habitats, associating with kelp forests and rocky substrates (Borges et al. 2007; Potts and McGuigan 1986)where they form structured schools with size-based social hierarchies, whereby larger individuals occupy central positions whilst smaller juveniles remain at the periphery (Potts and McGuigan 1986). These dynamics suggest that young gobies must balance social positioning, foraging, and predator avoidance—a set of trade-offs that likely shape their emerging behavioral profiles.

Although adult two-spotted gobies have been shown to exhibit stable behavioral traits (Magnhagen et al. 2014; Martins-Cardoso, in prep.), it remains unclear how these traits develop during early life and whether personality emerges or shifts during major life history transitions. This study aims to fill this gap by examining the presence and consistency of personality traits in wild juveniles.

Materials and methods

Ethical note

Two-spotted goby juveniles were collected from the wild under authorization from ICNF – Institute for Nature Conservation and Forests (25624/2018/DCNF-LVT/DPAP). All experimental procedures were conducted in accordance with European Directive 2010/63/EU for the protection of animals used for scientific purposes and followed ISPA's institutional animal ethics guidelines. The study was approved by ISPA's animal welfare body and conducted under the supervision of an accredited expert in laboratory animal science (FELASA category C certified). Additional authorization was obtained from DGAV - General Directorate of Food and Veterinary Affairs (permit 0421/000/000/2020).

Fish collection and maintenance

Juvenile *P. flavescens* were collected by SCUBA diving at the Arrábida Marine Park, Portugal (38° 28' N; 8° 59' W), in May 2020, being immediately transported to ISPA-Instituto Universitário fish facilities, and transferred to a 100 L tank, maintained at a constant temperature of 16 °C and salinity of 35 PSU, mirroring conditions from the collection site. The photoperiod was set to 14 L:10D to replicate the natural summer light cycle in Portugal. Fish were fed *ad libitum* with frozen *Artemia* spp. twice a day, and left for three days to recover from handling. Fish were then randomly assigned to 30-L aquaria, two per aquarium, in a total of 40 fish. Each tank was filled with artificial seawater, equipped with biological and chemical filtration, maintained at the same temperature, salinity, photoperiod and feeding regime as in the

habituation tank. To allow tracking each fish ID, each juvenile was placed inside a mesh-cage (two cages per aquarium). The mesh cage allowed the fish to keep intraspecific interactions based on visual and chemical cues, therefore avoiding the development of atypical behaviours caused by complete isolation. Fish were allowed to habituate to these conditions for three more days before the beginning of the behavioural trials.

At the end of the experiment, all fish were euthanized with an overdose of the anesthetic MS-222 (400 mg L^{-1}) buffered with sodium bicarbonate (400 mg L^{-1}), and their total lengths were measured (mean ± SE: 2.70 ± 0.054 cm).

Behavioural trials

To investigate individual consistency of behaviour within and between contexts, each individual was tested twice for boldness and exploration. "Time to emerge from shelter" was used as a proxy of boldness, while the "open field" test was used as a proxy for the exploration trait. Both behavioural assays were adapted from (Magnhagen et al. 2014), who studied boldness in adult males of the two-spotted goby.

During experimental days, fish were fed only after testing. All experimental trials were conducted in a temperature-controlled room to minimize temperature fluctuations during testing, with setups enclosed by a black curtain to prevent external disturbances, and uniform light conditions were installed above the experimental arenas. Recordings took place during the morning. Boldness and exploration were tested sequentially for each individual. Behaviour was filmed from above with a GOPRO3 camera. A total of 40 individuals were tested over 5 days. After testing, fish were placed back into the respective mesh-cage and re-tested one week later, in the same order, for the same behavioural trials. Video analysis was carried out using the Observer® XT software.

Boldness

The time to emerge from the shelter was considered the proxy for boldness (Toms et al. 2010). The test was conducted in a rectangular aquarium (80 × 30 × 30 cm), divided into a smaller compartment with a length of 25 cm and a larger compartment of 55 cm (Fig. 1a). The two compartments were divided by an opaque partition. The smaller compartment was enriched with artificial plants, and the bottom was covered with gravel to represent a protected area for the fish. The larger compartment had a white bottom and contained no structural elements, therefore, assumed to be perceived as an unsafe environment by the fish. An individual fish was introduced in the smaller compartment and left for a 30 min acclimation period, after which the partition was carefully pulled up, allowing the fish to enter the larger compartment. The larger compartment was filmed from above for an extra 30 min. For each fish, latency to leave the shelter and enter the larger compartment (seconds), and time spent in the larger compartment (seconds) were recorded. We expected that a bolder fish would take less time to leave the shelter and spend more time in the larger compartment.

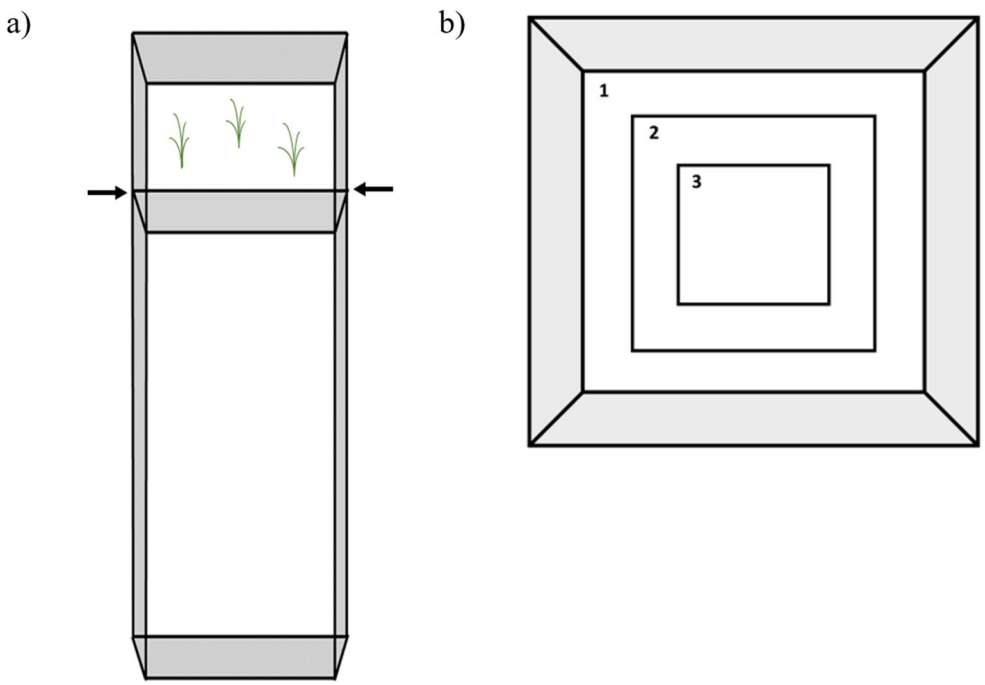

Fig. 1 Experimental set-up (top view) for behavioural assays. (**a**) Emergence test showing the sheltered area (top) and sliding divider (arrows); total area 25 × 55 cm. (**b**) Open field test showing zones 1–3; grid squares 6 × 6 cm; total area 45 × 45 cm. Adapted from (Magnhagen et al. 2014).

Exploration

The tendency to explore a novel environment as a proxy for exploration was tested in an open field arena (Burns 2008; Toms et al. 2010). The test was conducted in a square aquarium (45 × 45 cm) with a water depth of 30 cm, with a white bottom and no structural elements. The bottom of the aquarium was divided with a grid into three zones, to be able to register the fish's location, with zone 1 along the edge, and zone 3 in the centre (Fig. 1b). Each fish was released at the surface, in the centre of the tank (zone 3), carefully submerging the dip-net into the water and allowing the fish to swim out. The behaviour of the fish was then filmed from above for 10 min. Latency to reach zone 1 after release (seconds), and time spent in each zone (seconds) was recorded. We expected that a more exploratory fish would spend more time in the inner zones (zones 2 and 3), as opposed to a less exploratory fish which would spend more time close to the edge of the aquarium (zone 1).

Statistical analysis

All data were analyzed in R version 4.4.1(R Core Team, 2024), and all statistical tests were two-tailed.

Trait repeatability

Following Nakagawa and Schielzeth (2010); Stoffel et al. (2017) we estimated the repeatability (R) and associated 95% credible interval (CI) of each behavioural trait separately by fitting univariate linear mixed-effects models (LMMs) (Bates et al. 2015) to our repeated-measures data using the 'rptR' package.

The six behavioural trait measures—two boldness measures (time to leave shelter, time in outer compartment) and four exploration measures (time to enter zone 1, time in zone 1, time in zone 2, time in zone 3)—were log-transformed and modelled assuming Gaussian error distributions. All models included individual identification (ID) as a random effect, with individual total length (TL) and repeat test number as fixed effects.

Including repeat test number as a fixed effect controls for mean differences in behaviour across trials, while total length (TL) was included because body size can influence animal behaviour (e.g. Brown and Braithwaite 2004; Darby and McGhee 2019; Dowling and Godin 2002). Specifically, we used the 'rptGaussian()' function designed for fitting Gaussian data (Stoffel et al. 2017). The 'rpt' functions employ parametric bootstrapping to estimate 95% credible intervals (Nakagawa and Schielzeth 2010; Stoffel et al. 2017); we used 1,000 bootstrap iterations in our models.

To verify the normality of model residuals, we performed visual inspections of histograms and Q-Q plots, supplemented by Shapiro-Wilk tests. Two behaviours ('time to enter zone 1' and 'time in zone 3') showed normally distributed residuals (Shapiro-Wilk test: $W=0.981$; $0.379<P<0.385$). The remaining behaviours showed non-normal distributions (Shapiro-Wilk test: $0.640<W<0.939$; $1.246e^{-11} < P<0.00238$). However, Levene's test confirmed homoscedasticity for all behaviours ($0.186<Pr(F)<0.941$). Given that the residuals were homoscedastic and that mixed-effects models are generally robust to violations of normality assumptions (Schielzeth et al. 2020), we proceeded with the analysis.

Repeatability was calculated as the intraclass correlation coefficient: $R=V_I/(V_I + V_R)$, where V_I represents among-individual variance and V_R represents residual within-individual variance (Dingemanse and Dochtermann 2013; Nakagawa and Schielzeth 2010). Thus, R quantifies the proportion of total phenotypic variation attributable to differences among individuals (V_I). The residual within-individual variance (V_R) encompasses both measurement error and temporal environmental variation (Dingemanse and Dochtermann 2013; Dingemanse and Wolf 2010). V_R is biologically relevant as it captures within-individual plasticity in response to unaccounted stimuli (Westneat et al. 2015) and can influence trait correlations (Dingemanse and Wolf 2010; Mitchell and Houslay 2021). The variance components (V_I and V_R) underlying each repeatability estimate are presented in Table 1.

Trait (co)variation

The multivariate analysis was conducted using the 'MCMCglmm()' function in the R package 'MCMCglmm' (Hadfield 2010), following the approaches of Houslay and Wilson (2017) and Kniel and Godin (2019). This function fits generalized linear mixed-effects models (GLMMs) within a Bayesian framework using Markov chain Monte Carlo (MCMC) techniques. Our multivariate model specified the

Table 1 Variance components for behavioural traits

Trait	Trait measure	Variance	
		Among-individual	Within-individual
Boldness			
	Time to leave shelter	0.265 (0.515)	2.534 (1.592)
	Time in outer compartment	1.197(1.094)	4.290(2.071)
Exploration			
	Time to enter zone 1	0.365(0.604)	1.703(1.305)
	Time in zone 1	0.032(0.178)	0.136(0.369)
	Time in zone 2	0.156(0.394)	0.185(0.430)
	Time in zone 3	0.163(0.403)	0.508(0.713)

six repeatable behavioural traits as response variables, with total length (TL) and repeat test number as fixed effects, individual identity (ID) as a random effect, and a Gaussian family with identity link function. All response variables were mean-centred and standardized to unit variance, while repeat test number was mean-centred and total length was both mean-centred and standardized. This standardization ensures all behavioural variables are on comparable scales, facilitating model convergence and interpretation. The MCMC algorithm ran for 420,000 iterations with a burn-in period of 20,000 and a thinning interval of 100. Model convergence was verified by running four independent chains and applying both Gelman-Rubin and Heidelberger-Welch diagnostic tests using the 'gelman.diag()' and 'heidel.diag()' functions in the 'coda' package.

As recommended by (Dingemanse and Wright 2020) and (Houslay and Wilson 2017), we report the complete model results as separate matrix tables in the Supplementary Information (SI). These tables show among-individual mean variances (V_I), among-individual between-trait mean covariances (COVI), and among-individual correlations between paired traits (r_I) with their corresponding 95% CIs. The 95% CIs serve as informative indicators of statistical significance and uncertainty (Nakagawa and Schielzeth 2010). Following common practice (Houslay and Wilson 2017), we interpreted any Bayesian 95% CI that did not span zero as indicating statistical significance in the classical (frequentist) sense. Conversely, correlations with 95% Cis that crossed zero were deemed statistically non-significant.

Results

A total of 40 juvenile fish, ranging from 2.1 to 3.2 cm total length (TL), were tested. Due to technical issues, four videos from the boldness trial and two from the exploration trial were lost. Consequently, boldness data were available for 36 fish, exploration data for 38 fish, and complete data for both measures for 34 fish, which were used in the combined analyses. Descriptive statistics are presented in Table S1 (S.I.). In the boldness test, fish spent most of the trial inside the shelter (1161 ± 72 s). In the exploration test, fish preferred the periphery (zone 1: 623 ± 20 s) over the centre (zone 3: 90 ± 11 s). Despite stable group means across trials, individual rank order changed frequently (Figure S2, S.I.).

Trait repeatability

Analysis of variance components revealed that within-individual variance (V_R) substantially exceeded among-individual variance (V_I) for most measured traits, resulting in non-significant repeatability scores (Tables 2, 1). Boldness-related traits showed particularly high behavioral flexibility, with within-individual variance 9.6-fold higher than among-individual variance for "time to leave shelter" (V_R = 2.534, V_I = 0.265; R = 0.095, p > 0.05) and 3.6-fold higher for "time in outer compartment" (V_R = 4.290, V_I = 1.197; R = 0.218, p > 0.05). Similarly, exploration behaviours demonstrated low repeatability with predominant within-individual variation: "time to enter zone 1" (V_R:V_I ratio = 4.7; R = 0.176), "time in zone 1" (V_R:V_I ratio = 4.3; R = 0.012), and "time in zone 3" (V_R:V_I ratio = 3.1; *R* = 0.242), all with confidence intervals overlapping zero.

Table 2 Trait repeatability estimates

Trait	Trait measure	*R*	CI	ρ
Boldness				
	Time to leave shelter	0.095	(0, 0.415)	0.321
	Time in outer compartment	0.218	(0, 0.510)	0.115
Exploration				
	Time to enter zone 1	0.176	(0, 0.501)	0.172
	Time in zone 1	0.012	(0, 0.350)	0.153
	Time in zone 2	0.456	(0.158, 0.698)	0.003 *
	Time in zone 3	0.242	(0, 0.052)	0.089

The striking exception was "time in zone 2", where among-individual variance (V_I = 0.156) and within-individual variance (V_R = 0.185) were nearly equivalent, resulting in significant repeatability (*R* = 0.456, CI: 0.158–0.698, *p* < 0.05). This behaviour, occurring near the arena center, represented the only stable individual characteristic among all measured traits, contrasting sharply with the high behavioral plasticity observed in emergence and other exploration behaviours.

Repeat test number significantly reduces time to enter zone 1 (β = -0.767, *p* = 0.021), while TL (total length) significantly reduces time spent in outer compartment (β = -0.022, *p* = 0.032), but both variables show no significant effects on other boldness and exploration measures (all other *p* > 0.05).

Univariate rptR model estimates of repeatability (R), adjusted for individual total length and repeat test number, with 95% credible intervals (CI) for boldness and exploration measures in juvenile two-spotted goby (*N* = 34 individuals, k = 2 repeated measures). * indicates credible interval not overlapping zero (*p* < 0.05).

Estimates of the among-individual (V_I) and residuals within-individual (V_R) variances for each of the behavioural variables obtained from univariate linear mixed-effects models ('lmer()' function) in R package 'lme4'.

Trait (co)variation

Within-individual correlations revealed consistent situational responses. Boldness measures showed a strong

negative correlation between "time to leave shelter" and "time in outer compartment" (r_R = -0.989; S.I. Table S2), with a narrow credible interval indicating tightly coupled emergence responses. Among exploration traits, "time to enter zone 1" and "time in zone 3" displayed a strong positive correlation (r_R = 0.825; SI. Table S2), while "time in zone 1" and "time in zone 2" exhibited a strong negative correlation (r_R = -0.791; S.I. Table S2), reflecting consistent reciprocal patterns in spatial use.

Among-individual correlations, estimated by the multivariate model, quantified relationships between traits within each behavioral context. Boldness-related traits showed a strong negative correlation (r_I = -0.902; S.I. Table S3). Exploration behaviours displayed multiple significant correlations: "time in zone 1" was strongly negatively correlated with both "time in zone 2" (r_I = -0.971) and "time in zone 3" (r_I = -0.901; S.I. Table S3), while "time in zone 2" and "time in zone 3" showed a strong positive correlation (r_I = 0.833; S.I. Table S3).

The posterior mean intercept values for the fixed-effect covariables (total length, repeat test number) entered in our multivariate MCMCglmm models were statistically nonsignificant and therefore did not systematically influence any of the behavioural trait measures (total length: $0.236 < p < 0.867$; repeat test number: $0.078 < p < 0.862$). Although repeat test number showed a marginally significant tendency for total "time in zone 1" ($p = 0.078$), all remaining behavioral traits were not significantly affected by either covariate.

Importantly, no significant among-individual correlations emerged between boldness and exploration measures, with all cross-context correlation credible intervals overlapping zero. This absence of cross-context correlations indicates that boldness and exploration do not form an integrated behavioral syndrome in juvenile two-spotted goby, instead representing independent behavioral domains.

Discussion

Our findings provide new insights into individual behavioural variation and the organisation of behavioural syndromes during the early-life stages of the two-spotted goby. Repeatability analyses revealed that most behavioural traits exhibited low repeatability, suggesting limited evidence for consistent individual differences—or personality—in juveniles of this species.

To understand this pattern, we examined variance components and found that, for nearly all traits, within-individual variance (V_R) substantially exceeded among-individual variance (V_I), with ratios ranging from approximately 3:1 to 10:1. This dominance of within-individual variance points to high behavioural plasticity, whereby juvenile behaviour appears to be largely shaped by immediate environmental or internal conditions rather than stable personality traits. Such plasticity may be adaptive in early life stages, enabling rapid behavioural adjustments in dynamic and potentially risky environments (Mathot and Dingemanse 2014). An exception was observed for "time in zone 2", where among- and within-individual variances were roughly equal. This balance suggests that behaviour in intermediate zones - neither fully sheltered nor fully exposed -may capture a more stable, risk-assessment-related component of behavioural variation in this species.

Although consistent individual differences were limited, our correlation analyses revealed informative patterns. Most behavioural trait pairs exhibited similar magnitudes of among-individual (r_I) and within-individual (r_R) correlations (SI. Table 4), implying that both stable traits and context-dependent responses contribute to observed behaviour. Correlations were evident within domains -such as boldness or exploration - but we found no significant cross-context correlations, particularly between boldness and exploration traits. This lack of among-individual correlations suggests that these domains are behaviourally independent in juveniles, and do not constitute an integrated behavioural syndrome (Carter et al. 2013). Taken together with the low repeatability scores, this supports the conclusion that juvenile goby behaviour is primarily driven by situational responses rather than consistent individual behavioural types.

This finding contrasts with studies in other fish species that have documented boldness-exploration syndromes (e.g., Castanheira et al. 2013; Ferrari et al. 2014). For example, juvenile pikeperch (*Sander lucioperca*) display behavioural syndromes linking exploration and activity, where exploratory individuals demonstrated higher activity levels and greater boldness (Colchen et al. 2017). While juvenile European seabass (*Dicentrarchus labrax*) show associations between shy personality traits and self-feeding strategies (Ferrari et al. 2014). Similarly, Ferrari et al. (2014) revealed that juvenile European seabass (*Dicentrarchus labrax*) with high-triggering feeding behavior were characterized by shy personality traits, establishing that social organization around self-feeding systems is driven by personality differences rather than hierarchical dominance, sex ratios, or feeding motivation. Additionally, Castanheira et al. 2013 documented that juvenile Gilthead seabream (*Sparus aurata*) maintain consistent personality traits both temporally and across different contexts, showing that escape responses during restraining and risk-taking behaviors are stable over time,

with cross-context correlations revealing that individuals requiring more time to resume feeding in isolation also displayed increased escape attempts during restraining tests and more rapid escape from hypoxic conditions. These studies demonstrate that in some species, personality traits are detectable even in early life. By contrast, our results suggest that for the two-spotted goby, a more plastic, context-dependent behavioural strategy may be advantageous during the juvenile stage. This high degree of behavioural flexibility in juveniles likely reflects ecological pressures in the natural environment. In systems characterised by unpredictable changes in predation risk, social conditions, and resource availability, behavioural plasticity may offer greater fitness benefits than stable personality traits (Dall et al. 2004). Early life stages may particularly favour such flexibility, allowing individuals to respond rapidly to environmental challenges (Stamps and Groothuis 2010).

Interestingly, this juvenile plasticity appears to diminish with development. Previous work by (Magnhagen et al. 2014) demonstrated that adult two-spotted gobies exhibit clear behavioural syndromes, including consistent boldness across contexts. Bold individuals consistently emerged from shelter more quickly and spent more time in exposed zones, with boldness increasing during mating seasons. Complementary findings by Martins-Cardoso et al. (in prep.) reinforce boldness as a repeatable personality trait in adults. While studies on the ontogeny of personality remain limited, available evidence suggests that consistent behavioural traits may emerge post-maturation. For instance, Polverino et al. (2016) found that although behavioural traits in Eastern mosquitofish (*Gambusia holbrooki*) were repeatable across ontogeny, they only became detectable after sexual maturity.

These patterns support the idea that personality expression is not static, but varies across life stages, which underscores the importance of evaluating behavioural consistency and plasticity in a developmental context, rather than assuming continuity across the lifespan. The ontogeny of behavioural syndromes thus remains a promising area for future research.

A few experimental limitations warrant consideration. Our behavioural assays were conducted under laboratory conditions, which may not fully capture the complexity of natural environments. Incorporating social dynamics, such as shoaling, could provide a more ecologically relevant understanding of behavioural organisation. Moreover, our focus on juveniles limits conclusions about how behavioural traits develop over time. Longitudinal studies tracking individuals into adulthood would be instrumental in elucidating the emergence and stability of personality traits. Future work should also explore state-dependent factors—such as metabolic rate, nutritional status, or stress physiology—that might underlie within-individual behavioural variation. Finally, linking behaviour to fitness outcomes in natural settings would clarify the adaptive significance of plasticity versus consistency.

In summary, our study shows that behavioural variation in juvenile two-spotted goby is characterised by low trait repeatability, high plasticity, and limited cross-context organisation. The absence of behavioural syndromes suggests that boldness and exploration are modulated independently during early development, possibly reflecting adaptive flexibility in a variable environment. These findings contribute to a growing understanding of how behavioural organisation varies across species and life stages, highlighting the importance of considering both individual consistency and environmental responsiveness in behavioural ecology research.

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Data availability Data is submitted as electronic supplementary material.

Declarations

Competing interests The authors declare no competing interests.

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