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Influence of hook barbs on the "through-the-gill" hook removal method for deeply hooked Smallmouth Bass

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ABSTRACT

Sustainable catch-and-release fisheries are based on the assumption that most fish survive an angling event. The adoption of best practices has become important to help mitigate post-release injury, behavioral impairment and mortality. However, in any catch-and-release fishery, a proportion of fish will become inadvertently deeply hooked (e.g., in the gullet) and numerous studies have shown this to be a major driver of mortality. Although available science suggests that cutting the line tends to yield better outcomes than removing hooks in the gullet, there has been interest within the angling community with removing hooks using the "through-the-gill" method where the hook shaft is turned outwards into the gill region and then the hook is removed by pulling anteriorly by gripping the outside bend of the hook. Here, we tested the efficacy of removing barbed and barbless hooks though the gill opening from experimentally deep-hooked Smallmouth Bass (*Micropterus dolomieu*) relative to leaving the hooks in place. Using a control group and four experimental treatment groups (barbed and removed through the gills; barbless and removed through gills; barbed and left in; barbless and left in), we evaluated handling time, presence of bleeding, incidence of gill or esophageal injury, reflex impairment, incidence of hook shedding (for the left in treatment groups), and survival across a 24-hour monitoring period. Collectively, our results suggested that when hooks were barbed and removed through the gills, fish condition and survival were lower. In addition, barbed hooks were more likely to cause bleeding, gill damage, esophageal tearing, and impair reflexes. When hook removal was done through the gills, the chances of all sublethal outcomes across all categories were more likely to occur. While short-term mortality was not statistically linked with any treatment group, the greatest percentage of mortality (24%) occurred for fish that had barbed hooks removed using the through-the-gill method. These data suggest that when anglers use barbed hooks and encounter a deeply hooked fish, cutting the line poses the least risk to the fish.

1. Introduction

The single biggest determinant of the post-capture fate of an angled fish is anatomical hooking location, with deep hooks in the esophageal region (e.g., gullet) being more harmful than shallow locations such as the jaw (reviews in Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Arlinghaus et al., 2007). Although there have been a number of efforts to try and reduce deep hooking (e.g., by testing alternative hook types such as circle hooks (Cooke and Suski, 2004), encouraging use of active lures rather than organic baits (Brownscombe et al., 2017), the reality is that deep hooking will always occur for some angled fish. The best-case scenario with deeply hooked fish is that the anglers decides to harvest the fish, but regulations may not allow that as an option (e.g., not within the slot size, out-of-season, limits) and they must release the fish. When a fish is deeply hooked anglers have three choices – cut the line, cut the hook or remove the hook.

There have now been more than a dozen studies that compare outcomes for line cutting and deep hook removal, and almost all of them

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conclude that survival is higher when the line is cut (e.g., Fobert et al., 2009). The exceptions are few; for example, a study of adult American Eel (*Anguilla rostrata*) did not observe any mortality for fish that were deeply hooked and had the hook either left in or removed (Litt et al., 2020). Eel, however, have unique anatomy and morphology whereas the aforementioned examples were in fish with a more classical perciform body shape. The other exception is a study of Largemouth Bass (*Micropterus salmoides*; DeBoom et al., 2010) which employed a unique through-the-gill hook removal method. The through-the-gill method involves turning the hook shaft outwards into the gill region and then the hook is removed by pulling anteriorly by gripping the outside bend of the hook. That method has been adopted by Black bass (*Micropterus* spp) anglers (Cooke, Personal Observation) and is promoted by some of the angling media (e.g., Manns, 2002). DeBoom et al. (2010) concluded that for Largemouth Bass, the through-the-gill hook removal method yielded levels of mortality that were similar to other hook removal methods (e.g., removal via mouth with pliers), as well as fish for which the hook was not removed or when fish were only hooked in the oral cavity. That conclusion has potentially reinforced the use of the gill hook removal method by the Black bass angling community. However, this is based on a single study and there were some limitations that are worthy of consideration.

In the DeBoom et al. (2010) study there was very little mortality after 24 h for any treatment (5% for barbless and 10% for barbed hooks removed from the esophagus with pliers via the mouth). However, high levels of long-term mortality were observed in all groups including controls (e.g., 47% mortality in controls near the one-year mark). The DeBoom et al. (2010) study also relied on fish becoming deeply hooked on their own while using live bait. That approach limited the ability to fully control for hooking depth and hook position. Recent work involving the congeneric Smallmouth Bass (SMB; *Micropterus dolomieu*) found that removal of deep hooks using various purpose-built hook removal devices was so injurious to fish that they had to terminate the study (Cooke and Danylchuk, 2020). However, they did not include the through-the-gill hook removal method in that study. Indeed, as authors of that study we received significant feedback from Smallmouth Bass anglers noting that they used the through-the-gill method and without that our study was incomplete. Smallmouth Bass have a smaller mouth (as their name suggests) relative to Largemouth Bass which might make use of the technique more challenging. Given continued interest in use of the through-the-gill method for hook removal, conducting a follow-on study with SMB seems prudent.

Here we report a study that tested the efficacy of the through-the-gill method for removing hooks from the esophagus of SMB. To further our understanding of the contextual effectiveness of this method, we contrasted barbed and barbless hooks. We also included two treatments where barbed and barbless hooks were left in the esophagus of fish to contrast the gill removal method with cutting the line which is generally regarded as the best practice for most fish (see Brownscombe et al., 2017). We focused on short-term mortality as well as indicators of fish condition and welfare including bleeding, esophageal injury, reflex impairment, handling time (when comparing the gill removal method for barbed vs barbless hooks), and hook expulsion (when comparing cutting the line for barbed vs barbless hooks).

2. Materials and methods

2.1. Fish capture and treatments

The study was conducted under the auspices of a Scientific Collection Permit from the Ontario Ministry of Natural Resources and Forestry and an Animal Care Certificate from Carleton University (2021-Cooke-CRU). This research was conducted on Big Rideau Lake, Ontario, Canada (44°43.887' N, 76°13.975' W) between July 2nd and July 15th, 2021. Research was conducted during the COVID-19 pandemic, and thus we operated under the Cooke Lab Research Resumption Plan approved by Carleton University with all field work conducted by the Cooke family household bubble. Surface water temperature during the study was relatively stable at ~21–22 °C.

Angling was conducted from a Ranger RT178C fishing boat and SMB were captured on medium-heavy action rods and reels equipped with 4 kg line. Fish were captured on barbless soft plastic jigs with fight times standardized to 30 s. Fish were landed and immediately placed in a 20 L cooler filled with ambient lake water. If the fish was hooked anywhere other than the upper jaw and/or took more than 5 s to remove the hook underwater, they were immediately released. All other SMB were transferred to the onboard livewell (95 L) which was set to constantly circulate surface water (3028 L/ per hour). Fish were held for no more than 2 h before being transported less than 6 km back to the lab. Once back at the lab, Smallmouth Bass were individually transferred to a water filled 20 L cooler. The fish were then haphazardly assigned to one of five treatments: a control treatment, barbed or barbless hook left in, and barbed or barbless hook removed using the through-the-gill method. The same researcher (SJC) performed all experimental hooking (on land), scoring, and subsequent hook removal treatments to control for individual variation in hooking and removal ability as per DeBoom et al. (2010).

For fish in the control treatment, individuals were assessed for the presence of bleeding in the esophageal region, as well as any esophageal tearing and gill damage. To assess reflexes, fish were held upside down in the cooler to determine if they could right themselves within 3 s. Next, the tail of the fish was grabbed to determine if they responded by bursting away. These two reflexes, when absent, are deemed too be good indicators of the vigour of fish (Davis 2010). Individuals were then measured underwater (total length, to nearest mm) and an individually numbered fabric T-bar anchor tag was applied to the dorsal surface of the fish. Fish were then transferred to an 85-L common tank supplied with flow-through ambient lake water.

For fish in the two treatments where hooks (either barbed or barbless) were left in the gullet, fish were gripped by the lower jaw just above the water such that the fish hung vertically while the other hand of the researcher used a pair of hemostats to grip a size 4 baitholder hook (either barbed or barbless) that was passed through the esophagus until the point of the hook was no longer visible. The hook was then immediately pulled in an anterior direction such that it became lodged in the esophagus, which is typical of a deep hooking scenario during an angling event. The hooks were always oriented such that the hook point was centred on the dorsal aspect of the esophagus. An LED headlamp was worn by the researcher to allow better viewing of the esophagus. The hook along with 15 cm of monofilament line was then left in place, with the monofilament acting as an indicator of hook movement (Stein et al., 2012). The procedure took less than 5s, and the fish were then processed in the same manner as control fish.

Fish in the gill hook removal treatment were handled and assessed as above except rather than leaving the hook in place, the hook was removed using the through-the-gill method. We followed the methods used by DeBoom et al. (2010) as first described by Manns (2002). The individual who did the hook removal procedure had used this same procedure on ~20 Largemouth Bass and Smallmouth Bass over the past several years and has much experience with handling Black bass. The individual also watched a number of YouTube videos (e.g., https://www.youtube.com/watch?v=3RGTL9RBG2s&ab_channel=TexasParksandWildlife; https://www.youtube.com/watch?v=tdYM_Tp5C6c&ab_channel=Wired2Fish; https://www.youtube.com/watch?v=9FIJ74–79pk&ab_channel=TacticalBassin) to ensure that the methods being used aligned with those employed by the angling community. To remove a hook, hemostats were inserted anteriorly into the buccal cavity behind the last gill arch where the hook eye/shaft was grasped. The hook was then manipulated until the hook popped free (or slid out in the case of barbless hooks) from the esophagus, usually by grasping the outer bend of the hook (now facing anteriorly) with the same hemostats inserted via the mouth. The time to remove the hook was recorded to the nearest second and began when the researcher first inserted the hemostats into the gills. The procedure required holding the fish vertically by gripping the lower jaw such that the duration of hook removal equates to air exposure.

Survival was assessed at 10 min, one hour, six hours, 12 h, 18 h, and 24 h, while holding fish in the common holding tank. Fish were categorized as dead if they were clinically dead (i.e., the eye was fixed, the body was rigid and ventilation had ceased), or if they were moribund (e.g., gills were pale, and they were unable to maintain equilibrium with mortality anticipated within hours). Moribund fish were euthanized to comply with animal care protocols. All fish that were from the treatments where the hook was left in place were inspected at death or after 24 hr to determine if they had expelled the hooks. Research occurred over several weeks and thus involved several rounds of overnight holding. As such, control fish were included in every overnight holding session to evaluate any tank holding effects over time (although no control fish died in the study).

2.2. Data analysis

All statistical analyses were conducted using R 4.1.2 (R Development Core Team, 2021) and unless indicated otherwise, values are presented as mean ± 1 standard deviation. Statistical assumptions were evaluated following Zuur et al. (2010) and if violated (e.g., large outliers, homogeneity of variance, large deviations from normality), non-parametric methods were implemented. Because assessments were conducted over a short duration we pooled data across days for a single analysis.

A Kruskal Wallace test, via the Kruskal_test function in the rstatix package (Kassambara, 2020), was used to determine if mean fish size (mm) differed among the groups, i.e., the four experimental treatment groups and control. For the fish that had hooks removed through the gills, we used a Wilcoxon-rank-sum test via the wilcox_test function in the rstatix package (Kassambara, 2020) to determine if the mean time (s) differed between barbed and barbless hook types. For fish that had hooks left in, we assessed how many fish shed hooks at the end of the 24-hour monitoring period.

To determine how SMB observed sublethal responses (i.e., bled, gill damage, esophageal tear, lack of burst at release, and loss of equilibrium) and total length varied with one another and to determine if mean differences in those collective responses existed among the hook types and removal techniques, we first performed factor analysis using the six measured responses and total length. We used the FAMD function in the FactoMineR package (Lê et al., 2008) to reduce the dimensionality of the variables. This method uses both a mixture of principal component analysis and mixed correspondence analysis that allows for both continuous (measured fish length) and categorical (five observed responses coded as observed or not) variables, respectively (Lê et al., 2008). Subsequently, the explanatory power of each dimension and the contributions of each variable on each dimension were assessed. Using the values derived from the dimensional axis with the most explanatory power (i.e., the first axis), we then compared the value means across each treatment group using a Kruskal Wallace test and Wilcoxon-rank-sum tests via the Kruskal_test and wilcox_test functions in the rstatix package (Kassambara, 2020), respectively. Groups for the Kruskal Wallace test included treatment type (barbed and removed through gills; barbless and removed through gills; barbed and left in; barbless and left in) and if significant a pairwise Wilcoxon rank-sum tests with the Bonferroni correction was used to examine the differences between treatment groups. The Wilcoxon-rank-sum test separately compared hook type (barbed vs. barbless), and removal technique (through-the-gills vs. left in).

To test if there were non-random associations between the six observed responses i.e., bled, gill damage, esophageal tear, lack of burst at release, loss of equilibrium, and death) and removal techniques/hook types, we constructed contingency tables and then implemented multiple Fisher's exact tests using the stats package (R Core Team, 2021). Fisher's exact tests were used instead of chi-squared tests due to the relatively small sample size. Further, we also implemented Fisher's exact tests comparing instances of mortality across the control group and for when hooks were removed through the gills, left in, and, also, for barbed and barbless hooks.

To determine which measured variable(s) influenced mortality, we fit a logistic regression using the glmmTMB package (Brooks et al., 2017) with mortality (zero = no mortality; one = mortality occurred) as the dependent variable and the independent variables as bled, gill damage, esophagus tear, lack of burst at release, loss of equilibrium, and fish size. The combination of independent variables (additive) that best explained the outcome of mortality were determined through model validation processes and the Akaike information criterion via the dredge function in the MuMIn package (Bartón, 2019). Model assumptions and fit (e.g., normality of residuals, linear relationship, homogeneity of variance, multicollinearity) were also checked following protocols outlined by Zuur and Ieno (2016) and by using the performance (Lüdecke et al., 2021), DHARMa (Hartig, 2019), and sjPlot (Lüdecke, 2017; Lüdecke, 2021) packages.

Since fish were monitored for 24-hours post-capture and their mortality status, including instances of moribund, was assessed at 10 min, and at one hour, six hours, 12 h, 18 h, and 24 h, we examined SMB survival data across both time and treatment groups. Because many fish did not die during the 24-hour monitoring period, data were considered right censored (Harrell, 2015). We constructed a Kaplan-Meier survival curve (Cox and Oakes, 2018) for each treatment group, including the control, and used the log-rank test to determine if survival probability estimates differed among treatment groups (Harrell, 2015). The survival curve was produced using the survfit function in the survival package (Therneau, 2015) and plotted with ggplot2 (Wickham, 2016) using the ggsurv functions in the survminer package (Kassambara et al., 2021).

3. Results

A total of 115 individual Smallmouth Bass were captured, assigned to a control (n = 23) or experimental treatment group (n = 25, barbed and removed through the gills; n = 24, barbless and removed through the gills; n = 21, barbed and left in; n = 22, barbless and left in), and were assessed across six observational response variables including bleeding, gill damage, esophagus tear, lack of burst at release, loss of equilibrium, and death (Fig. 1). Fish size ranged from 198 to 442 mm (269 ± 69 mm) with no significant (Kruskal Wallace tests) differences among the treatment and control groups ($H(4) = 0.36, df = 4, p = 0.99$) and when assessing the treatment groups alone ($H(3) = 0.29, df = 3, p = 0.96$) (Table 1).

For the fish that had hooks removed through the gills (n = 49), hook removal times were significantly (Wilcoxon-rank-sum test) shorter with barbless hooks (n = 24, 9 ± 6.28 s) than when using barbed hooks (n = 25, 25.1 ± 12.4 s) ($W = 49.5, p < 0.001$). For fish with no hook removal and that had observational data after a 24-hour monitoring period (n = 41), only two fish had shed hooks (4.88%) and these were fish that had been hooked with barbless hooks. The remaining fish retained their hooks during the entire monitoring period (n = 20 with barbless hooks, n = 19 with barbed hooks).

The factor analysis reduced the five observed sublethal response variables and the measured total length variable into five dimensions with the first dimension explaining 48.33% of the variance, followed by 17.89% and 12.68% for the second and third dimension, respectively. The contributions of each variable on the first dimension included lack of burst response (23.70%), esophagus tear (21.62%), loss of equilibrium (20.24%), blood (19.07%), gill damage (15.18%), and total length (0.18%). Collectively, for the categorical variables on the first dimension, lower and more negative values indicated greater SMB condition and survival (Fig. 2a) than positive scores, which were largely associated with the barbed and removed through the gill treatment group (Fig. 2b).

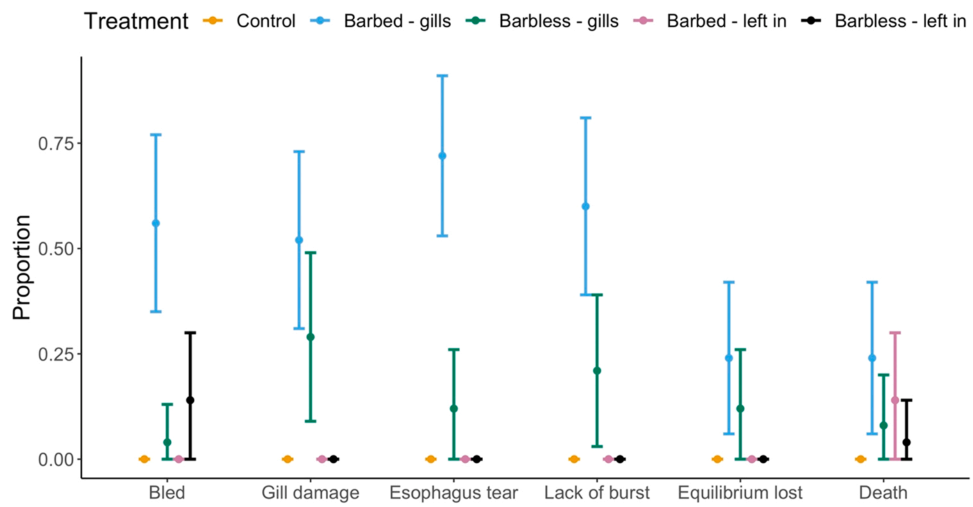

Fig. 1. Mean observed responses (± 95% confidence interval) of bleeding, gill damage, esophagus tear, lack of swimming burst, equilibrium loss, and mortality for Smallmouth Bass across each control and treatment group. Left to right: control, barbed - gills, barbless - gills, barbed - left in, and barbless - left in.

Table 1
Number of Smallmouth Bass in the control and treatment groups (barbed and removed through the gills; barbless and removed through gills; barbed and left in; barbless and left in), including their total length (mm) size range, mean, and standard deviation (SD). No significant differences in total length were found among groups.

Treatment	n	Min (mm)	Max (mm)	Mean (mm)	SD (mm)
Control	23	198	427	264	64
Barbed - gills	25	201	427	273	76
Barbless - gills	24	201	429	265	67
Barbed - left in	21	203	432	274	72
Barbless - left in	22	202	442	269	73

There were significant (Kruskal Wallace test) differences among treatment groups values on the first dimensional axis ($H(3) = 42$, $df = 3$, $p < 0.001$, eta-square = 0.44). Specifically, the barbed and removed-through-gill treatment group (n = 25, 1.89 +/- 1.88) was significantly (Wilcoxon-rank-sum tests) greater than barbless and removed through the gills (n = 24, −0.22 ± 1.72, $W = 517$, $p < 0.001$), barbed and left in (n = 21, −1.00 ± 3.51, $W = 510$, $p < 0.001$), and barbless and left in (n = 22, −0.95 ± 0.52, $W = 524$, $p < 0.001$). Barbed (n = 46, 0.57 ± 2.01) was significantly greater than barbless (n = 46, −0.57 ± 1.33, $W = 652.5$, $p = 0.002$), and the removal technique through the gills (n = 49, 0.85 ± 2.08) had greater values than when hooks were left in (n = 43, −0.97 ± 0.44) ($W = 421$, $p < 0.001$) (Fig. 3).

When hook removal was done through the gills there was a significantly (Fisher's exact tests) higher incidence of bleeding ($p = 0.01$), gill damage ($p < 0.001$), esophagus tear ($p < 0.001$), lack of burst ($p < 0.001$), and loss of equilibrium ($p < 0.001$) than when hooks were left in (Table 2a). Further, when hook removal was done through the gills vs. left in, respectively, bleeding occurred in 30.61% vs. 6.98% of fish, gill damage occurred in 40.82% vs. 0%, esophagus tear occurred in 42.86% vs. 0%, lack of burst occurred in 40.82% vs. 0%, loss of equilibrium occurred in 18.37% vs. 0%, and mortality occurred in 16.33% vs. 9.3%.

When fish were hooked with barbed hooks there was a higher incidence (Fisher's exact tests) of bleeding ($p = 0.02$), esophagus tear ($p < 0.001$), and lack of burst ($p = 0.02$) than when hooks were barbless (Table 2b). Further, when hooked with barbed hooks vs. barbless hooks, respectively, bleeding occurred in 30.43% vs. 8.70% of fish, gill damage occurred in 28.26% vs. 15.22%, esophagus tear occurred in 39.13% vs. 6.52%, lack of burst occurred in 32.61% vs. 10.87%, loss of equilibrium occurred in 13.04% vs. 6.52%, and mortality occurred in 19.57% vs. 6.52%.

There were no significant (Fisher's exact tests) differences in the proportions of mortality across removal techniques ($p = 0.37$) or hook types ($p = 0.12$). When proportions of mortality were compared to the control group (0 incidences of mortality), there was, again, no significant difference when hooks were left in (n = 4, 9.3%, $p = 0.29$), but a near significant trend when hooks were removed through the gills (n = 8, 16.33%, $p = 0.05$). Further, when assessing the proportions of hook type compared to the control group, while the proportions of mortality were near significant when compared to barbless hooks (n = 3, 6.52%, $p = 0.55$), they were when compared to when barbed hooks were used (n = 9, 19.57%, $p = 0.02$).

The top logistic regression model with mortality as the dependent variable and the other six response variables as independent variables included bled, equilibrium lost, and total length (Table 3). While when fish bled (odds ratio 5.19, CI 0.91–29.68, $p = 0.06$) and total length (odds ratio 1.01, CI 1.00–1.02, $p = 0.1$) were not significant, when fish lost equilibrium, the chance of mortality was 12.26 (CI 1.95–76.96, $p = 0.008$) times greater than when fish maintained equilibrium. While the top model was only slightly better than other candidate models (Table 3), loss of equilibrium was consistently included in each model.

While all fish survived in the control group, mortality was 13.04% across the experimental treatment groups. Specifically, the proportion of mortality was highest when barbed hooks were removed through the gills (n = 6, 24%), followed by when barbed hooks were left in (n = 3, 14.3%), barbless hooks were removed through the gills (n = 2, 8.33%), and when barbless hooks were left in (n = 1, 4.55%). For the four fish that had died and that had hooks left in, none had expelled them and three were barbed and one was barbless. Although fish with barbed hooks and removal through the gills appeared to have lower survival earlier during the monitoring period, the Kaplan-Meier survival curve (Fig. 4) and log-rank test indicated no difference ($p = 0.06$) in survival probability estimates among all groups.

4. Discussion

This study revealed that barbed hooks that were removed from the esophagus of SMB using the through-the-gill method took more than twice as long to remove than barbless hooks. Moreover, barbed hooks were more likely to cause esophageal tears and bleeding. No matter if the hook was barbed or barbless, removal through-the-gills had the potential to damage the gills. All of the sublethal outcomes that we assessed were worse for fish that had hooks removed than those that were left in place. Removal of hooks from the esophagus has the

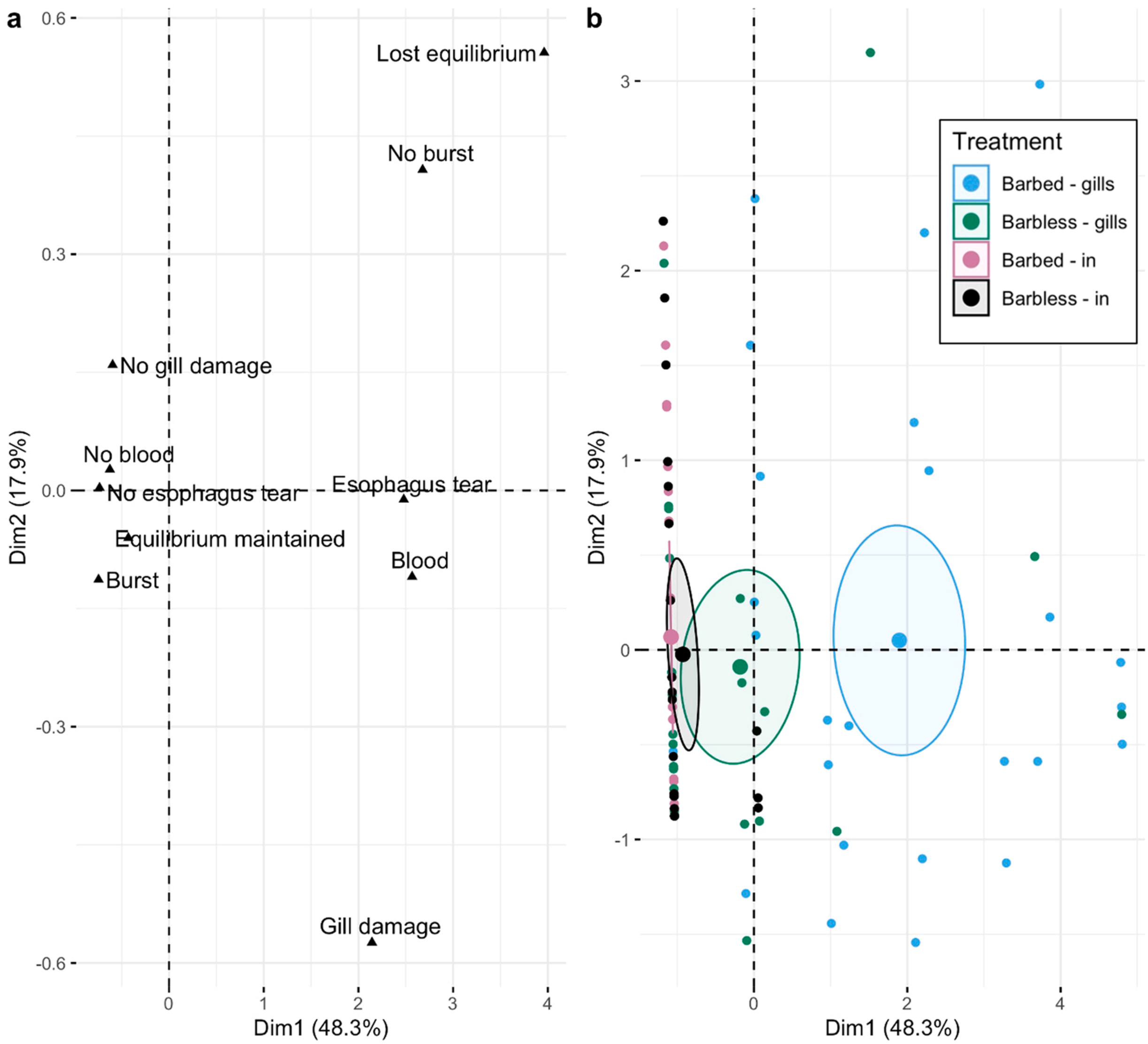

Fig. 2. Results across the first two dimensions of the factor analysis that reduced the dimensionality of the variables measured for Smallmouth bass, including bled, gill damage, esophagus tear, lack of burst at release, loss of equilibrium, and total length (mm). The categorical response variable locations are shown in panel a, with more negative values on the first dimension indicative of better condition and survival relative to positive values. In panel b, each trial location across the first two dimensions are shown and color is indicative of treatment group with ellipses highlighting the 95% confidence intervals. Percent explained is shown alongside the first dimension (x axis) and second dimension (y axis). The largest dots represent the mean. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

potential to damage vital organs and vasculature (Fobert et al., 2009; Robert et al., 2012). The previous descriptions of the through-the-gill method suggested that the hooks would "pop" out due to the relative position of the hemostats/ fishing pliers. Our experience suggested that when using barbed hooks, the "pop" was more like a tissue tear and hooks did tend to slide out once the correct angle had been achieved.

The level of mortality observed for the through-the-gill hook removal method when using barbed hooks was higher than that observed by DeBoom et al. (2010) at the end of the 24-hour monitoring period. Much of the mortality we observed for this treatment group occurred in the first hour or even by the 10-minute assessment period. That is suggestive of injury that was catastrophic and yielded blood loss or tissue damage that was not visible and that led to rapid mortality. Because it took longer to remove the barbed hooks than barbless hooks (and the cut the line treatments which required less than 5 s of air exposure), it is possible that the air exposure contributed to mortality. However, previous research on Smallmouth Bass in eastern Ontario at similar water temperatures, revealed that significant impairments were not observed until air exposure exceeded 120 s (White et al., 2008). The average time for hook removal for the barbless hook treatment was approximately 25 s, although some fish took as long as 60 s, suggesting that air exposure was unlikely to be the mortality driver. We did observe gill injuries that tended to occur with fish for which it was more difficult to remove the hook (i.e., some barbed hooks) but it was unlikely that the damage we observed (e.g., crushed gill filaments) was sufficient to cause mortality within the short-term period. Although it is impossible to determine the exact mechanism that caused the observed rapid mortality, when barbed hooks were removed, they had a number of impacts that were deleterious to fish welfare status. There are many potential factors that could explain differences between our findings and those of DeBoom et al. (2010) including species-specific variation in morphology and physiological tolerances or fish body size (fish in our study were smaller). Clearly, more research is needed.

The incidence of mortality for fish that had the line cut and hook left in place was low. Moreover, we saw low rates of hook shedding irrespective of whether hooks were barbed or barbless. This is not entirely

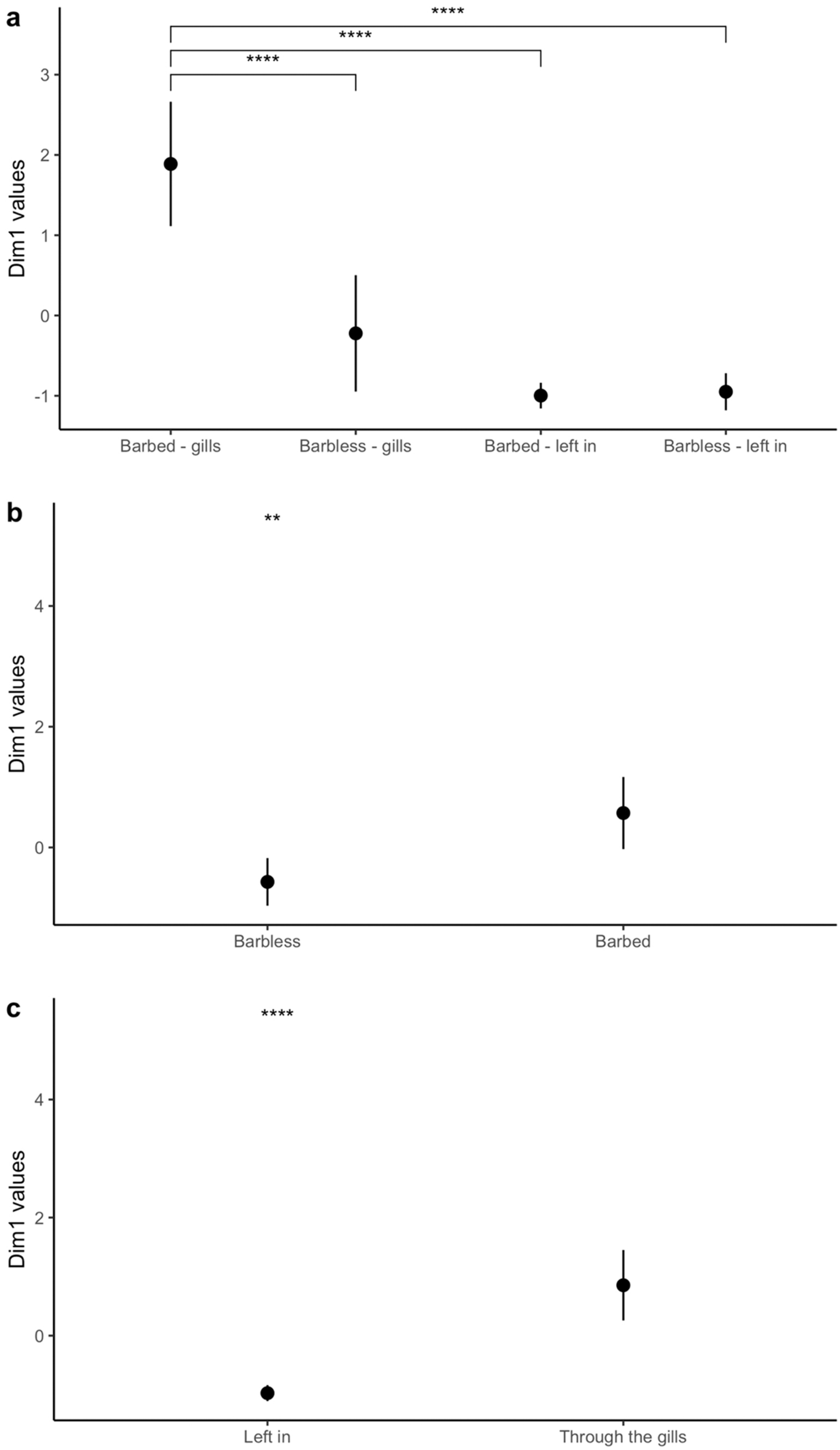

Fig. 3. Mean (± 95% confidence intervals) of the first dimension via the factor analysis for a) treatment groups, b) hook types, and c) removal techniques. Dimension values were derived using Smallmouth bass total length and the six response variables: blood, gill damage, esophagus tear, lack of burst at release, and loss of equilibrium. More negative values were associated with better levels of Smallmouth Bass condition / survival. If significant differences occurred, they were highlighted by asterisk ticks (** $= p \leq 0.01$, **** $= p \leq 0.0001$) above each comparison.

Table 2
Summary results from multiple Fisher's exact tests for Smallmouth Bass between the six observed responses (bled, gill damage, esophagus tear, lack of burst at release, loss of equilibrium, mortality) and a) hook removal techniques (through the gill or left in)and b) hook types (barbed or barbless). The observed and non-observed counts shown below were used in the contingency tables and Fisher's exact tests with significant values in bold.

A.						
Response	Through-the-gill	Left in	Odds Ratio	Lwr. 95% CI	Upr. 95% CI	P value
Bled	Not obs. = 34, Obs. = 15	Not obs. = 40, Obs. = 3	5.78	1.46	33.71	**0.007**
Gill damage	Not obs. = 29, Obs. = 20	Not obs. = 43, Obs. = 0	Inf	6.50	Inf	**< 0.001**
Esophagus tear	Not obs. = 28, Obs. = 21	Not obs. = 43, Obs. = 0	Inf	7.08	Inf	**< 0.001**
Lack of burst	Not obs. = 29, Obs. = 20	Not obs. = 43, Obs. = 0	Inf	6.50	Inf	**< 0.001**
Loss of equilibrium	Not obs. = 40, Obs. = 9	Not obs. = 43, Obs. = 0	Inf	1.95	Inf	**0.003**
Mortality	Not obs. = 41, Obs. = 8	Not obs. = 39, Obs. = 4	1.89	0.46	9.28	0.37
B.						
Response	Barbed	Barbless	Odds Ratio	Lwr. 95% CI	Upr. 95% CI	P value
Bled	Not obs. = 32, Obs. = 14	Not obs. = 42, Obs. = 4	4.52	1.26	20.67	**0.02**
Gill damage	Not obs. = 33, Obs. = 13	Not obs. = 39, Obs. = 7	2.18	0.71	7.25	0.21
Esophagus tear	Not obs. = 28, Obs. = 18	Not obs. = 43, Obs. = 3	9.00	2.32	52.08	**< 0.001**
Lack of burst	Not obs. = 31, Obs. = 15	Not obs. = 41, Obs. = 5	3.91	1.19	15.28	**0.02**
Loss of equilibrium	Not obs. = 40, Obs. = 6	Not obs. = 43, Obs. = 3	2.13	0.42	14.06	0.49
Mortality	Not obs. = 37, Obs. = 9	Not obs. = 43, Obs. = 3	3.44	0.78	21.21	0.12

Table 3
Logistic regression model selection summary results for Smallmouth Bass with mortality as the dependent variable and the independent variables as bled, gill damage, esophagus tear, lack of burst at release, loss of equilibrium, and body length (mm). The top model is indicated by the lowest the Akaike information criterion (AIC). Categorical covariates that were included in a given model are denoted with a plus (+) sign and if the covariate was not included in the given model, it is denoted as not applicable (NA).

Bled	Gill damage	Esophagus tear	Lack of burst	Loss of equilibrium	Total length	AIC	delta
+	NA	NA	NA	+	0.01	58.21	0.00
NA	NA	NA	NA	+	NA	58.67	0.46
+	NA	NA	NA	+	NA	58.80	0.58
NA	+	+	NA	+	NA	59.18	0.97
NA	NA	NA	NA	+	0.01	59.22	1.01

unexpected given that we only held fish for 24 h. Previous studies that investigated hook shedding in freshwater fish, documented shedding of hooks to occur over a period of days to weeks (see Tsuboi et al., 2006; DuBois and Pleski, 2007; Fobert et al., 2009). Although barbless hooks would presumably be easier to shed, loss rate of hooks by 24 h was sufficiently low where such a pattern was not evident if it existed.

The size of hook we used (size 4) is relatively small compared to the large hooks used by some anglers when fishing for bass. For example, it is not uncommon to use hooks in the size 1/0–5/0 range for Black bass when fishing with soft plastic lures. However, we wanted to use a hook that might be used by anglers who commonly target Smallmouth Bass using live bait such as dew worms, leeches, crayfish or small baitfish. DeBoom et al. (2010) used size 2 Kahle hooks which are commonly used when fishing for Largemouth Bass with live bait. Although it would be worthwhile to evaluate the hook removal and retention treatments using larger hooks, the size of the hook, and fact that large hooks tend to be used with soft plastic lures, inherently reduces the likelihood of deep hooking (see Brownscombe et al., 2017). Moreover, there may be an angler expertise component where anglers that tend to use organic baits may not be as advanced in skill as those who use artificial lures (e.g., a requirement in most black bass tournaments). The only study we are aware of on this topic evaluated the effects of hook size of hook retention in Bluegill (*Lepomis macrochirus*). Robert et al. (2012) reported that larger hooks tended to be retained longer and be associated with marginally higher levels of mortality than smaller hooks.

As with any empirical study there are limitations and findings are often most relevant to a given context. When combined with the only other study evaluating the through-the-gill removal method (i.e., DeBoom et al., 2010) we are starting to identify both generalities and knowledge gaps. What is clear is that more research is needed on this topic. Whenever we attempt to share best practices for catch-and-release with the massive Black bass fishing community, we are always challenged about the fact that deep hooking is not an issue for these fish because "it has been proven" that deep hooks can be removed safely. We do not disagree with the fact that the through-the-gill method enables the removal of hooks in a manner that is generally easier and superficially less traumatic than when other hook removal methods and gears are used (see Cooke and Danylchuk, 2020), however, the extent to which this is a best practice and actually benefits the fish, remains unclear. There are many different hook sizes and configurations that have the potential to influence the efficacy of this method.

What was apparent in this study, is whether a hook was barbed or not, influenced the efficacy and impact of this hook removal method. From a mortality perspective, leaving barbed or barbless hooks in the esophagus or removal of barbless hooks through-the-gills, yielded ~14% mortality, while the presence of the barb yielded mortality levels of ~25% after 24 h when the through-the-gill method was used. In other words, if Black bass anglers were to use barbless hooks, then they may decide whether they wish to remove the hook or leave it in place. Unlike salmonid fisheries where barbless hooks are common (Schill and Scarpella, 1997), use of barbless hooks for Black bass is rather uncommon (Quinn and Paukert, 2009). As such, based on our work and the existing literature base, we advise that anglers should cut the line, rather than try to remove hooks that are in the esophagus of Black bass. That perspective is further amplified by the fact that the fish in this study were handled by an expert on Black bass biology and catch-and-release wearing an LED headlamp – an unlikely combination for most Black bass fishing scenarios. We acknowledge the need for longer term research to understand the consequences of leaving hooks in fish on health and fitness.

We were unable to study the long-term consequences of esophageal and gill damage arising from the use of the through-the-gill method for hook removal, which is yet another reason to avoid using this method. Although DeBoom et al. (2010) monitored mortality for nearly a year, the levels of mortality in all groups, including the controls, makes it difficult to draw conclusions about the longer-term consequences of the

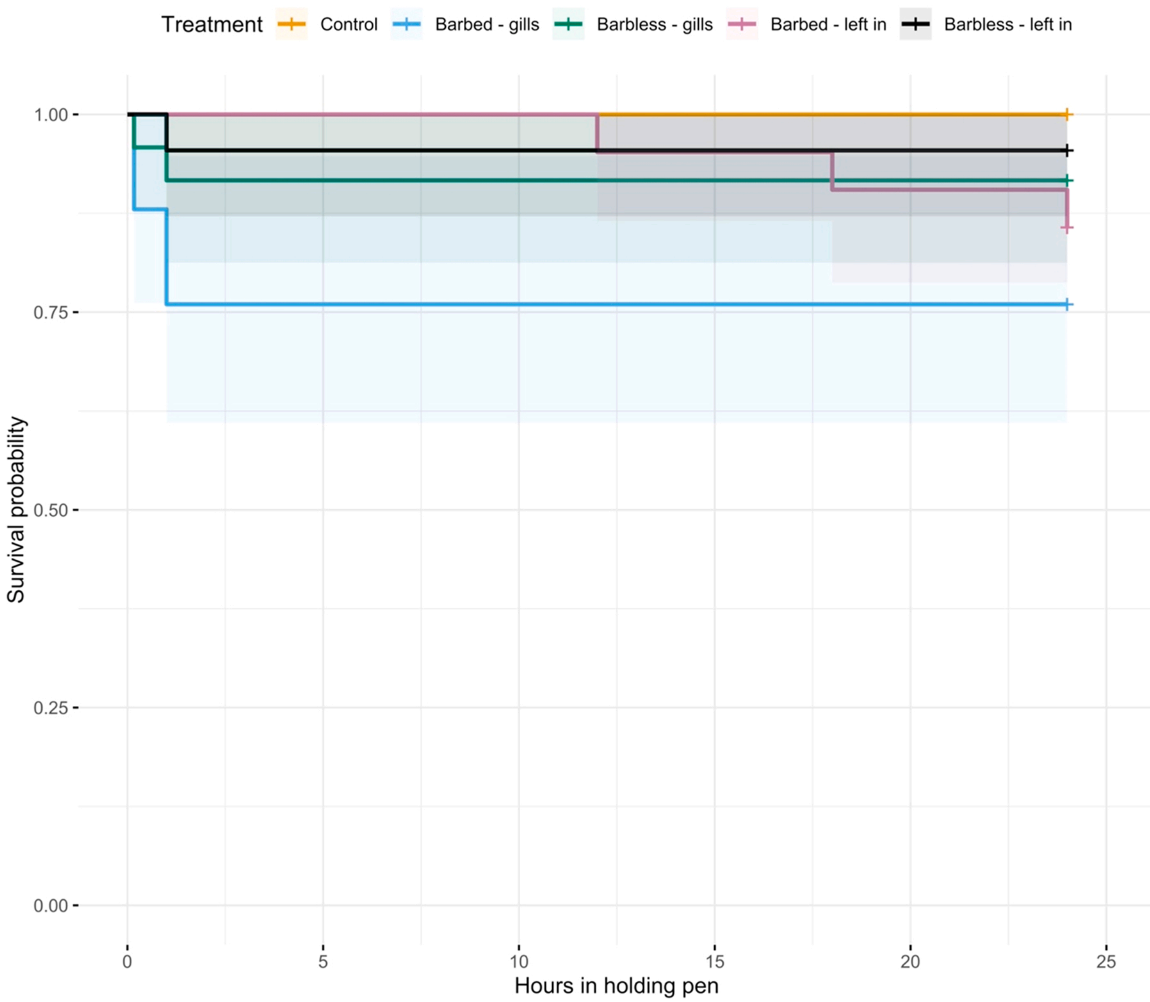

Fig. 4. Kaplan–Meier survival curve (95% confidence intervals shaded) of Smallmouth Bass survival in the treatment groups, including the control group.

through-the-gill hook removal method. There is a need for additional research on cardiorespiratory consequences of gill damage, as well as potential for gill damage to serve as a site of opportunistic pathogen infections (see Cooke and Hogle, 2000). A recent study that experimentally mimicked angling-related gill damage in SMB revealed impacts on fish behavior (Ekström et al., 2022). The study by DeBoom et al. (2010) suggests that feeding was not impaired by the through-the-gill hook removal method, but we documented esophageal tears which require further study as such injuries may impact hydromineral balance/osmoregulation.

Substantial effort will be needed to change the norm that has been established with in the Black bass fishing community where the through-the-gill hook removal method has been touted by influencers and media outlets as a panacea. Angler knowledge can be informative and has certainly advanced fish care on a number of fronts (see Cooke et al., 2017), but anglers do not typically have the opportunity to retain fish for long periods to assess fish condition/survival (as done in scientific studies) nor would they be likely to use robust experimental designs that include controls. While the through-the-gill method leads to successful hook removal, the process exposes fish to air for a lengthy period of time leading to loss of equilibrium (when hooks are barbed) and promotes injury to the esophagus and gills. Welfare outcomes were consistently worse for fish that had hooks removed using the through-the-gill method, especially when the hooks were barbed. Moreover, short-term mortality associated with deeply hooked Smallmouth Bass caught on barbed hooks with the hook removed using the through-the-gill method had the highest absolute level of mortality – somewhat higher than when the line was cut or when barbless hooks were used. There is more research needed (e.g., using different hook types and materials) but what is apparent from our study and that of DeBoom et al. (2010) is that avoiding deep hooking is the absolute best strategy and that if a fish is deeply hooked there appears to be some welfare benefits from cutting the line rather than removing the hook irrespective of the hook removal method used.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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