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Effect of Anthropogenic Disturbance Intensity on the Vigilance Mode of Wintering Hooded Crane (*Grus monacha*)

Xinran Wang[1,2] and Lizhi Zhou[1,2]*

[1]*School of Resources and Environment Engineering, Anhui University, Hefei 230601, China*

[2]*Anhui Province Key Laboratory of Wetland Ecosystem Protection and Restoration, Anhui University, Hefei 230601, China*

ABSTRACT

Wetland degradation has resulted in waterbirds choosing more habitats to forage and facing increased intensity of anthropogenic disturbance. Usually feeding in a large flock could provide safety by the vigilance partners through coordinated and synchronous vigilance modes. In this paper, we aimed to shed light on behavioral strategies adaptive to anthropogenic disturbances. Vigilance behavior of wintering *Grus monacha* was observed to assess the effect of traffic intensity on their vigilance mode at Shengjin Lake, a Ramsar Site in China. Disturbance intensity was divided into three levels, and the influence of disturbance intensity on collective vigilance was compared by one-way analysis of variance (low disturbance: $F = 1.854$, $P < 0.001$; moderate disturbance: $F = 1.854$, $P < 0.001$; high disturbance: $F = 1.637$). The relationship between disturbance intensity and vigilance mode was determined by analyzing the influence of disturbance intensity on the vigilance mode of the crane group. Anthropogenic disturbance intensity had a significant influence on vigilance mode of the wintering cranes. However, there were no significant differences between low and moderate disturbance groups (coordinated vigilance, low vs. moderate: $Q = 3.27$, $P = 0.056$; synchronized vigilance, low vs. moderate: $Q = 1.92$, $P = 0.364$), probably because of the close distance between both habitats and the presence of patrol boats and photography enthusiasts. Moreover, results showed that there was a significant difference in the frequency of the synchronized vigilance wave among disturbance intensity levels (low vs. high: $Q = 33.94$, $P < 0.001$; low vs. moderate: $Q = 3.557$, $P = 0.033730$; high vs. moderate: $Q = 28.24$, $P < 0.001$). Under high anthropogenic disturbance, wintering cranes mostly adopted coordinated vigilance mode (50%, 482.28±113.12s), while under low anthropogenic disturbance intensity, they adopted both coordinated (26%, 247.56±101.14s) and synchronous vigilance (45%, 289.28±88.29s). These behavioral strategies are of great significance to anti-predation vigilance.

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XW performed formal analysis and wrote, edited and reviewed the manuscript. LZ conceptualized and visualized the research.

Key words
Coordinated vigilance, Synchronous vigilance, *Grus monacha*, Disturbance intensity, Shengjin lake

INTRODUCTION

Waterbirds foraging in group face various dangers from natural and anthropogenic disturbance, and when disturbance intensity changes, they respond by adjusting their coordinated and synchronous vigilance modes. A classical stochastic independent model of sentinel behavior is the basis of most current research on waterbird sentinel behavior (Pulliam, 1973). Sentinel behavior usually means that members of a group take turns to detect predators at a height exposed to them, while other individuals engage in behaviors like eating (Beauchamp and Ruxton, 2003; Gayno and Cords, 2012). The discovery of sentinel behavior split the direction of waterbird behavior research at the time. Sentinel behavior is considered as coordinated vigilance. Coordinated vigilance as a sentry, when the "sentinel" can effectively detect risks and the information can be quickly transferred between "sentinel" and "forager," is very advantageous (Fernández-Juricic *et al*., 2004). For clustered birds, there are many examples of vigilance synchronization and coordination of natural observation. Several studies have confirmed that synchronous and coordinated vigilance are mostly used as vigilance modes in clustered birds (Rolando *et al*., 2001). Group size and predation risk had significant effects on alerting behavior of black-necked cranes (Cezilly and and Keddar, 2015). Similarly, other studies have confirmed the effects of group size and predation risk on vigilance behavior (Wood *et al*., 2010). The occurrence of synchronous vigilance is

* Corresponding author: zhoulz2009@qq.com
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accompanied by the formation of synchronous vigilance waves. Each fluctuation is caused by some individuals vigilancing at the same time (Pays *et al*., 2009).

Hooded cranes are listed as first-grade state protection wild waterbirds and endangered species in the Chinese red list of endangered waterbird species, as well as vulnerable species in the International Union for Conservation of Nature (IUCN) red list. Most of the domestic and foreign research on vigilance behavior of hooded cranes has stayed on the research of independent vigilance and vigilance distance, and few researches on synchronous vigilance and coordinated vigilance. Some studies have found that hooded cranes have significant differences between pedestrians and motor vehicles, are sensitive to anthropogenic activities (Zhou *et al*., 2010) and are less vigilance to motor vehicles (Zhang *et al*., 2009). Several studies have found that hooded cranes adapt to degraded habitats by adjusting vigilance behavior during the wintering period at Shengjin Lake. Moreover, it adapts to greater disturbance intensity by increasing vigilance duration and reducing other activity time (Li, 2015). The time budget of various behaviors of hooded cranes has a fixed allocation, and the proportion of vigilance behavior is second (Zhou *et al*., 2009). This study of vigilance mode provides new ideas for protecting hooded cranes, and it is also a new direction in the field of vigilance behavior.

Actually, in nature reserves, the biggest threat to waterbirds is anthropogenic disturbance instead of predators. Thus, elucidating the influence of anthropogenic disturbance intensity on vigilance mode and intensity would be a new direction to comprehensively understand vigilance behavior, especially anti-predation vigilance behavior of cranes, and to provide a basic line for protection of the endangered cranes (Li, 2016). In this study, disturbance intensity was classified by the relationship between the flow of people and the escape distance, into low, moderate, and high disturbance. When the disturbance intensity changes, the change of the reasonable vigilance mode will become the key to the hooded cranes to successfully pass the wintering period. In addition, researchers found that when the waves of collective vigilance ended, there would be a vigilance blank period (Kuang *et al*., 2014), *i.e.*, there was no vigilance behavior in the group. When the intensity of the disturbance affects the change of the synchronous vigilance mode, it causes the synchronous vigilance waves to change. How to deal with the relationship between the frequency of the vigilance waves and the duration of the vigilance blank period is an issue worthy of further study.

On this basis, this study assesses the anthropogenic disturbance intensity at Shengjin Lake and its effect on the type and intensity of vigilance mode by wintering hooded cranes. It is anticipated that hooded cranes will show coordinated vigilance under high disturbance intensity and synchronous vigilance mode under low disturbance intensity. Furthermore, the frequency and duration of the synchronous vigilance waves will decrease and increase, respectively, with the increase of the disturbance intensity.

MATERIALS AND METHODS

Research sites

Shengjin Lake (116° 55′−117° 15′ E,30° 15′−30° 30′ N), a lake on the verge of Yangtze River with an area of 13,300 hm^2, is located at the junction of Dongzhi County and Guichi District, Chizhou City, Anhui Province, on the East Asian-Australasian Flyway of migratory waterbirds. More than 70,000 waterbirds migrate to the lake for winter season every year in early October and leave at the end of April of the following year (Liu *et al*., 2001; Ge *et al*., 2011). Shengjin Lake Nature Reserve was established in 1986 and joined the "East Asia-Australasia wading Bird Reserve Network" in 2005 and the Ramsar sites of International Importance in 2015. The lake is divided into three parts: upper, middle, and lower lake. The main food resources of hooded crane are the root and stem of *Vallisneria natans*, *Ranunculus polii*, and *Oryza sativa*. The main habitats in the study area were grassland, mudflat, and paddy field (Fig. 1), with observation sites in Yangetou, Tongxinwei, and Xinshengwei, respectively, which had photographers, patrol ships, and farming activity and motor vehicles, respectively, as disturbance sources.

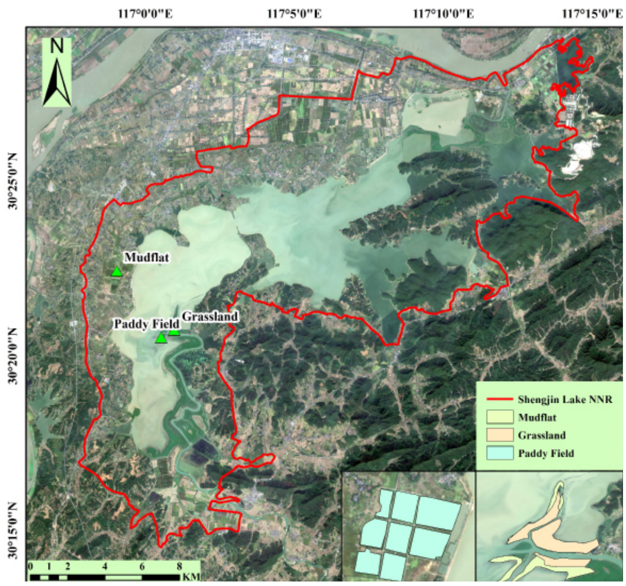

Fig. 1. The study sites including the mudflats, grasslands and paddy fields in Shengjin Lake National Nature Reserve (NNR), China.

Data collection

According to a reasonable selection of sampling points in the study area, the whole visible area can be scanned by single tube (SWAROVSKI 60 × 85) and binoculars (BOSMA 8 × 42), and the alert behavior data of hooded cranes were recorded by focus animal sampling at 7:00−11:00 and 13:00−17:00. At the time of implementation, the cluster was scanned from left to right in sequence, and the sentinel behavior data were recorded according to the standard of looking around. Similar group sizes were selected for investigation. The disturbance of group size was eliminated by recording the vigilance frequency of the hooded cranes in 10 minutes. When recording the vigilance mode, synchronous vigilance time of hooded crane cluster within 10 minutes was recorded by timer, and the frequency of collective vigilance wave was also recorded. In case of special weather, *i.e.*, strong wind and heavy rainfall, no data collection would be conducted. Vigilance frequency data were acquired as the alert frequency of individuals within 10 minutes. The vigilance behavior was defined as stopping feeding, extending neck, and looking around. The alert duration started from the moment of looking around to that of feeding.

A camera (Ordro, Z82) was used to record the vigilance mode, and the use of each sample should be over 10 minutes. In the filtering, focus animal sampling and instantaneous scanning method were used to calculate the vigilance mode time and record the number of collective vigilance waves within 10 minutes per unit time. When the group vigilance wave ended, there would be a vigilance blank period, which would also be recorded. The coordinated vigilance in mudflat, grassland, and paddy field habitat was recorded as N_X, C_X, and D_X, respectively, and their synchronous vigilance was recorded as N_T, C_T, and D_T, respectively.

The source of disturbance was recorded every ten minutes, including pedestrian flow and vehicle flow. The geographical distance of the crane group and the disturbance source's geographical coordinates were calculated by GPS.

Data analysis

The Kolmogorov-Smirnov test was used to assess data normality, and single factor ANOVA (normal distribution) or the nonparametric test (non-normal analysis) were used to analyze the influence of disturbance intensity on the vigilance mode of overwintering hooded cranes. Moreover, the difference in synchronous vigilance wave frequency among different disturbance intensities was analyzed by paired comparison test.

The comparative analysis showed that there were significant differences in the vigilance escape distance among the three habitats in winter. In the rice paddies habitat, there was not only the anthropogenic flow of 20 people per 15 min but also passing motor vehicles, carrying out secondary disturbance. According to the number of people passing every 10 min and the escape distance of the hooded crane, the intensity of anthropogenic disturbance was divided into three levels, low artificial disturbance, moderate anthropogenic disturbance, and high anthropogenic disturbance (Table I).

The 10-min vigilance frequency data of clusters sized 80−130 in the study comprised 454 groups, including 120 mudflat, 120 grassland, and 214 paddy field groups. The vigilance mode data included 416 groups, 208 groups of synchronous vigilance wave, *i.e.*, 71, 80, and 57 groups of N_X, D_X, and C_X, respectively, as well as 71, 80, and 57 groups of N_T, D_T, and C_T, respectively.

Table I. Definition of the external factors in the three disturbance intensities and the observed escape distance (mean±SD) of the hooded crane under the three disturbance intensities. The letter a, b, and c represent differences between escape distances. Superscript letters represent statistical differences between groups (Tukey's pairwise).

Item	Low disturbance	Moderate disturbance	High disturbance
Main habitat	Mudflats	Grassland	Paddy field
Number of people	<5	5−20	>20
Number of vehicles	0	0	>10
Escaping distance (Mean ± SD)	^{c}218.71 ± 15.47	^{b}324.99 ± 12.75	^{a}347.28 ± 14.82

RESULTS

Vigilance frequency

The results of single factor ANOVA showed that the intensity of anthropogenic disturbance had a significant effect on vigilance frequency (F = 72.256, P < 0.001). The vigilance frequency of hooded crane in high disturbance habitat was significantly higher than that in low and moderate disturbance habitats. (Low disturbance: F = 1.854, P < 0.001; Moderate disturbance: F = 1.854, P < 0.001; High disturbance: F = 1.637, P < 0.001) (Fig. 2). Under low disturbance, the average vigilance frequency is 32.77 times, under moderate disturbance, the average vigilance frequency is 41.42 times, and under high disturbance, the average vigilance frequency is 63.85 times.

Group vigilant model

Regarding time spent in each vigilance mode, pairwise comparison analysis showed no significant difference between the low and moderate disturbance intensities and significant differences between the low and high and the moderate and high disturbance intensities (Table II).

Table II. Vigilance time under three disturbance intensities. Data represent the average value, and the differences among the alert modes under the three disturbance intensities are compared in pairs.

Vigilance time	Vigilance time(s)			L_{NT} vs. M_{CT}	L_{CT} vs. H_{DT}	M_{CT} vs. H_{DT}
	Low disturbance (n=71)	Moderate disturbance (n=57)	High disturbance (n=81)			
Coordinated vigilance	247.56±101.14	225.64±13.7	482.28±113.12	Q=3.27 P=0.056	Q=38.26 P<0.001	Q=39.31 P<0.001
Synchronized vigilance	289.28±88.29	278.02±56.43	69.88±21.3	Q=1.92 F=0.364	Q=40.94 P<0.001	Q=36.42 P<0.001

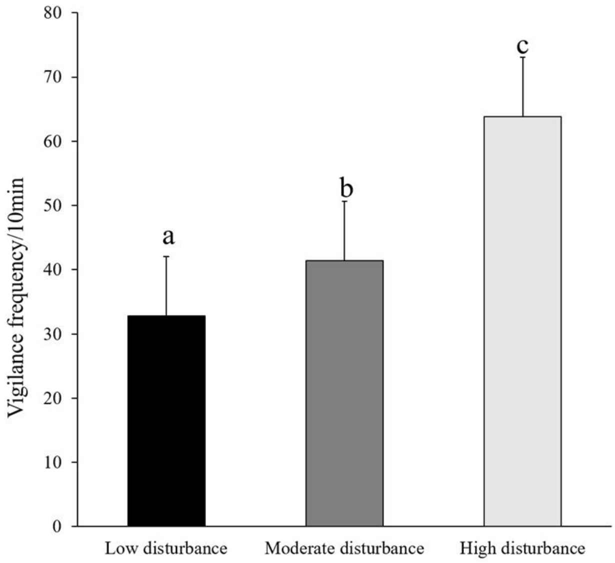

Fig. 2. Vigilance frequency under different disturbances. The letter a, b and c indicate that there are significant differences in vigilance frequency at three interference intensities.

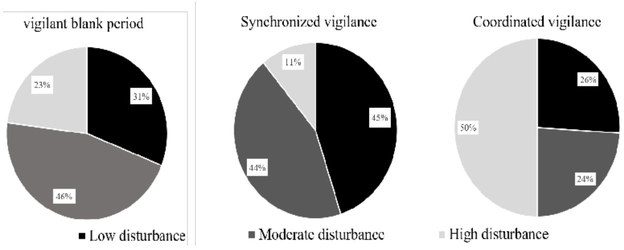

Fig. 3. Time ratios of synchronized vigilance time, coordinated vigilance time, and vigilance blank period under three disturbance intensity. Black represents low disturbance, dark gray represents moderate disturbance, and light gray represents high disturbance.

Under the three kinds of interference intensity, the proportion of time of coordinated alert, synchronous vigilance and vigilance blank period. Under low disturbance, the synchronization vigilance time accounts for 50% and the coordinated vigilance time accounts for 26%. Under moderate disturbance, the time of synchronous vigilance mode accounts for 44%, and the time of coordinated vigilance mode accounts for only 24%. Under high disturbance, the time of coordinated vigilance mode accounts for 50%, and the time of coordinated vigilance mode accounts for only 11%. (Fig. 3)

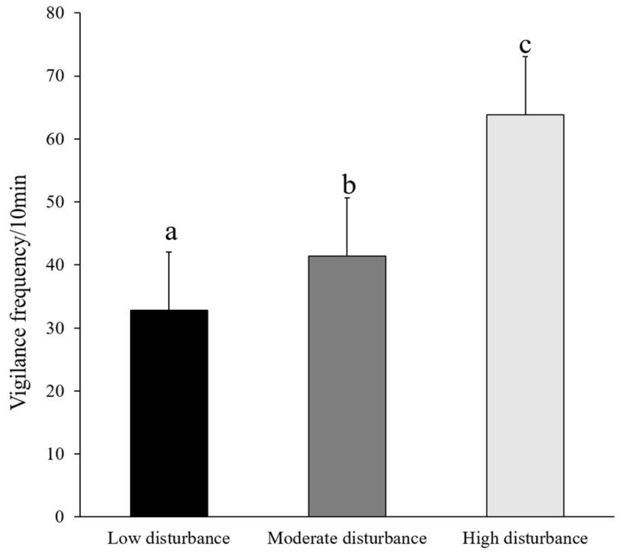

Fig. 4. Synchronous vigilance waves in three disturbance intensities. Different letters represent difference in the frequency and duration of the synchronization vigilance waves under different disturbance intensities. a, b and c represent differences.

Synchronous vigilance waves

Results of the paired comparison test showed significant differences in the frequency of synchronous vigilance wave of wintering hooded cranes among three disturbance intensities (low vs. high, $Q = 33.94$, $P < 0.001$; low vs. moderate, $Q = 3.557$, $P = 0.033730$; high vs. moderate, $Q = 28.24$, $P < 0.001$), as well as in its duration (low vs. high, $Q = 2.31$, $P = 0.021$; low vs. moderate, $Q = 1.22$, $P = 0.56$; high vs. moderate, $Q = 1.86$, $P = 0.045$). As the intensity of the disturbance increases, the frequency of vigilance waves increases, and the duration of vigilance decreases (Fig. 4).

DISCUSSION

In this study, the intensity of anthropogenic disturbance, which was expressed by the distance from anthropogenic activity, had a significant effect on the level of group alertness. The paddy field habitat was the closest to the village, where passing vehicles were frequent, so it had strong anthropogenic disturbance. Moreover, the grassland habitat was closer to the village, *i.e.*, had greater anthropogenic disturbance intensity, than the mudflat habitat. Results of single factor ANOVA showed a significant difference in the vigilance frequency among low, moderate, and high disturbance habitats, indicating that anthropogenic disturbance intensity had a significant effect on the collective vigilance level of wintering hooded cranes. Owing to the degradation of vegetation at Shengjin Lake, wintering hooded crane increased their vigilance frequency to keep the group vigilance level highly concentrated on anthropogenic disturbance. Meanwhile, with the decline of foraging efficiency, more foraging time is needed to meet their needs. Several studies have found that the red-crowned crane will increase the number of times looking around in environments with strong anthropogenic disturbance, which is consistent with the results of the study on vigilance frequency of wintering hooded crane (Li *et al*., 2007).

Coordinated vigilance can reduce the vigilant blank period and improve the overall vigilance level of the group and vigilance efficiency, having a significant impact on survival probability (Rodríguez-Gironés, 2002). The results of this study show that when the high disturbance intensity vigilance blank period is reduced by half compared to the low disturbance vigilance, the reason is that as the disturbance intensity increases, the use of coordinated vigilance increases (Ward, 2011). The results about of the vigilance blank period study are consistent with the previous studies. It has also the significant advantage of being conducive to avoiding the risk of predation. However, because it emphasizes that individuals avoid the simultaneous occurrence of vigilance behaviors by paying attention to nearby peers, the maintenance of this mode requires a considerable investment by individuals. Therefore, the realization of the coordinated vigilance model necessarily requires some conditions (Rodríguez-Gironés, 2002; Sirot, 2006). The research results in this paper show that hooded cranes are more likely to choose a coordinated vigilance mode under high disturbance intensity, which also confirms the previous scholars' conjecture that high disturbance habitats are an important condition for inducing coordinated vigilance.

Results showed that wintering hooded crane mostly adopted coordinated vigilance mode under high disturbance intensity. In this study, the intensity of artificial disturbance was determined by the distance between disturbance source and hooded crane. Depending on disturbance type, the vigilance distance and sensitivity of hooded cranes were significantly different, being more sensitive to anthropogenic activity than to motor vehicles. Single factor ANOVA did not show significant differences in synchronous and coordinated vigilance between mudflat and grassland habitats. This has several explanations. First, the distance between mudflat and grassland is small at Shengjin Lake, with ships going around on patrol that interfere with the hooded cranes foraging in the mudflat habitat, causing them to increase vigilance. Second, the artificial disturbance of grassland habitat mainly comes from tourists and photographers, and its time frequency is relatively scattered, with a certain amount of disturbance every weekend. The mudflat is closer to the lake and the ships go around on patrol regularly and frequently every day, which will also lead to the high vigilance of hooded cranes. Third, wintering cranes have increased tolerance to disturbance sources. Moderate and low disturbance sources mainly come from patrolling vessels, photography enthusiasts, grazing, long wintering cycles and regular circulation of disturbance, which may lead to wintering crane vigilance. Moreover, increased tolerance affects the vigilance mode but has no effect on vigilance frequency.

Under low disturbance intensity, hooded cranes will increase the synchronous vigilance time. But at the end of synchronous alert, there will be a vigilance blank period (Pays *et al*., 2009; Yang *et al*., 2006, 2016). Consistent with the results of this study, as the intensity of disturbance decreases, the use of synchronous vigilance mode will increase. Although this improves the foraging efficiency, it will lead to no crane vigilance behavior in the group (Frid *et al*., 2002). The research in this article shows that the increase in the synchronous vigilance time leads to an increase in the frequency of blank periods, but the vigilance time does not increase significantly. Hooded cranes will increase the frequency of blank periods but will not extend the duration of the gaps (Tierala, 2011; Treves, 2000). This is the best way to choose synchronous guards for low disturbance habitats to ensure the vigilance of the hooded cranes. Contrastingly, under high disturbance intensity the rate of coordinated vigilance mode is up to 50%. Graphic pairwise analysis showed that anthropogenic disturbance intensity had a significant influence on the coordinated vigilance of wintering hooded cranes, and frequent vehicles and anthropogenic activities were the main factors causing this phenomenon.

Vigilance behavior is a behavioral response of waterbirds to prevent risk. Since the "sentinel behavior" was proposed (Clutton-Brock *et al*., 1999; Radford *et al*., 2009), coordinated and synchronous vigilance have become research hotspots. Through the study of coordinated vigilance and synchronized vigilance, it is found that although the intensity of the disturbance throughout the winter period is constantly changing, the hooded cranes can always find the optimal vigilance mode. The change of this vigilance mode provides a guarantee for the hooded cranes to survive the wintering period. However, the results of the study on the vigilance mode under low and moderate disturbance are different from the expected results. The analysis may cause tolerance for some specific disturbance sources. The entire wintering period is as long as six months. The study of tolerance is also worthy of further research. Both of them have been defined as vigilance modes suitable for specific environments and predation risks (Xu *et al*., 2013a). Studies have shown that the coordinated vigilance mode is more likely to occur in small-sized groups and the tendency of coordinated alert will increase with increasing group size (Xu *et al*., 2013b). However, this study finds that large groups use more coordinated vigilance mode under high disturbance intensity. Therefore, the effect of group size on coordinated vigilance is worthy of further discussion. The emergence of synchronous vigilance is the adaptive performance against predator's target selection strategy, and behavioral synchronization between groups is also necessary to maintain and enhance group cohesion. However, synchronous vigilance mode will lead to the increase of vigilance blank periods. Therefore, it is not the best choice for group vigilance. Coordinating vigilance helps to reduce the proportion of group vigilance blanks, but individuals need to monitor their neighbors and take appropriate actions. Synchronized vigilance is suitable for low-interference habitats, and coordinated vigilance is more suitable for high-interference habitats. Research finds that wintering hooded cranes are resistant to certain disturbances, and the tolerance of vigilance behavior needs further research, which can provide more effective methods for protecting hooded cranes.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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