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The effect of visual focus on spatio-temporal and kinematic parameters of treadmill running

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ABSTRACT

The characteristics of a treadmill and the environment where it is based could influence the user's gaze and have an effect on their running kinematics and lower limb impacts. The aim of this study was to identify the effect of visual focus on spatio-temporal parameters and lower limb kinematics during treadmill running. Twenty six experienced runners ran at 3.33 m s^{-1} on a treadmill under two visual conditions, either looking ahead at a wall or looking down at the treadmill visual display. Spatio-temporal parameters, impact accelerations of the head and tibia, and knee and ankle kinematics were measured for the final 15 s of a 90 s bout of running under each condition. At the end of the test, participants reported their preference for the visual conditions assessed. Participants' stride angle, flight time, knee flexion during the flight phase, and ankle eversion during contact time were increased when runners directed visual focus toward the wall compared to the treadmill display ($p < 0.05$). Whilst head acceleration was also increased in the wall condition ($p < 0.05$), the other acceleration parameters were unaffected ($p > 0.05$). However, the effect size of all biomechanical alterations was small. The Treadmill condition was the preferred condition by the participants ($p < 0.001$; $ES_w = 1.0$). The results of the current study indicate that runners had a greater mass centre vertical displacement when they ran looking ahead, probably with the aim of compensating for reduced visual feedback, which resulted in larger head accelerations. Greater knee flexion during the flight phase and ankle eversion during the contact time were suggested as compensatory mechanisms for lower limb impacts.

1. Introduction

Running continues to be one of the most popular forms of indoor and outdoor exercise worldwide [1]. Indoor running is commonly performed on motorised treadmills which are located in fitness, clinical and research centres [1]. Different studies have demonstrated how running on a treadmill is not the same as running overground, which is demonstrated through differences in kinematic, kinetic and neuromuscular parameters [2–4]. However, there is a lack of information concerning the effects of other characteristics of treadmills during treadmill running, such as the effect of treadmill display position and shape on the orientation of the users gaze.

The ability to maintain normal functional gait can depend on the gaze behaviour which is used to identify the appropriate visual cues for safe and effective locomotion [5,6]. Visual feedback is used to maintain normal gait and its alteration could result in perturbations in locomotion such as the increase of minimum toe clearance and the decrease of the stride length and stride frequency [7–9]. In this sense, the characteristics of the treadmill and the environment surrounding it could guide the person's gaze and have an effect on their movements. While looking forward has been suggested as beneficial in the increase of peripheral vision leading to a better adaptation to perturbations of the environment, looking down could increase the visual feedback of the body motion and better inform the movement [5]. Although Goodworth et al. [5] observed a minimal impact of visual condition on medio-lateral upper body motion during walking and they only observed impact in perturbed walking (e.g. rotating the treadmill), local dynamic stability decreases and vertical displacement of center of mass increases during running [10,11] which could produce different results. In the context of gym-based exercise, then it is commonplace for treadmills to have displays that highlight pertinent health and fitness data or act as television displays. Similarly, gyms often mount

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televisions in the gym area on the walls near exercise equipment. These different visual displays may draw the runner's visual focus differently to over-ground running and this may result in changes to a runner's kinematics and kinetics.

Alongside this, changes in kinematic have been shown to be related with the magnitude of impact shocks experienced by the body during locomotion [12,13]. For example, increasing stride frequency by 10% was found to reduce impact accelerations at ground contact [13]. Furthermore, it has been observed that knee flexion at footstrike is correlated with tibial shock [14], and runners with chronic ankle instability present a larger ankle eversion range of motion, vertical peak and loading rate during the vertical drop [15]. Because impact accelerations during running have been associated with lower extremity injuries, in particular with tibial stress fractures [14], the assessment of the possible effect of visual focus on kinematic variables and on impact acceleration during running is of great importance.

Therefore, the aim of this study was to identify the effect of visual focus on spatio-temporal parameters and lower limb kinematics during treadmill running. It was hypothesized that maintaining gaze on a visual cue as by looking forward, might minimise visual information about the movement and elicit changes in spatio-temporal and kinematic parameters during treadmill running such as reduced stride length and increased impact accelerations.

2. Methods

2.1. Participants

Twenty six recreational male runners (age 27.9 ± 6.8 years; height 175.8 ± 7.2 cm; body mass 70.3 ± 10.3 kg; training distance 40.8 ± 7.1 km/week) with no history of lower extremity injuries within the last year and no history of foot and ankle surgery within the past 3 years, participated in the study. Procedures complied with the Declaration of Helsinki and were approved by the University ethics committee. Participants gave written informed consent prior to participating in the study.

2.2. Study design

Participants attended a single laboratory session and completed two randomised 90-s bouts of varied visual conditions whilst running on a motorized treadmill with length and width running surface of 1.52 and 0.52 m, respectively (Excite Run 700, TechnoGym, Gambettola, Italy). Participants completed a 5 min warm up at 2.22 m s^{-1}, then completed two randomised trials looking at either the wall in front of the treadmill (*Wall*) or the visual display of the treadmill (*Treadmill*) whilst running at 3.33 m s^{-1}. A bullseye type image was placed on both visual focus targets with the aim of ensuring the stabilization of the runner's gaze in one specific area (Fig. 1). The Bullseye image for the *Wall* condition was placed at a distance of 280 cm in front of the runner and at the same height as their eyes. For the Treadmill condition, the target was placed directly on top of the visual display unit. In addition, size of bullseye image for *Wall* was larger than *Treadmill* condition with the aim to be both scaled. Same instructions were given to all the participants. During the 90-s bout of each condition, participants were instructed to maintain their gaze focus on the target bullseye image (*Treadmill* or *Wall*) until new order. To ensure familiarisation with each condition prior to measurement of any gait parameters, all measurements were collected during the final 15 s of each 90 s condition. Participants did not know when the measurements started, finished or the time that they ran for each condition with the aim to avoid alterations of the gait. After completion of the laboratory session, participants reported their preference for visual condition.

2.3. Data analysis

Contact time, flight time and stride angle were measured using the optical detection system OptoGait (Microgate, Bolazano Italy). These parameters were defined as follow:

- Contact time: duration of the phase when one foot is in contact with the ground.
- Flight time: duration of the phase when neither foot is in contact with the ground.
- Stride angle: The angle of the parable tangent deriving from the movement of a stride.

Lateral and posterior angular kinematics were measured by tracking the position of skin/surface reflective markers using two video cameras (MotionScope®, Redlake, MASD Inc., San Diego, USA) sampling at 125 Hz and placed 1.5 m perpendicular to the motion plane and 0.5 m high. Seven markers were positioned on the right lower limb at the gastrocnemius (in the axial line of the leg, under the gastrocnemius bifurcation), on the Achilles tendon at the height of the malleolus, upper and lower posterior surface of the calcaneus, lateral malleolus, lateral femoral condyle, and greater trochanter. Ankle eversion and

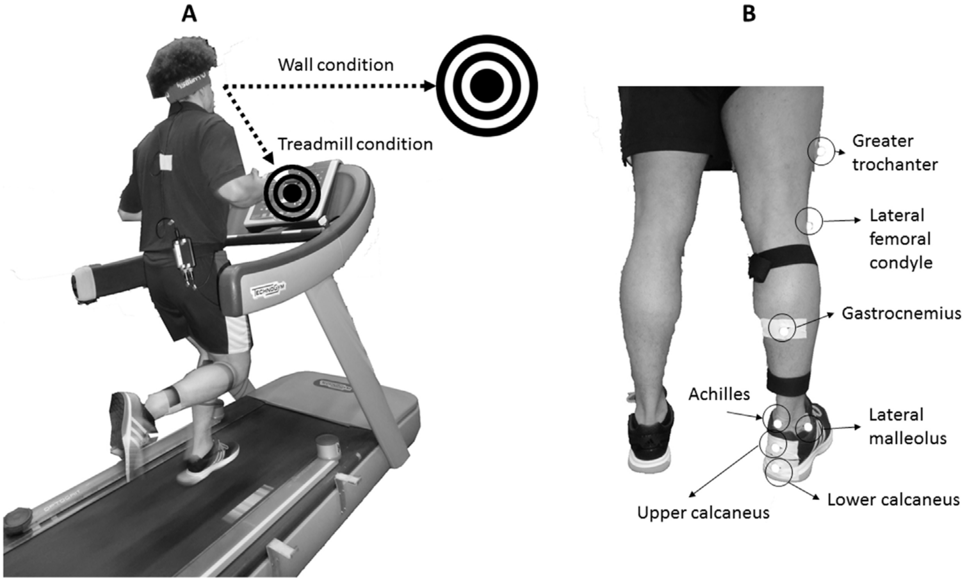

Fig. 1. (A) Representation of the two visual focus conditions assessed: running during looking forward or during looking down to the display of the treadmill (*Wall* vs. *Treadmill* conditions). (B) Placement of markers.

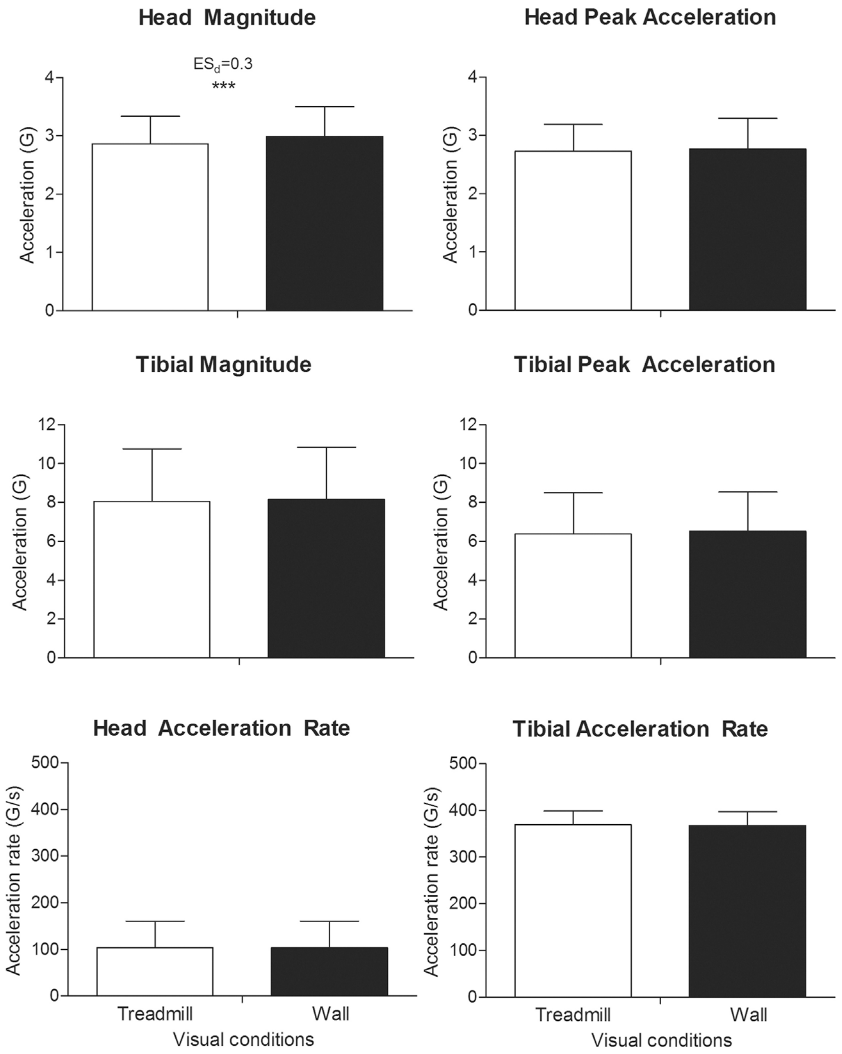

Fig. 2. Mean ± (SD) of head and tibial magnitude, acceleration and acceleration rate during treadmill running with different visual focus (Treadmill vs. Wall).
*** ($p < 0.001$); ES = Effect Size.

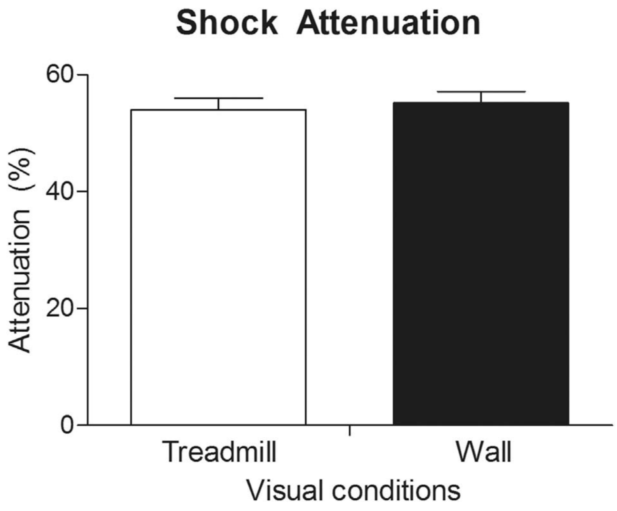

Fig. 3. Mean ± (SD) of shock attenuation during treadmill running with different visual focus (Treadmill vs. Wall).

Table 1
Mean (SD) of spatio-temporal parameters during treadmill running with different visual focus (Treadmill vs. Wall). Mean (SD) of the differences between visual conditions, p vales and effects sizes (ES_d) were determined.

	Treadmill	Wall	Treadmill vs. Wall		
	Mean (SD)	Mean (SD)	Diff (SD)	p	ES_d
Stride Length (m)	2.25 (0.16)	2.26 (0.15)	−0.01 (0.02)	0.06	0.1
Stride Frequency (Hz)	1.490 (0.106)	1.483 (0.100)	0.007 (0.016)	0.05	0.1
Contact time (s)	0.238 (0.021)	0.239 (0.018)	−0.001 (0.007)	0.34	0.1
Flight time (s)	0.117 (0.023)	0.120 (0.022)	-0.004^{**}(0.005)	< **0.01**	**0.2**
Stride angle (º)	3.30 (1.18)	3.47 (1.17)	-0.18^{**}(0.24)	< **0.01**	**0.2**

Significant *p*-values and ES are presented in bold letters.
** $P < 0.01$.

knee flexion were calculated by the projected β angle between the two segments (calcaneus and shank, and thigh and shank, respectively) [16,17]. Both angles were calculated from a static standing trial, which was considered as zero degrees [17,18]. Foot kinematics were measured using the associated camera analysis software (Redlake MASD MotionScope®, San Diego, USA) with kinematic variables of knee flexion contact time, maximum knee flexion during stance phase, time to maximum knee flexion during stance phase, maximal knee flexion flight phase, and time to max knee flexion flight phase calculated using models described by Kinescan motion analysis software (Kinescan/IBV System, Valencia, Spain). Prior to each measurement, optical distortion of the camera lens and calibration of the space were performed using a square object of known dimensions in which four space references were

Table 2
Mean (SD) of the kinematic parameters during treadmill running with different visual focus (Treadmill vs. Wall). Mean (SD) of the differences between visual conditions, p vales and effects sizes (ES_d) were determined.

	Treadmill	Wall	Treadmill vs. Wall		
	Mean (SD)	Mean (SD)	Diff (SD)	p	ES_d
Knee Flexion Contact Time (°)	10.46 (6.39)	11.03 (6.98)	−0.57 (1.65)	0.13	0.1
Max Knee Flexion Stance Phase (°)	37.33 (5.00)	38.14 (5.18)	−0.81 (2.14)	0.10	0.2
Time to Max Knee Flexion Stance Phase (s)	0.132 (0.014)	0.131 (0.012)	0.001 (0.009)	0.60	0.1
Knee Flexion at toe off (°)	11.60 (5.37)	11.47 (5.96)	0.13 (1.66)	0.72	0.0
Max Knee Flexion Flight Phase (°)	80.97 (11.13)	84.78 (11.94)	-3.81^{**}(5.44)	**< 0.01**	**0.3**
Time to Max Knee Flexion Flight Phase (s)	0.227 (0.021)	0.229 (0.022)	−0.002 (0.005)	0.06	0.1
Ankle Eversion Contact Time (°)	−0.983 (3.932)	−2.094 (3.549)	1.111^{*}(1.889)	**0.02**	**0.3**
Ankle Max Eversion Stance Phase (°)	15.999 (2.500)	15.538 (2.510)	0.461 (0.919)	0.05	0.2
Time to Ankle Max Eversion Stance Phase (s)	0.094 (0.023)	0.092 (0.017)	0.002 (0.021)	0.66	0.1

Significant *p*-values and ES are presented in bold letters.
* $P < 0.05$.
** $P < 0.01$.

attached. Calibration was performed via 2D direct linear transformation using the motion analysis software. A spline smoothing method was used automatically in the motion analysis software.

Impact acceleration analysis was performed according to the methods and recommendations of Lucas-Cuevas et al. [19]. Two lightweight tri-axial accelerometers (AcelSystem, Blautic, Spain; total mass: 2.5 g; dimensions: 40 mm × 22 mm × 12 mm) were fixed to the skin with double-sided adhesive tape and data were sampled at 300 Hz. The accelerometers were secured by elastic belts around the distal antero-medial aspect of the right tibia and upon the forehead [20]. The vertical axis of the accelerometer was aligned to be parallel to the long axis of the shank. Acceleration data were filtered using a 50 Hz low pass second order Butterworth filter developed in Matlab (MathWorks Inc., Natick, MA, USA). Head and tibial peak acceleration (maximum value of the acceleration signal), acceleration magnitude (difference between the minimum and maximum acceleration), acceleration rate (acceleration gradient between contact time and peak acceleration), and shock attenuation (reduction in peak impact acceleration from the tibia to the head) were calculated for each step of the right foot [19,20]. Stride length (distance between successive points of heel contact of the same foot) and Stride frequency (number of heel contacts of the same foot per second) were also calculated by the signal of the accelerometers.

Each one of the three measurement systems were controlled by one researcher and initiated at the same time. Then, data were manually synchronized in the analysis with the first heel impact of each measurement, moment that was visually identified clearly in the three systems.

2.4. Statistical analysis

All data were analysed with SPSS software (SPSS Statistics 21.0, IBM, Armonk, New York, USA). The Kolmogorov-Smirnov test was used to check for normality and Studenťs *t* test for paired samples was used to investigate spatio-temporal and kinematic intra-subject differences between visual focus conditions (Wall vs. Treadmill). Chi-square test was used to assess the difference between both visual conditions on participant's preference. Coheńs *d* effect size was computed for the Studenťs *t* tests (ES_d) and Coheńs *w* effect size for the Chi-square tests (ES_w). Effects sizes were classified as: small (ES_d 0.2–0.5; ES_w 0.1–0.3); moderate (ES_d 0.5–0.8; ES_w 0.3–0.5); and large ($ES_{d\,>}$ 0.8; $ES_{w\,>}$ 0.5). Significance was set at $\alpha = 0.05$. Results are presented as mean ± standard deviations (SD).

3. Results

Participants reported a preference of the *Treadmill* condition as opposed to the *Wall* condition (70% vs. 30%, $p < 0.001$ and $ES_w = 1.0$).

The *Wall* condition resulted in an increased head acceleration magnitude compared to *Treadmill* ($p < 0.001$ and $ES_d = 0.3$). No effect of visual condition was observed for any other acceleration parameters ($p > 0.05$) (Figs. 2 and 3).

The *Wall* condition had an associated increase in flight time and stride angle ($p < 0.01$ and $ES_d = 0.2$) (Table 1), maximum knee flexion during the flight phase ($p < 0.01$ and $ES_d = 0.3$), and ankle eversion contact time during running ($p = 0.02$ and $ES_d = 0.3$) (Table 2).

Stride length and stride frequency were unaffected by visual conditions ($p > 0.05$) (Table 1).

4. Discussion

The current study has investigated the effect of manipulating visual focus on spatio-temporal parameters and lower-limb kinematics. Two conditions of visual focus were assessed in order to reproduce different scenarios: looking forward and looking down to the display of the treadmill (*Wall* vs. *Treadmill* conditions). The main findings were that the *Wall* condition led to greater head acceleration, flight time, stride angle, maximum knee flexion during the flight phase, and ankle eversion contact time during running. However, the effect size of all these biomechanic alterations was small. The *Treadmill* condition was reported as the overall preferred condition for the participants.

Visual feedback has been identified as an important source of information to adjust gait mechanics [5,8,21]. In the present study, two visual conditions were assessed simulating two different predominant sources of visual information: one with a larger peripheral vision (*Wall*) and the other with a larger visual feedback of the body motion and its relation to the treadmill (*Treadmill*). Goodworth et al. observed that peripheral vision is important for balance during walking when perturbations are present in the environment [5]. However, a *Treadmill* type condition might improve proprioceptive and vestibular feedback by increasing the visual information of the movement [22,23]. The greater mass centre vertical displacement indicated during the *Wall* condition by larger values of flight time and stride angle, suggest that these kinematics changes are produced by the runners to compensate for lower proprioceptive and vestibular feedback as compared to the *Treadmill* condition. These kinematic modifications were similar to those found in previous studies regarding obstacle crossing exercises under reduced visual feedback conditions, a mechanism used during gait to reduce the risk of trips and collisions [9,21]. The larger mass centre vertical displacement resulted in a larger head acceleration. These differences between visual conditions might explain why runners preferred the *Treadmill* condition instead of the *Wall* condition.

Larsen et al. suggested recently that the increase of flight time during running to avoid an obstacle could lead to higher impact forces upon landing [24]. However, it is known that kinematic compensatory changes can be produced to counteract these forces [25,26]. This idea was confirmed by the results of the present study, where larger head accelerations were observed for the greater mass centre vertical displacement, but without changes to other acceleration parameters. Impact forces could be counteracted in the *Wall* condition by the larger maximum knee flexion and larger ankle eversion contact time. A larger knee flexion angle has been proposed as one of the main compensatory adjustments to reduce the impact forces acting on the lower limb during running [25]. Similarly, the increase in ankle eversion has been proposed as a mechanism to increase shock absorption and facilitate foot contact with the running surface [27].

The effect size of all the biomechanics results observed in the present study was small. Then, these differences cannot be considered to have an enough effect on injury risk or energy cost. However, future studies should explore if these differences may be increased when running fatigued or during more physically demanding situations (e.g. faster speeds).

The results of the present study have a number of practical applications. Firstly, this work supports the use of visualization of videos or feedback on the display of the treadmill instead of on televisions mounted on the wall of the fitness centre. Secondly, whilst other studies found in the literature have controlled many characteristics of their experiments to ensure good reproducibility, visual focus is rarely one of them. The results of the present study suggest that visual orientation during gait analysis is an important consideration to reduce the variability in many gait parameters.

The main limitation in the present study was that neck flexion was not measured. The position of the head could alter the interpretation of the galvanic vestibular signal for balance and orientation responses [28]. Possible differences in head position between the two visual conditions may have helped to explain the results obtained. However, although the orientation of the head and neck was not measured, it is possible to estimate the required shift of the whole-body mass minus the head given a change in configuration of the head and neck. Some assumptions are necessary for these calculations: 1) participant subconsciously attempts to maintain consistency in the position of their centre of gravity relative to the centre of pressure, 2) equal moments exist as a result of the whole-body weight generating a moment about the centre of pressure under both conditions, 3) head segment has a relative mass of 8% of whole-body mass [29], and 4) the head has a downward orientation in the 'Treadmill condition' which is greater than that of the 'Wall condition' by 6°, consistent with occlusion of the lower visual field [8]. Then, these assumptions result in an approximate length of the head-neck segment of 0.15 m, and by assuming an arbitrary maximum of up to 30°, the position of the whole-body mass minus the head and relative to the centre of pressure would move posteriorly 1 mm or 6 mm, respectively. It is feasible that this would cause small changes in either joint kinematics or foot-strike pattern, but these would be very difficult to detect. Also, it is possible that any variation in foot strike may result in a modification of the measured impact accelerations, but this would also be small and assumes a large variation in the ankle joint kinematics.

In conclusion, the present study has identified kinematic and spatiotemporal adaptations which result from manipulating the visual focus during treadmill running. When the visual focus was directed forward rather than towards the treadmill, runneŕs adaptations resulted in greater mass centre vertical displacement, probably with the aim to compensate lower proprioceptive and vestibular feedback, which resulted in larger head accelerations. Greater knee flexion during the flight phase and ankle eversion during the contact time were suggested as compensatory mechanisms of lower limb impacts. Also, the participanťs preference, in combination with the aforementioned biomechanical alterations, suggests that runners should look down to the display of the treadmill instead of looking forward. Although these differences between visual conditions were small and therefore not enough to be considered harmful, future studies should explore situations where the athletes run under a more intense fatigue state.

Conflict of interest

The authors declare that they have no conflict of interest.

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