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SHORT COMMUNICATION

VISUALLY INDUCED KINAESTHETIC ILLUSION COMBINED WITH THERAPEUTIC EXERCISE FOR PATIENTS WITH CHRONIC STROKE: A PILOT STUDY

Ryosuke TAKAHASHI, MS[1], Motoki KOIWA, MS[1], Wataru IDE, MD[2], Megumi OKAWADA, MS[1,3], Kazuto AKABOSHI, MD, PhD[3] and Fuminari KANEKO, PhD[3]

From the [1]Department of Rehabilitation, Hokuto Hospital, Obihiro, Hokkaido, [2]Department of Neurosurgery, Hokuto Hospital, Obihiro, Hokkaido and [3]Department of Rehabilitation Medicine, Keio University School of Medicine, Shinjuku-ku, Tokyo, Japan

Objective: Kinaesthetic perceptional illusion by visual stimulation (KINVIS) combined with neuromuscular electrical stimulation (NMES) and conventional therapeutic exercise (TherEX) has been shown previously to enhance motor function in stroke patients with chronic hemiparesis. The aim of this preliminary study is to assess the effects of a repetitive KINVIS intervention combined with TherEX, but without NMES, on upper limb motor function of patients with stroke-induced hemiparesis.

Design: A quasi-experimental study, with pretest–posttest for 1 group

Patients: Ten patients with stroke-induced, chronic, severe upper limb hemiparesis.

Methods: Patients were evaluated before and after a 10-day intervention, during which KINVIS and TherEX were applied for 20 and 60 min, respectively, for 5 days per week (Monday to Friday). Upper limb motor function was assessed using Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT), and resistance to passive movement in flexor muscles was assessed using the Modified Ashworth Scale (MAS). In addition, the amount of use and quality of movement of the affected upper limb in daily life were assessed using Motor Activity Log (MAL).

Results: Clinical assessments with FMA, ARAT, MAS, and MAL significantly improved after the intervention period.

Conclusion: A repetitive KINVIS intervention combined with TherEX may improve upper limb motor function in patients with chronic stroke and severe hemiparesis.

Key words: stroke; upper limb motor function; rehabilitation; augmented reality; illusion.

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Correspondence address: Fuminari Kaneko, Department of Rehabilitation Medicine, Keio University School of Medicine, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan. E-mail: f-kaneko@keio.jp

LAY ABSTRACT

Kinaesthetic perceptional illusion by visual stimulation (KINVIS) combined with neuromuscular electrical stimulation (NMES) and a conventional therapeutic exercise (TherEX) enhance muscle use in stroke patients with chronic paralysis. This preliminary study assessed the effects of a repetitive KINVIS intervention with added TherEX, but without NMES, on the use of the arm in Ten patients with stroke-induced paralysis. Ten patients with stroke-induced chronic paralysis were evaluated before and after a 10-day intervention, during which KINVIS and TherEX were applied for 20 and 60 min, respectively, for 5 days per week (Monday to Friday). The use of the paralysed arm improved significantly after the intervention. The repetitive KINVIS intervention combined with TherEX may improve the use of the arm in patients with chronic paralysis due to stroke.

Upper limb motor dysfunction is a common problem in stroke patients. It disrupts the patient's activities of daily living (ADL) and reduces their quality of life (QOL). Kinaesthetic perceptional illusion by visual stimulation (KINVIS) can be applied as a neurorehabilitation approach, which restores the upper limb motor function in post-stroke survivors. KINVIS is defined as a psychological phenomenon in which a resting person feels as if their own body part is moving or feels the desire to move a body part while watching a video of the same body part being moved (1). This is a implicit motor imagery that is carried as a result of cognitive substitution of the paralysed real body with a functioning virtual body. We have demonstrated previously that primary motor cortex excitability is increased during KINVIS (1). Moreover, previous studies have shown that motor-related areas are activated when experiencing KINVIS more than during simple observation of a similar movement (2). The psychological experiences in KINVIS and neurological effects may contribute to recovering post-stroke upper limb motor dysfunction. KINVIS has been shown to immediately improve motor function in patients with chronic stroke exhibiting severe hemiparesis (3).

We reported recently that an intervention of combined KINVIS and neuromuscular electrical stimulation

(NMES), in addition to conventional therapeutic exercise (TherEX) for 10 days, positively influenced upper limb motor function in chronic stroke patients with severe hemiparesis (4). However, we believe that the repetitive application of the KINVIS intervention without NMES may have a beneficial effect on motor function in patients with chronic stroke. The aim of the current pilot study was therefore to clarify the impact of a repetitive KINVIS intervention without NMES, but in combination with TherEX, on upper limb motor function in chronic stroke patients with severe hemiparesis.

METHODS

Study design

This was a non-randomized, quasi-experimental study, with pretest–posttest for 1 group.

Participants

Ten patients with hemiparetic stroke were included in the study. The inclusion criteria were: (*i*) stroke impairment assessment set (5) of the distal (finger function) score of 0 or 1A (a score of 1A is assigned for gross finger flexion and 0 for a complete lack of voluntary finger movement); (*ii*) period from stroke onset of > 6 months; (*iii*) patients older than 18 years; and (*iv*) patients who have not received special rehabilitation or treatment for upper limb hemiparesis, such as transcranial magnetic stimulation, repetitive facilitative exercise, and botulinum toxin within the last 3 months. Exclusion criteria were: (*i*) inability to understand the purpose and task of the study; and (*ii*) presence of severe internal disorders of the heart and metabolism. All patients provided written informed consent to participate in the study. The study was approved by the local ethics committee of our institution (Hokuto Hospital, Obihiro, Japan), conformed to the principles of the Declaration of Helsinki, and was registered as a clinical trial with the University Hospital Medical Information Network in Japan (UMIN Clinical Trial Registry UMIN000035985).

Interventions

The experimental period was 10 days (2 weeks) of intervention on weekdays (Monday to Friday), and evaluations were performed before and after each intervention (Fig. 1). The intervention included KINVIS (20 min), followed immediately by TherEX (60 min), as described previously (4).

KINVIS

KINVIS was applied for 20 min using the KiNvis™ System (IP-KINVIS-HT01, Inter Reha Co., Ltd, Tokyo, Japan) (4). Patients were seated on a chair with their forearms on the table. The hand movement of the unaffected side was recorded once using the KiNvis™ System camera before the intervention. The hand movement task involved opening and

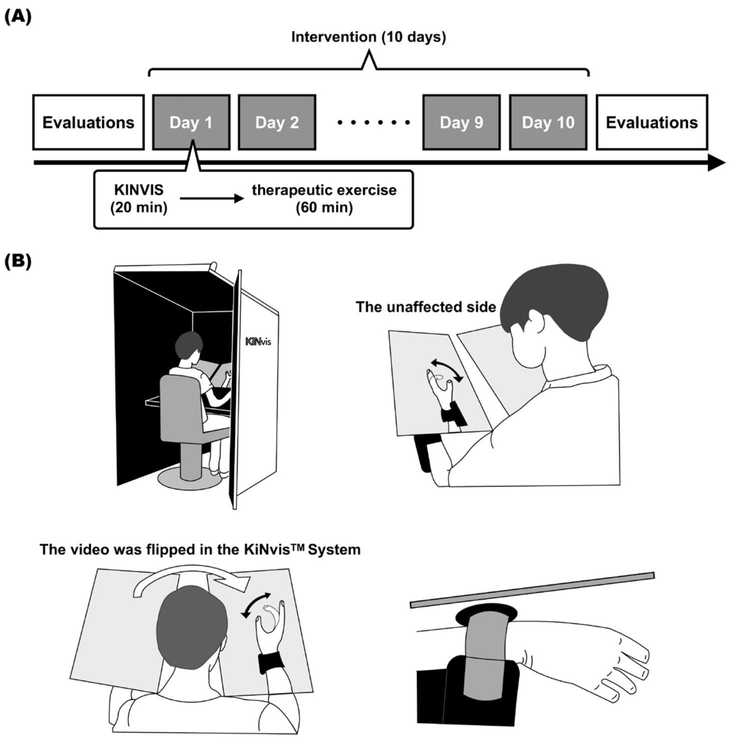

Fig. 1. (A) Study plan outline. The study comprised 10 days of intervention on weekdays, and evaluations were conducted before and after the intervention. The intervention included kinaesthetic perceptional illusion by visual stimulation (KINVIS) and conventional therapeutic exercise (TherEx). The KINVIS intervention was applied for 20 min, and TherEx was applied after KINVIS intervention for 60 min. (B) KINVIS intervention setup. *Upper left:* the KINVIS intervention used the KiNvis™ System, which consists of a table with 2 monitors and a chair for the patient to sit on. *Upper right:* hand movement on the unaffected side was recorded once using the KiNvis™ System camera before the intervention. *Lower left:* the video-recording of the unaffected side was flipped using the KiNvis™ System to mirror the movement of the affected side. *Lower right:* their arm was supported on a stand to avoid somatosensory input.

closing the hand on the unaffected side. The recorded video of the unaffected side was flipped using the KiNvis™ System to mirror the movement of the affected side, and the flipped video was adjusted such that the forearm in the video overlapped with the patient's actual forearm from the patient's viewpoint. Their arm was supported on a stand to avoid somatosensory input. During the KINVIS intervention, patients were instructed to relax and to not move either hand. KINVIS intervention was applied as 2 sets of 10 min each for a total of 20 min per week day (Monday to Friday).

TherEX

TherEX was applied for 60 min/session/day by a physical or occupational therapist after the KINVIS intervention. TherEx consisted of stretching, muscle strength training. Individual exercises for the upper limbs were selected for each patient to gradually increase the difficulty level using a graded approach.

Clinical evaluations

The clinical assessments included measurements of upper limb motor function, resistance to passive movement of the flexor muscles, and actual use of the affected upper limb in ADL. The Fugl–Meyer Assessment (FMA) scale was used to assess upper limb motor impairment (6). This test consisted of shoulder/elbow/forearm, wrist, hand movement, and coordination/speed assessment. The FMA upper limb motor score ranges from 0 to 66. The Action Research Arm Test (ARAT) was used to reflect activity capacity (7) and consists of 4 components: grasp, grip, pinch, and gross movements. The Modified Ashworth Scale (MAS) was employed to assess resistance to passive movement in the elbow flexor and wrist flexor muscles (8). The MAS is an original scale with scores of 0, 1, +1, 2, 3 and 4. This assessment scale provides high reliability for measuring the upper extremities (8). The Motor Activity Log (MAL) assesses the upper limbs' actual perceiver activity performance in ADL (9). The MAL consists of 2 components: the amount of use (AOU) and quality of movement (QOM). Both AOU and QOM scores ranged from 0 to 5.

Data analysis

To calculate the median value of the MAS scores, score 1+ was transposed to 2, and scores 2, 3, and 4 were transposed to 3, 4, and 5, respectively. The Wilcoxon signed-rank test was used to compare clinical assessments before and after the intervention. The statistical level of significance was 5% ($p<0.05$). All statistical analyses were performed using statistical software (SPSS Statistics version 20, IBM, Armonk, USA).

RESULTS

Ten patients (8 males, 2 females; 7 with left hemiparesis and 3 with right hemiparesis; mean age 67.7±7.9 years; mean height 164.3±5.9 cm; mean weight 63.8±9.2 kg) with hemiparetic stroke were included. All participants were right-handed, as indicated with the Edinburgh Handedness Inventory test (group scores 94.5±11.8%). Participant demographics and clinical characteristics are shown in Table I. The results of the clinical assessments are shown in Table II. In addition, Fig. 2 shows changes in the clinical assessments for each participant and score distribution. Regarding FMA, the Upper Extremity Motor ($p=0.005$), Shoulder/Elbow/Forearm ($p=0.007$), and Hand scores ($p=0.026$) improved following the intervention. The total ARAT score increased, as did the Grasp score

Table I. Demographic and clinical characteristics of patients

Patient	Sex	Diagnosis	Lesion Location	Age (Years)	Paretic Side	TFO (Months)	SIAS U/L	
							Proximal	Distal
1	male	CH	Putamen, Capsule internal	73	Lt	254	2	1A
2	male	CI	Capsule internal	74	Lt	7	1	1A
3	male	CI	Corona radiata, Insula, Putamen, Pallidum	66	Lt	93	2	1A
4	male	CI	Corona radiata, Insula, Putamen, Pallidum, Precentral gyrus	72	Lt	205	3	1A
5	male	CH	Precentral gyrus, Corona radiata, Insula, Putamen, Pallidum	65	Rt	76	2	1A
6	male	CH	Putamen, Capsule internal	67	Lt	32	3	1A
7	female	CH	Precentral gyrus, Corona radiata	47	Rt	26	0	0
8	male	CI	Precentral gyrus, Corona radiata, Insula, Putamen, Pallidum	72	Rt	137	0	0
9	male	CH	Putamen, Capsule internal, Pallidum	72	Lt	75	2	0
10	female	CH	Putamen, Capsule internal, Pallidum	69	Lt	16	2	1A

Abbreviations: CI, cerebral infraction; CH, cerebral hemorrhage; Rt, right; Lt, left; TFO, time from onset of stroke; SIAS, Stroke Impairment Assessment Set; U/L, Upper Limb.

A score of proximal; If a patient is able to touch his contralateral knee with his affected hand and bring it back to his mouth, a score of 3 is given. When the patient can only lift the hand to the level of the nipple, a score of 2 is given. If there is no muscle contraction noted in the biceps brachii, a score of 0 is given.

A score of distal; A score of 1A is given for gross finger flexion, and 0 is assigned for a complete lack of voluntary finger movement.

Table II. Clinical assessments of the upper limb

	Before	After		
	Median [IQR]	Median [IQR]	Z-value	p-value
FMA				
Upper extremity total score	13.0 [10.3-16.0]	15.5 [12.5-19.5]	2.83	0.005 **
Shoulder / Elbow / Fore-arm	12.5 [9.0-14.8]	14.5 [10.5-17.5]	2.71	0.007 **
Wrist	0.0 [0.0-0.0]	0.0 [0.0-0.0]	1.00	0.317
Hand	1.0 [0.3-2.0]	2.0 [1.3-2.0]	2.22	0.026 *
Coordination / Speed	0.0 [0.0-0.0]	0.0 [0.0-0.0]	-	-
ARAT				
Total score	3.0 [3.0-3.8]	5.5 [3.0-6.8]	2.21	0.027 *
Grasp	0.0 [0.0-0.0]	1.0 [0.0-3.5]	2.21	0.027 *
Grip	0.0 [0.0-0.0]	0.0 [0.0-0.0]	1.00	0.317
Pinch	0.0 [0.0-0.0]	0.0 [0.0-0.8]	1.60	0.109
Gross movement	3.0 [3.0-3.8]	3.0 [3.0-3.8]	-	-
MAS				
Elbow flexor muscles	2.0 [2.0-2.0]	2.0 [1.3-2.0]	1.00	0.317
Wrist flexor muscles	2.5 [2.0-3.0]	1.5 [1.0-2.0]	2.83	0.005 **
MAL				
Amount of use	0.0 [0.0-0.1]	0.6 [0.3-0.7]	2.80	0.005 **
Quality of movement	0.0 [0.0-0.1]	0.4 [0.3-0.7]	2.80	0.005 **

Abbreviations: FMA, Fugl-Meyer assessment scale; ARAT, Action research arm test; MAS, Modified ashworth scale; MAL, Motor activity log; IQR; interquartile range. *, $p < 0.05$ and **, $p < 0.01$. For the FMA coordination / speed score and the ARAT gross movement score, the p-value was not calculated because of the same value before and after the intervention for all participants.

(total score: $p=0.027$, Grasp: $p=0.027$). The MAS scores of the paretic side at the wrist flexors decreased ($p=0.005$). Furthermore, the AOU and QOM scores of MAL increased among the participants (AOU: $p=0.005$; QOM: $p=0.005$).

DISCUSSION

This investigation prospectively assessed the effect of a repetitive KINVIS intervention, followed by immediate TherEX on motor function in patients with stroke exhibiting severe hemiparesis. Clinical assessments with FMA, ARAT, MAS, and MAL demonstrated significant improvement after the therapeutic intervention period. This finding indicates that, in patients with stroke exhibiting severe hemiparesis, resistance to passive movement of the flexor muscles of the wrist had reduced, and the motor function of the upper limb, including the finger, had improved following the intervention. Therefore, a repetitive KINVIS intervention combined with TherEX may have a positive effect on upper limb motor function in stroke patients. Moreover, it was hypthesized that these upper limb function changes increased MAL by employing the paralysed upper limb for ADL. Thus, a repetitive KINVIS intervention combined with TherEX may have a positive effect on upper limb motor function in chronic stroke patients with severe hemiparesis. Although the total score of FMA and ARAT significantly increased, the median increase was 2.5 points, which was a small change. Hence, research that uses a larger sample size and confirms the effect size as a future prospect is necessary.

This study enrolled chronic stroke patients with severe hemiparesis, similar to a previous study that combined the KINVIS intervention and NMES (4). The KINVIS intervention effectively promotes motor learning (10). We found that the KINVIS intervention positively influenced upper limb motor function, even in the absence of NMES. According to a previous study involving healthy participants, increased cortical excitability was sustained when KINVIS was combined with peripheral nerve stimulation, rather than when the KINVIS intervention was used alone (11). Therefore, in terms of brain plasticity, the combination of KINVIS and NMES may be superior to the KINVIS intervention alone. However, this study did not draw comparisons from the combined KINVIS and NMES intervention. In the previous study combining the KINVIS intervention and NMES (4), the mean values of the total FMA score (before: 12.2±2.9; after: 14.5±4.0) and the total ARAT score (before: 5.3±4.4; after: 8.1±7.6) for the upper extremity increased by approximately 2.0–3.0 points after the intervention. Therefore, the upper limb motor function changes are comparable between this study and the previous study. Although the present study and the previous study (4) cannot be compared because of their sample size and the non-homogeneous sample populations. Therefore, the extent of the clinical implications of these differences in intervention methods remains unclear, and further research into this subject is necessary.

Mirror therapy is an intervention that is seemingly similar to the KINVIS intervention adopted in this study. A Cochrane review (12) reported that mirror therapy moderately improved motor function and ADL. In addition, mirror therapy has a small effect on the upper extremity total FMA score. In the current study, we also noted an increase in the FMA, ARAT total scores, and MAL, which may have positively affected upper limb motor function and ADL as well as mirror therapy.

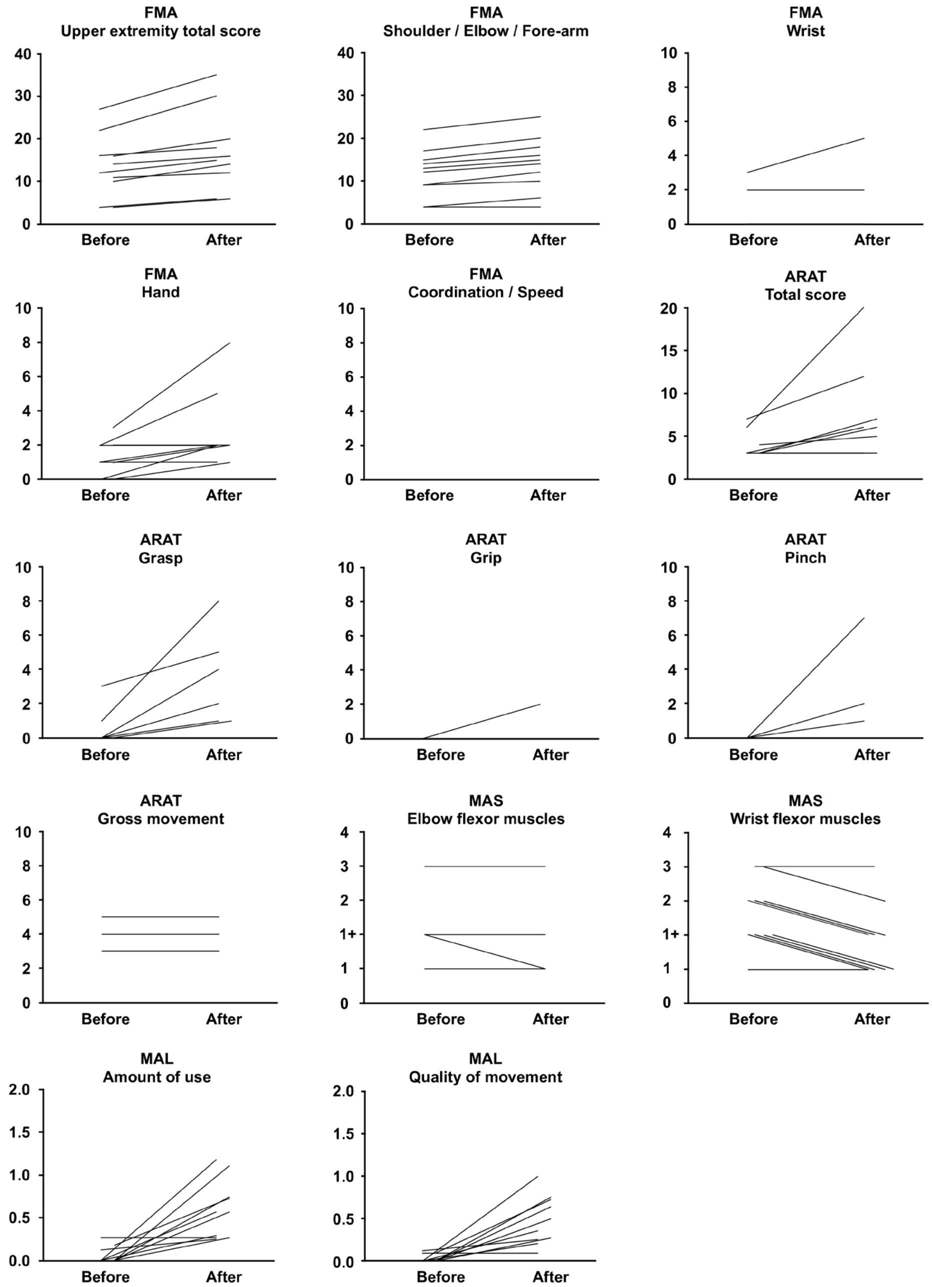

Fig. 2. Changes in clinical assessments in each participant. The line graph shows the changes before and after the intervention in each participant. The lines in the graphs are displaced to avoid overlap. However, Fugl-Meyer Assessment (FMA) (wrist, hand, and coordination/speed), Action Research Arm Test (ARAT), and Modified Ashworth Scale (MAS) appear blank or have a small number of lines because some participants had zero or the same points before and after the intervention.

The difference in the results between the report for the mirror therapy and the current study was due to the effect on MAS. For mirror therapy, absence of the effect on MAS was demonstrated (13); however, improvement in MAS was one of the main effects of KINVIS in this study. The kinaesthetic illusion during the mirror therapy is not a purely visually induced illusion, but emerges from proprioceptive afferents of the contralateral moving arm (14). In contrast, the kinaesthetic illusion during our intervention is induced only by visual input without the contralateral upper limb movement. Therefore, the mechanisms of KINVIS intervention and mirror therapy were different. This difference in mechanism may result in different effects on patients with hemiplegic stroke. This will be the topic of a future study.

Despite the favourable outcomes of this study, it has some limitations. First, the study lacked a control group. Although the FMA and ARAT total scores in this study improved, the sub-scores of the FMA showed a significant increase in the scores of shoulder/elbow/forearm as well as the hand. Strength training for stroke hemiplegic cases reportedly improves upper limb motor function (15). Therefore, changes in this study may have been influenced by TherEx.

Secondly, participants had chronic (with an onset period of ≥6 months) stroke, but with variations from 7 to 254 months. Hence, it was not possible to fully infer the effectiveness of the KINVIS intervention as a therapeutic manoeuvre. A randomized controlled study is therefore needed to explore the possibility of using the KINVIS intervention as a therapeutic intervention tool for improving upper limb motor function in stroke patients.

In conclusion, these preliminary results showed that a repetitive KINVIS intervention combined with TherEX might improve upper limb motor function in chronic stroke patients with severe hemiparesis. Nevertheless, as this study has several limitations, further investigations are required to validate the likely benefit of this approach in stroke patients with severe upper limb hemiparesis.

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Conflicts of interest

FK is the founding scientist of the start-up company INTEP Inc. for the social implementation of university research results. This company does not have any relationship with the device or setup used in the present study. FK received license fees from Inter Reha Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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