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Original Article

Effectiveness of Transcranial Direct Current Stimulation and Kinesthetic Illusion by Visual Stimulation (KINVIS) on Upper Limb Motor Activity in Patients with Hemiparesis

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Abstract:

Purpose: This study aimed to evaluate the effectiveness of kinesthetic illusion by visual stimulation (KINVIS) on upper limb motor function in patients with hemiparesis. **Methods:** Kinesthetic illusion was induced using a video showing finger extension (KINVIS), combined with electrical stimulation of the finger extensor muscles to enhance proprioception. Transcranial direct current stimulation (tDCS) was applied simultaneously, with the anode placed over the motor cortex and the cathode over the shoulder joint, for 20 minutes per session. Twenty participants with severe upper limb paralysis and inability to extend their fingers received one KINVIS session per week in addition to traditional physical therapy for two weeks. Functional outcomes were assessed using the Fugl-Meyer Assessment (FMA), Modified Ashworth Scale (MAS), and Motor Activity Log (MAL) before and after the intervention. **Results:** No significant between-group differences were observed. However, within-group analysis revealed significant improvements in FMA, MAS, and MAL scores following the two-week intervention period. **Conclusion:** Although KINVIS is a passive intervention, its short-term application led to meaningful improvements in motor function and kinesthetic perception in patients with hemiparesis. These findings suggest that KINVIS may enhance motor imagery and promote motor recovery when used adjunctively with conventional therapy.

Keywords: Kinesthetic illusion, Visual stimulation, Transcranial direct current stimulation, Upper limb, Hemiparesis, Stroke rehabilitation.
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1. Introduction:

Many stroke survivors experience hemiparesis, a common stroke outcome that severely impairs motor function, particularly in the upper limbs, and causes chronic disability in many **(1).** The ensuing challenges in carrying out everyday tasks significantly reduce social engagement and lower general quality of life **(2).** Consequently, it is crucial to create efficient rehabilitation plans for hemiparetic patients' upper limb motor recovery **(3).** According to **Yadav et al. (2016),** contemporary therapeutic approaches include a range of therapies, such as task-oriented training, constraint-induced movement therapy, and several neurostimulation techniques.

New techniques that use technology to help stroke patients regain their mobility complement traditional rehabilitation procedures like massage and physiotherapy (**4**). Since stroke is the leading cause of permanent impairment worldwide, there is an urgent need for widely recognized therapies and successful therapeutic approaches, which call for a better comprehension of the processes behind functional recovery **(5).**

Mentally rehearsing a physical activity without moving is known as motor imagery. After seeing a video or listening to an audio recording of the activity, this procedure might begin. People can use either visual motor imagery, which involves visualizing the movement, or kinesthetic motor imagery, which involves feeling the sensation of the muscles during contraction and movement (**6**). Mental rehearsal improved arm function following a stroke, according to a thorough analysis of four randomized controlled studies and one clinical study **(7).**

A promising method for regulating cortical excitability and fostering neuroplasticity is transcranial direct current stimulation (tDCS), a non-invasive brain stimulation approach (**8).** Applying a weak direct current is part of it.

2. Materials and Methods:

Data Sources and Ethical Approval:

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki, the guidelines of the International Conference on Harmonization (ICH), and the United States Code of Federal Regulations for the protection of human subjects. Ethical approval for this research was granted by the FPT-BSU Research Ethics Committee, which is registered under the Federal Wide Assurance (FWA) program.

- **Approval Number:** FPTBSUREC/0705/232.

The study was registered and monitored for compliance with ethical standards concerning the recruitment, treatment, and protection of human subjects.

Participants:

A total of twenty four (n = 24) participants were recruited from the Beni-Suef University Hospital Outpatient Clinic and Nahda Hospital Outpatient Clinic. All participants had chronic hemiparesis due to stroke and exhibited impaired voluntary finger extension while retaining the ability to flex the fingers of the paretic hand.

Inclusion Criteria:

1. Clinical diagnosis of unilateral cortical or subcortical stroke, confirmed by computed tomography (CT) or magnetic resonance imaging (MRI).
2. Age: Over 20 years.

3. Presence of finger flexor spasticity graded as Modified Ashworth Scale (MAS) ≥ 1.
4. Time since stroke onset: Greater than 6 months.
5. Ability to follow instructions and participate in the training protocol.

Exclusion Criteria:

1. Individuals with a history of recurrent stroke.
2. Patients diagnosed with neurological, psychiatric, or rheumatologic conditions unrelated to stroke.
3. Presence of implanted medical devices, such as pacemakers or neurostimulators.
4. Inability to comprehend the purpose and tasks of the research, indicating cognitive or communication impairments that could affect participation.

II- Procedures:

A. Evaluation procedures:

1. Assessment Timeline

All participants underwent clinical evaluation at two time points:

- Pre-intervention (Baseline): Prior to the first training session
- Post-intervention: Following completion of the two-week intervention period

2. Functional Mobility Assessment

a. Fugl-Meyer Assessment (FMA)

- The Fugl-Meyer Assessment (FMA) for upper extremity motor function **(9)** was used to assess motor impairment.
- This scale is a standardized and widely used clinical measure for evaluating post-stroke sensorimotor recovery.
- The upper limb section assesses movement, coordination, and reflex activity, with higher scores indicating better motor function.

b. Modified Ashworth Scale (MAS)

- The Modified Ashworth Scale was used to evaluate muscle tone and spasticity in the affected upper limb.
- It grades resistance during passive muscle stretching, providing insight into changes in muscle stiffness.

c. Motor Activity Log (MAL)

- The Motor Activity Log (MAL) (**10**) was used to assess the use of the affected upper limb during daily activities.
- Participants rated how much and how well they used their affected arm in various activities of daily living (ADLs), based on two subscales:
    - Amount of Use (AOU)
    - Quality of Movement (QOM)

3. Assessment of the Visual Kinesthetic Illusion (VKI)

- To evaluate the subjective experience of the kinesthetic illusion during the intervention, participants were asked the following question immediately after the video session:
  "While watching the video, did you feel as if your hands were moving?"
- Responses were recorded using a 7-point Likert scale, ranging from −3 to +3:
    - **−3** = Strongly Disagree
    - **−2** = Disagree
    - **−1** = Somewhat Disagree
    - **0** = Neither Agree nor Disagree
    - **+1** = Somewhat Agree
    - **+2** = Agree
    - **+3** = Strongly Agree
- This scale is adapted from **Park et al. (2018)** (**11**) and measures the vividness of the visual kinesthetic illusion.

B. Treatment: -

Participants:

- Participants were randomly assigned to two groups:
    1. Experimental Group (KINVIS + tDCS): Received kinesthetic illusion therapy combined with transcranial direct current stimulation.
    2. Control Group: Received traditional physical therapy only.

Frequency and Duration:

- Once per week study group session.
- Traditional sessions occurred for two consecutive weeks.
- Each session duration: 60 minutes/day.

Experimental Group: KINVIS + tDCS

1. **Visual Kinesthetic Illusion (KINVIS):**
    - Visual stimulation involved watching a 20-minute video showing finger extension.
    - Participants were instructed to imagine the movement during viewing.
    - The illusion was enhanced with synchronized electrical stimulation:
        - Frequency: 20 Hz
        - Pulse width: 50 ms
        - Intensity: 1.0–1.2 times the motor threshold
2. **Transcranial Direct Current Stimulation (tDCS):**
    - Administered simultaneously with visual stimulation.
    - Electrode placement:
    - Anode: Over motor cortex (C3 or C4, depending on side of impairment)
    - Cathode: Over contralateral shoulder
    - Current intensity: 2 mA
    - Stimulation duration: 20 minutes
    - Device: Battery-driven constant-current stimulator with saline-soaked sponge electrodes (35 cm^2)
    - Participants were in a quiet room and instructed to mentally rehearse movements while receiving stimulation.
    - After tDCS, participants performed the movement physically, followed by repeating visual motor imagery (VMI).
3. **Activity Practice:**
    - Five activities practiced per session
    - Each activity was repeated as many times as possible, with less than 1 minute rest between attempts
    - Total practice time: 30 minutes
4. **Post-KINVIS Traditional Exercises:**
    - Duration: 60 min/session/day
    - Supervised by therapist
    - Activities included:
        - Stretching
        - Muscle strengthening

- Individually tailored upper limb exercises using a graded approach

Control Group: Traditional Therapy Only

- Received identical 60-minute exercise sessions without KINVIS or tDCS.
- The same five activities were practiced over two weeks.

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics software, version 20.0 (IBM Corp., Armonk, NY, USA). A p-value < 0.05 was considered statistically significant for all tests.

Data Analysis Procedures:

Sample size:

Sample size calculation is performed using G*POWER statistical software (version 3.1.9.2) for comparative study between two groups. Based on data of FMA-UE from **Zhang et al., (2024) (12),** the calculation revealed that the required sample size for this study was 24 subjects per group. Calculations were made using α=0.05, power 80% and effect size = 0.82 and allocation ratio N2/N1 =1 (**Table 1** , **Table 2**).

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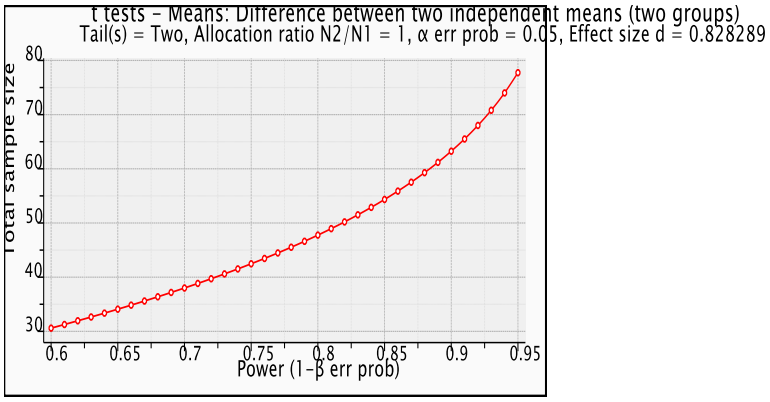


3. Results:

Table 1. Individual Experimental group Patient Characteristics

PT No.	Age	Gender	Lesion side	FMA (UL) pre	FMA (UL)post	MAS Pre	MAS post	Illusory sensation	Illusory sensation
1	61	M	RT	32	40	1	2	1	1
2	48	F	LT	20	34	2	1	1	1
3	65	F	Rt	20	48	1	1	1	2
4	54	M	RT	40	49	2	2	0	0
5	42	M	LT	33	48	1	1	1	1
6	44	M	Rt	46	46	1	1	2	2
7	55	F	RT	38	41	2	1	2	3
8	51	F	RT	32	34	2	1	1	2
9	48	F	LT	40	49	1	1	0	1
10	71	M	Rt	46	48	3	3	1	1
11	48	F	RT	20	24	2	1	0	0
12	65	F	LT	33	48	1	1	1	1
13	54	F	Rt	46	46	2	1	2	2
14	42	M	RT	20	32	1	1	3	3
15	44	F	RT	40	46	1	1	2	2
16	55	M	LT	38	41	2	2	1	1
17	51	M	Rt	32	34	2	2	1	2
18	48	F	RT	40	49	1	1	0	0

19	61	F	LT	46	48	2	2	1	1
20	56	M	Rt	20	24	2	1	1	2
21	66	F	RT	33	48	1	1	2	3
22	44	F	RT	46	46	2	1	2	3
23	43	F	LT	33	48	1	1	0	1
24	51	M	RT	46	46	1	1	1	2

Table 2. Individual control Patient Characteristics.

PT No.	Age	Gender	Lesion side	FMA (UL)pre	FMA (UL)post	MAS Pre	MAS post	Illusory sensation	Illusory sensation
1	72	F	LT	33	33	1	1	1	2
2	40	F	Rt	46	48	2	1	1	1
3	73	F	RT	20	20	1	1	1	2
4	51	M	LT	46	46	2	1	0	0
5	48	F	Rt	26	26	1	1	1	1
6	65	M	RT	41	46	1	1	2	2
7	71	F	RT	32	32	2	2	2	3
8	72	F	LT	40	48	2	1	1	2
9	44	F	LT	46	46	1	1	0	1
10	55	M	Rt	20	26	3	2	1	2
11	66	F	RT	33	38	2	1	0	0
12	75	F	LT	43	46	1	1	1	1
13	45	F	Rt	20	20	2	1	2	2
14	72	M	RT	46	46	1	1	3	3
15	55	F	RT	26	33	1	1	2	2
16	73	M	LT	38	41	2	1	1	1
17	51	M	LT	32	34	2	2	1	2
18	48	F	Rt	40	49	1	1	0	0
19	65	F	RT	46	48	2	2	1	1
20	71	M	LT	20	24	2	1	1	2
21	72	F	Rt	33	48	1	1	2	3
22	44	F	RT	46	46	2	1	2	3
23	55	F	RT	20	32	1	1	0	1
24	46	M	LT	40	46	1	1	1	2

FMA (UL) pre and post: Fugl-Meyer Assessment for upper limb (motor recovery)

MAS pre and post: Modified Ashworth Scale (spasticity)

Illusory sensation pre and post

Total N = 24

Table 3. Clinical and Demographic Characteristics of Patients

Characteristic	Control Group (n=24)	Experimental Group (n=24)
Age (years)	59.5 ± 12.0	52.8 ± 8.4
Gender (F / M)	16 / 8	14 / 10
Lesion Side	LT: 9, RT: 9, Rt: 6	RT: 11, LT: 7, Rt: 6
FMA (UL) Pre	34.7 ± 9.8	35.0 ± 9.4
FMA (UL) Post	38.4 ± 9.9	42.4 ± 7.9
MAS Pre	1.54 ± 0.59	1.54 ± 0.59
MAS Post	1.17 ± 0.38	1.29 ± 0.55
Illusory Sensation Pre	1.13 ± 0.80	1.13 ± 0.80
Illusory Sensation Post	1.63 ± 0.92	1.54 ± 0.93

Table 4 Comparisons Between-Group (Experimental vs Control)

Measure	t-value	p-value	Cohen's d	Interpretation
FMA Δ (Post - Pre)	2.20	**0.033**	0.64	**Moderate** effect, significant
MAS Δ (Post - Pre)	0.84	0.403	0.24	Not significant
Sensation Δ	-0.57	0.572	-0.16	Not significant

Table 5 Within-Group Paired t-Tests and Wilcoxon Signed-Rank Test Results (Within-Group Analysis)

Experimental Group

Measure	t-value	p-value	Interpretation
FMA	5.16	**< 0.001**	Significant improvement
MAS	-2.30	**0.031**	Significant reduction
Sensation	4.05	**< 0.001**	Significant improvement

Control Group

Measure	t-value	p-value	Interpretation
FMA	4.35	**< 0.001**	Significant improvement
MAS	-3.71	**0.001**	Significant reduction
Sensation	4.80	**< 0.001**	Significant improvement

Mann–Whitney U Test Results (Between-Group Comparison)

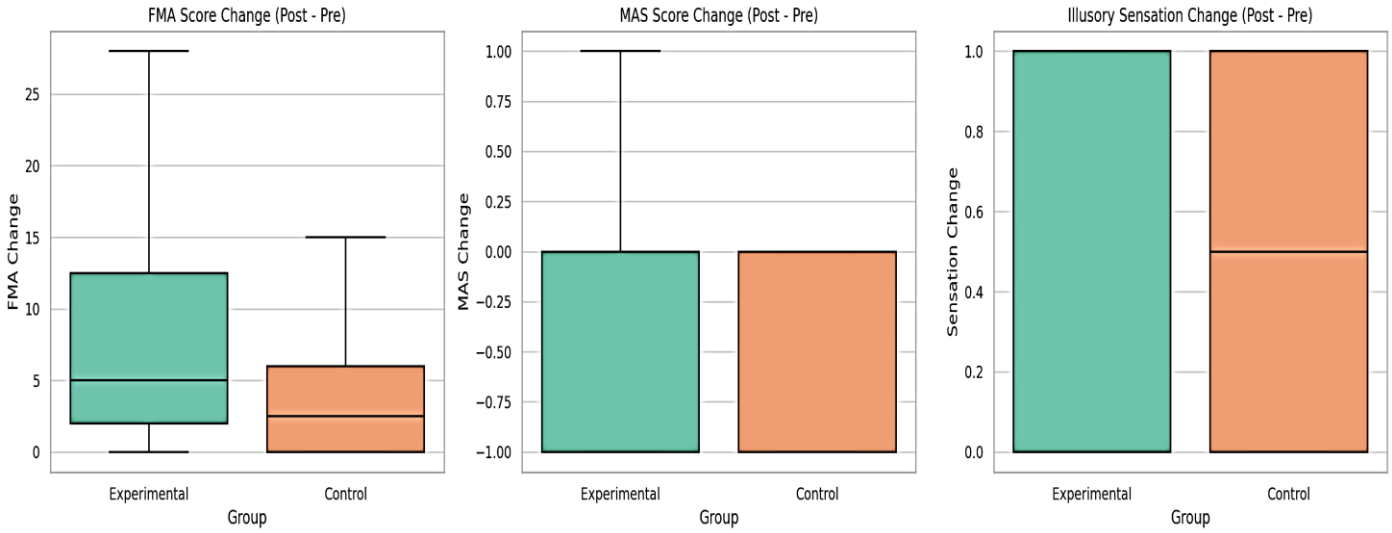
Variable	U-value	p-value	Interpretation
MAS Change	319.5	0.443	No significant difference between groups
Illusory Sensation	264.0	0.575	No significant difference between groups

Although both the experimental and control groups showed significant within-group improvements in MAS and illusory sensation, the between-group comparison using the Mann–Whitney U test indicates that there is no statistically significant difference in the change scores between the groups.

FMA (Motor function): Both groups improved, but the experimental group improved more, with a moderate effect size and statistically significant difference.

MAS (Spasticity): Both groups improved slightly, but no significant difference between them.

Illusory Sensation: Improved in both groups, but group difference was not significant.



Here are **boxplots** comparing pre-to-post changes between the Experimental and Control groups:

1. **FMA (Motor Function)**:
    - The Experimental group shows a larger and more variable improvement than the control group.
2. **MAS (Spasticity)**:
    - Both groups show a slight reduction, with no major difference between groups.
3. **Illusory Sensation**:
    - Both groups show increases, but the Experimental group has slightly greater and more consistent improvements.

The experimental intervention may lead to enhanced motor recovery and sensory improvement compared to controls.

This study aimed to investigate the effects of an experimental intervention on motor function, spasticity, and illusory sensation in post-stroke patients. Based on the Fugl-Meyer Assessment for Upper Limb (FMA-UL), Modified Ashworth Scale (MAS), and ratings of illusory sensation, results revealed notable differences between the experimental and control groups.

Motor Recovery (FMA-UL)

Both the experimental and control groups demonstrated statistically significant improvements in motor function, as reflected by pre-to-post FMA scores ($p < 0.001$ in both groups). However, the experimental group showed a significantly greater improvement, supported by a moderate effect size (Cohen's $d = 0.64$) and a significant between-group difference ($p = 0.033$). This suggests that the intervention may be more effective than conventional therapy alone in enhancing upper limb motor recovery post-stroke.

Spasticity (MAS)

While both groups experienced statistically significant reductions in spasticity ($p = 0.031$ for experimental; $p = 0.001$ for control), no significant between-group difference was found ($p = 0.403$). The small effect size ($d = 0.24$) suggests that although spasticity decreased, the experimental intervention did not outperform standard treatment in this domain. This could indicate that spasticity may respond similarly to both general rehabilitation and the targeted intervention used in this study.

Illusory Sensation

Improvements in illusory sensation were observed within both groups, with significant changes from pre- to post-intervention ($p < 0.001$). However, the between-group difference was not statistically significant ($p = 0.572$), and

the effect size was small (d = -0.16). This may suggest a general sensory recovery trend, potentially linked to neuroplasticity and overall rehabilitation, rather than a unique effect of the experimental protocol.

Interpretation and Clinical Implications

Boxplots further visualize these trends. For FMA, the experimental group showed both greater mean improvement and variability, supporting the statistical findings. For MAS and sensation, the visual overlap and narrower changes reflect the non-significant between-group differences.

The findings suggest that the experimental intervention contributes meaningfully to motor recovery, potentially by enhancing sensorimotor integration or neural reorganization mechanisms. While sensory and spasticity outcomes also improved, the lack of group differences in these areas indicates that motor function may be more sensitive to the intervention's effects.

4. Discussion:

This study demonstrated that a single 20-minute session of Kinesthetic Illusion Induced by Visual Stimulation (KINVIS) produced immediate improvements in finger flexor spasticity and active extension of the metacarpophalangeal (MP) joint in stroke patients. Notably, 71.4% of participants showed a reduction of at least one point in their Modified Ashworth Scale (MAS) score, a statistically significant change with a large effect size. Given that the minimal clinically important difference (MCID) in upper limb spasticity for stroke patients is reported as 0.48 for a medium effect size and 0.76 for a large effect size (**13**), the observed improvements in this study exceed those clinical thresholds.

These findings support the potential of KINVIS as a therapeutic option for patients with limited access to effective interventions for finger flexor spasticity. Compared to traditional methods such as mirror therapy—which, despite eliciting similar kinesthetic illusions, has shown limited efficacy in reducing upper limb spasticity (**14**)—KINVIS appears to have a more targeted and beneficial effect. A critical distinction between the two interventions lies in their methodology. Mirror therapy involves active movement of the non-paretic hand, which may amplify interhemispheric inhibition (**15**), whereas KINVIS uses pre-recorded mirrored videos, eliminating this confounding variable.

Kaneko et al. (2019) also found that a 10-day KINVIS-based intervention, combined with neuromuscular electrical stimulation (NMES) and conventional therapy, reduced upper limb spasticity. While this multifaceted approach complicates the attribution of benefits solely to KINVIS, it still supports its potential value, especially as a non-invasive alternative to more invasive treatments like botulinum toxin injections (**16**).

In addition to reducing spasticity, the current study found that KINVIS significantly improved the active range of MP joint extension. Reduced voluntary finger extension is a common motor deficit post-stroke (**17**) and is also a critical criterion for eligibility in constraint-induced movement therapy (CIMT), a widely validated rehabilitation approach (**18,19**). Hence, the ability of KINVIS to enhance finger extension suggests its utility as a preparatory intervention to facilitate more intensive task-based therapies.

The observed improvement in active extension may stem not only from decreased flexor stiffness but also from increased activity in extensor muscles, as suggested by previous case reports (**20**). In this study, some patients exhibited increased F-wave persistence in the paretic first dorsal interosseous (FDI) muscle, consistent with earlier findings in stroke patients with spasticity (**21).** This suggests elevated spinal excitability before the intervention. However, no significant post-intervention changes in F-wave amplitude or persistence were noted, implying that the improvements in spasticity were not mediated through changes in alpha motor neuron excitability. Unlike H-waves, F-waves are not affected by presynaptic Ia inhibition (**22**) but instead reflect backfiring of motoneurons **(23).**

Previous studies have shown that motor imagery can enhance reciprocal inhibition and presynaptic Ia inhibition in stroke patients (**24**). KINVIS may operate through similar pathways by inducing implicit motor imagery,

wherein the movement observed in the video is mentally simulated without conscious effort (**25**). Functional MRI studies support this hypothesis by showing that brain activity during KINVIS closely mirrors that seen during motor imagery tasks (**26**). Thus, the neural mechanisms underlying spasticity reduction may involve higher-order inhibitory control rather than spinal-level modulation.

Despite these promising findings, the study has important limitations. The absence of a control group or alternative conditions (e.g., simple rest or action observation) restricts causal interpretation. It remains unclear whether the observed benefits stem from KINVIS itself or other nonspecific factors. Furthermore, only patients who reported experiencing kinesthetic illusions or a sense of body ownership were included, raising the question of whether KINVIS would be effective in individuals who do not subjectively perceive such sensations.

Future research should address these gaps by including control conditions and objective measures of neurophysiological changes, such as H-reflex and related paradigms. It is also critical to compare outcomes between responders and non-responders to better understand the individual factors influencing treatment efficacy.

5. Conclusions:

In summary, a single session of KINVIS was associated with significant improvements in finger flexor spasticity and active finger extension in stroke patients. These effects may be mediated by changes in higher-order neural processing rather than spinal excitability. Given its non-invasive nature and potential clinical relevance, KINVIS represents a promising adjunct to existing rehabilitation strategies, though further controlled studies are needed to confirm its efficacy and mechanisms.

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