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Combined action observation and motor imagery influences hand movement amplitude in Parkinson's disease

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1. Introduction

External sensory cues can help to overcome difficulties with movement initiation and control in Parkinson's disease (PD) [1], typically targeting gait impairments such as reduced stride length and freezing. However, the applicability of such cues to other functional tasks (e.g., manual actions) is limited, and the longer-term effects of cueing are unclear [2]. Observation of human movement provides a powerful external stimulus that facilitates movement and increases motor learning in healthy individuals [3], by activating a network of fronto-parietal neural structures also engaged during motor execution [4]. Action observation (AO) training has shown encouraging effects in neurorehabilitation [5] and may help to reinforce or reorganise neural connections involved in motor control [6].

AO can facilitate manual actions (reducing bradykinesia and temporal variability) in people with PD [7]. Moreover, AO-based interventions have been found to increase functional independence, improve balance and mobility, and reduce freezing of gait, in PD [5,8]. However, such therapies rely on the ability to internally represent actions, which may be affected by PD [7]. Indeed, impaired imitation of gestures and facial expressions has been documented in PD [9,10], as well as an altered corticomotor response to observed actions [11]. Therefore, it is important to further investigate these processes in people with PD. In particular, quantitative effects on movement amplitude have not been demonstrated, despite the significant impact of reduced movement size (e.g., micrographia, shorter steps) on daily functioning.

Motor imagery (MI; the imagination of movement including associated images and sensations) also recruits neural regions overlapping with action execution [12], and facilitates movement and learning [13]. Recent studies of healthy participants have demonstrated greater effects on movement (e.g., sequential and rhythmic actions) when AO is combined with MI, compared with either AO or MI alone; moreover, combined AO + MI increases cortico-motor activity relative to either approach in isolation [14]. There is also some evidence of beneficial effects of combined AO + MI in stroke rehabilitation [15]. However, the therapeutic potential of this approach has not previously been examined in PD [7]. People with PD are capable of engaging in MI [16], and MI can improve their performance of functional movements [17] and reduce freezing of gait [18]. Nevertheless, differences in neurophysiological responses during MI between people with PD and healthy controls suggest the use of compensatory (e.g., visual) mechanisms [19].

This study investigated the effects of (i) AO and (ii) combined AO + MI on hand movement amplitude in people with PD. Our first aim was to examine the effect of AO by comparing imitation of simple hand movements involving elevated (high) vs. direct (low) trajectories. Our second aim was to determine whether combining AO with MI increased the effects of the observed actions. Combined AO + MI was examined using the same imitation task, but explicitly instructing participants to engage in MI while observing the movements. Participants were encouraged to focus on the sensations associated with executing the action, since kinaesthetic MI produces greater sensorimotor activations than visual MI [20].

Based on previous evidence of AO and imitation in PD, we hypothesised that participants would imitate the amplitude of observed actions by modulating the height of their own movements. Moreover, if people with PD are able to engage in MI during AO, combined AO + MI should increase imitation of movement amplitude, as found in healthy young adults [21]. Conversely, if MI is compromised, people with PD may fail to exhibit an effect of MI on imitation. We therefore also examined the relationship between imitation and self-reported MI.

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Table 1
Demographic characteristics and motor imagery (KVIQ) scores in each group.

	PD	Control	*Statistic*	*p*
Age (M, SD)	63.5 (6.34)	68.33 (5.38)	t = 2.85	.007
Sex (% female)	37.5	54.2	χ^2 = 1.34	.25
UPDRS motor score (M, SD)	38.4 (11.33)	N/A		
Hoehn & Yahr (Mdn, IQR)	2.00 (1.5)	N/A		
Years since diagnosis (M, SD)	6.8 (4.8)	N/A		
Levodopa equivalent daily dose; LEDD (mg; M, SD)	519.08 (300.77)	N/A		
KVIQ-visual (Mdn, IQR)	64.23 (20.78)	79.34 (17.00)	Z = 1.89	.059
KVIQ-kinaesthetic (Mdn, IQR)	60.45 (17.00)	54.78 (24.56)	Z = .032	.97

2. Method

2.1. Participants

Participant characteristics are shown in Table 1. A convenience sample of 24 participants (9 females) with mild to moderate idiopathic PD (Hoehn & Yahr stage 1–3) were recruited through local neurology clinics and Parkinson's UK. All but one were taking dopaminergic medication. Participants remained on their usual medication during the study and were tested in the 'on' state where applicable. 24 control participants (13 females) with no history of neurological injury or illness were recruited from among relatives/friends of participants with PD and the local community. All participants except two in the PD group were right-handed. Participants had normal or corrected-to-normal vision and were screened for dementia using the Addenbrookes Cognitive Examination; ACE-III [22] or a brief version if they had been assessed recently for a previous study (M-ACE) [23]. Although three participants in the PD group scored within the borderline range on the M-ACE, the main results were not altered by removal of these participants, so their data were retained in the final analysis. The study was approved by a UK National Health Service Research Ethics Committee and participants provided written informed consent.

2.2. Stimuli and procedure

Imitation was examined using a video-based task [24]. Participants observed, and immediately replicated, movement sequences performed by a human hand with the index finger extended, shown as a mirror-image (right-handed participants viewed a left hand). Sequences consisted of two movements between three of four positions (e.g., 4-2-1) spaced 150 mm apart horizontally (Fig. 1). In elevated trials, the hand moved between positions via an indirect trajectory, with a vertical amplitude of 130.9 mm. Direct trials showed a lower movement trajectory with an amplitude of 21.5 mm. In half of the trials, the four possible target positions were marked by small grey circles (see supplementary materials). The model's movements were paced using a metronome during recording of the stimulus videos (not audible during the imitation task).

Stimuli were projected at life-size onto a 1000 mm × 750 mm screen, positioned 1200 mm from the participant, who was seated at a table with their hand concealed from view by an occluding box (650 mm × 450 mm x 200 mm). A motion sensor was attached to the intermediate phalanx of the index finger of the dominant hand, and movements were tracked in X, Y and Z axes at 120 Hz, using a Polhemus Liberty motion tracking system with Motion Monitor software (Innovative Sports Training).

The trial sequence is illustrated in Fig. 1. Following a fixation cross (4000 ms), a still image indicated the starting position for the sequence (4000 ms). The participant placed their index finger in the start position and the stimulus video was then displayed (4000 ms). The action execution phase was indicated by a go-signal (green cross and "beep"; 1000 ms), presented at a variable post-stimulus delay (1000–2000 ms). Finally, a blank screen was displayed (4000 ms) while the action was performed.

The task began with a short practice block (4 trials), followed by four blocks of 30 trials. For the first two blocks (AO), participants were given the following instruction: *"Copy what you have seen as closely as you can in terms of the timing and size of the movement"*.

For the final two blocks (AO + MI), the following additional instruction was given: *"Imagine what it feels like to make the movements yourself. As you watch the hand move from one place to another, imagine what your arm, hand and finger would feel like to make the movements"*.

Each block consisted of 20 test trials (10 elevated, 10 direct) containing a movement between the second and fourth positions, with 10 filler trials containing different sequences to reduce predictability. Trials were randomized within blocks. A pause halfway through each block allowed participants to take a short break.

2.3. Motor imagery

MI was assessed using a short form of the Kinaesthetic and Visual Imagery Questionnaire (KVIQ), which has been validated in people with PD [25]. Participants are asked to first perform, and then imagine performing, each of a set of simple movements, rating the clarity of images (visual subscale) and intensity of sensations (kinaesthetic subscale) using 5-point scales.

Task-specific MI was measured by asking participants to report their use and vividness of MI while watching the videos. Ratings were completed following the second block (prior to MI instructions), and again after the final block (post MI instructions), using a 5-point scale similar to the KVIQ (see Table 3).

2.4. Data processing and statistical analysis

Kinematic data from correctly-executed movements were analysed using Matlab (Mathworks Inc.). Errors or missing data were excluded (0.7% of trials in the PD group; none in the control group) and outliers for each trajectory condition (elevated/direct) at each time-point (pre/post MI instructions) were then removed according to the procedure outlined by van Selst and Jolicoeur [26]. This resulted in the exclusion of 1.93% individual trials in the PD group (M = 1.54 trials; range = 0–5) and 1.61% trials in the control group (M = 1.29 trials; range = 0–3). Mean vertical amplitude was then calculated for each participant, for each trajectory and time-point. Between-participant outliers were identified using the same procedure, resulting in exclusion of data for two participants in the control group only.

To first determine the effect of AO, imitation of vertical amplitude prior to MI instructions was analysed using a Group x Trajectory ANOVA. The effect of MI instructions (AO + MI) was then analysed with a Group x Trajectory x Time ANOVA. To examine any differences in imitation of movements toward visible targets, the above analyses were repeated with Target included as an additional factor, but no main effects of Target or interactions with Trajectory or Time were found (see supplementary material).

Between-group differences in general MI (KVIQ visual and kinaesthetic subscales) and on the task-specific MI questions were analysed using Mann-Whitney U tests. Task-specific MI ratings for AO and AO + MI blocks were then compared within each group using Wilcoxon signed rank tests. Finally, correlations between imitation of amplitude (elevated – direct trials) and MI measures, UPDRS motor examination, time since diagnosis and levodopa equivalent daily dose (LEDD) were analysed using Spearman's correlation coefficient. Statistical analysis was conducted using IBM SPSS v.22, with an accepted significance level of $p < .05$.

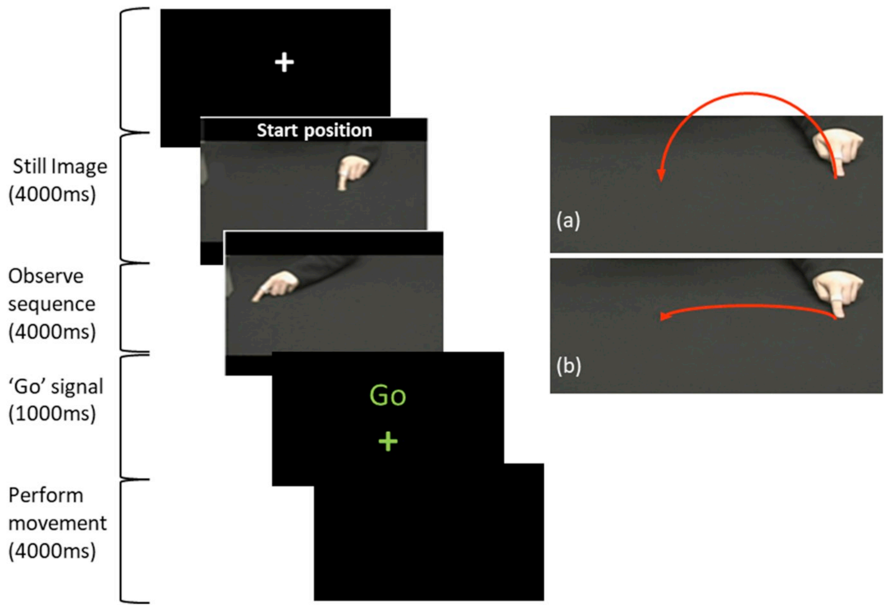

Fig. 1. Illustration of trial sequence: Participants observed videos depicting (a) elevated or (b) direct hand movement sequences, which they imitated following a short delay (1000–2000 ms).

3. Results

The two groups did not differ significantly in sex, but participants in the control group were significantly older (see Table 1). However, age did not correlate significantly with modulation of amplitude before or after MI instructions (all r < 0.4; p > .09).

3.1. Effects of action observation

Prior to MI instructions, there was a significant effect of Trajectory (F (1,44) = 49.16; p < .001; $\eta^2 p$ = .53), with greater amplitude for elevated trials (M = 72.82 mm) than direct trials (M = 39.96 mm), demonstrating modulation in response to the observed movements (Fig. 2). The effect of Group and the interaction between Group and Trajectory were not significant (see Table 2).

3.2. Combined action observation and motor imagery

Following MI instructions (AO + MI), a significant effect of Trajectory remained (F (1,44) = 77.90; p < .001; $\eta^2 p$ = .64), again reflecting greater amplitude for elevated (M = 79.69 mm) than direct (M = 39.80 mm) trials. There was a significant effect of Time (F (1,44) = 17.73; p < .001; $\eta^2 p$ = .64), and a Trajectory × Time interaction (F (1,44) = 12.74; p = .001; $\eta^2 p$ = .22), demonstrating that amplitude increased post-instructions in elevated trials (mean difference = 13.73 mm; t (46) = 4.44; p < .001; d = 0.65) but not direct trials (mean difference = −0.32 mm; t (46) = 0.19; p = .85; d = 0.027). The difference in amplitude between elevated and direct trials was significantly larger following instructions (mean difference = 13.81 mm; t (45) = 3.47; p = .001; d = 0.52), confirming an increase in modulation (see Fig. 2). Effects of Group, Group x Trajectory, Group x Time, and Group x Trajectory x Time were non-significant (see Table 2). Paired t-tests confirmed that modulation increased post-instructions in both the PD group (t (23) = 2.39; p = .026; d = 0.49) and the control group (t (21) = 2.71; p = .013; d = 0.58).

3.3. Relationships with motor imagery measures

As shown in Table 1, the two groups did not differ significantly on the visual or kinaesthetic subscales of the KVIQ. Task-specific ratings of

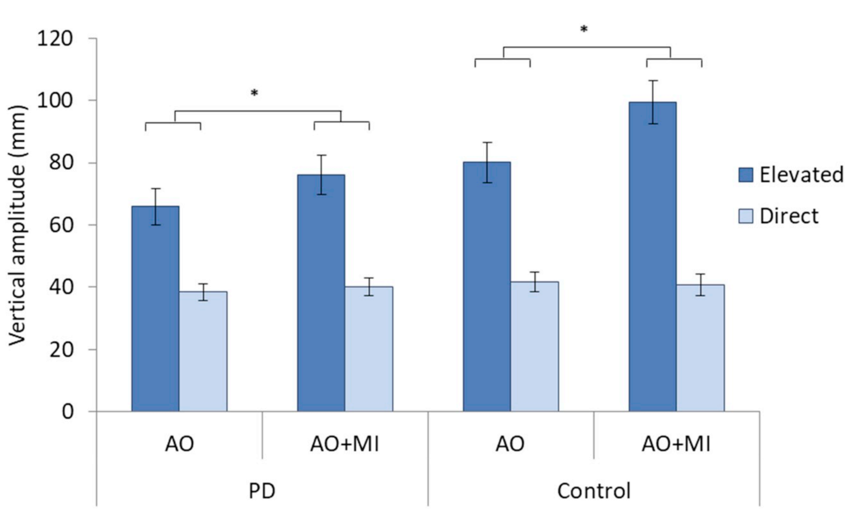

Fig. 2. Vertical amplitude was significantly greater when imitating elevated vs. direct hand movements across both PD and control groups. Both groups exhibited a significant increase in imitation of elevated trials when action observation was combined with motor imagery (*p < .05). The mean amplitude for stimuli with and without visible targets is shown (see supplementary materials). Error bars represent ± 1SEM.

Table 2
Effects of *AO* and *AO + MI* on hand movement amplitude.

	df	F	*p*	$\eta^2 p$
AO-only:				
Group	1,44	3.05	.088	.065
Trajectory	1,44	49.16	< .001	.53
Group x Trajectory	1,44	1.29	.26	.028
AO + MI:				
Group	1,44	3.54	.066	.075
Trajectory	1,44	77.90	< .001	.64
Time	1,44	17.73	< .001	.64
Trajectory x Time	1,44	12.74	.001	.22
Group x Trajectory	1,44	3.27	.078	.069
Group x Time	1,44	.22	.64	.005
Group x Trajectory x Time	1,44	2.09	.16	.045

visual and kinaesthetic imagery did not differ between groups either before or after MI instructions (see Table 3). Both groups reported a significant increase in the use of kinaesthetic imagery (PD, $Z = 2.73$, $p = .006$; control, $Z = 3.47$, $p = .001$) and visual imagery (PD, $Z = 2.45$, $p = .014$; control, $Z = 3.15$, $p = .002$) following MI instructions. The control group also reported increased vividness of sensations ($Z = 2.14$; $p = .032$) and images ($Z = 2.35$; $p = .019$) after instructions, while the PD group showed no significant change in reported vividness of sensations or images.

Scores on the KVIQ subscales did not correlate significantly with imitation of amplitude in either group, before or after MI instructions (all $r_s < .3$; $p > .1$). In the PD group, task-specific ratings of visual MI prior to instructions correlated positively with modulation of amplitude both before (r_s (22) = 0.45; $p = .028$) and after (r_s (22) = 0.51; $p = .01$) instructions. In contrast, modulation of amplitude correlated positively with kinaesthetic imagery ratings after MI instructions in the control group (r_s (21) = 0.46; $p = .026$). There were no other significant correlations between task-specific MI ratings and amplitude modulation. There were no significant correlations between modulation and UPDRS motor score, time since diagnosis, or LEDD (all $r_s < 0.3$; $p > .1$).

4. Discussion

The present study demonstrated for the first time that people with PD can modulate the amplitude of their movements during imitation of observed hand actions, and that combining action observation with motor imagery increases this effect.

4.1. Effects of action observation

Reduced movement amplitude can be a debilitating consequence of PD, affecting everyday activities such as walking and handwriting. While previous studies have found that AO can influence temporal characteristics of movement in PD [7], our results provide the first quantitative evidence that people with PD can successfully adjust the amplitude of their hand movements in response to observed actions, indicating the potential for AO-based interventions to increase amplitude as well as speed.

4.2. Combined action observation and motor imagery

Combining observation and imagery has been found to increase behavioural and neural effects in healthy individuals relative to AO or MI alone [14]. However, despite evidence of motor facilitation in PD when these approaches are used separately, AO and MI have not previously been combined in studies of PD. It has been proposed that combined AO + MI may improve movement in PD by increasing corticospinal excitability, thereby enhancing pre-movement facilitation [8]. Here, we demonstrate that both people with PD and healthy older adults show increased imitation of hand movements when instructed to engage in MI during AO, consistent with our findings in young healthy adults [21].

The present results are complemented by our recent finding that people with PD exhibit motor resonance, whereby even without the intention to imitate, hand movements were influenced by compatibility with observed actions [27]. Action observation may therefore provide an effective external trigger for action simulation. AO may also facilitate MI by reducing the need to generate visual images, thereby allowing an increased focus on kinaesthetic elements of imagery [14]. This facilitatory effect may be somewhat independent of MI ability, as suggested by the absence of a relationship between imitation and a general MI measure (KVIQ) in the present study.

To avoid carry-over effects, whereby participants may apply MI during an ostensible AO-only condition, the task conditions were presented in a fixed order. It is thus possible that the increase in imitation with AO + MI is partly attributable to simple practice effects; however, additional analysis showed that this increase was greater following MI instructions than between pre-instruction blocks (see supplementary materials). Additionally, we have previously found that imitation of elevated movements increased in young healthy participants instructed to engage in MI, compared with a control group [21]. Moreover, any practice effects might be expected to be counteracted by fatigue, particularly in the PD group, since the imitation task required repeated movements over multiple trials. The increase in imitation despite these demands therefore strengthens the conclusion that MI can boost the

Table 3
Task-specific MI: ratings of imagery use and vividness (median, interquartile range).

Question	Pre-instruction (AO)			Post-instruction (AO + MI)		
	PD	Control	*p*	PD	Control	*p*
1. Kinaesthetic Did you try to imagine how it would feel to make the movement yourself? (Not at all … Very much)	4.00 (2.00)	2.00 (3.00)	.34	5.00 (1.00)	5.00 (1.00)	.34
2. Kinaesthetic-Sensations How strong was your feeling (if any) of making the movement yourself? (No sensation … As intense as performing action)	3.00 (2.00)	2.00 (2.00)	.63	3.00 (1.00)	3.00 (2.00)	.63
3. Visual Did you try to imagine what it would look like to make the movement yourself? (Not at all … Very much)	3.00 (3.00)	2.00 (3.00)	.46	4.00 (1.00)	4.00 (2.00)	.98
4. Visual-Images How clear was your image (if any) of making the movement yourself? (No image … As clear as seeing action)	3.00 (3.00)	3.00 (3.00)	.34	3.50 (1.00)	3.00 (2.00)	.90

Note. Scores range from 1 to 5; 5 representing the highest degree of engagement (Q. 1, 3) or vividness (Q. 2, 4).

effects of AO in PD.

4.3. Relationships with motor imagery measures

Although both groups reported increased engagement in kinaesthetic and visual imagery while observing actions after MI instructions were provided, only the control group reported increased vividness of sensations and images. Additionally, imitation of movement amplitude correlated with self-reported use of kinaesthetic MI in controls, but with visual MI in the PD group. These findings suggest that participants with PD may have had difficulty in generating or effectively applying MI during AO, perhaps relying more on visual processes, consistent with neurophysiological evidence indicating possible compensatory mechanisms during MI [19]. The roles of different imagery modalities during AO in PD and healthy adults, and the relationship between MI ability and AO + MI effects, require further investigation and clarification.

4.4. Clinical implications

These findings have clear relevance for the design of interventions for PD based on AO and MI, which could offer a safe, effective and economically viable option for home-based therapy that patients find acceptable [28]. Although we did not test the effects of AO + MI in the absence of dopaminergic medication, previous studies have documented benefits of AO in patients both on and off medication (e.g. [29]), and it is anticipated that AO-based therapy would improve daily activities in PD as a supplement to pharmacological treatments. Future studies should further explore the therapeutic potential of AO + MI, including effects on meaningful everyday actions, and longer-term behavioural and neural outcomes.

The absence of a correlation between imitation and disease severity suggests that imitation and MI may not be directly influenced by motor impairment, at least in mild to moderate PD. MI has been found to be slowed but not inaccurate in PD [16], suggesting that imagery may reflect the individual's current motor repertoire [8]. However, facilitation of MI by AO offers the possibility of increasing the parameters of imagined actions beyond physical ability; combined AO + MI may thus provide a viable therapeutic option even in individuals with limited ability to overtly practice actions. Our findings also support the use of AO + MI training to improve action representation and motor control in healthy older adults [14]. Additionally, since imitation contributes to social processes, interventions based on AO and MI might improve social understanding and interaction, which may be compromised in PD and ageing [30].

In conclusion, people with PD are able to modulate the amplitude of their hand movements when imitating observed actions, and motor imagery instructions can boost this imitation. Future studies should explore potential therapeutic applications of combined AO + MI in neurorehabilitation for PD and other conditions, as well as in healthy ageing.

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Declaration of interests

None.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.parkreldis.2018.11.001.

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