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Impaired Switching from Self-Prepared Actions in Mild Parkinson Disease

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Abstract

Background—Planned and initiated actions frequently need to be terminated in favor of another action. It is known that many individuals with Parkinson's disease (PD) have more difficulty self-initiating movement (i.e., endogenously evoked movement) than moving in response to environmental stimuli (i.e., exogenously evoked movement). However, it is not known if individuals with PD display this same endogenous-exogenous asymmetry when needing to terminate, disengage, and reprogram movements.

Objective—This study used a novel reaction time (RT) paradigm to test whether patients with mild PD have subclinical deficits of endogenous movement initiation and endogenous movement reprogramming.

Methods—Twelve non-demented individuals with PD on medication and 15 demographically similar healthy control (HC) participants completed an experimental paradigm that examined their RTs (key press) following self-selected valid action preparation (endogenous cues) versus valid exogenously presented cues. The paradigm also assessed participants' ability to rapidly stop their endogenous or exogenous preparation following an invalid cue and execute an alternative action (key press).

Results—Participants with PD produced similar RTs as controls following endogenous and exogenous valid cues, and following invalid exogenous cues. However, following invalid endogenous cues, PD participants were slower than HC participants to stop an endogenous preparation and execute an alternative action.

Conclusions—Despite having mild disease and being on dopaminergic medication, these individuals with PD displayed deficits in motor disengagement and reprogramming of self-selected actions. Future studies should examine how this phenomenon influences every day actions, as well as possible treatments for this deficit.

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Conflict of Interest

The authors have no conflict of interest to report.

Introduction

Bradykinesia (slow movement) is one of the clinical hallmarks of Parkinson's disease (PD) [1]. However, individuals with PD may move more quickly or easily when their actions are in response to environmental stimuli (i.e., exogenously evoked) than when their actions are spontaneous and self-initiated (i.e., endogenously evoked) [2, 3]. The term *kinesia paradoxa* is applied to the phenomenon where patients have a paucity of self-initiated movements that is paradoxically altered with external prompting [4, 5]. Most behaviors fall on a continuum between being initiated solely in response to endogenous motivation versus exogenous stimuli [6], but the neural systems supporting each type of movement may be dissociated or partially dissociated, as demonstrated with human neuroimaging [7–10] and primate ablation paradigms [11].

One of the prime examples of kinesia paradoxa associated with PD is gait hesitation or freezing of gait. Individuals with this symptom have an impaired ability to initiate stepping despite the volition to do so [12], but move more easily with external prompts (e.g., having marks on the floor indicating where to step). The finding that exogenous stimuli, such as visual, auditory, or tactile cues, are often very effective in breaking a freeze and prompting movement [13, 14], indicates that the exogenous movement system is relatively preserved. Although freezing is most commonly described as affecting gait, it also affects upper limb motor behaviors [15, 16]. Freezing is being increasingly appreciated as an important symptom because it is associated with an increased risk of falling and significantly reduced quality of life [17, 18].

Impaired endogenous action is not only a motor phenomenon, but appears to be caused by a “complex interplay between motor, cognitive, and affective factors” (p. 543)[19]. These factors include action selection and initiation [20], the ability to efficiently allocate processing resources among two or more concurrent tasks [21, 22], and the ability to switch cognitive and motor sets (i.e., executive functions) [23–27].

Deficits of endogenous action (e.g., freezing) tend not to be observed until PD is relatively advanced, and it is unclear if less overt dysfunction of endogenously evoked movement is present earlier in the disease. Neuroimaging studies suggest that subtle alterations of endogenous movement do exist early in the disease. For example, during endogenously evoked action individuals with mild PD exhibit reduced activity within the supplementary motor area, pre-supplementary motor area, anterior cingulate cortex, putamen, insula, dorsolateral prefrontal cortex, and supramarginal gyrus [8, 28]. During exogenously evoked actions, however, individuals with mild PD and control participants show similar brain activity patterns [29], suggesting relatively preserved functioning of neural systems supporting exogenously evoked movements. Despite this neuroimaging evidence, there are no behavioral paradigms to assess whether endogenous evoked movement dysfunction is present early in PD.

This study uses a novel reaction time (RT) paradigm to detect deficits of endogenously evoked movement, compared with exogenously evoked movement, early in PD. The paradigm assesses participants' initiation of finger movements under two states of certainty

of the action: when the prepared action is certain to be executed, and when there is a small chance that the prepared action will need to be stopped and another action executed. This will increase the attentional demand of the task, which has been shown to exacerbate freezing behavior [20–22]. This paradigm also quantifies patients' ability to stop endogenously versus exogenously prepared movement and execute an alternative movement. It is hypothesized that PD participants will be slower than healthy control participants when initiating and also when stopping/switching endogenously evoked actions compared to exogenously evoked actions. It is further hypothesized that these slower endogenously evoked reaction times, like overt freezing behaviors [23–27], will associate with poorer performance on measures of cognitive set shifting.

Methods

Participants

The participants were 12 individuals with idiopathic PD and 15 healthy control (HC) participants matched for age and education. PD was diagnosed by a movement disorders neurologist based on the Parkinson's Disease Society Brain Bank Criteria [30]. The University of Florida Institutional Review Board approved this study and participants provided written informed consent in accord with the Declaration of Helsinki.

All participants had normal or corrected-to-normal vision, were strongly right-hand dominant, as determined by the Handedness Questionnaire [31] and were not demented, as defined by a Dementia Rating Scale – Second Ed. (DRS-2) [32] total raw score ≥ 130 [33]. PD participants were on their usual medication(s), which is/are reported in levodopa-equivalent daily dose (LEDD)[34], and between Hoehn & Yahr [35] stages 1 and 3. Exclusion criteria were: uncorrected vision or hearing impairments, treatment with either deep brain stimulation or ablation surgery, history of neurological injury or illness (other than PD), untreated psychiatric illness, medical diseases with organ failure, diagnosed learning disorder, and current use of psychotropic medications other than antidepressants. Participants' motor symptoms were rated with the Unified Parkinson's Disease Rating Scale (UPDRS) [36], part III (motor score).

Neuropsychological tests

The Wechsler Test of Adult Reading (WTAR)[37] estimated participants' premorbid intellect to ensure the groups were comparable. The Wisconsin Card Sort Test (WCST)[38] assessed participants' ability to disengage and switch cognitive set (dependent variables = failures to maintain set; number of perseverative errors). The Trail Making Test [39], parts A and B, tested participants' ability to rapidly alternate attentional set ($DV = [(Trail Making Test B time) - (Trail Making Test A time)]$). This score was calculated to isolate the switching component of the test [40].

Apparatus, stimuli, and reaction time paradigm

The software, DirectRT (Version 2012), presented the stimuli and collected the reaction time data. Participants sat approximately 18 inches away from a computer screen with their left and right index fingers resting on the left and right SHIFT keys of a standard computer

keyboard. All trials began with a white fixation cross in the center of the screen. For the uncued RT trials, a large orange letter “L” or “R” served as the imperative stimulus that instructed the participant to press the key under his or her left or right index finger, respectively (Figure 1). On exogenously cued trials, a white letter “L” or “R” was the cue to prepare for a left or right button press. The time that the cue was visible before the imperative stimulus, the stimulus onset asynchrony (SOA; 1000, 2000, or 4000ms), was varied to avoid anticipation. For exogenously cued valid trials, the white letter (cue) turned orange after the SOA, and this was the imperative stimulus for the participant to execute the prepared response. For invalid trials, the white letter turned blue, which was the imperative stimulus to execute a response with the non-prepared hand. For endogenously cued trials, the fixation cross was followed by a white letter “C” (i.e., “choose”) which alerted the participant to internally select and prepare either their right or left index finger for a key press. For valid trials, the “C” turned orange after the SOA, which was the imperative stimulus for participants to press their chosen key. For invalid trials, the ‘C’ turned blue, which was the imperative stimulus for participants to execute the action with their non-prepared hand. Following each endogenously cued invalid trial, the participant pressed a key to indicate whether he/she was successfully able to switch. Participants were instructed to select each hand at least some of the time, but were not corrected if they only selected one hand. The colors associated with valid and invalid imperative stimuli, orange and blue, were counterbalanced across participants. The SOAs were 1000, 2000 or 4000 milliseconds for all trials because preliminary data with healthy control participants (not shown) suggested that they required at least 1000ms for endogenous cueing. This is the approximate time course of the Bereitschaftspotential [41], which accompanies endogenous movement preparation [42].

Participants completed 232 experimental trials that were organized into 5 blocks (0,1,2,3,4; Table 1). Block 0 contained only simple reaction time trials - 8 sequential trials with one hand, followed by 8 trials with the other hand. The order in which the hands were tested was counterbalanced across participants. Block 1 included uncued choice RT trials as well as exogenously cued valid (i.e., ‘exo-valid’) trials. Block 2 included uncued choice RT trials, 80% exo-valid trials, and 20% exogenously-cued invalid (i.e., exo-invalid) trials. The 80%-20% valid-invalid division was based on similar paradigms reported by others [43]. Block 3 included uncued choice RT trials and endogenously cued valid (‘endo-valid’) trials. Block 4 included uncued choice RT trials, 80% endo-valid trials, and 20% endogenously cued invalid (‘endo-invalid’) trials.

Block 0 was always administered first. Blocks 1 and 2 (exogenously-cued trials) were yoked in order (i.e., 1 always preceded 2), and Blocks 3 and 4 (endogenously-cued trials) were also yoked in order. However, the order of the cue types was counterbalanced across participants, so that half of the participants were tested in the 0–1–2–3–4 order and the other half in the 0–3–4–1–2 order. The blocks composed of valid trials only were performed before the blocks with some invalid trials in order to capture participants’ performance without the cognitive concern of potential switch, and also to strengthen participants’ trust in the cue. Before each block, the trial types included in that block were practiced for 8 trials.

An error was defined as an incorrect response, for example, pressing the left key rather than the right key, and failing to switch on invalid trials. An omission was defined as a failure to

select one hand in the course of any full block of endogenous trials despite instruction to do so. Approximately every three minutes the participants were offered a brief rest and were asked to rate their level of fatigue and motivation on 7-point Likert scales (higher=more fatigue, less motivation). The administration of all trials took participants approximately 30 minutes.

Statistical Analyses

Participants' demographic, clinical, and neuropsychological variables were compared with student *t* tests, Mann-Whitney U tests, or chi-squared tests, depending on the variable's nature and distribution. For all reaction time trials, outliers less than 100ms were excluded from analyses. Slow reaction times were not excluded because these may have been reflective of slowed initiation speed, the target of the investigation. The following millisecond reaction time variables were collected: Simple RT Without Cues (Block 0), Choice RT Without Cues (combined trials from Blocks 1–4), Exo-Valid Cues with Certainty (Block 1), Exo-Valid Cues with Uncertainty (Block 2), Endo-Valid Cues with Certainty (Block 3), Endo-Valid Cues with Uncertainty (Block 4), Exo-Invalid Cues (Block 2), and Endo-Invalid Cues (Block 4). Valid trials "with certainty" or "uncertainty" refers to whether valid trials were presented in isolation (Blocks 1 and 3) versus having validly cued trials (80%) randomly mixed with twenty percent invalid trials (blocks 2 and 4), thus introducing uncertainty as to whether the imperative stimuli would match the cue. Five difference scores, computed from the RT variables above, were the main dependent variables of interest. They were computed to compare participants' relative difficulty between two cue conditions as a percentage of the total speed.

Difference Score 1. The influence of valid and certain exogenous cues versus no cues:

$$\frac{(\text{Choice RT without cues mean}) - (\text{Block1 exo- valid trial mean})}{(\text{Choice RT without cues mean}) + (\text{Block 1 exo- valid trial mean})} * 100$$

Higher values on Difference Score 1 indicate larger discrepancies between the slower uncued trials and the faster certain exo-valid reaction time scores. Participants with larger values were better able to benefit from the certain exo-valid cue. It was hypothesized that participants with PD would produce larger values for Discrepancy Score 1 than Discrepancy Score 2.

Difference Score 2. The influence of valid and certain endogenous cues versus no cues:

$$\frac{(\text{Choice RT without cues mean}) - (\text{Block3 endo- valid trial mean})}{(\text{Choice RT without cues mean}) + (\text{Block 3 endo- valid trial mean})} * 100$$

Higher values on Difference Score 2 indicate larger discrepancies between the slower uncued trials and the faster certain endo-valid reaction time scores. Participants with larger values were better able to benefit from the certain endo-valid cue.

Difference Score 3. The influence of valid and certain endogenous versus exogenous cues:

$$\frac{(\text{Block 3 endo- valid trial mean}) - (\text{Block 1 exo- valid trial mean})}{(\text{Block 3 endo- valid trial mean}) + (\text{Block 1 exo- valid trial mean})} * 100$$

Higher values on Difference Score 3 indicate a larger discrepancy between the slower certain endo-valid RTs and the faster certain exo-valid RTs. Values closer to zero indicate that reaction times scores were more similar between these two trial types. It was hypothesized that participants with PD would produce disproportionately slower endogenous RTs, resulting in larger values for Discrepancy Score 3.

Difference Score 4. The influence of valid but uncertain endogenous versus exogenous cues:

$$\frac{(\text{Block 4 endo- valid trial mean}) - (\text{Block 2 exo- valid trial mean})}{(\text{Block 4 endo- valid trial mean}) + (\text{Block 2 exo- valid trial mean})} * 100$$

Higher values on Difference Score 4 indicate a larger discrepancy between the slower uncertain endo-valid RTs and the faster uncertain exo-valid RTs. Values closer to zero indicate that reaction times scores were more similar between these two trial types. It was hypothesized that participants with PD would produce disproportionately slower endogenous RTs, resulting in larger values for Discrepancy Score 4.

Difference Score 5. The influence of invalid endogenous versus invalid exogenous cues:

$$\frac{(\text{Block 4 endo- invalid trial mean}) - (\text{Block 2 exo- invalid trial mean})}{(\text{Block 4 endo- invalid trial mean}) + (\text{Block 2 exo- invalid trial mean})} * 100$$

Higher values on Difference Score 5 indicate a larger discrepancy between the slower endo-invalid RTs and the faster exo-invalid RTs. Values closer to zero indicate that reaction times scores were more similar between these two trial types. It was hypothesized that participants with PD would produce disproportionately slower endogenous RTs, resulting in larger values for Discrepancy Score 5.

Mann-Whitney tests compared the groups' reaction time variables and difference scores. For each trial type, Mann-Whitney tests also compared the errors committed by each group for each trial type, as well as omissions, and self-reported fatigue and motivation. Reaction time variables that yielded group differences were Spearman correlated within each group with the LEDD, GDS total score, UPDRS part III score, WCST, and TMT B-A scores.

Results

PD participants were similar to the HC participants with regard to age, sex, education, global cognition (on the DRS-2), and estimated premorbid intelligence (Table 2). PD participants displayed more severe motor signs than the HC group on the UPDRS, part III, endorsed more symptoms of depression, and more often failed to maintain cognitive set on the WCST. The groups performed statistically similar on the Trail Making Test B-A score.

The PD and HC groups' median RT scores, difference scores, and statistical comparisons are shown in Table 3. The groups' Simple RT Without Cues and Choice RT Without Cues scores did not significantly differ, nor did they differ on individual RT conditions. Difference Scores 1 and 2 did not significantly differ, indicating that the groups were equally able to benefit from valid endogenous and exogenous cues (compared with no cue). When the valid cue types were directly contrasted there were still no group differences in RTs following valid cues, either with certainty (Difference Score 3) or uncertainty (Difference Score 4). The only significant difference score was Difference Score 5, which contrasted participants' RT speed following invalid endogenous versus invalid exogenous cues. This difference indicates that PD participants were slower when they endogenously selected an action, but had to perform a different action, than when they prepared for an exogenously selected action, but had to perform a different action.

Difference Score 5 (endo-invalid vs. exo-invalid) did not correlate with the WCST variables (failure to maintain set $r_s = .23$, $p = .25$; perseverative errors $r_s = .17$, $p = .40$), with the TMT variable ($r_s = .05$, $p = .81$), or with GDS score ($r_s = .07$, $p = .78$), LEDD ($r_s = .35$, $p = .08$), or the UPDRS-III total score ($r_s = .28$, $p = .17$). As shown in Table 4, there were no group differences for any trial type in the number of errors, omissions, or reported motivation. The PD group reported more fatigue than the HC group in Block 4, but not in any other block.

Discussion

This study objectively quantified and compared endogenously and exogenously cued actions in medication-managed individuals with mild idiopathic PD relative to healthy control (HC) peers. Our results indicated that PD participants' speed following valid endogenous cues (relative to valid exogenous cues) was not different from HC participants. Furthermore, the possibility of having to switch the action (i.e., the introduction of uncertainty) affected the PD and HC groups similarly. The major group distinction was the difference between the invalid endogenously cued trials and the invalid exogenously cued trials. PD participants were relatively slower than HC participants when performing the invalid endogenous trials, indicating that stopping and switching self-selected action was more difficult for PD participants than for HC participants.

These results support the finding that individuals with PD have greater difficulty disengaging from actions that are self-selected [3]. Not only were PD participants relatively slower on the endo-invalid trials, but they also reported more subjective fatigue than controls during these trials (but not during any other trial type). This finding cannot be explained as an artifact of task order because for some participants the endo-invalid cued trials (Block 4) were presented third in order, while for other participants they were presented fifth in order. Thus, PD participants' subjective fatigue may instead be an additional sign that they found endogenous disengagement to be disproportionately effortful.

This study demonstrates that even medically managed individuals with mild idiopathic PD have deficits in shifting motor sets when the motor set is endogenously generated. However, the mechanism(s) underlying this impaired motor disengagement are not fully known. Impaired cognitive set switching in PD has been associated with dopamine depletion in the

dorsal striatum [44–49]. However, our PD and HC groups performed similarly on tests of cognitive set shifting (WCST) and attentional switching (TMT). PD participants failed to maintain cognitive set on the WCST more frequently, but the groups produced a similar number of perseverative errors, as well as similar scores on the Trail Making Test. These similar performances may have been due to participants being on dopaminergic medication and/or having mild disease. Why PD participants displayed impaired motor set shifting but not cognitive set shifting is unclear, but may be due to partially dissociable networks underlying cognitive versus motor sets [50, 51] or set shifting.

The basal ganglia are known to enhance the signal-to-noise ratio of cortical processing by enhancing the desired output via the “direct” pathway and by inhibiting competing outputs via the “indirect” pathway [52, 53]. In PD, dopamine depletion leads to increased activity in the indirect pathway and reduced activity in the direct pathway, resulting in excessive inhibition of the thalamus [54]. It is possible that for the PD participants completing our experimental paradigm the motor program of the “competing,” unselected endogenous action during the endo-invalid trials was more inhibited than the unselected exogenous action during the exo-invalid trials, and the reversal of this inhibition lead to slower response times on endo-invalid trials than on the exo-invalid trials. However, this postulate - that non-selected endogenous action is more inhibited than non-selected exogenous action in persons with PD - will have to be further studied.

The PD participants included in this study produced simple reaction time scores that were statistically similar to the HC participants. This is contrary to the typical finding that PD participants are slower on simple RT tasks [55]. The reason for this atypical finding is not known. We considered that it might be related to the PD participants being on dopaminergic medications, but previous studies have not revealed an effect of these medications on reaction times [56, 57]. It may instead be due to many of our PD participants having mild disease. By its nature, endogenous movement eludes measurement in a controlled laboratory setting. It is true that our endogenous cues were not entirely endogenous. However, they offer an important contrast of being more endogenous than the exogenous cues. Our study was also limited by small sample sizes. Some of the results may not have reached statistical significance because of limited statistical power.

Severe deficits of endogenously evoked movement (e.g., freezing) are known to be disabling [58, 59]. However, the impact of more subtle endogenous movement deficits are unknown because there have not been objective and behavioral methods for quantifying endogenous versus exogenously evoked movement. When performing prepared endogenous actions of the upper or lower extremity in everyday life, conditions may suddenly alter and a rapid change in action may be important to successfully complete the task or even to prevent injury. The paradigm used in this study may be useful for examining the early stages of endogenous movement deficits. In particular, this line of research may have implications for the creation or modification of compensatory strategies and devices. Whereas current assistive devices cue movement initiation [59, 60], our results suggest that individuals with these deficits may also benefit from assistance with movement termination/switching.

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Figure 1.

Experimental Stimuli. A) An uncued choice RT trial. B) An exogenously cued trial. For both of these examples, there is a left ('L') imperative stimulus, but there were also right ('R') imperative stimuli in the paradigm. C) An endogenously cued trial. Endogenously cued valid trials ended with the imperative stimulus, but the invalid trials had an additional component that asked participants about their ability to switch. The imperative stimuli were filled orange (valid) or blue (invalid; colors counterbalanced) (color indicated here with gray stripes). Intertrial intervals (ITI) were 4000 and 6000 (randomized). The stimulus onset asynchrony (SOA) was 1000ms, 2000ms, or 4000ms (randomized).

Table 1

Blocks and Trials.

Block	Cue Types	Trial Types	# Trials	Presentation
0	Uncued	Simple RT	16	Each response hand individually
1	Uncued Exogenous	Choice RT Valid	16 48	Randomized
2	Uncued Exogenous	Choice RT Valid Invalid	16 48 12	Randomized
3	Uncued Endogenous	Choice RT Valid	16 16	Randomized
4	Uncued Endogenous	Choice RT Valid Invalid	16 48 12	Randomized
			232 Trials	

RT = reaction time.

Table 2

Demographic, Clinical, and Neuropsychological Variables.

	Healthy Control (n=15)		Parkinson's Disease (n=12)		PD vs. HC
	Mean	SD	Mean	SD	p=
Age (years)	69.2	4.2	68.6	5.5	.75
Sex (%male)	93.3		83.3		.41
Education (years)	18.1	1.5	16.6	2.9	.12
WTAR Estimated IQ	113.5	4.9	110.5	5.6	.16
DRS-2 Total Score	139.7	5.6	139.5	3.4	.89
GDS Total Score	1.0	1.3	6.5	8.6	<.01
UPDRS part III (motor severity)	6.0	5.4	19.3	9.4	<.01
Levodopa Equiv. Dose (mg/day)	--	--	862.1	461.6	--
Years with Symptoms	--	--	8.9	3.4	--
Hoehn & Yahr Stage 1			n = 4		
1.5			n = 2		
2			n = 3		
2.5			n = 2		
3			n = 1		
WCST Perseverative Errors (# errors)	13.1	9.8	20.7	15.6	.17
WCST Failures to Maintain Set	0.7	0.9	1.8	1.4	.03
Trails B – Trails A (seconds)	37.6	21.1	58.7	44.7	.15

The groups were compared on the variables above with a *t* test, Mann-Whitney *U* test, or Chi-squared test.

WTAR = Wechsler Test of Adult Reading

DRS = Dementia Rating Scale

GDS = Geriatric Depression Scale

UPDRS = Unified Parkinson's Disease Rating Scale

WCST = Wisconsin Card Sorting Test

Table 3

Median Reaction Times (in milliseconds) and Difference Scores.

	<i>PD</i>		<i>HC</i>		<i>U</i>	<i>p</i>
	<i>Median</i>	<i>25–75%ile</i>	<i>Median</i>	<i>25–75%ile</i>		
Simple RT Without Cues	509.4	500.6 – 553.9	546.0	501.7 – 562.1	57.0	.11
Choice RT Without Cues	976.8	808.6 – 1283.6	833.2	790.6 – 995.7	60.0	.15
Exo-Valid Trials with Certainty	547.6	437.6 – 818.0	547.4	461.6 – 614.6	78.0	.58
Exo-Valid Trials with Uncertainty	748.9	626.5 – 957.4	725.1	619.2 – 838.7	85.0	.83
Endo-Valid Trials with Certainty	706.3	542.2 – 968.8	565.2	484.4 – 720.0	65.0	.24
Endo-Valid Trials w/ Uncertainty	887.1	676.0 – 1319.2	752.5	640.3 – 952.8	71.0	.37
Exo-Invalid Trials	824.9	707.5 – 1046.8	761.7	634.0 – 1185.8	86.0	.87
Endo-Invalid Trials	1213.4	847.6 – 1461.7	849.3	650.6 – 1291.9	50.0	.07
Difference Score 1	25.3		24.9		88.0	.94
Difference Score 2	17.6		19.8		110.0	.35
Difference Score 3	6.9		6.9		82.0	.72
Difference Score 4	5.0		6.5		85.0	.83
Difference Score 5	16.5		2.2		48.0	.04

Difference Scores: 1 = The influence of valid and certain exogenous cues vs. no cue

2 = The influence of valid and certain endogenous cues vs. no cues

3 = The influence of valid and certain endogenous vs. exogenous cues

4 = The influence of valid but uncertain endogenous vs. exogenous cues

5 = The influence of invalid endogenous vs. exogenous cues

Bold text indicates significance at $p < 0.05$

Table 4

Errors, Omissions, Motivation, and Fatigue.

	# Errors				# Omissions			
	PD	HC	U	p	PD	HC	U	p
Exo-Valid Trials with Certainty	6	4	88.0	.86	--	--	--	--
Exo-Valid Trials with Uncertainty	3	1	100.5	.61	--	--	--	--
Endo-Valid Trials with Certainty	--	--	--	--	1	1	88.5	.94
Endo-Valid Trials w/ Uncertainty	--	--	--	--	0	3	67.5	.28
Exo-Invalid Trials	6	4	92.0	.94	--	--	--	--
Endo-Invalid Trials	9	5	95.5	.79	2	8	55.0	.09

	Mean Fatigue				Mean Motivation			
	PD	HC	U	p	PD	HC	U	p
Block 0	1.6	1.7	26.0	.70	1.4	1.5	59.0	.65
Block 1	2.0	1.8	66.0	.41	1.7	1.4	67.0	.44
Block 2	2.2	1.8	54.5	.26	1.7	1.5	67.0	.44
Block 3	2.2	2.0	73.5	.65	1.8	1.6	66.5	.41
Block 4	3.1	2.0	40.0	.03	2.2	1.7	18.2	.24

Note: Errors and omissions were calculated by trial type, while motivation and fatigue were reported by block, some of which contained multiple trial types. An error was defined as an incorrect response, for example, pressing the left key rather than the right key, and failing to switch on invalid trials. Therefore, it was not possible to commit an error on the endo-valid trials. An omission was defined as a failure to select one hand in the course of any full block of endogenous trials despite instruction to do so. Participants rated their level of fatigue and motivation on 7-point Likert scales, where 1 indicated maximum motivation (*I am highly motivated and know I will do my best*) and alertness (*Feeling active, vital, alert, or wide awake*). Bold text indicates $p < .05$.