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Functional improvements associated with upper extremity motor stimulation in individuals with Parkinson's disease

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Abstract

Background: While traditional neurotherapy promotes motor function in people living with Parkinson's disease (PD), the benefits may be limited by compounding physical, cognitive, and attentional barriers. Since the non-traditional exercise of ice-skating is proving to positively influence motor function and postural control, the purpose of this study was to explore whether the addition of an upper body sensory-driven motor coordination task (stickhandling) would provide upper extremity neuromotor benefit among people with moderate PD.

Methods: Seven non-PD control (CTRL) and 22 PD (14 ON-ICE, 8 OFF-ICE) participants completed three trials of a reaching-to-eat (fine motor) task and a button-push (gross motor) task, PRE-and POST-completion of two dynamic – either on- or off-ice – stickhandling tasks. Reaching-to-eat and button-push scores were compared between time periods (PRE, POST) and groups (CTRL, PD ON-ICE, PD OFF-ICE).

Results: CTRL participants demonstrated higher scores when compared to the PD groups. Both PD groups demonstrated an improvement in reaching-to-eat and button-push scores immediately following the intervention.

Conclusions: These findings suggest that sport-derived exercise programs may provide neuromotor benefit to people living with PD.

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Introduction

Parkinson's disease (PD) is a progressive neurodegenerative movement disorder that produces a multitude of progressively worsening and debilitating functional motor symptoms [1, 2]. Underlying pathophysiology exhibits decreased dopamine production resulting from or precipitating depleted substantia nigra neurons in the midbrain [2]. Since dopamine functions as a neurotransmitter, this interferes with basal ganglia-thalamocortical circuitry which, in turn, negatively impacts sensory-motor coupling and produces kinesthesia deficits [1, 3]. The physiologic mechanism is such that the dopamine-deficient basal ganglia are no longer able to match the cortically induced stride amplitude to induce normal locomotion, and the result is an array of movement disorders including tremor-at-rest, freezing of gait (FOG), akinesia, bradykinesia, and hypokinesia [1, 2, 4]. Sensory loss associated with kinesthesia, evident by increased patterns of sway, precipitates postural instability, which negatively impacts balance and increases the risk of falls [3, 5, 6]. This may be due to an impaired neurotransmitting network that extensively involves the frontal lobe, basal ganglia, cerebellum, and brainstem [4]. Previous work has demonstrated that the resulting proprioceptive deficits may be central to the motor problems that occur in PD [3]. It is already known that goal-directed ethological movements, such as reaching and grasping, are adversely impacted by postural motor and trunk control [3, 7]. Increased onset of muscle activation, reaction time, and movement time reduces upper extremity flexion and extension during functional reach-to-grasp tasks [3, 7]. Since these joint-position deficits appear relatively early in the course of PD, by examining bilateral upper extremity functional tasks as biomarkers of disease progression, it may possible to find ways to stimulate sensorimotor integration, and thereby mitigate functional motor deterioration.

The primary treatment for PD is aimed at increasing dopamine levels using a biosynthetic precursor of dopamine such as Levodopa [2]. Although initial improvement in motor control is generally seen, long-term use is also associated with dyskinesia and worsening sensorimotor deficits that are difficult to manage [2, 8]. It is theorized that functional improvement in body position, movement, and acceleration can occur through actions that affect either the basal ganglia or the cerebellar circuit [1, 9, 10]. Studies on early- and mid-stage PD subjects suggest exercise-induced neuroplasticity in dopaminergic signaling may be an effective method to improve motor function [11, 12, 13]. Biomechanical studies specific to the PD population have, in fact, established secondary kinematic and neuromotor benefits associated with the stimulated non-traditional biomechanically efficient exercise of ice-skating [14, 15, 16]. Preliminary research has shown that people living with PD preserve the capacity to safely and effectively perform ice-skating maneuvers despite marked deficits in a range of functional movements [14, 15, 16]. PD individuals experienced significant increases in velocity during ice-skating and, moreover, a brief period of ice-skating implementing visually stimulated cues was shown to positively influence balance and coordination [15, 17]. No PD study participants fell during any of the ice-skating trials, implying that it is also a safe mode of exercise in this population [14, 16, 17]. In fact, research on falls demonstrates that exercise programs that target reflexive sensorimotor mechanisms may be beneficial for preventing falls in specific populations such as those with PD [6, 18].

Given the positive findings on motor and kinesthesia improvement in ice-skating PD individuals thus far, combined with the link between visual cues and proprioceptive function, we predicted that adding an upper body motor sensorimotor (i.e., eye–hand) coordination activity (stickhandling) may confer additional benefits by increasing gross and fine motor skill of the upper extremities. The outcome of this Phase I study will support the design and methodology for a second phase large-scale longitudinal study of ice-skating maneuvers and PD, which integrates measures of postural control and overall motor performance. Accordingly, the purpose of this study was to explore the effects of a proprioception-stimulating activity (stickhandling) on upper motor performance among people with moderate PD.

Methods

Subjects

The study protocol conformed to the Declaration of Helsinki and was approved by the University of Lethbridge Ethics Committee. All participants gave written informed consent. Twenty-two participants with moderate PD were recruited to the study. Seven non-parkinsonism control (CTRL) participants were recruited for comparison (Table 1).

Table 1. Participant demographics and clinical characteristics at baseline. Values are mean (standard deviation) for continuous variables and number for discrete variables.

Characteristic	CTRL (On-Ice)	PD ON-ICE	PD OFF-ICE
No. of participants	7	14	8
Age (yrs)	51.7 (4.9)	55.8 (8.2)	73.8 (7.7)
Sex (M/F)	4/3	12/2	5/3
Disease duration (yrs)	N/A	6.0 (4.1)	9.1 (5.2)

Protocol

Novel experimental biomarkers to evaluate upper limb kinetics were used in the form of skilled reaching and button-push tasks [7].

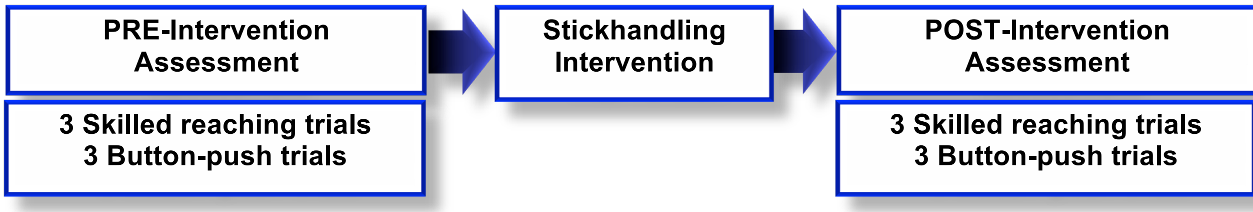

Figure 1. PRE-and POST stick-handling intervention tasks consisted of 3 reaching-to-eat and 3 button-push trials

Each participant completed three trials of a reaching-to-eat (fine motor) task and a button-push (gross motor) task with their dominant arm PRE-and POST-intervention. The intervention involved effecting two dynamic stickhandling tasks (using an ice hockey stick and puck) either on- or off-ice depending on the physical ability and comfort level of each participant (Figure 1).

Reach-to-eat task (Figure 2A)

Participants were studied in a seated position with the palm of each hand rested comfortably on their thigh. On a 'go' signal, participants were instructed to reach for a single food item (a Cheerio™) that was placed on a pedestal positioned directly parallel to the participants' midline at arm's length distance. The Cheerio™ was placed in the mouth, consumed, and the hand returned to the starting position. Participants performed three trials with each hand, with only the dominant limb used for data analysis.

Reach-to-eat trials were captured in sagittal plane video and transferred to a computer for further analysis. A trained rater manually assessed and scored each reach for movement quality according to the human version of the reach-to-eat scale. The scale, as previously used in human PD studies [7], consists of seven components subdivided into two or more subcomponents for a total of 21 items. The best score for a reaching subcomponent was a value of 1, while a score of 0.5 was assigned if the movement was present but to a lesser amplitude than normal, and 0 if the movement was completely absent (Table 2). Rater scores were averaged for the dominant limb of each participant.

Button-push task (Figure 2B)

Participants stood facing a table with the palm of either hand facing downwards, digits extended, and index finger placed comfortably on a red push-button attached to a counting device. On a 'go' signal, participants were instructed to tap their index finger as many times as possible in a 10 s period, keeping the hand and arm in a fixed position. Three trials were performed with each hand, with only the dominant limb scores being used for data analysis.

Button-push scores were collected automatically and averaged across the three trials for the dominant limb of each patient.

Figure 2. PRE- and POST-intervention assessment.

A) Fine motor task: Skilled reaching. Participants reached for a CheerioTM, placed it in their mouth, and returned their hand to their thigh; B) Gross motor task: Button-push. Participants pushed a button as many times as possible in 10 s.

Table 2. Reach-to-eat scoring criteria

Component	Sub-component	Description
Orient	Head	Head is moving freely then fixes on target at beginning of trial = 1. Head continuously fixed on target = 0.5.
	Eyes	Eyes locate target prior to movement of head/reach.
Lift	Point at target	Hand supinates towards target, index finger points towards target.
	Early pincer	Index finger and thumb begin to form a pincer grip.
	Flex elbow	Initial hand lift due to flexion of elbow = 1. Any change of flexion = 0.5.
Aim	Hand to target	Hand takes shortest path to target = 1. Off in one dimension = 0.5; off in both dimensions = 0.
	Hand ends at target	Hand stops at target, does not require secondary adjustments in A/P.
	Trunk ends w/ hand at target	Trunk leans to side opposite reach as hand approaches target.
Pronate	Full hand turn	Knuckles on reaching hand form horizontal line.
	Extend elbow	Elbow opens to full arm length as subject reaches.
	Thumb and index close	Index finger and thumb are two closest digits to target: yes = 1, no = 0.
Grasp	Use pincer grasp	Thumb and one finger = 1; thumb and two fingers = 0.5; any other organization = 0.
	Digits 3, 4, 5 independent	Digits 3, 4, 5 remain still as grasp is executed.
	Lift on grasp	Three frames of vertical hand movement before rotation.
Supinate	Supinate I	Reaching hand supinates 45° immediately after vertical lift.
	Supinate II	Hand rotates when in close proximity to mouth.
	Head to hand	Head adjust back towards midline and lowers to ingest target.
	Trunk moves w/ hand	Trunk leans back towards midline.
Return	Hand pronates	Hand rotates until knuckles align horizontally, prior to top of pedestal.
	Free digits from grasp	Index finger and thumb release from pincer grasp to relaxed positions, prior to top of pedestal.
	Hand on lap	Hand is placed on lap with fingers unfurled and palm down.

Each subcomponent is scored on a three-point scale (0, 0.5, 1). The action is given a score of 1 if normal movement is present; a score of 0.5 when normal movement is present but not executed completely or correctly; and a score of 0 if the required movement is absent.

Three-way stickhandling task (Figure 3A)

Using a single hockey puck, the participants stood in a 'ready stance' with both hands gripping a hockey stick of their choice. On a 'go' signal, participants moved a puck back and forth on the left side of the body for 10 s, in front of the body for 10 s, and on the right side of the body for 10 s (30 s total). Participants were instructed when to transition to the next position during the task. Three sets were completed with a 10 s rest between sets.

Three-puck drill task (Figure 3B)

Three hockey pucks were set up in a triangle on the ice and a fourth puck was given to each participant to perform the drill. Participants were instructed to stand in a 'ready stance' facing the triangle of pucks with both hands gripping a hockey stick of its choice. On a 'go' signal, subjects performed a figure-8 pattern by weaving the fourth puck through the triangle for 30 s. Three sets were completed with a 10 s rest between sets.

Statistical analysis

All analyses were conducted using SPSS 19.0. A two-way repeated measures analysis of variance (ANOVA) test was used to establish the effect of the stickhandling intervention and group for each motor task. Reaching-to-eat and button-push scores were compared between time periods (PRE, POST) and groups (CTRL/PD ON-ICE/PD OFF-ICE). Statistical significance was set at 0.05.

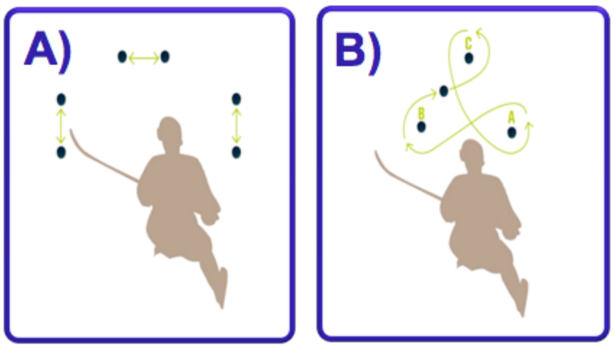

Figure 3. Stickhandling intervention

A) Task 1: Three-way stickhandling. Participants performed each of 3 patterns for 10 s (30 s total) with a 10 s rest between each set; B) Task 2: Three-puck drill. Participants performed the pattern 3 times for 30 s each time and with a 10 s rest between each set.

Results

Effect of stickhandling on skilled reaching

Skilled reaching (fine motor) scores were compared between the CTRL group and PD groups (Figure 4A). A main effect of time was observed for skilled reaching (F(1, 25)=21.401, $p<0.001$, $\eta^2=0.451$). Follow-up t-tests revealed the PD ON-ICE group significantly improved their SRRS score from pre- (M=14.59, SD=1.81) to post- (M=15.78, SD=1.68) intervention (t(13)=3.37, $p<0.05$). A similar improvement in the PD OFF-ICE group was observed between pre- (M=15.81, SD=1.16) and post- (M=17.13, SD=0.99) intervention scores (t(7)=5.70, $p<0.001$). The CTRL group did not show a significant improvement from pre- (M=19.93, SD=1.11) to post- (M=20.50, SD=0.50) intervention ($p=0.246$). Main effects of group were observed for skilled reaching (F(2, 25)=35.322, p<0.001, $\eta^2=0.731$). Pairwise comparisons revealed that SRSS scores were significantly higher in the CTRL group (M=20.21, SD=1.21) than in both the PD ON-ICE (M=15.19, SD=1.75) and PD OFF-ICE (M=16.47, SD=1.21) groups ($p<0.001$). The difference between the PD ON-ICE and PD OFF-ICE groups was not significant ($p=0.601$). No other main effects or interactions were observed.

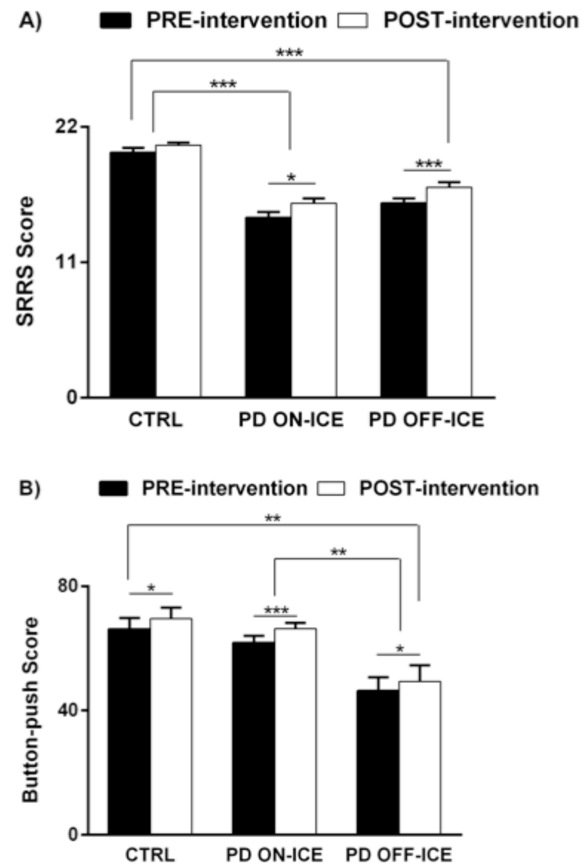

Figure 4. Effect of stickhandling intervention

A) skilled reaching-to-eat rating scale (SRRS) score, and B) button-push score. Values are means and standard errors. * $p\leq.05$, ** $p\leq.01$, *** $p\leq.001$

Effect of stickhandling on button-push skill

Button-push (gross motor) scores were compared between the CTRL group and PD groups (Figure 4B). A main effect of time was observed for the button-push task (F(1, 25)=43.242, $p<0.001$, $\eta^2=0.625$). Follow-up t-tests revealed the PD ON-ICE group significantly improved their button-push score from pre- (M=61.75, SD=8.10) to post- (M=66.29, SD=7.00) intervention (t(13)=6.10, $p<0.001$). A similar improvement in the PD OFF-ICE group was observed between pre- (M=46.25, SD=12.54) and post- (M=49.33, SD=14.88) intervention scores (t(7)=2.34, $p<0.05$). This effect was also significant in the CTRL group from pre- (M=66.19, SD=9.49) to

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post- (M=69.59, SD=9.30) intervention (t(6)=4.61, $p<0.05$). Main effects of group were observed for the button-push task (F(2, 25) =9.436, $p<0.001$, $\eta^2=0.421$). Pairwise comparisons revealed that button-push scores were significantly higher in the CTRL group (M=67.89, SD=10.47) than in the PD OFF-ICE (M=47.79, SD=10.47) group ($p<0.01$). The difference between the CTRL group and the PD ON-ICE (M=64.02, SD=7.55) group was not significant ($p=0.861$). Button-push scores were also significantly higher in the PD ON-ICE group than in the PD OFF-ICE group ($p<0.01$). No other main effects or interactions were observed.

Discussion

This study addressed the question of whether adding an upper body motor coordination task to ice-skating maneuvers resulted in additional neurotherapeutic improvements to functional mobility in the presence of moderate PD. Individuals with PD were able to perform the stickhandling tasks safely and effectively. Fine and gross upper extremity motor skills were improved immediately following the stickhandling intervention in both on- and off-ice conditions. Although no significant time by group effect between the CTRL group and PD groups was evident, the results suggest this type of intervention may provide neuromotor benefit in people with PD.

Animal experiments have demonstrated that exercise, by increasing serum calcium levels, can normalize brain dopamine levels and stimulate synthesis of dopamine [20]. Recent research has thus been aimed at exercise as a means of treating PD by stimulating dopamine production or, at the very least, targeting the dopaminergic neurotransmitters or cerebellar feedback systems to produce synaptic plasticity and improve motor function [2, 11]. This may be especially important for individuals in the early and moderate stages of PD as a preventative measure to delay and counteract disease progression. Despite the mobility restrictions seen in moderate PD, preliminary trials demonstrate that ice-skating may be an ideal exercise for PD individuals, as implied by functional improvements demonstrating kinesia paradoxa during and immediately after low level trials of ice-skating [14, 16]. This may be contributed to the multiple angle movement patterns required in ice-skating as opposed to traditional exercises such as running or biking [21]. Skating locomotion requires biphasic stride motion in the frontal and sagittal planes thus creating linear and angular motions of the body, and producing internal/external rotation and adduction/abduction of the hip [22]. This effectively allows the muscles to slowly shorten, independent of speed, in correspondence with maximum mechanical power [21].

Balance control, coordination, and motor learning are associated with the cerebellum, and there is evidence to support that ice-skating improves all three [23, 24]. Since the underlying pathophysiology of PD may, at least in part, be related to abnormal cerebellar activity, it makes sense that regimented ice-skating programs that implement upper and lower body sensory-sensitive coordination tasks could contribute to central nervous system preservation and improved postural control [1]. In a study that compared postural-challenging patterns of body sway between young adults, the active elderly, and the sedentary elderly, the postural control of the young adults and the ice-skating elderly was similar [25]. In demonstrating significantly higher stability and lower regularity than the sedentary elderly, these findings are important since they essentially negate age-related changes in postural control, while effectively removing the barrier of ageing, which is a primary risk factor for PD [25]. Focus can thus remain on the sensory and cerebellar processes that lead to postural stability. It is already known that cerebellar structural and neurophysiological changes can be induced through visually stimulated motor learning, as demonstrated in a study on short-track speed skaters whose increased cerebellar volume explains their unusual ability to maintain balance and coordination [24]. It is also known that posture and balance are regulated by a multitude of sensory processes, including the visual, somatesthetic, and vestibular systems [23]. Recent trials show that when individuals were required to process visual input during ice-skating, improved postural response was seen, thereby mitigating the unexpected perturbation associated with falls [15, 17]. Another study, which implemented visual and rhythmic auditory cues with exercise, further implied that providing sensory stimulation to the brain generates stride improvement [26].

This strengthens the case to add an eye-hand proprioception activity such as stickhandling to ice-skating since, while creating lateral movement, the center of gravity is effectively displaced by the horizontal position of the lower body [22]. In addition, ice-skating is unique in that it does not include the same up-and-down motion that occurs in traditional weight-bearing exercises, and the resultant strengthened abductor and adductor muscles, as well as the gluteal, hamstring, and quadriceps muscles utilized during the glide phase, further contribute to postural stability [22]. Thus, from a kinetic perspective the type of movement created, when adding stickhandling to ice-skating, counteracts many of the PD-induced motor disorders by increasing angular displacement and velocity of the upper and lower body [4, 26]. Visual stimulation guides the reach-for-target task, which in turn, optimizes body position and movement. The result is improved dynamic stability with increased ability to accelerate and regain balance associated with forward falling [3, 6, 10]. Balance and coordination are enhanced, and the risk of falls is decreased.

Aside from the potential benefits of a sport that integrates multiple angle movements with sensory stimulation, it has also been suggested that increased attention to extraneous factors, such as those which occur in an environment outside of the home (i.e., at the skating rink), might be enough to stimulate a different locomotion pathophysiologic network and induce a therapeutic effect on movement [4]. Secondary to the suggested motor and balance benefits emanated in PD ice-skating individuals, the intrinsically motivating advantages of an activity that is enjoyable, promotes social inclusion, and facilitates independence may, at least in part, counteract the physiologic deficits that further affect quality of life and predispose PD individuals to mood and behavioral disorders [1, 9].

Although limited by a small sample size, selection bias, and a single exercise trial session, this study reveals a number of elements to improve the design of a Phase II large-scale study on PD individuals who are exposed to ice-skating maneuvers. For example, adding pre- and post-UPDRS testing, and measurements of seated postural control to upper body motor coordination analysis may strengthen the results and validate preliminary evidence that ice-skating maneuvers improve overall motor function and coordination. In addition, the current study enrolled only moderate stage PD individuals, and this may have contributed to the lack of significant time by group differences between the CTRL group and PD groups. Since it is known that functional deficits worsen with disease progression, a comparison of early-stage PD and moderate-stage PD individuals would fuel speculation that early non-traditional exercise could actually alter the course of the disease.

Conclusions

The short-term improvements in upper extremity neuromotor performance among people living with PD following a period of stickhandling during ice-skating implies that sport-derived non-traditional exercise programs may provide neurotherapeutic benefit to PD individuals in sustaining functional mobility. PD is a complex multi-faceted disease, and further research is required to explore the neurofeedback mechanisms that support ice-skating as a novel therapeutic strategy and a life-long non-pharmaceutical activity that can, in the long-term, preserve and improve the neurological and musculoskeletal systems in individuals with PD.

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