Reduced frequency of knowledge of results enhances learning in persons with Parkinson’s disease

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INTRODUCTION

Parkinson’s disease (PD) is a progressive neurological disorder, known to cause a large number of motor and non-motor limitations. Research related to factors that affect motor control and learning in people with PD is still relatively limited. The purpose of this study was to compare the effects of different frequencies (100 versus 66%) of knowledge of results (KR) on the learning of a motor skill with spatial demands in participants with PD. Twenty individuals with PD were randomly assigned to one of two groups. The 100% group received KR after each trial, while the 66% group received KR on two thirds of the trials. A linear positioning task with a spatial target was used. Participants carried out the task with the dominant hand while blindfolded. In the acquisition and retention phases, the goal was to position the cursor at a distance of 60 cm from the starting point. The hypothesis was that participants with PD, who practiced with a reduced KR frequency, would demonstrate more effective learning than those who practiced with a 100% KR frequency, similar to previous findings with adults without neurological disorders. The results showed differences between the groups in the retention phase (without KR): The 66% KR group was more accurate and less variable in their performance than the 100% KR group. Thus, reducing KR frequency can enhance motor learning in persons with PD, similar to what has previously been found for unimpaired participants.

Keywords: motor learning, feedback, knowledge of results, Parkinson’s disease
Given the lack of studies and the importance of this variable for learning, in general, and rehabilitation, in particular, the purpose of the present study was to compare the effects of a reduced frequency of KR in participants with PD. As people with PD appear to require more feedback than typical participants, we predict that a “slightly” reduced frequency of KR (66%) could potentially enhance learning, compared with a 100% frequency, when measured in a delayed retention test without KR. Different from previous studies, which used very low frequencies of KR (e.g., 20%) in comparison with frequent feedback, we speculated that a relatively small percentage of trials without KR could give learners the opportunity to process important intrinsic information, enhancing retention when extrinsic feedback is no longer available. In other words, not receiving feedback on a few trials could impose an important challenge for the impaired PD intrinsic feedback system, possibly enabling participants to develop a more accurate internal sense of arm and hand position, while strengthening relationships between motor commands and their effects in the environment. To test this hypothesis, a linear positioning task with a spatial target was used. While the 100% group received KR after each trial, the 66% group received KR on two thirds of the trials. To assess learning, a retention test was used one day after the practice phase.

MATERIALS AND METHODS

PARTICIPANTS

Twenty individuals with PD (10 men and 10 women), aged 53–87 years (mean age of the 100% group: 68.3 years; mean age of the 66% group: 69.0 years) participated in the study. Only persons in Stages 2 and 3 of the Hoehn and Yahr scale (Goetz et al., 2004) participated in the study. They were optimally medicated for PD and participated in the investigation during the “on” medication cycle. To ensure homogeneity they were divided according to gender (five women in each group), and clinical stage (six participants in stage II and four in stage III in each group). Characteristics of the patients are shown in Table 1. The acquisition and retention phases were carried out at the same time of day on two consecutive days. Informed consent was obtained from the participants and the study was approved by the university’s ethics committee. Participants were unaware of the purpose of the experiment, and the task was unfamiliar to all of them.

APPARATUS AND TASK

A linear positioning task consisting of a straight slide bar, approximately 1 m in length and fastened to a sturdy base was used (Figure 1). A measuring device secured to the base was used to measure the horizontal displacement of the slide, which was attached to the slide bar. Participants sat with their left shoulder in line with the starting point of the slide. To prevent the use of visual cues, they wore opaque swimming goggles. They were also asked to move the slide and stop it on the target using their right hand (they were all right-handed). In the acquisition and retention phases, the goal was to position the cursor at a distance of 60 cm from the starting point.

PROCEDURE

The 20 individuals with PD were randomly assigned to one of two groups, with an equal number of male and female in each group. The 100% group received KR after each trial, while the 66% group...
Constant error (CE), absolute constant error (ACE), and variable error (VE) in cm were our dependent variables. CE is the difference between the actual distance and goal movement distance, representing distance error. ACE is the absolute value of CE for each participant, representing distance error regardless of direction. VE is calculated based on the within-subject variability of the mean for each block of trials, representing a measure of distance consistency (see Schmidt and Lee, 2005 for formula descriptions). Data were averaged across blocks of five trials. The acquisition phase data were analyzed in a 2 (group: 100 versus 66% KR) × 6 (blocks of five trials) analysis of variance (ANOVA), with repeated measures on the last factor. Retention data were analyzed in one-way ANOVA. The Greenhouse–Geisser df adjustment was used to report $F$ values in repeated measures factors, if necessary. In order to indicate effect sizes for significant results, partial eta-squared values are reported. Alpha level for significance was set at 0.05 for all analyses.

**RESULTS**

**Practice**

**Constant error**

Both groups tended to undershoot the target on the first block and to overshoot it somewhat on the remaining practice blocks (see Figure 2, left). The main effects of block, $F(5, 90) = 6.67, p < 0.001, \eta^2 = 0.27$, was significant. The main effect of group, $F(1, 18) < 1$, and the interaction between group and block were not significant, $F(5, 90) < 1$.

**Absolute constant error**

Both groups reduced their absolute errors similarly across practice blocks (see Figure 3, left), particularly on the first three blocks. The main effects of block, $F(5, 90) = 6.32, p < 0.001$,
The 66% KR group showed less variability in performance compared with the 100% group (see Figure 4, right). The group difference was significant, with $F(1, 19) = 19.02, p < 0.01, \eta^2 = 0.51$.

**DISCUSSION**

People with PD differ from typical adults in several ways (Rand et al., 2000; Berardelli et al., 2001; Guadagnoli et al., 2002; Konczak et al., 2007, 2009; Jankovic, 2008; Nieuwboer et al., 2009). Specifically, studies utilizing tasks with spatial goals that demand appropriate use of feedback information, as the linear positioning task used in the present experiment, have demonstrated that people with PD present motor control deficits, resulting, for example, in poorer arm matching accuracy (Rabin et al., 2010) than shown by the typical population. Impairments in the basal ganglia can be responsible for the reduced capability to control and regulate spatial and force parameters. Therefore, individuals with PD are less able to regulate velocity and acceleration magnitudes when accuracy constraints are imposed (Rand et al., 2000). Together with abnormal proprioception (Adamovich et al., 2001), the deficits in the central processing and integration of kinesthetic signals, resulting in incorrect formulations of motor plans (Contreras-Vidal and Gold, 2004), may explain the greater dependency on extrinsic feedback information in persons with PD.

As previous studies examining feedback frequency effects used very low KR frequencies (Verschueren et al., 1997; Guadagnoli et al., 2002), it was not clear whether a “slightly” reduced KR frequency would enhance the learning of a motor task, compared to feedback after every trial, in this population. Considering that individuals with PD have difficulty in processing intrinsic feedback, with treatment often involving the use of external cues as compensation, the purpose of the present study was to examine whether the learning advantages of a reduced frequency of KR found in typical participants (see Swinnen, 1996; Wulf and Shea, 2004, for reviews) would generalize to motor learning in participants with PD.

Our results are in line with previous studies using typical populations in showing that a reduced frequency of feedback can also benefit the learning of motor skills in participants with PD. According to the guidance hypothesis (Salmoni et al., 1984; Schmidt, 1991), extrinsic feedback guides the learner to the goal
behavior. However, when provided too frequently, it can cause a dependency, blocking the processing of intrinsic feedback. Also, according to the maladaptive short-term corrections notion, frequent feedback can cause some instability during the practice phase, since the learner makes constant corrections to the action plan, even when errors are small. The result can be less consistent performance in retention and transfer phases. A low frequency of feedback could help the improvement of some stability between trials, resulting in a stronger basis for the use of the feedback information, when provided.

The present results contrast with those of previous studies with PD participants (Verschueren et al., 1997; Guadagnoli et al., 2002), where learning advantages were found for high frequencies of extrinsic feedback. In these studies, severely reduced frequencies of KR were used, leading to inferior learning in comparison with feedback provided after all trials. A possible explanation for the differences in the results could be related to the frequency used in our study. The use of a slightly reduced (66%) frequency of feedback could have helped participants with PD to rely on intrinsic feedback, despite their difficulties in processing it, during the few trials where the KR was not provided. In this way, the participants were provided with both sufficient extrinsic information and the opportunity to process intrinsic information (on trials without feedback) – enhancing learning and aiding retention in a situation, in which augmented feedback was no longer available.

An alternative interpretation of the present results is that the feedback tended to direct participants’ attention to their own movements (i.e., induced an internal focus), which has been shown to be detrimental to learning (Wulf, 2007) – and that frequent feedback (i.e., 100%) exacerbated this effect. The reduced feedback frequency (i.e., 66%) may have provided at least some relief from these constant internal focus reminders, resulting in more effective learning (see Wulf et al., 2002, 2010a). Furthermore, the constant error information may have promoted self-related thoughts or concerns, and negatively influenced participants’ perception of their capability, which can disrupt movement automaticity and hamper learning (Lewthwaite and Wulf, 2010a,b; Wulf and Lewthwaite, 2010). However, the fact that results of previous studies showed more effective learning with frequent relative to severely reduced frequencies of feedback (e.g., 20%) demonstrates the importance of the informational function of extrinsic feedback for PD patients. Slightly reduced frequencies of feedback may have the benefit of not disrupting automaticity, while providing enough information to enhance learning in this population.

Overall, the present findings demonstrate that reduced frequencies of KR can challenge and enhance learning in people with PD. We conclude that, specifically compared to 100% KR, a reduced KR frequency of 66% can result in both greater movement accuracy and movement stability in the learning of a spatial control demand task. To our knowledge, the present study is the first to demonstrate that the benefits of reduced frequencies of KR generalize to motor learning in the PD population. These results may influence the rehabilitation process and procedures used by healthcare professionals working with persons affected by PD in physical activity or exercise-based programs. Using somewhat reduced frequencies of feedback, instructors, or physical therapists may facilitate the learning/relearning of motor skills.

The task used in the present experiment can be considered different from the tasks used in some previous studies (Verschueren et al., 1997; Guadagnoli et al., 2002), since it involved spatial control demands only, without involving temporal aspects. Given that, an important direction for future studies would be to examine whether the benefits of somewhat reduced frequencies of feedback generalize to more complex tasks or situations in people with PD. Since reduced frequencies have the potential to benefit learning in this population, it would also be interesting to examine if feedback provided after effective or “good” trials instead after less effective or “poor” trials (for which benefits have been observed in several recent experiments; Badami et al., in press; Chiviacowsky and Wulf, 2007), would also benefit learning in the PD population. Furthermore, the effects of self-controlled feedback or practice schedules (for a review, see Wulf, 2007) – benefits of which have been shown in typical as well as other special populations – should be examined in participants with PD.

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**REFERENCES**

Abbruzzese, G., Trompetto, C., and Marinelli, L. (2009). The rationale for motor learning in Parkinson’s disease. Eur. J. Phys. Rehabil. Med. 45, 209–214.

Adamovich, S. V., Berkinblit, M. B., Hening, W., Sage, J., and Poizner, H. (2001). The interaction of visual and proprioceptive inputs in pointing to actual and remembered targets in Parkinson’s disease. Neuroscience 104, 1027–1041.

Badami, R., VaezMousavi, M., Wulf, G., and Namazizadeh, M. (in press). Feedback after good trials enhances intrinsic motivation. Res. Q. Exerc. Sport.

Berardelli, A. Rothwell, J. C., Thompson, P. D., and Hallett, M. (2001). Pathophysiology of bradykinesia in Parkinson’s disease. Brain 124, 2131–2146.

Chiviacowsky, S., and Wulf, G. (2007). Feedback after good trials enhances learning. Res. Q. Exerc. Sport 78, 40–47.

Contreras-Vidal, J. L., and Gold, D. R. (2004). Dynamic estimation of hand position is abnormal in Parkinson’s disease. Parkinsonism Relat. Disord. 10, 501–506.

Demirci, M., Grill, S., McShane, I., and Hallett, M. (1997). A mismatch between kinesthetic and visual perception in Parkinson’s disease. Ann. Neurol. 41, 781–788.

Fisher, B. E., Petzinger, G. M., Nixon, K., Hogg, E., Bremsen, S., Meshul, C. K., and Jakowec, M. W. (2004). Exercise-induced behavioral recovery and neuroplasticity in the 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine-lesioned mouse basal ganglia. J. Neurosci. Res. 77, 378–390.

Goetz, C. G., Poewe, W., Rascas, O. Sampaoio, C., Stebbins, G. T., Coullion, C., Giladi, N., Holloway, R. G., Moore, C. G., Wenning, G. K., Yahr, M. D., and Seidl, L. (2004). Movement disorder society task-force report on the Hoehn and Yahr staging scale: status and recommendations. Mov. Disord. 19, 1020–1028.

Guadagnoli, M. A., Leis, B., Van Gemert, A. W., and Stelmach, G. E. (2002). The relationship between knowledge of results and motor learning in Parkinsonian patients. Parkinsonism Relat. Disord. 9, 89–95.

Herman, T., Giladi, N., Gruendlenger, L., and Hausdorff, J. M. (2007). Six weeks of intensive treadmill training improves gait and quality of life in patients with Parkinson’s disease: a pilot study. Arch. Phys. Med. Rehabil. 88, 1154–1158.

Hirsch, M. A., and Farley, B. G. (2009). Exercise and neuroplasticity in persons living with Parkinson’s disease. Eur. J. Phys. Rehabil. Med. 45, 215–229.

Jankovic, J. (2008). Parkinson’s disease: clinical features and diagnosis.

www.frontiersin.org
Enhancing neuroplasticity in the basal ganglia: the role of exercise in Parkinson's disease. Mov. Disord. 25, S141–S145.

Petzinger, G. M., Walsh, J. P., Akopian, G., Hogg, E., Abernathy, A., Arevalo, P., Turnquist, P., Vuckovic, M., Fisher, B. E., Togasaki, D. M., and Jakowec, M. W. (2007). Effects of treadmill exercise on dopaminergic transmission in the 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine-lesioned mouse model of basal ganglia injury. J. Neurosci. 27, 5391–5390.

Rabin, E., Muratori, L., Sveskos, K., and Gordon, A. (2010). Tactile/proproriceptive integration during arm localization is intact in individuals with Parkinson’s disease. Neurosci. Lett. 5, 470, 38–42.

Rand, M. K., Stelmach, G. E., and Bloedel, J. R. (2000). Movement accuracy constraints in Parkinson’s disease patients. Neurepsychologia 38, 203–212.

Salmoni, A. W., Schmidt, R. A., and Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. Psychol. Bull. 95, 355–386.

Schmidt, R. A. (1991). “Frequent augmented feedback can degrade learning: evidence and interpretations,” in Tutorials in Motor Neuroscience, eds J. Requin and G. E. Stelmach (Dordrecht: Kluwer Academic Publishers), 59–75.

Schmidt, R. A., and Lee, T. D. (2005). Motor Control and Learning: A Behavioral Emphasis, 4th Edn. Champaign, IL: Human Kinetics.

Swinnen, S. P. (1996). “Information feedback for motor skill learning: a review,” in Advances in Motor Learning and Control, ed. H.N. Zelaznik (Champaign, IL: Human Kinetics), 37–66.

Tillerson, J. L., Caudle, W. M., Reveron, A. W., Schmidt, R. A., and Miller, G. W. (2003). Exercise induced behavioral recovery and attenuates neurochemical deficits in rodent models of Parkinson’s disease. Neuroscience 119, 899–911.

Verschueren, S. M., Swinnen, S. P., Dom, R., and De Weerd, W. (1997). Interlimb coordination in patients with Parkinson’s disease: motor learning deficits and the importance of augmented feedback information. Exp. Brain Res. 113, 497–508.

Winstein, C. J., and Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. J. Exp. Psychol. Learn. Mem. Cogn. 16, 677–691.

Wulf, G. (2007). Self-controlled practice enhances motor learning: implications for physiotherapy. Physiotherapy 93, 96–101.

Wulf, G., Chiviacowsky, S., Schiller, E., and Avila, L. T. G. (2010a). Frequent external-focus feedback enhances motor learning. Front. Psychol. 1:190. doi: 10.3389/fpsyg.2010.00190

Wulf, G., Shea, C., and Lewthwaite, R. (2010b). Motor skill learning and performance: a review of influential factors. Med. Educ. 44: 75–84.

Wulf, G., and Lewthwaite, R. (2010). “Effortless motor learning? An external focus of attention enhances movement effectiveness and efficiency,” in Effortless Attention: A New Perspective in Attention and Action, ed. B. Bruya (Cambridge, MA: MIT Press), 75–101.

Wulf, G., McConnel, N., Gaetner, M., and Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. J. Mot. Behav. 34, 171–182.

Wulf, G., and Schmidt, R. A. (1989). The learning of generalized motor programs: reducing the relative frequency of knowledge of results enhances memory. J. Exp. Psychol. Learn. Mem. Cogn. 15, 748–757.

Wulf, G., and Shea, C. H. (2004). “Understanding the role of augmented feedback: the good, the bad, and the ugly,” in Skill Acquisition in Sport: Research, Theory and Practice, eds A. M. Williams and N. J. Hodges (London: Routledge), 121–144.

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