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Neurorehabilitation for Parkinson's disease: Future perspectives for behavioural adaptation

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ABSTRACT

Parkinson's disease is a common neurodegenerative disorder, resulting in both motor and non-motor symptoms that significantly reduce quality of life. Treatment consists of both pharmaceutical and non-pharmaceutical treatment approaches. Neurorehabilitation is an important non-pharmaceutical treatment approach, and a prime component of this is formed by the training of behavioural adaptations that can assist patients to cope better with their motor and non-motor symptoms. Optimal delivery of neurorehabilitation requires a tailor-made, personalized approach. In this review we discuss the great potential for growth in the field of neurorehabilitation. Specifically, we will focus on four relatively new developments: visual rehabilitation (because Parkinson patients are very dependent on optimal vision); cueing delivered by wearable devices (allowing for objective, continuous, and quantitative detection of mobility problems, such that cueing can be delivered effectively in an on-demand manner – i.e., with external cues being delivered only at a time when they are needed most); exergaming (to promote compliance with exercise programs); and telemedicine (allowing for delivery of expert rehabilitation advice to the patient's own home). Evidence in these new fields is growing, based on good clinical trials, fuelling hope that state-of-the-art neurorehabilitation can make a real impact on improving the quality of life of patients affected by Parkinson's disease.

1. Introduction

Parkinson's disease (PD) is characterized by the progressive development of a wide array of motor and non-motor symptoms. The resultant disability can be alleviated only in part by pharmaceutical agents, which have only a limited effect on axial motor symptoms, and no effect on many non-motor symptoms. Moreover, pharmacotherapy is hampered by the progressive development of dose-limiting side-effects. Postural instability and freezing of gait (FOG) – brief episodes of inability to produce effective forward steps despite the intention to walk – are examples of common and disabling symptoms that respond insufficiently to medication. This commonly leads to falls, reduced mobility and diminished quality of life [1]. Fortunately, evidence is growing that neurorehabilitation approaches can offer relief of such treatment-resistant symptoms and signs, by exploiting behavioural adaptations that bypass the defective motor circuitries.

2. Illustrative case

As an example we introduce an 82-year old man with PD who developed severe FOG. He had successfully used auditory cues to improve his FOG for several years, but over time he had started to notice that these cues began losing their effectiveness. Being a former engineer, he invented his own new cueing strategy, using various types of 3D visual cues that he incorporated in and around his house, with robust effects. This included e.g. wooden bars nailed to the floor, which forced him to consciously step over these obstacles. Surprisingly, these beneficial effects were totally absent

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when using 2D visual cues, such as pieces of white tape pasted onto the floor [2]. This example underscores several messages: (a) the potential effectiveness of behavioural adaptations, as an important component of neurorehabilitation for patients with PD [3]; (b) the creativity of patients in finding these solutions themselves; (c) the need for an individually tailored approach; and (d) the need to have a good vision (otherwise the visual cues would go by unnoticed).

3. Neurorehabilitation for Parkinson patients

Neurorehabilitation, including behavioural adaptations, can play an important role in the management of PD, by helping patients to deal with the decline in functioning while optimizing participation and quality of life. Donaghy [4] defined neurorehabilitation as '*a process that aims to optimize a person's participation in society and sense of well-being*'. This broad definition highlights the scope of the domain of neurorehabilitation; it offers a wide range of therapies that are potentially helpful for many aspects of PD. The focus is on the patient as a person; the goals usually relate not only to disease symptoms, but also to social functioning and well-being [4]. Compared to medical management (pharmacotherapy and, to a lesser extent, neurosurgery), neurorehabilitation has historically played a relatively modest role in the management of PD. However, this field has recently gone through major developments; the scientific evidence on its' effectiveness is increasing [5], and neurorehabilitation is increasingly being integrated in the multidisciplinary care pathways for patients with PD [6]. Moreover, interesting new treatment modalities are arising, with positive initial experience in clinical studies. Many professional disciplines are involved in neurorehabilitation, including e.g. physiotherapists, occupational therapists and speech-language therapists; all these professionals need to integrate their own specific treatment contribution with each other, and align this with medical management [7]. This review does not aim to review all aspects of neurorehabilitation in PD. Instead, we focus on several promising new perspectives (Fig. 1). Specifically, we will first address an important, but easily overlooked requirement for effective neurorehabilitation: optimal visual functioning. Next, we will describe three relatively new emerging technological developments that can be integrated into neurorehabilitation: cueing via wearables, exergaming and telemedicine.

4. Visual impairment

Treatment of visual impairments is not traditionally part of neurorehabilitation. Ophthalmologic problems are, however, very common in PD [8]. Optimal vision is an important requirement for mobility for any person, but in particular for patients with PD who are exceptionally dependent upon their vision to compensate for defects in their automatic motor behaviour, e.g. gait impairments (take visual cueing as an example). Screening for (and dedicated treatment of) visual impairment therefore deserves careful attention during neurorehabilitation. Indeed, ophthalmologic problems negatively affect walking, mobility, reading, driving, social participation, and quality of life [9]. Moreover, PD patients with visual problems have higher fall rates [10]. Importantly, numerous visual problems can arise at many levels of the visual pathway in patients with PD. This includes e.g. dry eyes, ocular motor disturbances, impaired colour and contrast vision, and visual hallucinations [8,11–13]. Both clinicians and patients are mostly unaware of these visual impairments. Obviously, rehabilitation professionals are not equipped to diagnose or treat the whole gamut of visual impairments. However, screening for presence of gross visual or oculomotor abnormalities should always be part of the rehabilitation approach. Sometimes small adjustments can be recommended that may already make a huge difference. Prescription of base in prisms by an ophthalmologist or optometrist can, for example, help to overcome convergence insufficiency; enabling patients to see more depth, which helps them in daily life with walking the stairs and seeing for example 3D visual cues. Other problems are more complex and require treatment by an ophthalmologist. We therefore feel that close cooperation with an ophthalmologist is needed during neurorehabilitation in PD.

We will illustrate the potential effectiveness of screening for (and treatment of) visual impairments in neurorehabilitation by introducing three frequently occurring visual problems. First, PD patients often blink less frequently. This can cause dry eyes and, in turn, result in blurry vision, pain, a sandy/gritty feeling in the eyes and intermittent tearing. This is troublesome for patients, and visual acuity can be endangered due to the blurring. With a Schirmer's test, a brief test using a thin paper stroke that absorbs the tear fluid, it is possible to evaluate the amount of tear production of a patient. If dry eyes exist, artificial tears and explanation about blinking can reduce complaints and improve visual functioning, making it easier to see sharp and avoid pain and irritation [8,9].

A second visual problem that limits both patients' mobility and safety is impaired contrast sensitivity and colour discrimination. This reduces the patient's ability to see in situations with low light, and makes driving, walking or cycling in darkness more dangerous. Non-invasive testing with specific charts and colour arranging tests can identify these problems. Special contrast enhancing glasses exist that improve these impairments and can be prescribed by an ophthalmologist or optometrist. Problems with reading in the dark, e.g. on a computer, tablet or smartphone, can quite easily be improved by changing settings that enable patients to work with different coloured backgrounds and font types [8,9].

Third, like mentioned before, PD patients often have convergence insufficiency and oculomotor troubles, so both eyes cannot fully cooperate to see depth and follow what a patient wants to see. This makes it difficult to read for example a newspaper or labels. Patients are sometimes unable to see the outer lines of the text they read. An ophthalmologist or optometrist can prescribe base-in prisms that can help to solve convergence insufficiency.

In summary, although visual impairments cannot necessarily be solved by neurorehabilitation, allied health professionals are important in screening for visual impairments that disable PD patients in daily life. Together with ophthalmologists, some visual problems can be solved or improved, making rehabilitation more effective. In addition, allied health professionals can practice with patients how to use visual assistive devices to improve functioning in daily life.

5. Cueing via wearables

External auditory, visual or tactile cues like a metronome beat or striped bars on the floor are established non-pharmaceutical methods to overcome gait difficulties by bypassing deficient activation of the basal ganglia/supplementary motor area circuit [13]. Interestingly, improvements in gait and mobility – achieved in a cueing training program delivered at home – decreased considerably within weeks after discontinuing the training program [14], stressing the need for permanent cueing devices that provide external cues during, but not interfering with, daily life. Cues sometimes lose their effectiveness over time, as was illustrated by the case history in the Introduction. This might be overcome by only offering cues 'on demand' or by adjusting the nature of the cues when the effect is wearing off. Different cues appear to be effective in, and preferred by, different patients, underscoring the need for personalized care [14,15]. There is a need for portable,

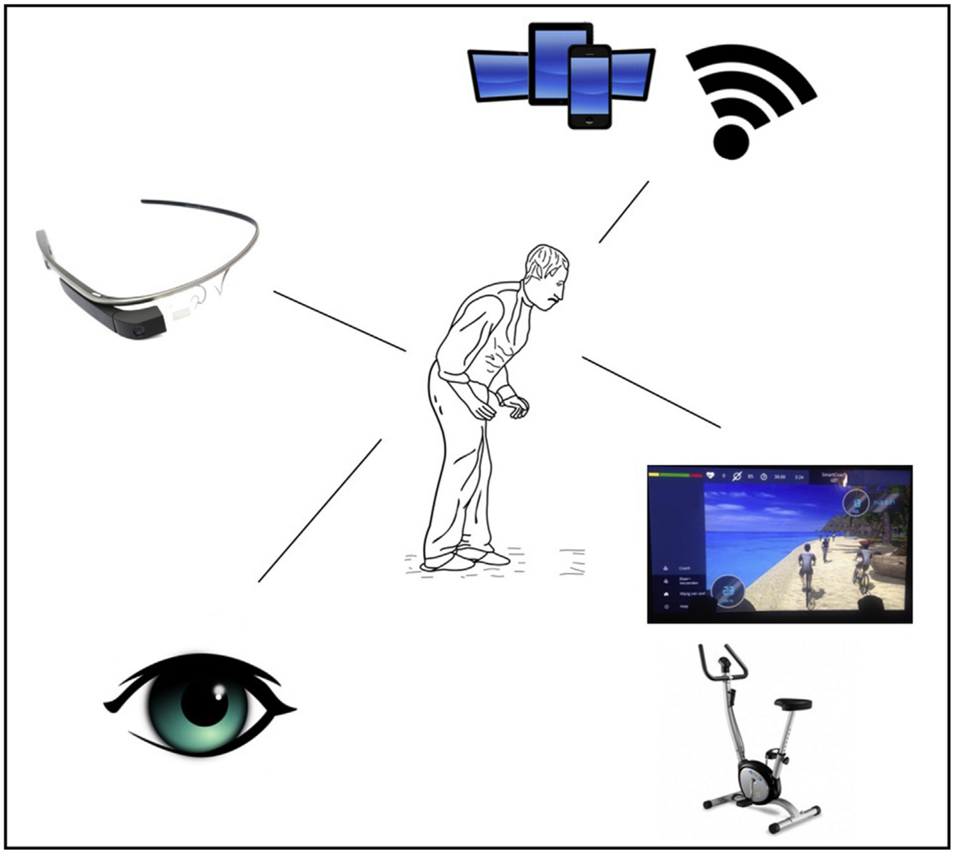

Fig. 1. Overview of promising new treatment modalities that can contribute to optimal and personalized delivery of neurorehabilitation.

inconspicuous, user-friendly, cost efficient devices providing personalized cues 'on demand' in daily life situations. Such devices are currently being developed, incorporating new technologies. Walking sticks [16,17] and rolling walkers [18] projecting a laser line on the floor have shown efficacy in overcoming FOG and reducing falls in some, but not all patients [1,16,17]. Light emitting diodes (LEDs) [15,19] and an auditory device [20] incorporated in glasses are effective in improving gait parameters in laboratory settings, but the practical applicability in the home setting has not yet been established. Wearable 'mini computers' in the form of smart glasses can augment reality, overlaying pertinent information (like visual cues) on top of the users' visual field. These devices may respond to voice or gesture commands, but even more importantly, can potentially also respond to automatically sensed episodes of FOG or real-time object recognition, thereby offering cues at a time when they are needed most. The type, appearance and frequency of cues should be adapted to each patient's personal needs. Smart glasses can also support other neurorehabilitation applications, e.g. by supporting visually impaired patients through contrast-enhancing functions and magnification of view [21]. In order to provide cues 'on demand', detection strategies are being developed which reliably detect (preferably early markers of) episodes of FOG [1]. In a user requirements survey, PD patients responded enthusiastically to the idea of smart glasses and assistive technology to facilitate daily living activities. However, respondents were concerned about cost, appearance, efficacy and potential side effects [21]. The next generation of devices for FOG detection and provision of cues should be developed together with patients and be tested thoroughly on efficacy, side effects and, cost-effectiveness. As such, these devices hold great promise for becoming personalized, patient-tailored neurorehabilitation assistants in PD.

6. Gaming

Gaming, e.g. the use of videogames and virtual reality, is a relatively new aspect of training, not only in PD, but also for other patient populations like stroke, dementia or, cancer [22]. Gaming has a number of advantages compared to traditional neurorehabilitation: training can be aimed very specifically on e.g. balance, endurance or cognition, exercises are (or gradually become) more challenging, it is often perceived as enjoyable which increases long term adherence, a competitive element can be a motivating factor, and, gaming can in many cases be performed in the home situation which increases the frequency of training [5,22].

The two main goals of gaming include: gaming to promote compliance to another intervention, like exercise (this combination has been termed exergaming); or to offer a new treatment modality in its own right (e.g. gaming to enhance cognition and motor functioning).

6.1. Exergaming

Adding cognitive elements to physical training has recently been suggested to be beneficial for PD patients [23]. Gaming usually requires physical and cognitive capacities and gaming may also result in both motor- and cognitive improvements. In addition to the previously mentioned advantages of gaming, incorporating goal-based training with aerobic exercise potentially also enhances experience-dependent neuroplasticity and may improve both cognitive and automatic components of motor control [23]. Gaming is extremely suitable for adding cognitive elements to exercise.

Games using for example virtual dancing and virtual bicycling [24] are examples of new interventions being studied [5,25].

6.2. Gaming as a new treatment modality

Rehabilitation programs using gaming can also be primarily physical or cognitive in nature [5]. Games are being used to offer gait and balance training, for example by virtual cues and obstacles on a treadmill [5,24].

Other games are purely cognitive and do not require movements or physical capacities. A recent study compared a pure cognitive game on a computer with a motion-controlled sports game (Nintendo Wii sports) [26]. Specifically, the cognitive training focused on multiple domains including attention, working memory and executive functioning. The results showed that both training approaches improved cognition equally, but the physical training afforded greater improvements in attention. Which is interesting because of the potential additional motor benefits of performing a physical game.

Gaming obviously also introduces several challenges. Safety is a major issue when advising a physical game in the home situation; this should be assessed and supervised carefully by a professional. Also, the costs of gaming devices or equipment are a concern. Furthermore, games should be tailored specifically to the needs and capacities of PD patients. Taken together, the perceived benefits of gaming on both cognition and motor functioning warrant further exploration. Certainly, research in this field represents an exciting new domain of neurorehabilitation.

7. Telemedicine

Use of telecommunication technology to deliver care at a distance is a potentially cost-effective and efficient upcoming phenomenon that can be used in neurorehabilitation [27]. Healthcare access is currently limited for many patients worldwide, for several reasons. Examples include understaffing and an uneven distribution of highly specialized clinicians. Also, disabled patients have difficulty travelling (long) distances to the clinic. Certainly for rehabilitation, many PD patients are required to visit an (outpatient) clinic regularly. Delivering care at a distance could offer a solution for the growing number of PD patients that need treatment by experts, and for a long period of time [27].

The advantages of using telemedicine are not just restricted to reducing travelling time. It also gives patients the opportunity to integrate training or practice into their daily life circumstances. Rehabilitation at a distance, like physiotherapy and speech therapy at home, can increase the maintenance of effect. Furthermore, gaming elements, as described above, can also be integrated into remote care. An excellent example is the treatment offered in an ongoing randomized controlled trial [24] where patients perform an aerobic exercise training at home. Training is performed on a stationary bicycle that is equipped with gaming elements; training intensity is adjusted automatically to the patients' heart rate. Progress is monitored from a distance by the research team, and is also made accessible to the patient on an iPad app. A personal coach (physiotherapist) can access the progress booked in each training session through an online application and has telephone contact with the patient every fortnight to adjust the training frequency or intensity when necessary.

Another emerging field is the remote monitoring of daily functioning using wearable sensors. For example, smartphone apps can be used to monitor symptoms (e.g. voice, gait, finger tapping) and behaviour (e.g. physical activity) longitudinally on a day-by-day basis [28]. Gathering such data with a smartphone application seems feasible [28,29], although the validity of the findings remains an issue. In the future, real-life information gathered by wearable sensors may be used by clinicians in making better informed management decisions.

Online or remote consultation of professionals has been explored using virtual house calls done by a PD specialist. This method proved to be feasible, both to patients and clinicians, while cost-effectiveness will be determined in an ongoing study [28,30]. Most patients would prefer to get a well-balanced combination of real life and telemedicine contact [29–31]. In Canada (the Ontario Telemedicine Network) and the Netherlands (ParkinsonNet approach), advanced systems already use telemedicine successfully in daily practice [7,27]. Important limitations in implementing telemedicine include the limited reimbursement for remote care, the costs of high-quality telecommunication equipment and privacy issues considering data-transfer of patients. Ongoing technological advances, however, will offer ample opportunity to further utilize telemedicine in neurorehabilitation.

8. Discussion

We have described several emerging developments in the field of neurorehabilitation. We have highlighted the importance of good vision, as an essential requirement for optimal neurorehabilitation, and we have advocated the integration of ophthalmologists into the multidisciplinary treatment team in PD. A lot of work, however, remains to be done. The exact pathophysiological mechanisms underlying visual problems in PD remain unknown, and optimal screening and management protocols must be determined. Other work should identify the optimal behavioural adaptations that can be applied in rehabilitation to compensate for disturbed vision. Additionally, we have reviewed several promising technological advances that may support both patients and clinicians in their desire for delivery of more personalized care, tailored to actual needs as they are perceived in the home situation. We discussed some interesting developments, including wearable cueing methods (like those provided by smart glasses), gaming techniques and telemedicine approaches.

The biggest challenge remains to gather robust scientific evidence on the (cost-) effectiveness of these new rehabilitation approaches. It has, for example, proved difficult to select appropriate outcome measures that are capable of measuring all clinically relevant changes in a heterogeneous population that received a tailor-made, personalized (and therefore also heterogeneous) intervention. The question is whether traditional study designs such as RCTs are the only way to gather the required evidence, or whether e.g. real-life observational studies in large and unselected populations (with long follow-up) might also create useful new insights. Finally, more works needs to determine the adequate “dosage” of neurorehabilitation. Pending these new studies, the good news for patients is that various exciting new developments are appearing on the horizon, and that the evidence-base for these novel interventions is growing [5], creating realistic perspectives for greater independence and less disability in the foreseeable future.

Conflicts of interest

The authors declare no conflicts of interest.

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