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Validation of an environmentally-friendly and affordable cardboard 9-hole peg test

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ABSTRACT

Background: In multiple sclerosis (MS) upper limb neurological impairments, are an important driver of disability and handicap. The gold standard for assessing upper limb function is the 9-hole peg test (9HPT). One disadvantage of the current plastic version is its price, which prevents its widespread use as a self-monitoring tool by the MS community.

Objective: To develop and validate an affordable cardboard version of 9HPT for patients to self-monitor upper limb function at home. The aim is not to replace the plastic version, which would stay the gold standard in MS centers.

Methods: We enrolled 177 volunteers, 68 healthy controls and 109 people with MS (pwMS) at varying stages of their disease. Volunteers performed two trials of the 9HPT with their dominant hand and two with their non-dominant hand using both plastic 9HPT and cardboard 9HPT. The primary comparison parameter was the time needed to perform the task.

Results: The mean score for the cardboard 9HPT was 24.58 (SEM 1.54 s) seconds compared to 26.03 (SEM 1.44 s) seconds for the plastic 9HPT ($p = 0.007$). However, the two versions of the tests correlated very strongly, $r = 0.96$ ($p < 0.001$). The coefficient of variation, repeat-repeat testing, showed less variability with the cardboard version than in the plastic one with 10% and 14%, respectively. Two-thirds of pwMS preferred using the cardboard version.

Conclusion: This study demonstrates that the cardboard version is at least equivalent to the plastic version of the test with arguably better design attributes making it the preferred option for self-monitoring.

1. Introduction

Multiple sclerosis (MS) is a chronic immune-mediated and degenerative disease of the central nervous system (Barnett and Prineas, 2004; Compston and Coles, 2008).

Among the symptoms observed in PwMS, upper limb (UL) dysfunction are of particular importance. Together with difficulties walking, fatigue, and cognitive deficits, UL dysfunction is among the most common neurological problem in pwMS (Kister et al., 2013).

In MS, the 9-hole peg test (9HPT) has been standardised and validated (Schwid et al., 1997). Changes in the 9HPT scores have been found to be closely related to disabilities that impact on activities of daily living (Kragt et al., 2006). Importantly the 9HPT interrogates the functioning of several neurological systems, i.e. Power, visual attention, depth perception, sensory perception and coordination. The 9HPT has become de facto the gold standard outcome measure for assessing, and monitoring, UL function in MS.

The current 9HPT plastic version is expensive, not environmentally friendly and the plastic pegs are slippery. The current commercial test kit is only available as a "plastic" version to allow disinfection between subjects, costing approximately $55 online (Amazon, last accessed 14/03/2017).

As part of a PPI (patient public involvement) programme, with the aim of empowering people to monitor their disease using validated outcome measures, we designed a cheap and environmentally friendly version of the 9HPT using cardboard and commercially available

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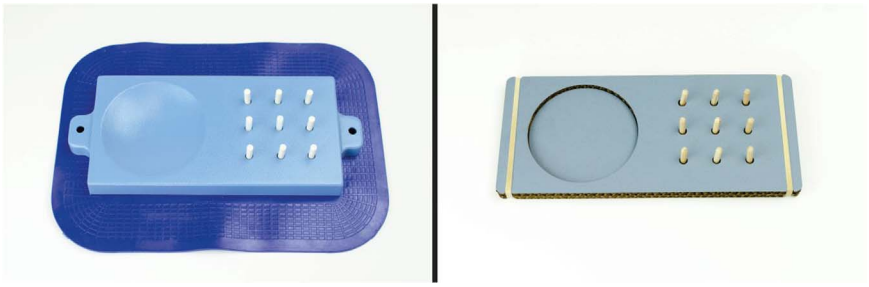

Fig. 1. Cardboard and plastic 9HPT. The original plastic 9HPT on the left and our new cardboard 9HPT on the right. See http://www.clinicspeak.com/9-hole-peg-test/ for more information on how to order or manufacture a cardboard 9HPT, how to replace lost pegs, an instruction video and how to record your times.

wooden dowel pegs (Fig. 1) and mass-produced it. In this study, we validated our 9HPT version by comparison of the scores collected using the cardboard version with the scores collected using the 'plastic version'.

2. Methods

2.1. Volunteers

Between August and September 2016, 177 male and female subjects, of which 68 were normal controls, and 109 pwMS, mean age 46 years [range = 20–84]), volunteered to validate the 9HPT. Volunteers were recruited in day care unit, clinics, research day and conferences. The only inclusion criteria was being diagnosed with MS. The 9HPT validation did not meet the NHS definition of research hence IRB approval was not required. Volunteers performed two trials of the 9HPT with their dominant hand and two with their non-dominant hand using both the plastic 9HPT and the cardboard 9HPT. In the MS group, 4 patients did not manage to use their dominant hand because of pain, hence these volunteers were excluded from the study. The 9HPT was first performed with the dominant hand and subsequently with the non-dominant hand, according to the standardised instructions given as part of the MSFC (MS functional composite)(Ontaneda et al., 2012). Cardboard and plastic tests were performed strictly one after the other. We consecutively alternated the starting test, according to the patient's arrival order in the 9HPT stand, to prevent a systematic learning effect affecting the performance of the second test.

The primary comparison parameter was the time needed to perform the task. Each task being composed of two attempts, with an average calculated for each volunteer. Once the tests were completed, 87 of the 106 pwMS, were asked which version of the 9HPT they preferred using the most (cardboard or the plastic).

2.2. Statistical analysis

Excel 2016 was used to perform all the statistics. A Q-Q plot tested whether the sample population was normally distributed. The overall distribution of the 9HPT times were positively skewed by some very slow times. Therefore, the continuous variables were converted to log scale. Results are reported as mean ± standard deviation of the mean (SD) and were represented in the form of a box-and-whisker plot (see Table 1). Paired *t*-Test p values < 0.05 were performed to explore whether the two groups (cardboard and plastic) are equivalent. The two-tailed p-value are indicated to confirm the significance of the results. Spearman's rank correlation was used to estimate correlations between the cardboard and plastic user groups in order to confirm the equivalence of the two 9HPT versions. Finally, the coefficient of variation (CV) of both group was assessed to explore differences between them.

3. Results

A total of 177 people participated in the study, 121 females (68%) and 56 males (32%).

Volunteers were allocated into (see Table 2) Group 1 that contained 68 healthy control (HC) people, while Group 2 was composed of 109 pwMS, 71 females (65%). The pwMS were at varying stages of their disease. Results from 4 volunteers from Group 2 were excluded as they could not use their dominant hand because of pain.

We focused exclusively on the scores obtained with the dominant hand (173 patients).

When all the volunteers were considered together, the mean score for the cardboard 9HPT (c9HPT) was 24.58 s (SEM 1.54 s) compared to 26.03 s (SEM 1.44 s) for the plastic 9HPT (p9HPT) ($p = 0.007$).

In the HC the mean results were 18.35 ± 0.9 s for the c9HPT versus 19.19 ± 0.9 for the p9HPT ($p < 0.001$). In the pwMS group mean for the c9HPT was 28.61 ± 2.38 versus 30.47 ± 2.19 s for the p9HPT ($p = 0.03$).

The Q-Q plot test showed that the population distribution was not normal. In the Cardboard group patients perform the test with a minimum at 12.66 s, the median was 19.39 s and a maximum of 229 s. The IQR was 9 s. In the Plastic group the minimum was 12.85 s, the median was 20.78 s and the maximum was 177.58 s with an IQR = 8.5 s.

Although the performance of the c9HPT was slightly quicker than the p9HPT the results of the two tests correlated very strongly. Overall the correlation (r) taken with a logarithmic conversion of the mean was 0.96 ($p < 0.001$), 0.94 for the HCs ($p < 0.001$) and 0.95 for the pwMS ($p < 0.001$) (Fig. 2).

The coefficient of variation within each group was assessed to explore differences between the two 9HPT versions. The CV is the result of the intra-subject variation between the first and the second attempt. In this specific comparison, 8 volunteers from Group 2 were excluded because they were unable to perform two attempts in a row.

When HC and pwMS were considered together, the c9HPT group performed both attempts with a CV of 10% compared to the p9HPT group where the CV was 14%.

This difference is probably due to fewer slower times from dropping

Table 1
Summary results of the cardboard (c9HPT) and plastic 9HPT (p9HPT).

	Combined c9HPT	Combined p9HPT	Dominant c9HPT	Dominant p9HPT	Non-dominant c9HPT	Non-Dominant p9HPT
Overall group	23.13 (n = 109)	24.88 (n = 108)	24.58 (n = 173)	26.03 (n = 173)	23.83 (n = 112)	25.22 (n = 111)
Heath Controls	19.52 (n = 43)	20.39 (n = 43)	18.35 (n = 68)	19.19 (n = 68)	20.23 (n = 43)	20.76 (n = 43)
People with MS	25.48 (n = 66)	27.85 (n = 65)	28.61 (n = 105)	30.47 (n = 105)	26.08 (n = 69)	28.04 (n = 68)

Table 2
Descriptive data.

	Healthy control (n = 68)	pwMS (n = 109)
Sex	18 males (26%) 50 females (74%)	71 females (65%) 38 males (35%)
Mean age	41 ± 16.12	49 ± 12.95
Dominant hand	60 right-handed (88%), 6 left handed (9%) 2 ambidextrous (3%).	82 right-handed (75%), 19 left-handed (17.5%) 5 ambidextrous (4.5%), 3 missing (3%).

the pegs or displacing them from the bowl. This indicate a smaller variability with the cardboard version.

Overall 58 (66.7%) of pwMS preferred the c9HPT, whereas only 25 (28.7%) of them preferred the p9HPT and four (4.6%) volunteers rating them equivalent.

4. Discussion

Among the symptoms observed in pwMS, upper limb (UL) dysfunction are of particular importance. Together with difficulties walking, fatigue, and cognitive deficits, upper limb dysfunction is among the most common neurological problem in pwMS (Kister et al., 2013). This assessment was confirmed when we approached pwMS on the perceived importance of arm function. In fact, 95% of pwMS considered their UL function to be more important than their lower limb function. The latter is not surprising considering how important arm and hand function are in relation to performing most activities of daily living.

Recent clinical studies renewed the interest in the assessment of upper limb function in MS (Lamers et al., 2016). More than 50% of 205 pwMS reported impairments, or restrictions, related to upper limb function, which was more common in people with progressive forms of the disease (Holper et al., 2010). In another study, 76% of 219 pwMS had problems with manual dexterity (Johansson et al., 2007). Importantly, manual dexterity is an important predictor of overall physical activity and participation in the general population (Kierkegaard et al., 2012). In people with walking difficulties and particularly those who need a walking aid (EDSS > = 6.0), several DMTs (disease modifying therapies) are more effective in protecting hand function than to lower limb function. Indeed, the data from the Natalizumab in secondary progressive MS, or ASCEND trial (NCT01416181), provide evidence that upper limb deterioration can be halted in pwMS, whilst lower limb function continued to deteriorate. The differential effect of DMTs on upper limb, compared to lower limb, function may be explained by therapeutic lag hypotheses (Tur et al., 2011; Sastre-Garriga et al., 2015). As 55% of cortico-spinal tracts terminate at cervical spinal cord level (Patestas and Gartner, 2006), axons destined to the lower limbs are more vulnerable due to their smaller number and longer length. This difference of neuronal reserve capacity between upper and lower limbs allow us to explain firstly that the disability in pwMS began mostly with the lower limbs and secondly that the upper limbs are the first to be improved under DMT.

A post hoc analysis of the SPECTRIMS (Cohen et al., 2002; Leary et al., 2003) and PROMISE (Wolinsky et al., 2007) (Giovannoni and Sormani, ECTRIMS 2016 London) confirmed that the Interferon and Glatiramer acetate did have a delayed effect by reducing the risk of progression from approximately 35%. This effect became evident only after 2–2.5 years from treatment start. Moreover, the delay in treatment effect seemed to be directly related to the level of disability.

The 9HPT has become de facto the gold standard outcome measure for assessing, and monitoring, upper limb function in MS, thwarting the Scripps Neurological Rating Scale (Carpinella et al., 2014; Sipe et al., 1984; Carpinella et al., 2014), Fugl-Meyer Assessment, Action Research Arm Test, Box & Block Test (Platz et al., 2005), TEMPA (Feys et al., 2002), and Jebsen-Taylor Test (Jebsen et al., 1969).

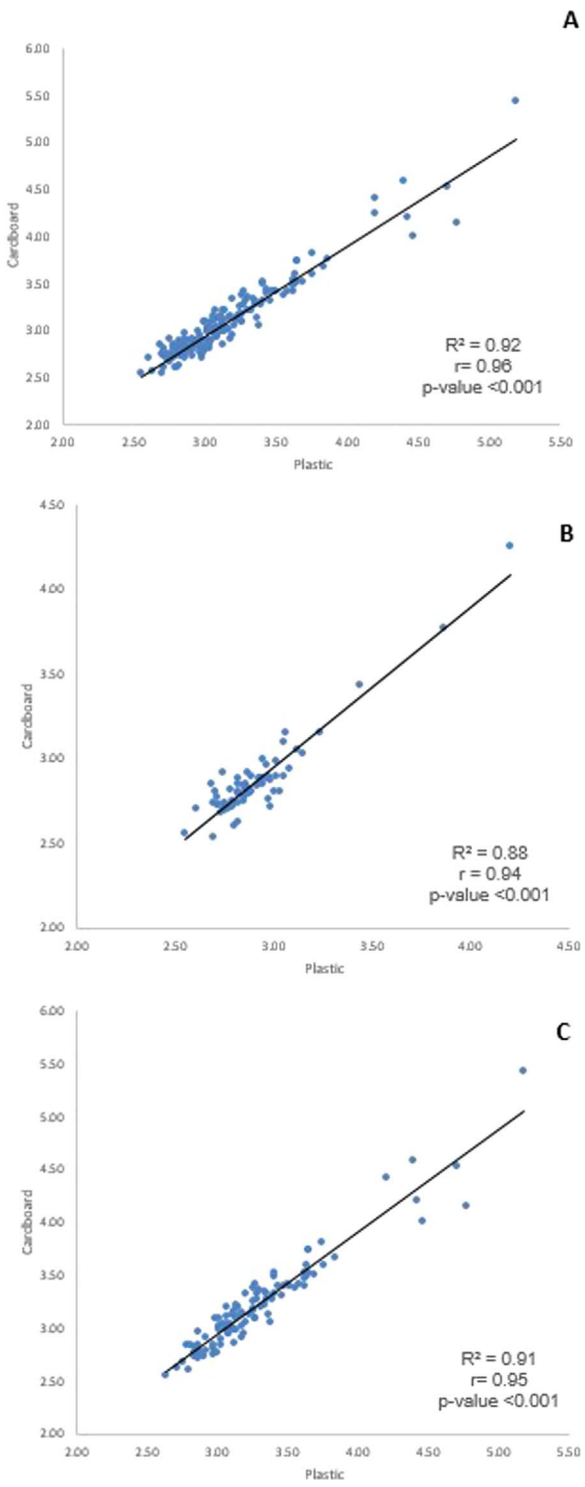

Fig. 2. A: Scatter plots comparing the performance of all the patients for the c9HPT versus the p9HPT (log conversion of the mean). B: Scatter plots comparing the performance of healthy controls for the c9HPT versus the p9HPT (log conversion of the mean). C: Scatter plots comparing the performance of patients with MS for the c9HPT versus the p9HPT (log conversion of the mean).

We developed in collaboration with a design agency a 9HPT out of cardboard.

Our results show a strong correlation in performance between cardboard (c9HPT) and plastic (p9HPT) versions with a mean correlation coefficient of 0.96 ($p < 0.001$), which indicates at least an equivalence of both 9HPT versions. Secondly, the overall mean time to

perform the test was slightly quicker in the c9HPT cohort 24.58 s (SEM 1.54 s) compared to 26.03 s (SEM 1.44 s). In addition, the coefficient of variation is lower in the c9HPT cohort, 10% vs 14%, illustrating a lower variability when the same patient performs the same test twice a few minutes apart. Finally, the c9HPT was preferred by the majority of study volunteers (66.7%).

We think this relates to specific design features of the two forms of the 9HPT. Firstly, the wooden dowel pegs are rigid and easier to pick-up and grip than the plastic pegs, which are smooth, slippery and more difficult to manipulate. Although not captured in this study it is clear that volunteers dropped fewer wooden than plastic pegs when performing the tests.

Another design feature, or fault, that distinguishes the two versions of the test is that the bowl that holds the pegs in the plastic version has a gradual slope rather than a sharp ridge. The gradual slope of the peg bowl and the slippery quality of plastic, compared to cardboard bowl, frequently results in plastic pegs being pushed out of the bowl and onto the table during the performance of the 9HPT. These design features almost certainly explain why performance of the cardboard 9HPT is superior to the plastic 9HPT; not only are time on average quicker, but the coefficient of variation is smaller. Both of these are almost certainly driven by more frequent dropping of pegs with the plastic version.

Other design features that differentiate the cardboard from the plastic version of the 9HPT is that it is cheaper to manufacture, it is made from recyclable materials and it is much lighter and hence easier and cheaper to transport and post. The cardboard version, however, cannot be easily wiped down and sterilized and hence is more suitable for single-users, which is what it has been designed for.

We have therefore achieved our primary aim to develop and validate an affordable 9HPT for pwMS to self-monitor their upper limb function. This study demonstrates that it is at least equivalent to the plastic version of test with arguably better design attributes. (Fig. 3) However, the aim is not to replace the plastic version, which will keep his significance in MS centers, as it allows a repeat use for different patients, whereas the cardboard version is specifically dedicated to self-monitoring.

Now that the c9HPT has been validated, we plan to assess whether or not it can be used reliably by pwMS to self-monitor the impact of MS on their upper limb function. Self-monitoring of neurological function, using a validated and accepted outcome measures could potentially have several benefits. A remote self-assessed 9HPT could potentially be used in pragmatic web-based asynchronous clinical trials, either to establish whether pwMS are eligible for enrollment into a trial, or as an outcome measure in the trial, i.e. for documenting change in neurological function over time. We also envisage self-assessed disability progression being used as part of the assessment for confirming eligibility for emerging treatments for progressive forms of MS. Almost all contemporary progressive trials require evidence of recent progression in disability, it is therefore conceivable that documentation of progression may be required by payers and/or regulators as part of the eligibility criteria or marketing authorization of the particular treatment.

Study funding

Supported by Biogen, UK, for an unrestricted educational grant to develop, design, manufacture and test the cardboard version of the 9HPT.

Conflicts of interest

Nicolas Dubuisson is an ECTRIMS fellow, which is unrelated to the contents of this publication.

Angelika Bauer reports no disclosures.

Mark Buckley reports no disclosures.

Rich Gilbert reports no disclosures.

Adam Paterson reports no disclosures.

Monica Marta has received honoraria and travel costs from Genzyme, AbbVie and Novartis, unrelated to the context of this publication.

Sharmilee Gnanapavan has received honoraria for advisory boards and presentations from Genzyme and Novartis and travel support from Genzyme, Novartis and Teva. SG has received grant funding from Genzyme, which is unrelated to the contents of this publication.

Benjamin Turner: has received travel grants and consultant fees for attending advisory boards from Biogen-Idec, TEVA, Merk-Serono, Novartis and Genzyme.

David Baker is a founder and consultant to Canbex therapeutics and has received research funds from Canbex therapeutics, Sanofi-Genzyme and Takeda in the past 3 years.

Gavin Giovannoni has received compensation for participating on Advisory Boards in relation to clinical trial design, trial steering committees and data and safety monitoring committees from: Abbvie, Bayer-Schering Healthcare, Biogen-Idec, Eisai, Elan, Fiveprime, Genzyme, Genentech, GSK, GW Pharma, Ironwood, Merck-Serono, Novartis, Pfizer, Roche, Sanofi-Aventis, Synthon BV, Teva, UCB Pharma and Vertex Pharmaceuticals.

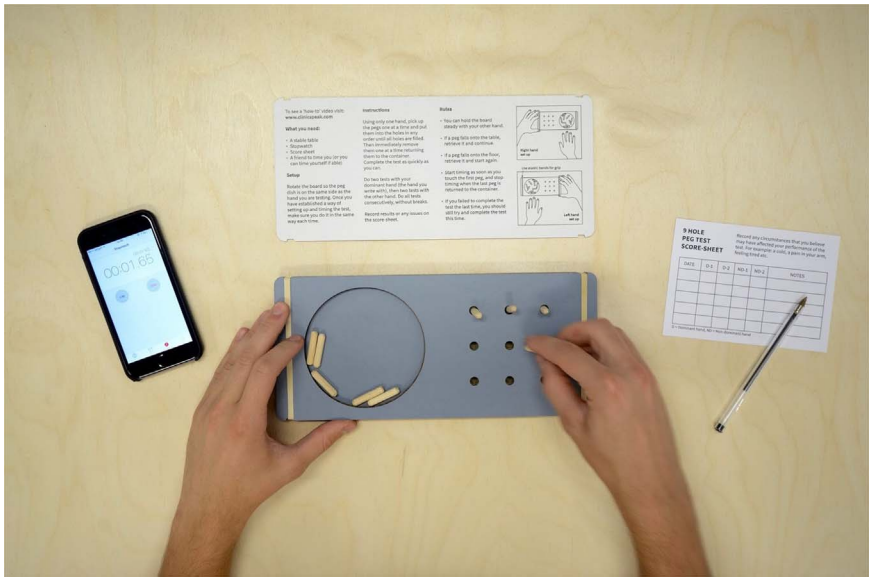

Fig. 3. Material needed to realise a 9-HPT. Photograph of how the cardboard 9HPT can be used for self-monitoring with instructions, a sheet to record times and device to record the time.

Klaus Schmierer has received speaking honoraria from and/or served on advisory boards for Biogen, Merck-Serono, Merck Inc, Novartis, Roche, and Teva, support for attending international conferences by Genzyme and Novartis, and has been a PI on studies sponsored by Novartis, Roche, Teva and Medday. Through KS Queen Mary University of London received non-promotional educational grants from Novartis.

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