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Clinical relevance of low serum vitamin B12 concentrations in older people: the Banbury B12 study

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Abstract

Background: low vitamin B12 concentrations are common in older people, but the clinical relevance of biochemical evidence of vitamin B12 deficiency in the absence of anaemia is uncertain.
Objective: to examine associations of cognitive impairment, depression and neuropathy with blood measurements of vitamin B12 and folate status in older people.
Design: cross-sectional study in general practice in Banbury, England.
Participants: a total of 1,000 individuals aged 75 years or older living in the community.
Results: low vitamin B12 concentrations were identified in 13% of older people and were associated with memory impairment and depression. After adjustment for age, sex and smoking, individuals with vitamin B12 or holotranscobalamin (holoTC) in the bottom compared with top quartiles had a 2-fold risk (OR = 2.17; 95% CI 1.11–4.27) and a 3-fold risk (OR = 3.02; 95% CI 1.31–6.98) of cognitive impairment, respectively. Low vitamin B12 status was also associated with missing ankle tendon jerks but not with depression. Treatment with vitamin B12 for 3 months corrected the biochemical abnormalities but had no effect on any of the clinical measurements.
Conclusions: low vitamin B12 concentrations are associated with cognitive impairment and missing ankle tendon jerks in older people in the absence of anaemia. Large-scale trials of vitamin B12 supplementation are required to assess the clinical significance of these associations.

Keywords: *vitamin B12, cognitive impairment, depression, neuropathy*

Introduction

Low serum vitamin B12 concentrations have been reported in about 10% of older people, and the prevalence increases with age from around 5% at age 65 years to 20% at age 85 years [1–3]. In older people, individuals presenting with low vitamin B12 concentrations rarely have the classical features of macrocytic anaemia and neuropathy [4]. More commonly,

such individuals present with non-specific symptoms of fatigue and cognitive impairment that can be attributed to 'old age'. Some of the uncertainty about the importance of vitamin B12 deficiency relates to the limitations of the standard vitamin B12 assays. Low serum vitamin B12 concentrations do not accurately reflect intracellular vitamin B12 concentrations, and blood levels of homocysteine (tHcy) or methylmalonic acid (MMA) are believed to be more reliable indicators of intracellular vitamin B12 status [2]. About 80% of vitamin B12 circulating in blood is biologically unavailable for most cells; the rest comprises holotranscobalamin (holoTC), which is the part of serum vitamin B12 bound to transcobalamin, the protein that delivers the vitamin to cells in the body [5] and is easily measured [6].

In a primary care setting, the indications for the measurement of serum vitamin B12 concentrations typically include a history suggestive of pernicious anaemia, poor nutritional status, cognitive impairment, dementia, neuropathy or malabsorption. But although vitamin B12 supplementation is clearly indicated for the treatment of pernicious anaemia or malabsorption associated with low vitamin B12, the relevance of supplementation with vitamin B12 (and other B vitamins) for the treatment of cognitive impairment is uncertain. Because poor nutritional status is common among older people with dementia, as is age-associated decline in the intestinal absorption of vitamin B12, it is not surprising that a substantial proportion of older people with dementia have low serum vitamin B12 concentrations. Nevertheless, it is widely believed that vitamin B12 deficiency accounts for only a small fraction of the reversible causes of dementia in older people [7, 8]. The aim of this study was to assess if objective evidence for cognitive impairment, depression and peripheral neuropathy was associated with low vitamin B12 concentrations and related markers of vitamin B12 status in a population-based study of older people.

Methods

Participants

Participants were recruited from a random sample of people aged 75 years or older living in their own homes and registered with three general practitioners in Banbury, Oxfordshire, England. Individuals who were known to have a terminal illness or were living in institutions were excluded. Eligible participants were invited to participate in the study and those who agreed were asked to provide written informed consent (see Appendix Figure 1, available online at http://ageing.oxfordjournals.org). Little is known about the reasons for non-participation, but it is likely that the non-responders had a higher proportion with cognitive impairment. The study protocol was approved by the Central Oxford Research Ethics Committee (COREC CO2.219). Individuals who agreed to participate were visited in their own homes by one of two research nurses between March 2003 and April 2004. Participants underwent a structured interview to record medical history, use of medication and neurological symptoms affecting the lower extremities. Cognitive function was assessed using the Mini-Mental State Examination (MMSE), cognitive impairment being defined as a MMSE score <22/30 [9]. Depression and anxiety were assessed using a version of the Hospital Anxiety and Depression Scale (HAD-d), and probable depression was defined as a score of 11 or more [10]. A brief neurological examination of the lower limbs included bilateral assessment of knee jerks, ankle tendon jerks, joint position sense of the great toe and plantar responses (see Appendix Table 1, available online at http://ageing.oxfordjournals.org). Individuals were defined as having neuropathy if they had more than two symptoms of neuropathy and more than two abnormalities detected on neurological examination of their lower limbs (see Appendix Table 1, available online at http://ageing.oxfordjournals.org). Missing ankle tendon jerks were also analysed separately as a more sensitive marker of peripheral neuropathy.

Venous blood samples were collected and kept chilled (using a cooling box to ensure that the temperature was maintained below 4°C) until the serum was separated at the local hospital laboratory within 2 h of blood collection. Blood was drawn into vacutainers containing EDTA for full blood count and lithium heparin for creatinine and plain tubes for assessment of markers of vitamin status. Serum was separated and stored at –40°C for subsequent measurement of holoTC, tHcy, MMA and folate. To assess intra-individual variability, we selected a 10% random sample (n = 87) of the participants not receiving vitamin B12 injections or B-vitamin supplements (n = 868) for repeat clinical and blood measurements after 3 months. Individuals with serum vitamin B12 concentrations below 133 pmol/l were treated with hydroxycobalamin (1,000 μg intramuscularly/month) for 3 months, after which all clinical and laboratory assessments were repeated within 1–2 weeks after receiving the third injection.

Laboratory methods

Vitamin B12 concentrations were measured at the Horton General Hospital, Banbury, using a Beckman immunoassay that has a reference range of 133–675 pmol/l (180–914 ng/l). Vitamin B12 concentrations were also measured using a Bayer assay at the Department of Clinical Chemistry, Aarhus University Hospital, Aarhus, Denmark. Serum holoTC concentrations were measured at the Clinical Trial Service Unit using a radioimmunoassay (AXIS-Shield ASA, Oslo, Norway) that has a lower reference limit of 40 pmol/l [6]. MMA and tHcy concentrations were measured in the Department of Pharmacology, Bergen, Norway, using stable isotope-dilution capillary gas chromatography–mass spectrometry [11]. Serum folate concentrations were measured using a microbiological assay at the Department of Biochemistry, Trinity College, Dublin, Ireland [12]. Full blood count and creatinine were measured at the Horton General Hospital laboratory in Banbury using standard methods. Individuals identified with low vitamin B12 concentrations also had their intrinsic factor antibodies and parietal cell antibodies measured in the Radcliffe Hospital Trust Immunology laboratory.

Statistical methods

Continuous variables were summarised as means and standard deviations. Individuals with extreme elevations of vita-

min B12 (>1,000 pmol/l) or holoTC (>400 pmol/l) or who reported the use of vitamin B12 injections or any B-vitamin supplements were excluded from comparisons of associations of clinical outcomes with measurements of vitamin status. Logistic regression was used to assess associations of cognitive impairment, depression or neuropathy with quartiles of vitamin status after adjustment for age, sex and smoking. T-tests were used to assess the effect of treatment on measurements of vitamin status. One-way random effects analysis of variance models was used to estimate between- and within-person variability, and hence reliability coefficients, in assays of vitamin status in the 87 subjects selected for repeat measurements. Measurements were log transformed so that the normality assumptions were not seriously violated. Measurements from individuals with low vitamin B12 status who received treatment before obtaining replicate measurements were treated as missing at the follow-up visit [13]. Provided that, conditional on baseline measurements, such data are 'missing at random' [13], a statistical model that includes both the follow-up and baseline measurements will yield unbiased estimates.

Results

Associations with low vitamin B12 concentrations

Table 1 summarises the characteristics of the overall population and of those with and without low serum vitamin B12 concentrations (using the lower cut-off of the laboratory reference range of <133 pmol/l for the Beckman vitamin B12 assay). Low vitamin B12 concentrations were identified in 125 of the 1,000 participants (13%) and were correlated with cognitive impairment and depression. Although symptoms of neuropathy were common in this age group, they were unrelated to low vitamin B12 concentrations. Medications producing gastric hypochlorhydria, such as H_2-antagonists and proton pump inhibitors, were in common use but were unrelated to low vitamin B12 concentrations. Among the 49 participants who reported having vitamin B12 injections, four had had gastric surgery and three had small bowel surgery; the remainder had been previously identified as having low blood levels of vitamin B12, but few had true pernicious anaemia. There were no differences in the haemo-

Table 1. Characteristics of the total sample (n = 1,000) and of the subgroups with normal (≥133 pmol/l) or low serum vitamin B12 (<133 pmol/l) concentrations

	All (n = 1,000)	Normal serum vitamin B12 (n = 875)	Low serum vitamin B12 (n = 125)
Medical history			
Age, mean (SD) (years)	81.4 (4.6)	81.3	82.2 (5.4)
Sex (% male)	40	39	49
Current smoker (%)	5.1	5.2	5.8
Myocardial infarction (%)	11.3	11.5	9.9
Angina (%)	17.0	16.9	18.2
Stroke (%)	3.1	2.8	6.0
Transient ischaemic attack (%)	11.1	10.9	12.4
Hypertension (%)	48.6	49.1	45.5
Diabetes mellitus (%)	8.6	8.1	12.4
Vitamin B12 injections (%)	4.9	5.6	0
H_2-antagonists/proton pump inhibitors (%)	18.9	19.7	13.2
Any B vitamins (%)	8.7	9.3	5.0
Folic acid (>200 μg/day) supplements	7.0	7.4	4.1
Cognitive impairment and depression			
MMSE (max 30), mean (SD)	26.0 (3.3)	26.1 (3.2)	25.6 (3.7)
Cognitive impairment (MMSE <22/30) (%)	9.8	12.0	15.8
HAD-d (min 0), mean (SD)	4.9 (3.4)	4.9 (3.4)	5.2 (3.8)
Depression (HAD-d >11) (%)	7.9	11.9	19.0
Neurological symptoms			
Feel unsteady on walking in the dark (%)	19.6	19.1	23.2
Altered sensation in feet on walking (%)	26.0	26.2	24.8
Falls in last month (%)	10.0	9.7	12.0
Pins and needles in feet (%)	14.1	14.1	14.4
Burning pain in feet (%)	15.3	15.7	12.8
Paraesthesia in feet (%)	16.0	15.9	16.8
Neurological signs			
Absent knee tendon jerk	16.0	16.3	14.0
Absent ankle tendon jerk	42.2	41.8	44.7
Absent joint position sense	4.9	4.5	7.9
Absent plantar response	47.7	46.7	54.4
Haematological findings			
Haemoglobin, mean (SD) (g/l)	13.2 (1.4)	13.2 (1.4)	13.2 (1.2)
MCV, mean (SD) (f/l)	91.5 (5.0)	91.3 (5.0)	92.8 (5.4)**

*P = 0.04; **P = 0.0025; MMSE, Mini-Mental State Examination; MCV, mean corpuscular volume.

globin concentrations between those participants with or without low serum vitamin B12 concentrations, but the group with low levels had a slightly higher mean corpuscular volume ($P = 0.0025$).

Antibodies

Testing for parietal cell antibodies was undertaken in 95 of the 125 people with low serum vitamin B12 concentrations. Intrinsic factor antibodies were sought only if the parietal cell antibody test was positive. Parietal cell antibodies were found in 13 of the 95 people tested, and intrinsic cell antibodies indicative of pernicious anaemia were identified in 3 of the 13 people.

Distribution and variability of markers of vitamin B12 status

Table 2 summarises the distribution and variability of the different biochemical markers of vitamin B12 status. Among the 87 participants randomly selected for replicate measurements, data were not obtained from 7, and 16 had vitamin B12 concentrations <133 pmol/l and were commenced on vitamin B12 treatment. Table 2 shows that the vitamin B12 concentrations measured using the Bayer assay were higher than those measured using the Beckman assay. The reliability coefficients for the two methods were comparable with each other and with those for holoTC, tHcy and MMA. The correlation coefficient between holoTC and total vitamin B12 (Bayer method) was 0.71.

Association with cognitive impairment, depression and neuropathy

Table 3 summarises the association of cognitive impairment, depression or neuropathy with various markers of vitamin status in participants with no history of prior treatment with vitamin B12 ($n = 830$). Individuals with vitamin B12 or holoTC in the bottom quartiles compared with those in the top quartiles had a 2-fold risk (OR = 2.17; 95% CI 1.11–4.27) and a 3-fold risk (OR = 3.02; 95% CI 1.31–6.98) of cognitive impairment, respectively, after adjustment for age, sex and smoking. Similarly, individuals with tHcy or MMA in the top quartiles compared with those in the bottom quartiles had a 4-fold risk (OR = 4.07; 95% CI 1.70–9.75) and a 3.7-fold risk (OR = 3.75; 95% CI 1.68–8.04) of cognitive impairment, respectively, after adjustment for age, sex and smoking. Table 3 also summarises that there was a significant association of cognitive impairment with low serum folate concentrations (OR = 3.38; 95% CI 1.31–8.70) that were independent of vitamin B12. There was no significant association of depression or of neuropathy with any of the laboratory measurements. However, there were significant associations of low holoTC and elevated tHcy and elevated MMA concentrations, respectively, with the risk of missing ankle tendon jerks, which are regarded as a sensitive marker of peripheral neuropathy.

Effects of treatment with vitamin B12 on laboratory measurements

The effects of vitamin B12 supplementation on biochemical markers of vitamin B12 status among participants identified with low serum vitamin B12 concentrations are summarised in Table 2 in the Appendix (available online at http://ageing.oxfordjournals.org). The data are derived from 100 participants who had a blood sample collected 1–2 weeks after receiving the third intramuscular injection of 1,000 μg of vitamin B12. Treatment was associated with substantial increases in serum vitamin B12 and holoTC concentrations and in substantial reductions in tHcy and MMA concentrations, with a good response to treatment obtained in 99 of the 100 participants treated (data not shown). Treatment with vitamin B12 injections for a 3 month period was not associated with significant changes in any of the clinical variables (data not shown).

Discussion

Low vitamin B12 concentrations were identified in 13% of this free-living population aged 75 years or greater, a finding consistent with other reports from UK population studies of older people [1–3]. This study showed that people with low vitamin B12 concentrations rarely had

Table 2. Blood levels of vitamin B12, holoTC and related metabolites

	Serum vitamin B12 (Beckman) (pmol/l)	Serum vitamin B12 (Bayer) (pmol/l)	holoTC (pmol/l)	tHcy (μmol/l)	MMA (μmol/l)
Baseline values ($n = 868$)[a]					
Mean	224	246	69	15.5	0.36
SD	92	93	41	7.2	0.28
Median	209	230	61	14.0	0.28
25th–75th percentile	157–275	180–292	43–87	11.6–17.6	0.22–0.39
Range	38–645	46–573	2–325	4.2–46.5	0.13–2.03
10% sample selected for repeat measurement ($n = 87$)[b]					
Geometric mean	213	239	61	14.2	0.28
95% confidence intervals	196–233	221–259	55–68	13.4–15.1	0.26–0.31
Geometric between-person SD[c]	1.52	1.48	1.73	1.34	1.55
Geometric within-person SD[c]	1.13	1.11	1.20	1.09	1.12
Reliability coefficient	0.92	0.94	0.90	0.92	0.94

SD ± mean is 213 × 1.52 = 324 pmol/l (213/1.52 = 140 pmol/l). holoTC, holotranscobalamin; MMA, methylmalonic acid; tHcy, homocysteine.

[a]Individuals receiving vitamin B12 injections or B-vitamin supplements at baseline excluded.

[b]Sixty-four subjects not receiving vitamin B12 injections or B-vitamin supplements at follow-up.

[c]Geometric SDs act multiplicatively on the geometric mean, e.g. serum vitamin B12 (Beckman) 1 between-person.

Table 3. Absolute risk and OR (95% CI) of cognitive impairment, depression, neuropathy and missing ankle tendon jerks by quartiles of vitamin status in participants with no history of prior treatment (n = 830)

Quartiles of vitamin status		Mean level	Cognitive impairment (MMSE <22/30) (n = 75)		Depression (HAD-d >11) (n = 62)		Neuropathy[b] (n = 30)		Missing ankle tendon jerks (n = 360)	
			%	OR (95% CI)[a]	%	OR (95% CI)[a]	%	OR (95% CI)[a]	%	OR (95% CI)[a]
holoTC (pmol/l)	IV	122	3.8	1.0	4.7	1.0	2.9	1.0	35.1	1.0
	III	74	9.6	2.50 (1.06–5.88)	5.7	1.11 (0.47–2.67)	3.8	1.35 (0.46–3.96)	45.5	1.53 (1.03–2.26)
	II	53	10.5	2.62 (1.12–6.11)	9.8	2.02 (0.92–4.47)	3.4	1.15 (0.38–3.51)	42.5	1.35 (0.91–2.00)
	I	30	12.0	3.02 (1.31–6.98)	8.9	1.66 (0.74–3.71)	4.3	1.51 (0.52–4.38)	45.8	1.49 (1.00–2.21)
B12 (pmol/l)	IV	350	7.2	1.0	6.1	1.0	3.4	1.0	20.8	1.0
	III	240	7.3	0.99 (0.46–2.12)	9.3	1.47 (0.70–3.08)	3.9	1.21 (0.43–3.42)	44.4	1.46 (0.98–2.16)
	II	185	7.6	1.00 (0.47–2.12)	6.6	1.00 (0.45–2.20)	2.4	0.71 (0.22–2.29)	46.5	1.59 (1.07–2.36)
	I	125	13.9	2.17 (1.11–4.27)	7.1	1.00 (0.46–2.20)	4.8	1.52 (0.56–4.11)	42.5	1.30 (0.88–1.94)
Folate (nmol/l)	IV	55.3	2.9	1.0	5.2	1.0	2.4	1.0	39.4	1.0
	III	27.9	8.7	3.31 (1.27–8.60)	6.1	1.19 (0.51–2.74)	2.9	1.21 (0.36–4.02)	41.8	1.11 (0.75–1.65)
	II	18.6	14.4	5.34 (2.14–13.31)	10.4	2.07 (0.97–4.42)	4.3	1.81 (0.59–5.51)	42.7	1.09 (0.74–1.61)
	I	11.0	9.7	3.38 (1.31–8.70)	7.5	1.38 (0.62–3.08)	4.3	1.85 (0.61–3.64)	44.9	1.25 (0.85–1.85)
tHcy (μmol/l)	I	9.92	3.4	1.0	5.2	1.0	1.9	1.0	33.8	1.0
	II	12.69	7.7	2.35 (0.93–5.92)	6.1	1.04 (0.45–2.41)	2.4	1.34 (0.35–5.11)	43.4	1.47 (0.99–2.19)
	III	15.52	12.0	3.61 (1.50–8.68)	7.0	1.23 (0.54–2.79)	4.3	2.35 (0.70–7.84)	44.4	1.47 (0.99–2.19)
	IV	22.34	13.0	4.07 (1.70–9.75)	10.8	1.91 (0.89–4.09)	5.7	3.19 (0.99–10.27)	47.2	1.59 (1.06–2.37)
MMA (μmol/l)	I	0.18	4.4	1.0	5.6	1.0	2.9	1.0	32.6	1.0
	II	0.25	8.1	1.79 (0.60–3.41)	6.2	1.12 (0.49–2.58)	2.4	0.78 (0.23–2.60)	43.3	1.50 (1.00–2.23)
	III	0.32	7.2	1.43 (0.60–3.42)	7.0	1.19 (0.54–2.65)	5.2	1.78 (0.64–4.96)	44.4	1.55 (1.05–2.31)
	IV	0.68	16.4	3.67 (1.68–8.04)	10.3	1.72 (0.81–3.66)	3.9	1.27 (0.42–3.78)	48.6	1.76 (1.18–2.62)

CI, confidence interval; HAD-d, Hospital Anxiety and Depression Scale; holoTC, holotranscobalamin; MMA, methylmalonic acid; MMSE, Mini-Mental State Examination; tHcy, homocysteine.

[a]Adjusted for age, sex and smoking.

[b]Neuropathy was defined if they had more than two symptoms and more than two signs indicative of neuropathy.

anaemia or macrocytosis. Moreover, only 3 of the 125 people identified with low vitamin B12 concentrations had antibody evidence suggestive of pernicious anaemia. Thus, most older individuals identified with low serum vitamin B12 concentrations have either dietary deficiency or poor absorption of food cobalamin due to gastric atrophy, other malabsorption or a combination, rather than having pernicious anaemia [14–16].

This study showed that low serum vitamin B12 concentrations were associated with symptoms of memory impairment (P = 0.04) and with objective evidence of cognitive impairment. Low vitamin B12 status was associated with a 2- to 4-fold risk of cognitive impairment, after adjustment for age, sex and smoking. The associations of cognitive impairment with holoTC and with metabolites of vitamin B12 (tHcy and MMA) were stronger than those with serum vitamin B12 concentrations. These associations provide support for the suggestion that holoTC, the biologically active fraction of vitamin B12, is a more reliable indicator of intracellular vitamin B12 status than the standard vitamin B12 assay, and the associations were comparable with those assessed using tHcy and MMA. Low serum folate concentrations were also associated with cognitive impairment, as in other studies [17–19]. Alzheimer's disease and cerebrovascular disease may be linked aetiologically, possibly through elevated blood tHcy concentrations or other mechanisms [17]. However, it is not possible to exclude reverse causality in that low vitamin B12 or folate levels may be an effect rather than a cause of cognitive impairment [17].

Low holoTC and elevated tHcy and MMA concentrations were significantly associated with absent ankle tendon jerks, a sensitive marker of peripheral neuropathy. In a previous study of 324 patients presenting with polyneuropathy, Saperstein *et al.* [20] found that evidence of neuropathy was more likely in individuals with low vitamin B12 status. Above the age of 65 years, missing ankle tendon jerks or loss of vibration sense become more frequent with age in asymptomatic people [21, 22]. This probably reflects age-associated loss of peripheral nerve fibres [23], and our findings raise the possibility that vitamin B12 deficiency may be a contributing factor.

Depression was unrelated to any of the measurements of vitamin B12 status or to folate status. It is possible that the instruments used to assess depression were not sensitive enough to detect an association. In the Rotterdam study [24], there was an association between low vitamin B12 status and depression, but was only detected in a two-stage assessment involving an initial screen for depressive symptoms, followed by a more detailed clinical evaluation using Diagnostic and Statistical Manual-IV criteria [24].

Some European countries are considering folic acid fortification of food, but there are concerns about possible masking of vitamin B12 deficiency. Combined fortification with folic acid and vitamin B12 might offer a solution [25], but before advocating such a strategy, randomised trials of vitamin B12 supplementation are required to assess the clinical and public health significance of low vitamin B12 levels in older people. The lack of improvement in the cognitive function of individuals with low vitamin B12 after 3 months

of vitamin B12 supplementation in our study does not exclude a causative relationship; a mechanism linking mild vitamin B12 deficiency with brain damage would probably be long term in nature. Previous trials of vitamin B12 supplementation for prevention of cognitive decline have been too small to address this question [7, 26]. Trials of vitamin B12 supplementation are feasible because oral vitamin B12 has been shown to be effective in normalising blood metabolite levels [27]. The lowest dose of oral vitamin B12 associated with the maximum reduction in serum MMA concentrations was 650 μg/day, and such treatment would be expected to reduce MMA concentrations by one-third [28]. Long-term trials are required to assess the relevance of vitamin B12 for the prevention of cognitive decline in older people.

Key points

- Low serum vitamin B12 concentrations affect about one in six people aged 75 years or older.
- Individuals with vitamin B12 concentrations in the bottom quartile had twice the risk of cognitive impairment compared with those in the top quartile.
- Long-term trials are currently assessing the effects of high-dose oral vitamin B12 and folic acid on the risk of vascular disease, and some may also assess their relevance for cognitive function.
- Further trials of high-dose oral vitamin B12 without added folic acid are required to assess the relevance of vitamin B12 supplementation for prevention of dementia in older people.

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H.H., R.C., J.G.E., M.D. and J.B. designed the study. H.H. supervised the recruitment and management of the study. R.C. and P.S. carried out the statistical analyses. W.A., K.E., J.S., P.M.U., E.N., J.S. and A.M. carried out laboratory analyses. All authors commented on drafts and agreed on the manuscript.

Conflicts of interest

None of the authors have any conflicts of interest with this report.

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Motor plasticity in a juggling task in older adults—a developmental study

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Abstract

Objective: to examine the plasticity of motor performance in old age. Older adults were instructed and trained in a juggling task and their performances were compared, first, within the group of older adults and, second, with the performances of children, youths and younger adults.
Subjects: older adults, children, youths and younger adults (n = 1,206, range 6–89 years).
Methods: participants were asked to learn a juggling task. Performance was tested before semantic instruction (pre-test 1), after semantic instruction (pre-test 2) and after 6 days of juggling practice (post-test). None of the participants had prior experiences in juggling. Results were analysed using repeated measure analysis of variance (ANOVA).
Results: older adults showed a clear improvement in juggling performance after instruction and after six training sessions. On average, they reached performances comparable with those of children aged between 10 and 14 years, and with those of younger adults aged between 30 and 59 years. Only youths and younger adults aged between 15 and 29 years showed significantly higher performances at baseline, after instruction and after training.
Conclusions: older adults exhibit high reserve capacity, that is, a potential for learning 'new' motor skills.

Keywords: *ageing, human development, practice, learning, motor skills, elderly*

Introduction

Physical function is central to most of our activities. Our physical efficiency permeates all aspects of our life, and it becomes a constraining factor in what we can do, and in turn it can define our quality of life. There is broad evidence that a physically active lifestyle is associated with improvements in functional abilities and health status and that it may prevent certain diseases or diminish their severity [1, 2]. Consequently, the World Health Organization defines active ageing as one important factor to optimise health and to enhance quality of life, and it promotes physically active lifestyles in older adults [3, 4].

Previous research has shown the age-related impairments of and the benefits of physical activity on motor functions [5, 6]. Many of these articles on healthy older adults