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Reduced motor asymmetry in older adults when manually tracing paths

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Handedness, a preference towards using the right or left hand, is established in early childhood. Such specialisation allows a higher level of skill to be maintained in the preferred hand on specific tasks through continuous practice and performance. Hand asymmetries might be expected to increase with age because of the time spent practising with the preferred hand. However, neurophysiological work has suggested reduced hemispheric function lateralisation in the aging brain, and behavioural studies have found reduced motor asymmetries in older adults (Przybla, Haaland, Bagesterio and Sainburg 2011). We therefore tested the predictions of behavioural change from reduced hemispheric function by measuring tracing performance (arguably one of the most lateralised of human behaviours) along paths of different thickness in a group of healthy young and older adults. Participants completed the task once with their preferred (right) hand and once with their non- preferred (left) hand. Movement Time (MT) and Shape Accuracy (SA) were dependant variables. A composite measure of MT and SA, the Speed Accuracy Cost Function (SACF) provided an overall measure of motor performance. Older participants were slower and less accurate when task demands were high. Combined analyses of both hands revealed reduced asymmetries in MT and SACF in the older group. The young were significantly faster when tracing with their preferred hand but older participants were equally slow with either hand. Our results are consistent with the growing literature reporting decreased hemispheric function lateralisation in the aging brain.

Key terms: Manual control, movement, kinematic, motor asymmetry, ageing, older adult.

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Introduction

Handedness, a preference towards using either the right or left hand when completing motor tasks, is established in early childhood and maintained throughout life. Studies with children and younger adults report superior motor performance in the preferred hand (e.g. Fagard 1987; Truman and Hammond 1990; Culmer, Levesley, Mon-Williams and Williams 1990). The fact that older adults have had decades of practice with the preferred hand might suggest that older adults should exhibit large motor asymmetries, perhaps even to a greater extent than when young. Aging is, however, associated with changes in motor ability whereby movements become slower and less accurate over time (Desrosiers, Herbert, Bravo and Dutil 1995; Verkerk, Schouten and Oosterhuis 1990; Morgan, Phillips and Bradshaw et al. 1994; Pohl, Winstein and Fisher 1995; Welsh, Higgins and Ketcham et al. 2002). It is unclear whether this decline in motor ability alters the propensity toward motor asymmetries seen in younger adulthood.

At the neurological level, motor asymmetry can be explained by lateralisation of brain function. Nevertheless, the aging brain appears to show greater bilateral patterns of activation, especially during cognitive processes (a phenomenon termed 'HAROLD'; Hemispheric Asymmetry Reduction in Older Adults). The HAROLD model (Cabeza 2002) is based on neurophysiological evidence which shows reduced asymmetry between dominant and non-dominant hemisphere activation in older adults when completing cognitive tasks (e.g. episodic/semantic memory encoding/retrieval and inhibitory response). For example, during episodic memory encoding and retrieval, increased Prefrontal Cortex (PFC) activity is observed in the left hemisphere during encoding and in the right hemisphere during recall in the younger population; whereas in older groups there is a greater bilateral pattern of activation throughout both parts of the task (e.g. Cabeza, Grady and Nyberg et al. 1997). Furthermore, bilateral patterns of activation are associated with better performance in the old, which suggests that HAROLD may serve a compensatory purpose (Cabeza, Anderson, Locantore and McIntosh 2002).

If reduced asymmetry of function is evident for a range of different cognitive processes (i.e. HAROLD is not task-specific), it is likely that the phenomenon may be generalised to other brain regions and tasks. This might include lower-level sensory-motor processes that occur outside of the PFC. In line with this, recent functional imaging research has indicated an age-related reduction in lateralisation in the temporal and parietal areas (Grady, Bernstein, Beig and Siegenthaler 2002). Moreover, increased bilateral activation in motor regions has been found when older adults perform basic motor tasks such as finger-tapping and button-pressing (Calautti, Serrati and Baron 2001; Mattay, Fera and Tessitore et al 2002; Ward and Frackowiak 2003). It has been suggested that transcallosal inhibition usually ensures ipsilateral deactivation of primary motor cortex in the young, but this process may be reduced in older individuals (Ward and Frackowiak 2003; Peinemann, Lehner, Conrad and Sibner 2001). Findings of reduced lateralisation in the old, however, do seem to be somewhat task dependent; both motor sequence learning (Daselaar, Rombouts, and Veltman et al, 2003) and cued simple movements (Fang, Li and Lu et al. 2005) do not appear to exhibit age-related cortical reorganisation. Rowe, Sibner and Filipovic et al. (2006) used low-frequency repetitive transcranial magnetic stimulation (rTMS) and positron emission tomography to study age-related changes in connectivity. Rowe et al. found that older adults exhibited increased movement-related activation of premotor cortex bilaterally during a button pressing task, and that this cortical region was also more susceptible to the inhibitory effects of rTMS in the old. They did not, however, report a general loss of lateralisation of frontal cortical specialization (as would be expected based upon the HAROLD model; Cabeza 2002) but (as they highlighted) their measures may have lacked the requisite sensitivity to detect changes in the motor system.

Whilst there are now a number of studies that show age-differences in lateralisation of cortical activity, to date, there are few studies that have examined age-related motor asymmetries in skilled behavioural tasks. A skilled action that has been examined is the efficiency of reaching movements, where there do appear to be reduced asymmetries in older adults (Przybyla, Haaland, Bagesteiro and Sainburg 2011). The coordination of reaching movements is usually superior in the preferred arm (Bagesteiro and Sainburg 2002; Sainburg and Kalakanis 2002), however, Przybyla et al. (2011) found that in older adults these asymmetries were reduced. One possibility is that aging leads to reduced asymmetries simply because of a greater impairment to the most skilled (preferred) hand. The results showed, however, that young participants tended to overshoot leftwards of the target when using their non-preferred hand, the older participants produced straighter trajectories that were similar to those shown by the preferred hand (in both age groups). Furthermore, there was no difference in accuracy between the arms in the older group, whereas the young were more accurate when using their preferred arm. One particularly elegant study investigated visuomotor adaptation during reaching and found that older adults showed a similar degree of interlimb transfer after adaptation for both left and right arms, whereas adaptation mainly occurred between the preferred to non-preferred arm in the young (Wang, Pszybyla and Wuebbenhorst et al. 2011). Such reduced asymmetries would support the idea that interhemispheric inhibition declines with increased age.

Evidence for reduced motor asymmetries in older adults performing gross motor reaches is an interesting and important empirical observation, especially in light of the well-documented support for HAROLD in the cognitive domain. The findings of Przybyla et al. (2011), Wang et al. (2011) and the HAROLD model clearly predict that the normal manual asymmetries found in younger adults should be absent in older adults. We wished to examine these predictions using a task that is almost a canonical example of motor asymmetries – the fine visuomotor task of holding a pen within the hand to trace a shape. This task yields a large degree of lateralisation in younger groups and captures many critical aspects of skilled motor control (Culmer, Levesley, Mon-Williams and Williams 2009). Interestingly, large manual asymmetries have been observed in both young and older adults when drawing circles within a series of square boxes (Teixeira 2008). This task, however, required participants to complete the boxes from right to left with the left hand, and vice-versa with the right hand. The asymmetries in drawing time for each hand may, therefore, have been purely due to task differences as it has been shown that there are costs involved with moving both the preferred and non-preferred hand in the opposite direction to that used when writing (Johnson, Culmer, Burke, Mon-Williams and Wilkie 2010).

In this study we used a sophisticated kinematic assessment tool to compare hand performance when carrying out fine motor tracing. We asked participants to trace a line along paths of different thickness. Whereas Przybla et al. (2001) controlled speed, our participants were told that their line must not leave the path, but they must also try to complete the task as quickly as possible (i.e. no specific time-constraint). We used one path that was sufficiently thin to ensure that the task had to be completed by tracing the path's shape precisely. We also used thicker paths where the task could be completed more quickly by 'cutting-the-corners' (Raw, Kountouriotis, Mon-Williams and Wilkie, in press). To explore age differences in manual asymmetries, we asked participants to complete the task once with their preferred (right) and once with their non- preferred (left) hand. We then looked at age and hand differences in speed and accuracy, as well as a measure of overall performance efficiency (the 'Speed Accuracy Cost Function', SACF).

Method

Thirty seven individuals were recruited from the University of Leeds and a local amateur dramatics society (Teesside Musical Theatre Company). Participants were healthy with no history of ophthalmological or neurological problems. All participants were also right-handed as indexed by the Edinburgh Handedness Inventory (EHI) (Oldfield 1971) with an average score = 90.53 (*SD* = 13.66) out of the maximum 100 (scores of 40+ indicate right-handedness). To establish age differences, participants were split into two groups; the 'young' group consisted of 20 participants (12 females, 8 males) aged between 18 and 31 years (average 25.5) and the 'old' group comprised 17 people (11 females, 6 males) aged between 62 and 79 years (average age = 69 years). The University of Leeds' ethics and research committee approved this study in January 2010, and all participants gave written informed consent in accordance with the Declaration of Helsinki.

Participants used a handheld stylus to trace a line (displayed real-time) along paths presented on a tablet PC. Each path was the same shape (see figure 1), but varied in thickness (4mm, 9mm, 14mm) and was presented five times each in a randomised order (total of 15 paths, random order different for each participant). The paths measured 166.42mm in height from top to bottom, and 131.72mm in width from left to right. The stylus used to trace the paths was the same shape as a ballpoint pen measuring 150mm from nib to end, with the nib itself measuring 1mm in length. Given that the thinnest condition was only 4mm thick, corner-cutting was not a feasible strategy when tracing the thin paths. Even when tracing centrally, it would only leave a 1.5mm gap either side of the nib, thus making it particularly difficult to avoid crossing outside of the path boundaries when the path was thin. Participants completed the task twice; once with their preferred right hand, and once with their non- preferred left hand (the order of hand use was counterbalanced across all groups so half started with their preferred hand and half with their non-preferred hand). Participants were provided with the following instructions; *"follow the path from start to finish as quickly as possible. You must*

NOT go outside of the path". Participants were also asked to not touch the screen with anything other than the pen (jewellery was removed and sleeves were rolled up).

The tracing task was created using the KineLab/Kinematic Assessment Tool (Culmer et al 2009). We took three measures of tracing performance. First, Movement Time (MT) indicated the time taken (in seconds) from tracing onset to trial completion. Second, Shape Accuracy (SA) was determined by matching the path made by the participant (i.e. the input path) with the reference path (i.e. the centre of the path displayed in the task) using a 'point-set registration' technique. Point-sets were generated for the input and reference paths by discarding temporal information and re-sampling the X and Y coordinates at a spatial resolution of 1mm using linear interpolation. A robust point-registration method (Myronenko and SongPoint 2010) was then used to determine the rigid transformation that best transformed the input path to match the reference path. SA was then calculated by evaluating the mean distance between points in the transformed input path and the reference path. This measure was extremely useful as it gave a metric of accuracy (i.e. indicating the extent to which participants remained within the path boundaries and the deviation from the shape of the path). Finally, we also considered movement duration and accuracy together as a composite measure. The Speed Accuracy Cost Function (SACF) is calculated by multiplying SA by MT to provide an overall measure of task performance, with higher scores indicating poorer performance. This measure has been found to distinguish reliably between preferred and non- preferred hand performance in the past (e.g. Culmer et al. 2009).

The occasional spurious extreme value needed to be excluded from the data-set caused by erroneous recording of the touch screen. At most, one of the five trials per path thickness condition was lost, but no more than one trial per participant. Only five trials were excluded from the data collected from the preferred and non- preferred hand. After removing extreme values, we calculated each participant's median score for the three path thickness conditions on each measure (MT, SA, SACF). A separate ANOVA was carried out on each measure.

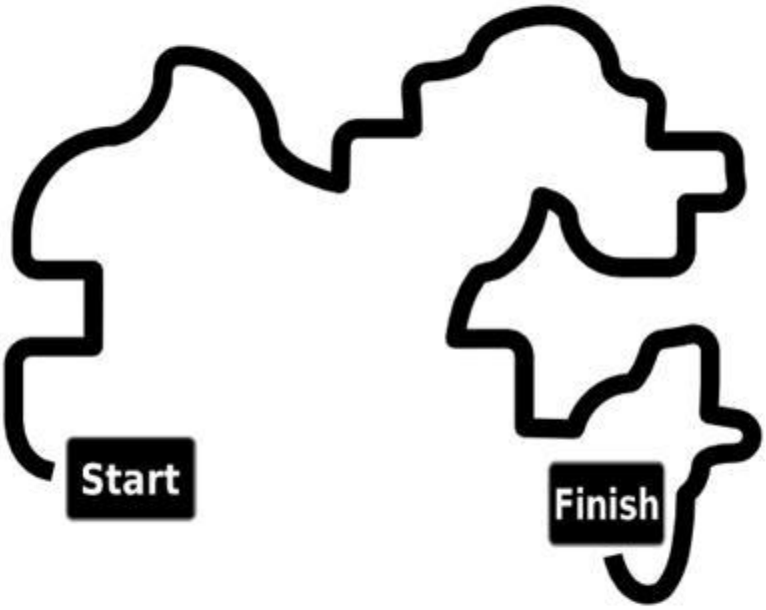

Figure 1. An example of the path when the width was 'thin'.

Results

A Mixed Model ANOVA (hand ✕ path thickness ✕ age) was conducted on each measure. Because participants were free to trade off speed and accuracy we calculated a composite measure of movement efficiency (MT x SA) whereby a larger number indicates worse performance. The ANOVA on SACF (Table 1 and Figure 2) revealed significant interactions between hand and age (F (1, 35) = 8.09, $p < 0.05$), path thickness and age (F (2, 45) = 8.53, $p < 0.05$), and most importantly between hand, path thickness and age (F (2, 60) = 11.35, $p < 0.001$). The older participants were significantly worse than the young (F (1, 35) = 19.81, $p < 0.001$) but seemed to perform equivalently with both hands. To test this formally we carried out a posthoc t-test on the thin path performance of the old, and there was no significant difference (t (16)=1.9, $p > 0.05$). In contrast, the young performed significantly worse with their left hand than with their right hand on thin paths (t (19) = 4.0, $p < 0.001$), though left hand performance in the young was still better than in the old (t (35) = 3.29, $p < 0.05$).

It is possible that the reason we found no differences between performance in the two hands for the old using the SACF measure is because both MT and SA are changing by equal and opposite amounts (i.e. the left hand is slower but more accurate, so performance looks similar across both hands). Figure 3b and 3d demonstrate that this is not the case, with similar MT and SA performance for both hands in the older group. To examine this issue formally we applied an ANOVA to the Movement Time data (MT; Figure 3a and 3b). This analysis revealed a three-way interaction between hand, path thickness and age group (see Table 2, F (2, 70) = 4.50, $p < 0.05$). Participants took longer when using the non- preferred hand (F (1, 35) = 6.289, $p < 0.05$), but when examining performance on thin paths this increase was only significant for the young (t (19) = 3.1, $p < 0.01$) and not the old (t (16) = 0.4, $p > 0.05$). MT did increase as the path became thinner (F (2, 70) = 494.09, $p < 0.001$) demonstrating that participants were slower to complete paths in the thin condition, but there were no significant interactions found between hand and age, or path thickness and age (see Table 2). Analysis of Shape Accuracy (SA) showed that corner-cutting increased as the path became thicker (F (2, 70) = 494.09, p < 0.001), but there was no main effect of age, no significant interactions between hand and age, or between path thickness, hand and age (see Table 3). This pattern suggests that both young and old prioritised accuracy equally with each hand. There was an interaction between path thickness and age (F (2, 70) = 3.27, p < 0.05) indicative of reduced accuracy by the young on thick paths (consistent with greater corner cutting to reduce MTs, see Raw et al, submitted). Overall the analyses of MT and SA confirm the original SACF analysis that the old perform similarly with both hands, whereas the young perform better when using their preferred hand.

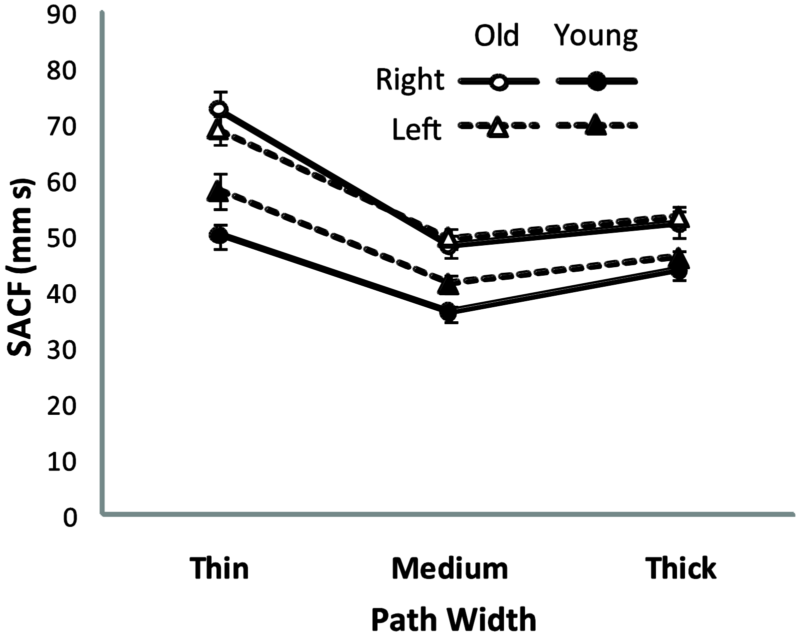

Figure 2. Mean Speed Accuracy Cost Function (mm s) for the young (filled symbols) and old (open symbols) groups on the narrow, medium and thick paths when using the dominant (bold lines and circles) and non-dominant (dashed lines and triangles) hand. All bars = Standard Error of Mean (SEM).

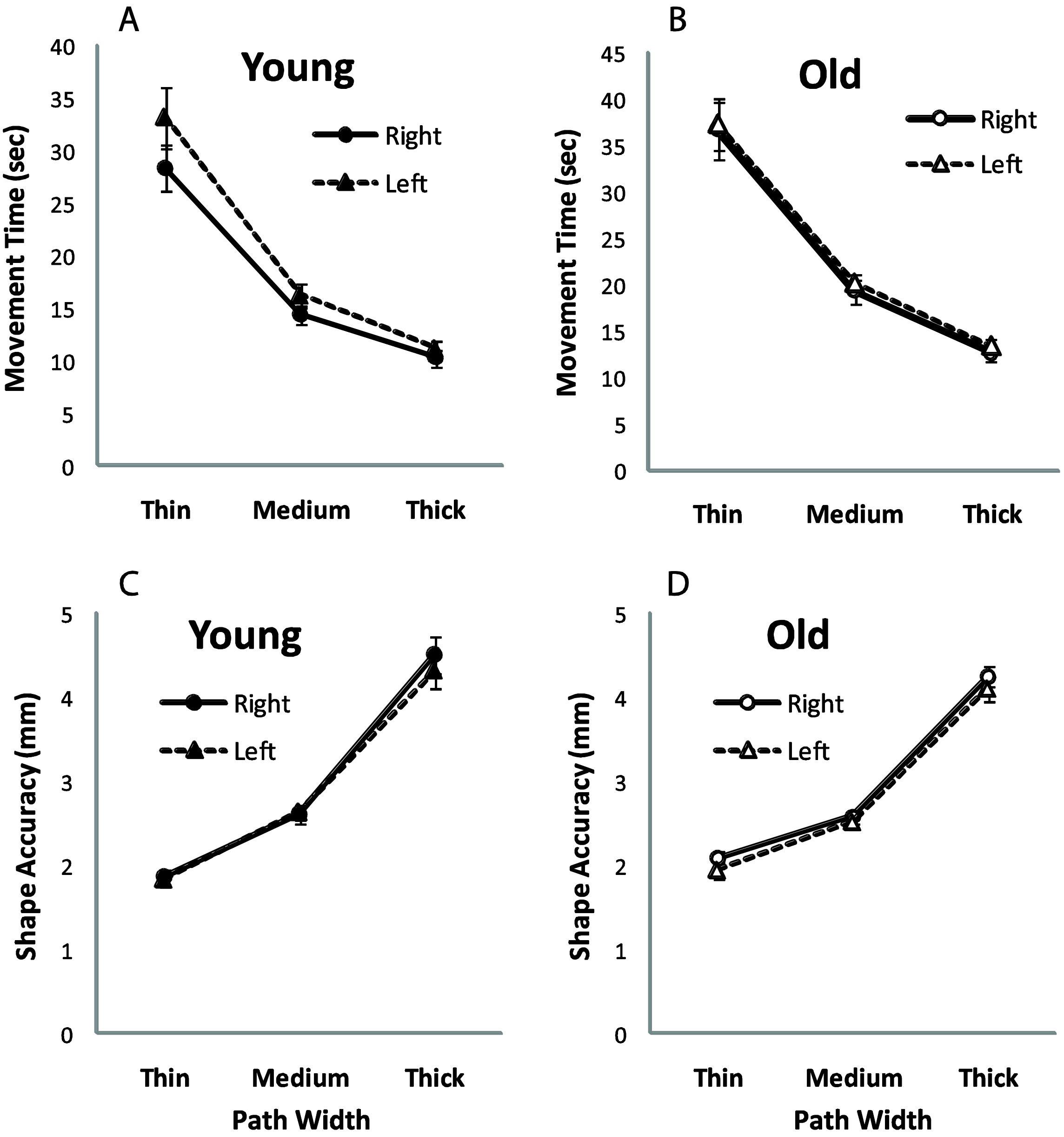

Figure 3: Performance for young (filled symbols) and old groups (open symbols) on the thin, medium and thick paths using the preferred hand (solid lines and circles) and non- preferred hand (dashed lines and triangles). a) Movement Time (sec) for the young group; b) Movement Time (sec) for the old group; c) Shape Accuracy (mm) for the young group; d) Shape Accuracy (mm) for the old group. All bars = Standard Error of Mean (SEM).

Discussion

We measured the movement time and shape accuracy of old and young participants tracing paths of varied thickness using each hand, then calculated overall motor performance (Speed Accuracy Cost Function; SACF). The data confirmed that while the young showed clear hand asymmetries, these differences disappeared in the older group. The differences in the young seem to be mainly driven by faster movement times for the right hand, especially when tracing the thin paths (Figure 2a). In contrast, for the older adults there were no differences in accuracy or movement times for either hand. This shows that when an older adult is given an equivalent task to perform with their left and right hands the asymmetries observed previously (Teixeira 2008) disappear.

The purpose of the experiment was to subject the predictions of the HAROLD model (Cabeza 2002) to an extreme test. The findings of this study are consistent with the HAROLD model and previous empirical reports (Przybyla et al. 2011) of reduced motor asymmetries in older adults. Our data are open to an alternative explanation – namely, the older adults adopted a highly conservative strategy whereby they moved at a low baseline duration that allowed them to meet the accuracy requirement of the task with either hand. This proposal effectively suggests that the older participants were not tailoring their behaviour to the task. We reject this explanation because it is clear that old participants did adjust their movement speed as a function of path thickness, which shows that they did adapt their motor behaviour based on task demands. We would therefore suggest that the data appear to support the suggestions of reduced hemispheric function asymmetry.

A reduction in hemispheric asymmetry has been linked with greater bilateral patterns of brain activity during cognitive tasks (Cabaza, Grady and Nyberg et al. 1997) as well as basic motor tasks (Calautti, Serrati and Baron 2001; Mattay, Fera and Tessitore et al. 2002). Calautti, Serrati and Baron (2001) found overactivation in right-side motor regions in a group of right-handed older adults who were required to produce repeated thumb-to-index-tapping movements. Similarly, Mattay et al. (2002) suggested that the older brain appears to recruit additional motor regions, which are not activated in younger groups, even during a very basic button-pressing task. A bilateral pattern of brain activity in older adults was also linked to better performance, since older participants who did not show the same degree of bilateral activation had longer reaction times. This suggests that reduced hemispheric asymmetry may serve a compensatory purpose whereby older people engage the assistance of additional brain regions, which younger people do not require, in order to maintain a better level of performance. Furthermore, in previous research, older participants produced trajectories with their non- preferred hand that were similar to the preferred hand in both age groups (Przybyla et al. 2011). Our data do not seem to match these previous findings. Though the older adults showed no differences in performance between their two hands, they performed at a lower level than seen in the non- preferred hand of the young. We examined our data to see whether those adults with less asymmetry performed better, but there were no clear links between degree of lateralisation and performance on our measures. One possibility is that it would have been necessary to increase the constraints over movement time (e.g. Raw et al. in press; Przybyla et al. 2011) in order to push the performance of the older adults nearer to their limits, in order to detect a relationship between performance and asymmetry.

Reports of reduced hemispheric asymmetry in the motor domain have a wider application to the growing literature in support of the HAROLD hypothesis. Thus far, the majority of research into age differences in hemispheric asymmetry has focused on the higher-level cognitive processes of the PFC (i.e. basis of the HAROLD model). Nevertheless, emerging evidence of age-related reductions in manual asymmetry at both the behavioural and neurophysiological level provides support for the generalisation of HAROLD to brain regions outside of the frontal cortex. The present results suggest that similar reduced asymmetries may be expected in the brain regions associated with the control of fine motor actions. This is an observation that clearly requires further empirical investigation, especially with respect to HAROLD acting as a compensatory mechanism.

We also note that regardless of the cause of reduced motor asymmetries, there are practical implications to our empirical finding of similar performance between the hands. Our results suggest that the impact of a stroke might be less dependent than previously thought on whether the damage is ipsilateral or contralateral to the preferred hand. The observation of reduced asymmetries also implies that there there may be benefits to switching to use the non-preferred limb when the preferred limb is affected by an age-related condition such as arthritis.

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Table Titles and Captions

Table 1. Speed Accuracy Cost Function (SACF): The effect of Hand (Dominant or Non-dominant) and Path Thickness (Thin, Medium, Thick) in old and young participants. Greenhouse-Geisser ε values are reported where degrees of freedom were adjusted to account for sphericity.

	SACF (mm s)				
	F	*df*	η^2	*ε*	*p*
Hand	5.59	1, 35	.14		.024 *
Path Thickness (PT)	148.14	2, 70	.81	.63	<.001 **
Age[a]	19.81	1, 35	.36		<.001 **
Hand × Age	8.09	1, 35			.007*
PT × Age	8.53	2, 70	.20	.63	.003 *
Hand × PT	1.11	2, 70	.03	.85	.329
Hand × PT × Age	11.35	2, 70	.25	.85	<.001 **

[a]Age was the only between-subjects factor.

*Result significant at the *p* < .05 level.

**Result significant at the *p* < .001 level.

Table 2. Movement Time (MT): The effect of Hand (Dominant or Non-dominant) and Path Thickness (Thin, Medium, Thick) in old and young participants. Greenhouse-Geisser ε values are reported where degrees of freedom were adjusted to account for sphericity

	MT (s)				
	F	*df*	η^2	*ε*	*p*
Hand	6.29	1, 35	.15		.017 *
Path Thickness (PT)	193.41	2, 70	.85	.51	<.001 **
Age[a]	4.66	1, 35	.12		.038 *
Hand × Age	2.00	1, 35			.17
PT × Age	1.48	2, 70			.23
Hand × PT	4.11	2, 70	.11	.61	.042 *
Hand × PT × Age	4.50	2, 70	.11	.61	.033 *

[a]Age was the only between-subjects factor.

*Result significant at the *p* < .05 level.

**Result significant at the *p* < .001 level.

Table 3. Shape Accuracy (SA): The effect of Hand (Dominant or Non-dominant) and Path Thickness (Thin, Medium, Thick) in old and young participants. Greenhouse-Geisser ε values are reported where degrees of freedom were adjusted to account for sphericity.

	SA (mm)				
	F	*df*	η^2	*ε*	*p*
Hand	3.11	1, 35			.086
Path Thickness (PT)	493.86	2, 70	.93	.58	<.001 **
Age[a]	0.10	1, 35			.75
Hand × Age	0.29	1, 35			.59
PT × Age	3.28	2, 70	.09		.044 *
Hand × PT	3.23	2, 70	.08	.78	.059
Hand × PT × Age	1.08	2, 70			.35

[a] Age was the only between-subjects factor.

*Result significant at the $p < .05$ level.

**Result significant at the $p < .001$ level.