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Attentional focus of feedback for improving performance of reach-to-grasp after stroke: a randomised crossover study

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Abstract

Objective To investigate whether feedback inducing an external focus (EF) of attention (about movement effects) was more effective for retraining reach-to-grasp after stroke compared with feedback inducing an internal focus (IF) of attention (about body movement). It was predicted that inducing an EF of attention would be more beneficial to motor performance.
Design Crossover trial where participants were assigned at random to two feedback order groups: IF followed by EF or EF followed by IF.
Setting Research laboratory.
Participants Forty-two people with upper limb impairment after stroke.
Intervention Participants performed three reaching tasks: (A) reaching to grasp a jar; (B) placing a jar forwards on to a table; and (C) placing a jar on to a shelf. Ninety-six reaches were performed in total over one training session.
Main outcome measures Kinematic measures were collected using motion analysis. Primary outcome measures were movement duration, peak velocity of the wrist, size of peak aperture and peak elbow extension.
Results Feedback inducing an EF of attention produced shorter movement durations {first feedback order group: IF mean 2.53 seconds [standard deviation (SD) 1.85]; EF mean 2.12 seconds (SD 1.63), mean difference 0.41 seconds; 95% confidence interval -0.68 to 1.5; $P = 0.008$}, an increased percentage time to peak deceleration ($P = 0.01$) when performing Task B, and an increased percentage time to peak velocity ($P = 0.039$) when performing Task A compared with feedback inducing an IF of attention. However, an order effect was present whereby performance was improved if an EF of attention was preceded by an IF of attention.
Conclusions Feedback inducing an EF of attention may be of some benefit for improving motor performance of reaching in people with stroke in the short term; however, these results should be interpreted with caution. Further research using a randomised design is recommended to enable effects on motor learning to be assessed.

Keywords: Rehabilitation; Stroke; Feedback; Upper extremity

Introduction

Feedback about motor performance, defined as 'observable production of a motor action' [1], calibrates a motor response to the aims of the task [2] and can increase the level or rate at which motor learning occurs. When provided verbally, it can be directed to focus attention either on the body movement [internal focus (IF); e.g. 'next time, straighten your elbow more'] or on the effects of the movement on the environment [external focus (EF); e.g. 'next time, move closer to the jar'] [3]. In healthy participants, information feedback which induces an EF of attention has consistently led to improved motor performance compared with information feedback which induces an IF of attention [4,5]. Following stroke, the effect of EF feedback on motor performance vs IF

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feedback is not known [6], but EF instructions have resulted in shorter movement times and greater peak velocities during functional reaching tasks [7] and improvements in balance [8].

The 'constrained action hypothesis' [9,10] has been suggested to explain the advantage of inducing an EF of attention. This states that directing attention to movement itself (IF) causes the person to consciously intervene in automatic control processes, thereby disrupting them. In contrast, focusing on the movement effect (EF) reduces a person's ability to actively intervene in their control processes and consequently enables faster, more efficient automatic movements.

Not all studies have supported the advantage of feedback with an EF. In healthy novice performers learning a new skill, a small number of studies have found a benefit from instructions inducing an IF [11,12]. It is possible that stroke participants may respond differently to type of attentional focus according to level of arm impairment, where those with severe motor impairment may benefit less from feedback inducing an EF of attention.

The influence of available working memory may also influence the benefit conferred by different attentional foci. Adopting an EF has been associated with using less explicit processes and so requires less working memory capacity [13,14]. The 'conscious processing hypothesis' [15] proposes that explicit knowledge about the movement impedes performance and places increased load on working memory. It has been suggested that more working memory is required when inducing an IF of attention, as information from both body and salient features in the environment need to be processed, whereas with EF, only information from the environment is used [14]. Therefore, the motor performance of participants with impaired working memory may improve with an EF of attention.

In summary, it is not clear whether the benefit of EF over IF in healthy participants extends to improving motor performance after stroke. It is also unknown whether the level of motor impairment and working memory capacity are influential factors. In this exploratory study, it was hypothesised that feedback inducing an EF would be more effective than feedback inducing an IF in improving motor performance of reach-to-grasp after stroke. The study did not aim to assess retention of changes in motor performance (motor learning). Measures indicating motor performance of reach-to-grasp (transport of the hand and opening and closing of the hand) and the amplitude of joint movements were used to describe motor performance in this study, since both of these aspects are important in the therapeutic context [16,17]. Secondly, it was predicted that stroke participants with greater arm impairment would benefit less from receiving feedback inducing an EF compared than those with lesser arm impairment. Thirdly, it was predicted that stroke participants with impaired working memory would benefit more from receiving feedback inducing an EF compared with those with good working memory.

Methods

Design

A crossover trial was employed where stratified randomisation via a computer-generated randomised sequence was used to assign participants to one of two feedback order groups: IF followed by EF or EF followed by IF. All participants performed reaching movements under both feedback conditions with a rest between conditions.

Stratification was performed to balance groups on two variables: upper limb impairment (upper limb section of the Fugl-Meyer Assessment: greater arm impairment ≤44; lesser arm impairment ≥45 [18,19]) and working memory (auditory attention section of the Birmingham University Cognitive Scale: poor working memory = score of 1 or 2; good working memory = score of 3). Ethical approval for the study was granted by a local research committee (05/Q2709/126) and all participants gave written consent.

Participants

Forty-two stroke participants were recruited consecutively from stroke units and physiotherapy outpatient departments in five local hospitals. Inclusion criteria for the study were upper limb score between 19 and 61 on the upper limb section of the Fugl-Meyer assessment [20], <18 months post stroke and medically stable. Exclusion criteria were upper limb movement deficits unrelated to stroke, severe somatosensory disturbance (<1 on the Erasmus MC modification to the revised Nottingham Sensory Assessment [21]) and receptive aphasia (<5 on the 'receptive skills' section of the Sheffield Screening Test for Acquired Language Disorders) [22]. Fig. 1 (see supplementary online material) shows a flow diagram of participants recruited to the study. Table 1 shows the demographic characteristics and baseline assessment results of participants.

Sample size was decided based upon a power analysis using standard deviation (SD) estimates from a previous study with a similar stroke population [23]. This analysis revealed that a study with 42 participants would have 95% power to detect a 50 mm/second difference in peak velocity of the wrist and a 1 second difference in movement duration, and 80% power to detect a difference of 5% in percentage time of peak velocity ($P < 0.05$).

Tasks

To assess the effect of EF or IF on reach-to-grasp performance across a range of everyday tasks, three types of reaching tasks were performed: (A) reaching to grasp a jar (ability to transport the hand to an object, whilst opening and closing the hand); (B) placing a jar forwards on to a table (moving an object); and (C) placing a jar on a 28-cm wooden platform (a more challenging task for more able participants).

Table 1
Characteristics of stroke participants.

Characteristic	IF then EF ($n=21$)	EF then IF ($n=21$)
Age (years)	63 (13)	59 (14)
Time since stroke (months)	7.5 (5.6)	8.7 (5.6)
Side of lesion		
Left ($n=20$)	11	9
Right ($n=22$)	10	12
Fugl-Meyer	45.6 (13.3)	42.1 (16.4)
Sex		
Male ($n=30$)	15	15
Female ($n=12$)	6	6
eNSA (poor sensation = 3)	1.1 (0.4)	1.1 (0.2)
SSTALD – receptive speech	7.2 (2)	7.9 (1.2)
Praxis (BUCS)	1.4 (0.6)	1.2 (0.4)
Long-term memory (BUCS)	1.5 (0.7)	1.5 (0.6)
Attention (BUCS)	1.5 (0.8)	1.6 (0.9)
MMSE	8.6 (1.2)	8.5 (1)
Anxiety	6 (5.8)	4.8 (4.1)
Depression	6 (5)	5.7 (2.6)
Motivation	33.4 (9.9)	34.4 (7.5)
Tardieu (spasticity)	1.1 (0.3)	1.1 (0.2)
10-hole peg test		
Affected ($n=11$)	54 (42)	70 (45)
Unaffected ($n=42$)	18 (5)	17 (7)
Pain	1.5 (0.5)	1.6 (0.6)

Data are mean (standard deviation) unless otherwise indicated.
IF, internal focus; EF, external focus; eNSA, Erasmus revised Nottingham Sensory Assessment; MMSE, Mini-Mental State Examination; BUCS, Birmingham University Cognitive Scale; SSTALD, Sheffield Screening Test for Acquired Language Disorders.
Fugl-Meyer scale: max. score 66; eNSA: 0 = absent, 2 = normal; Tardieu: scale of 0 to 4, 0 = no spasticity; MMSE: <7 out of 10 is indicative of cognitive impairment; BUCS: each subsection was scored individually: 'spared = 2′, 'relatively spared = 1′ or 'impaired = 0′; pain: scale of 0 to 10.

The combination of feedback order and tasks proceeded as follows. For Task A, 16 trials were performed with the first assigned feedback condition followed by a 5-minute rest, then 16 trials were performed with the second feedback condition. Tasks B and C proceeded in the same manner as Task A. Five minutes of rest between conditions has been shown to be a sufficient washout period in previous studies of attentional focus [8]. In total, 96 reaches were completed by each subject, 16 for each type of feedback in each task. This number of trials was close to the maximum that could be performed by stroke participants with the level of impairment present in this group [24], and was sufficient to detect significant differences in kinematic performance in a previous study [7].

Both feedback types were given before changing to a new task so that the effect of feedback type on each particular task could be assessed. Although this required the participant to switch their attention between the two feedback types, it was considered important for the participant to experience both types of feedback whilst performing a single task. An alternative approach could have been to ask the participant to practice the first type of feedback with all three tasks, followed by the second type of feedback with all three tasks. However, a considerable time would then have elapsed between the first and second performance of each task, during which the participant's performance could be influenced by practice of the other tasks, thereby acting as a confounder. Therefore, it was decided to expose the participants to both types of feedback for the first task, and then repeat the pattern with the next two tasks. The 5-minute rest between tasks was intended to allow the effect of previous feedback to dissipate, allowing the participant to start afresh with the new task.

Procedure

All movements were performed in a single data collection session. The jar was placed at 90% of arms length to reduce use of the trunk, but trunk movement was not restricted [25]. Participants were seated at a table with their hips and knees at 90° and elbow flexed to approximately 90°. The starting position for Task A was with the thumb and index finger placed together over a mark placed 15 cm from the table edge in a midline position. For Tasks B and C, the participant started with the hand grasping the jar that was placed on the same 15-cm midline marker. Three practice trials occurred before each task, during which the therapist observed the performance and chose a maximum of three components of reach-to-grasp to provide feedback about, selected from a predetermined list (Table 2). Each task was then performed in the assigned order, so that both feedback conditions were received before moving on to the next task. A feedback statement was given after each trial. On the last five trials of each set of 16 trials, the feedback statements from that set of trials were combined. A physiotherapist experienced in training reach-to-grasp movements delivered the feedback. Feedback delivery by the therapist was practised and then assessed by another member of the research team for two pilot participants prior to the start of the trial to ensure that feedback complied with the defined feedback schedules. For each IF feedback statement, there was an equivalent EF statement.

Five external cues were placed within the environment to provide reference points for the tasks: tape was placed from the start position to end position of the jar to indicate hand path, stickers were placed on the jar and thumb for opposition feedback, a sticker was placed 10 cm ahead of the start marker for grasp timing feedback, and a marker was placed on the wooden platform to indicate where the jar should be placed. A flexible straw was attached to the wrist (to indicate wrist extension in the EF condition) and was present in both conditions.

Data collection

A motion analysis system (Qualisys AB – Gothenberg, Sweden; static spatial error 0.0058 mm, dynamic spatial error 0.3606 mm [26]) was used to collect kinematic data from reaching movements using four infra-red cameras. Several upper limb kinematic models are available in the literature [27,28]. The upper limb kinematic model used was chosen to suit the requirements of the data analysis package

Table 2
Feedback statements.

Desired body movement	Internal focus	External focus
Trunk (E)	This time, I would like you to try and stretch your arm rather than move your body forward (demonstration of movement coming from arm not body)	This time, you need to keep close to the chair behind as you reach (demonstration is given) as you move the jar forwards
Shoulder (F)	This time, as you reach, think about lifting your arm up higher	This time, as you reach forwards, think about being higher off the table
Shoulder (ER) and adduction	Bring your arm straight ahead rather than across your body/out to the side	Do you see the tape I have just placed on the table? (tape placed vertically between start and endpoint) Try to follow it
Elbow (E)	This time as you reach further forwards, you need to straighten your elbow more	This time, try and reach closer to the jar
Wrist (E)	As you bring your arm forwards, try and bring your wrist back as well	With this straw I have taped on, can you ensure you keep close to it as you approach the jar (flexible straw on dorsum of hand, taped to wrist and straw bent to required amount of wrist extension)
Fingers (E) (amount)	This time, try and open out your fingers wider as you bring your arm forwards	This time, open out wider in preparation for the jar
Finger (F)	Try and grip with your thumb and all of your fingers (demonstrate without jar)	To grip well, you need to curl around the jar more (demonstration is given with the jar)
Thumb (abd) during transport	This time, try to open out your thumb wider as you bring your arm forwards	This time, open wider as you move to the jar
Thumb (abd) at jar	This time, try and get your thumb right the way around to form a good grip	This time, try to open as wide as you can to encompass the jar (demonstration is given with the jar)
Thumb (opposition)	This time, try to get firm contact with the pad of your thumb (indicate pad of thumb)	This time, try and get the two stickers to touch (sticker on the jar and sticker on pad of thumb)
Grasp (amount)	This time, try and get more contact with your fingers and thumb so you have a firm grasp	This time, try and encompass the jar fully to make it more secure
Speed	This time, can you bring your arm forwards faster?	This time, can you move faster to the jar?
Accuracy	This time, aim for the hand closing to be as precise as possible	This time, can you grasp the jar as accurately as you can?
Smoothness	This time, try to keep your hand moving smoothly through space as you bring it forwards	This time, try to keep the jar moving smoothly through space as you bring it forwards
Coordination at start	This time, as you start to bring your arm forwards, try and open your fingers out (demonstration is given)	This time, when you pass this marker, can you be opening out more in preparation for the jar (demonstration is given and marker is indicated)

E, extension; F, flexion; ER, external rotation; abd, abduction.

used (Visual 3D – C-Motion, Inc. Germantown, USA). The kinematic model was as follows: seven reflective markers with a 5-mm diameter were placed on the hemiplegic arm: (1) 1 cm distal to the bicipital groove, (2) 4 cm lateral to the lateral epicondyle of the elbow, (3) 14 cm down the shaft of the humerus and 1 cm medial to the line connecting the shoulder and elbow markers, the radial styloid, (4) 1 cm medial to the midpoint between the elbow and wrist markers, (5) on the medial aspect between the thumbnail and the distal interphalangeal joint, and (6) on the lateral aspect between the nail of the index finger and the distal interphalangeal joint. To measure trunk flexion, a rigid body consisting of three markers placed 50-mm apart was placed 20 mm below the sternal notch. Each marker provided positional data in the x, y and z planes, and three markers were used for each segment. This positional information was used to form a local coordinate system for each segment using the positional data of all markers used for each segment. Joint angles were measured using the rotations of the local coordinate system of one segment relative to another segment. For example, the local coordinate system of the upper arm segment and the local coordinate system of the forearm segment was used for calculation of the joint angle of the elbow.

Outcome measures

Outcome measures were chosen to reflect movement organisation of reach-to-grasp by the central nervous system using a widely accepted set of kinematic parameters [29], and the observations typically made by therapists in the clinical setting (joint angles). Movement organisation measures included movement duration, peak velocity, time to peak velocity, time to peak deceleration, percentage time to peak velocity (%TPV) and percentage time to peak deceleration (%TPD) to describe the transport component; peak aperture size, time to peak aperture and percentage time to peak aperture (%TPA) to describe the grasp component; and the path deviation of the wrist to describe movement smoothness. Joint motion measures included peak elbow extension, peak shoulder flexion and peak trunk flexion. Primary outcome measures were movement duration, peak velocity, peak elbow extension and peak aperture (Task A only).

Data analysis

Kinematic data were digitally filtered at 10 Hz using a dual-pass Butterworth filter. Movement onset for each trial was defined as the time at which the three-dimensional resultant velocity of the wrist marker first exceeded 25 mm/second. Movement endpoint was defined as the maximum two-dimensional resultant displacement of the wrist in the horizontal plane. Movement duration was defined as the time between movement start and end, peak velocity as the maximum three-dimensional velocity of the wrist between movement onset and endpoint, and peak aperture as the maximum distance between the thumb and index finger markers. Peak elbow extension and shoulder flexion were calculated using Euler angles. Using the sequence x–y–z, the angle formed between the forearm with respect to the humerus was calculated with peak elbow extension taken as the measure about the x axis between movement onset and endpoint. The x axis represented the line perpendicular to the plane formed by the wrist and elbow, the y axis represented the direction of travel of the arm and was perpendicular to the x axis, and the z axis was vertical and perpendicular to the x and y axes. Peak shoulder flexion was calculated from the angle formed between the humerus and trunk using the sequence x–y–z with peak shoulder flexion taken as the measure about the x axis between movement onset and endpoint. Trunk flexion was calculated as the maximum angle formed between the trunk and the global coordinate system around the x axis, with the x axis representing the frontal plane of the body between movement onset and endpoint. Peak velocity, peak deceleration and peak aperture were also expressed as percentages of total movement durations (%TPV, %TPD, %TPA). Path deviation of the wrist was measured as the maximum displacement of the wrist in the y axis relative to the straight line path.

Statistical analysis

Statistical Package for the Social Sciences Version 17 (IBM Corp., New York, NY, USA) was used for all statistical analyses with the significance level set at $P < 0.05$.

Comparison of feedback conditions

All kinematic outcome measures were subjected to a repeated measures analysis of variance (ANOVA), with feedback type (IF or EF) as the repeated measure and order of feedback (IF then EF or EF then IF) as the between-subject factor. Analyses were conducted on mean values for the last five trials for each condition. A three-way ANOVA was conducted on impairment level (high or low Fugl-Meyer score), feedback type and order of feedback. Further, a three-way ANOVA was conducted on working memory (good or poor scores on the BUCS), feedback type and order of feedback. Normality of data distribution was checked by examining the residual plots and statistics of the residuals, and these were normally distributed.

Table 3
Results of motor performance of reach-to-grasp measures.

Task	Order	Movement duration (seconds)	Peak velocity (mm/second)	Aperture (cm)	Time peak velocity (seconds)	% Time peak velocity	Time peak decel. (seconds)	% Time peak decel.	Time max. aperture (seconds)	% Time max. aperture	Wrist deviation
Grasp jar IF	IF1	3.0 (1.8)	321 (143)	9.9 (2.8)	0.6 (0.3)	22.0[a] (8.7)	0.8 (0.3)	33.9 (14.0)	1.6 (1.4)	55.0 (25.7)	18.2 (10.2)
	IF2	3.1 (2.0)	317 (177)	10.1 (2.8)	0.8 (0.6)	26.6[a] (8.9)	1.1 (0.8)	41.6 (16.3)	1.8 (1.61)	65.5 (19.3)	17.9 (10.0)
Grasp jar EF	EF2	3.0 (1.9)	333 (181)	9.8 (2.8)	0.6 (0.4)	26.4[a] (10.4)	0.9 (0.5)	38.1 (13.5)	1.4 (0.9)	63.9 (21.5)	18.1 (9.8)
	EF1	3.1 (1.9)	286 (158)	10.0 (2.8)	0.9 (0.8)	28.5[a] (11.0)	1.3 (0.9)	43.5 (15.2)	1.75 (1.74)	63.1 (22.6)	19.0 (11.2)
Move jar forwards											
IF	IF1	2.5[a] (1.9)	301 (205)		0.8 (0.8)	27.7 (11.6)	1.0 (0.9)	37.2[a] (16.0)			18.16 (9.79)
	IF2	2.4[a] (1.2)	322 (139)		0.6 (0.4)	24.5 (9.5)	0.9 (0.5)	37.0[a] (11.0)			18.0 (10.2)
Move jar forwards											
EF	EF2	2.1[a] (1.6)	324 (172)		0.6 (0.5)	28.6 (11.4)	0.9 (0.6)	44.3[a] (15.0)			15.5 (9.0)
	EF1	2.3[a] (1.1)	321 (126)		0.7 (0.6)	26.9 (10.6)	1.0 (0.8)	41.0[a] (13.1)			16.5 (8.4)
Jar to shelf IF	IF1	1.6 (0.8)	714 (283)		0.5 (0.4)	30.4 (8.6)	0.7 (0.4)	42.7 (11.2)			18.1 (8.7)
	IF2	2.1 (1.2)	620 (222)		0.7 (0.5)	43.8 (12.6)	1.1 (0.8)	43.8 (12.6)			20.6 (6.5)
Jar to shelf EF	EF2	1.8 (1.2)	680 (259)		0.8 (0.9)	36.7 (17.3)	1.0 (0.91)	49.1 (16.4)			17.5 (5.4)
	EF1	2.4 (2.1)	639 (240)		0.7 (0.4)	41.8 (12.8)	1.0 (0.6)	41.8 (12.8)			20.9 (5.8)

Data are mean (standard deviation).
Max. aperture, maximum distance between the thumb and index finger markers; EF1, external focus presented first; EF2, external focus presented second; IF1, internal focus presented first; IF2, internal focus presented second.
[a] Significant main effect.

Table 4
Amplitude of joint movements.

Task	Order	Elbow flexion (degrees)	Shoulder flexion (degrees)	Trunk flexion (degrees)
Grasp jar IF	IF1	125 (32)	31 (10)	8 (7)
	IF2	130 (22)	26 (9)	11 (5)
Grasp jar EF	EF2	125 (35)	31 (10)	9 (7)
	EF1	121 (29)	26 (9)	11 (5)
Move jar forwards IF	IF1	128 (36)	31 (11)	8 (5)
	IF2	139 (19)	29 (9)	10 (6)
Move jar forwards EF	EF2	125 (36)	31 (11)	10 (5)
	EF1	138 (21)	26 (10)	11 (6)
Jar to shelf IF	IF1	130 (28)	48 (14)	6 (3)
	IF2	136 (22)	46 (10)	9 (6)
Jar to shelf EF	EF2	128 (27)	49 (13)	6 (2)
	EF1	133 (18)	46 (9)	8 (4)

Data are mean (standard deviation).
EF1, external focus presented first; EF2, external focus presented second; IF1, internal focus presented first; IF2, internal focus presented second.

Results

Stroke participants

Baseline characteristics of the two groups were similar with respect to age, time since stroke, and Fugl-Meyer and 10-hole peg test scores (Table 1).

A significantly shorter movement duration ($F_{1,40} = 7.927$, $P = 0.008$) and significantly increased %TPD was found for Task B ($F_{1,35} = 7.405$, $P = 0.01$) using EF compared with IF feedback. For Task A, a significantly increased %TPV ($F_{1,40} = 4.539$, $P = 0.039$) was found using EF compared with IF feedback. Movement duration in Task B was nearly 0.5 seconds faster with the EF feedback condition. In patients who received IF followed by EF feedback, the mean movement duration with IF feedback was 2.53 (SD 1.85) seconds compared with 2.12 (SD 1.63) seconds for EF feedback. Means for the motor performance of reach-to-grasp measures and amplitude of joint movements are presented in Tables 3 and 4.

Three significant interaction effects between feedback and order were found when EF was preceded by IF. There was a significant reduction in mean movement duration for Task B ($F_{1,34} = 6.158$, $P = 0.018$), a significant increase in mean %TPA was achieved for Task B ($F_{1,33} = 4.569$, $P = 0.04$) and a significant increase in mean time to peak deceleration was achieved for Task C ($F_{1,40} = 6.596$, $P = 0.017$). There were no other significant main or interaction effects.

Table 5 shows the frequency of use of the individual feedback statements.

Table 5
Frequency of feedback statements used.

Feedback statement	Task A	Task B	Task C
Trunk (E)	18	8	6
Shoulder (F)	11	12	5
Shoulder (ER) and adduction	10	8	12
Elbow (E)	11	15	7
Wrist (E)	1	2	0
Fingers (E) (amount)	6	1	0
Finger (F)	0	2	0
Thumb (abd) during transport	0	0	0
Thumb (abd) at jar	4	5	0
Thumb (opposition)	2	0	3
Grasp (amount)	23	9	6
Speed	23	27	21
Accuracy	0	3	3
Smoothness	4	11	3
Coordination at start	4	0	0
Total	117	103	66

E, extension; F, flexion; ER, external rotation; abd, abduction; Task A, reaching to grasp a jar (ability to transport the hand to an object, whilst opening and closing the hand); Task B, placing a jar forwards on to a table (moving an object); Task C, placing a jar on a 28-cm wooden platform (a more challenging task for more able participants).

Effect of severity

No significant differences were found between the effects of IF or EF feedback in participants with greater or lesser arm impairment.

Effect of working memory

No significant differences were found between the effect of feedback with an IF or an EF in participants with good or poor working memory.

Discussion

The results provide some support for the hypothesis that feedback inducing an EF of attention is more effective than feedback inducing an IF of attention in improving motor performance of reach-to-grasp movements after stroke. First, feedback inducing an EF of attention produced a shorter movement duration in Task B. An increased movement duration has been negatively associated with performing activities of daily living [30,31]. As reach-to-grasp was over 1 second slower (between 2 and 2.5 seconds) in stroke participants compared with healthy controls [24], a reduction in movement duration found by inducing an EF is likely to be clinically significant.

Second, feedback inducing an EF of attention produced an increased %TPD in Task B and an increased %TPV in Task A. This indicates that less time is spent in the deceleration phase which represents a change towards a more normalised mode of control with increased reliance on a pre-planned movement pattern [32]. These results concur with previous studies showing that inducing an EF of attention in people with stroke who are learning motor skills is advantageous for motor performance [7,8].

While there were significant differences between feedback conditions for measures of movement organisation, the different feedback foci had no effect on joint angles. This is likely due to the fact that the feedback statements about trunk, shoulder and elbow angles were not used sufficiently frequently to make a difference (Table 5).

The results also suggest that the benefit from EF feedback was accentuated when it was preceded by IF feedback. As use of implicit information has been found to be impaired after stroke [33], this could be explained by the presence of the additional explicit information provided by feedback with an IF [14] which was first integrated and then used to promote implicit processes during the EF condition. If this finding is corroborated by future studies, the clinical implication is that giving some patients information about the movement itself initially and then following up with information about the movement effect could improve their motor performance.

Unlike previous studies suggesting that the benefit of focus type varies with level of skill [11,12,34–36], no difference was found between IF and EF in participants with different degrees of arm impairment. It is possible that the range of impairments of the participants in this study were not sufficiently different to influence benefit from a particular focus.

The benefit of adopting an EF has been reported to be due to reduced cognitive demands [13,14], so it was predicted that participants with reduced working memory capacity would benefit more from EF. However, no difference was found between IF and EF in participants with different levels of working memory.

The success of feedback delivery, both in this study and in clinical practice, is dependent partially on the therapist's skill in analysing the movement correctly in order to choose the most appropriate movement components for feedback, and also on the skill with which feedback is delivered. The practice of the therapist delivering the feedback in this study and the assessment of feedback from another member of the research team ensured that feedback was delivered consistently about the important movement components contributing to an abnormal performance of reach-to-grasp.

Study limitations

The aims of this study did not encompass investigation of retention of change in motor performance. It has provided initial data suggesting that feedback with an EF may be of benefit in the short term. However, an order effect was present whereby performance was improved if EF feedback was preceded by IF feedback. Although the chosen rest period between conditions has been found to be sufficient previously, it may not have been sufficient to dissipate effects of the previous feedback condition in this study. Therefore, the results suggesting feedback with EF may be more beneficial should be interpreted with caution.

There was also a wide range of upper limb impairment (Fugl-Meyer score of 19 to 61). Although representative of the stroke population, this variability could have limited the observed effects.

As a next step, a study using random allocation of participants to the two feedback interventions, with each group receiving a single type of feedback, is recommended with a retention test included some time after cessation of the intervention. Such a design will remove order effects and enable effects on motor learning to be assessed. Existing studies [7,8] indicate a possible advantage for using feedback with an EF to improve motor performance, but these findings need to be translated into the context of motor learning before firm clinical recommendations can be made.

Future studies would benefit from adopting standardised upper limb kinematic models to be consistent with other studies. This would also allow a more complex kinematic analysis to be performed. In this study, amplitude of joint angles was reported as this was considered to provide a clinically meaningful measure.

Conclusions

Feedback inducing an EF of attention may be of some benefit for improving motor performance of reaching in people with stroke in the short term. However, an order effect was present whereby performance was improved if EF feedback was preceded by IF feedback. Therefore, these results should be interpreted with caution. Further research using a randomised design is recommended to enable effects on motor learning to be assessed.

Ethical approval: Black Country Research Ethics Committee (05/Q2709/126). All participants gave written consent.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2013.03.004.

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