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**Title:**

COMBined Physical and somatoSEnsory training after stroke: Development and description of a novel intervention to improve upper limb function

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## **ABSTRACT**

**Title:** COMbined Physical and somatoSEnsory training (COMPoSE) after stroke: Development and description of a novel intervention to improve upper limb function.

**Background and Purpose:** After stroke, reach-to-grasp (RTG) goal-directed movements are disrupted as a result of both residual motor and somatosensory impairments. This report describes the rationale and development of a new upper limb stroke rehabilitation intervention known as COMPoSE: “COMbined Physical and somatoSEnsory training”, designed to improve somatosensory and motor deficits in the upper limb after stroke. A standardised training matrix has been developed to facilitate intervention delivery.

**Methods:** The COMPoSE intervention was developed through the following stages: 1) Definition and operationalisation of somatosensory and motor variables used in training sensation and movement after stroke; 2) Development of methods to give feedback to enhance skill acquisition; and 3) Combination of somatosensory and motor variables, and feedback, into a standardised training matrix. The reporting of the COMPoSE intervention adheres to the recommendations of the Template for Intervention Description and Replication (TIDieR) checklist to facilitate replication of the intervention in the future.

**Results:** The essential features of COMPoSE include: combined somatosensory-motor training variables (grasp pressure, distance, object size, crushability, surface texture and friction), feedback and calibration using a haptic device providing

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measures of grasp pressure, use of anticipation trials, and high dose repetitive task practice. Ten treatment sessions are delivered over 3 weeks, using a standardised matrix for treatment delivery.

**Conclusion:** COMPoSE is a new intervention that combines somatosensory and movement training, delivered *synchronously, within the same intervention and within the same task.*

**Key words:** Motor, Upper limb, Somatosensory, Stroke, Touch, Hand, Reach

## INTRODUCTION

After stroke, reach-to-grasp (RTG) movements are disrupted as a result of residual motor and somatosensory impairments(Cirstea & Levin, 2000). Compared to healthy adults, stroke survivors with motor impairment experience deficits, such as longer movement duration, slower peak velocity(van Vliet & Sheridan, 2007), earlier peak deceleration(van Vliet & Sheridan, 2007) and reduced movement smoothness(Thielman et al., 2004) during the transport phase of RTG movements. Stroke survivors also suffer from impairments in grasp formation and release, such as inconsistent grasp apertures, which result from disruption in the coordination of muscle activity between finger flexors and extensors, as well as between proximal muscles involved in the hand transport phase of a RTG(Lang et al., 2005). A lack of volitional control of finger and thumb extension further contributes to deficits in hand shaping during grasping and incorrect positioning of fingers for effective hand use(Lang et al., 2009).

Somatosensory function plays a critical role in controlled grasp and is tightly coupled with action. Impaired touch sensation after stroke makes it difficult to discriminate different physical properties of objects, such as texture, hardness and surface friction(Carey & Matyas, 2011). As a result, the fingers and the hand are limited in their ability to effectively coordinate grip and lift forces and to appropriately scale grip force for effective object handling, lifting and manipulation(Blennerhassett et al., 2007; Nowak et al., 2007). The selection of appropriate grip forces is largely determined by object properties, including weight, surface texture, slipperiness and shape, as well as the magnitude, direction and points of application of these grip forces on the objects(Flanagan & Johansson, 2002). As a consequence, people with somatosensory impairment rely extensively on vision to help gauge the force required in object grasping(Blennerhassett et al., 2007; Lederman et al., 1986). Effective grip force modulation is the result of a complex interplay of tactile sensory feedback signals provided by cutaneous mechanoreceptors found in the glabrous skin of the grasping fingers and modulated muscle activity in the hand and arm(Johansson & Westling, 1984, 1988; Kwakkel et al., 2003) . Proprioceptive and cutaneous information also play a significant role in controlling finger span and hand shape during object handling(Santello & Soechting, 1997). Further, proprioceptive information is important for internal models of the body and peripersonal space(Proske & Gandevia, 2012), and is thus crucial in the planning, execution, correction and learning of goal-directed actions.

Significant correlation between motor and somatosensory impairment (tactile sensation and proprioception) has been found in the upper limb after stroke(Scalha et al., 2011), suggesting that an underlying somatosensory impairment may limit performance of motor tasks(Hunter & Crome, 2002). In addition, controlled experimentation of the relative contribution of somatosensory and motor impairment to the fundamental pinch-grip lift-and-hold task identified that somatosensory impairment (in particular surface friction discrimination) has an additional and negative impact on timing and force adjustment during pinch grip(Blennerhasset et al., 2007). Finally, functional arm use has been associated with improved somatosensory skills (tactile, proprioception and haptic object recognition) following sensory discrimination training; although the amount of change in arm use varied across survivors(Turville et al., 2017) .

Functional imaging studies in humans have demonstrated enhanced activation of the somatosensory cortex following motor training(Laible et al., 2012; Liu et al., 2014). Similar studies also found that motor recovery is associated with reorganisation of somatosensory cortices after stroke(Laible et al., 2012; Liu et al., 2014; Roiha et al., 2011; Rossini et al., 1998; Schaechter et al., 2006). For example, following tactile stimulation, increased activation responses were observed not only in the primary and secondary somatosensory cortices but also in the primary motor cortex and supplementary motor area(Schaechter et al., 2006). This suggests that there may be benefits to synchronously coupling somatosensory training with motor training to enhance activation responses in the somatosensory and motor cortices.

Conditions of training and methods to enhance learning of somatosensory discriminations and controlled movement execution are also likely to be important. Additionally, augmented feedback is an important element to enhance motor learning and somatosensory re-training in upper limb stroke rehabilitation(Carey, 2012a; Carey, 2012b; Carey et al., 2011; Subramanian et al., 2010; van Vliet & Wulf, 2006). Similarly, the use of attention and a graded matrix of training tasks are important in skill based learning(Carey et al., 2012).

We therefore sought to develop an intervention combining somatosensory and motor functions, *within the same intervention and within the same task*, to improve upper limb function after stroke. The intervention uses principles of learning and conditions of training that have shown to be effective in task-specific motor training(Hubbard et al., 2009) and in training somatosensory discriminations(Carey et al., 2011). Principles are applied to both motor and somatosensory components of the task and to the overall task, and are facilitated by specialised equipment such as the Tactarray.

The aim of this report is to describe the development and rationale for the essential features of this intervention, which we have named “COMbined Physical and somatoSEnsory training” (COMPoSE). In order to describe COMPoSE with sufficient detail and rigor to allow its application in a future randomised controlled trial, and in clinical practice should COMPoSE prove effective, we used the recommended Template for Intervention Description and Replication (TIDieR) checklist(Hoffmann et al., 2014), an extension of the CONSORT 2010

statement(Schulz et al., 2010). The COMPoSE intervention is being tested in a Phase II study to determine the feasibility of delivery of the intervention and to monitor the responses of participants with stroke to the intervention to improve somatosensory and motor deficits and upper limb function after stroke.

## **METHODS**

The development of the COMPoSE intervention was informed by a review of the literature and consensus was used to agree on the somatosensory and motor variables from the literature to be targeted in this combined intervention. The COMPoSE intervention was developed following three sequential stages:

1) Definition and operationalisation of somatosensory and motor variables used in training sensation and movement in the context of upper limb function after stroke.

COMPoSE is designed to improve reach and grasp, two fundamental actions needed for goal-directed use of the arm. Two motor and three somatosensory parameters were selected for training in the context of the reach and grasp task. Two motor parameters (object distance and object width) are combined with three somatosensory parameters (texture, friction and crushability) and three selected grasp pressures (preferred, minimum and maximum grasp pressure-the output). Each parameter has two variables. Object distance and object size were selected to vary as they impact the kinematics of the task(Michaelsen et al., 2009; van Vliet & Sheridan, 2009). Texture, friction and crushability were selected as they directly

impact controlled grasp and manipulation of objects(Blennerhasset et al., 2007; Carey et al., 2011). Each combination is performed with and without vision.

## 2) Development of methods to give feedback to enhance skill acquisition

Principles of training and conditions of practice are primarily derived from approaches to task-specific training(Hubbard et al., 2009) and SENSE discrimination training(Carey, 2011; Carey, 2012b; Carey et al., 2011). These include augmented feedback enhanced by specially designed tasks, that are graded in relation to motor and somatosensory features. The mechanisms and rationales are discussed later.

## 3) Combination of somatosensory and motor variables, and feedback, into a standardised training matrix

A matrix approach was adopted consistent with that described for SENSE discrimination training(Carey, 2011; Carey, 2012b; Carey et al., 2011). Use of a matrix approach allows for graded progression within motor and somatosensory functions and across sensorimotor actions and tasks(Carey, 2012b). This approach aligns with neuroscience evidence that motor and somatosensory functions/attributes are distributed in interconnected networks with gradients of separation between them(Frey et al., 2011) and transfer may be facilitated with multimodal training(Olsson et al., 2008).

The potential order of variables in the matrix was mapped using consensus based on a logical and pragmatic training approach consistent with the complex functional use of the upper limb and with regards to levels of difficulty of the somatosensory and motor components of reach and grasp. For example, integrated

somatosensory and motor functions and graded levels of difficulty were considered in relation to object size, distance, texture, crushability etc. Furthermore, the training of adaptive pressure is closely related to training of discrimination of properties of the object, such as crushability of the object(Hermsdorfer et al., 2011), as well as for training for discrimination of surface properties, such as texture(Johansson et al., 1992) and friction(Cadoret & Smith, 1996; Flanagan & Johansson, 2002; Johansson & Westling, 1984, 1988). Training and grading of these attributes have been tested in the context of the SENSE intervention(Carey et al., 2011).

## RESULTS

*Description of the COMPoSE intervention using the TIDieR checklist*

Item 1. Brief name:

COMbined Physical and somatoSEnsory training (COMPoSE)

Item 2. Why: Rationale for the intervention

Motor and somatosensory functions are jointly integrated and tightly coupled in actions performed in everyday life(Frey et al., 2011). However, in clinical practice, interventions directed at motor deficits have traditionally been separated from interventions directed at somatosensory deficits(Ackerley et al., 2016; Pollock et al., 2014; Veerbeek et al., 2014). Moreover, treatment of somatosensory functions is often neglected(Kalra, 2010). By treating motor and somatosensory impairments

separately, the potential beneficial effects of combining somatosensory training to further enhance sensorimotor function and action are not utilised. This notion could partially explain the relative lack of effectiveness or limited gains in upper limb functions from current interventions in stroke rehabilitation. A Cochrane review of systematic reviews (n=40 reviews; 503 RCTs; 18,078 participants) found moderate quality evidence for motor only interventions, such as constraint-induced movement therapy, mental practice, mirror therapy, virtual reality, and relatively high-dose repetitive task practice (Pollock et al., 2014). There was insufficient evidence to recommend upper limb interventions including task-specific training, robotics, Bobath approach, brain stimulation, and strength training (Pollock et al., 2014). Although another meta-analysis found significant improvements in upper limb motor function with motor interventions, such as robotics, neuromuscular stimulation and constraint-induced movement therapy, the evidence indicates only small to moderate effects, except for constraint-induced movement therapy (Veerbeek et al., 2014).

Studies reporting the efficacy of somatosensory interventions after stroke are currently limited. A Cochrane review (Doyle et al., 2010) (n=13; without meta-analysis) found only preliminary evidence of efficacious sensory interventions after stroke, such as somatosensory discrimination training, thermal stimulation, and intermittent pneumatic compression. More recently, a meta-analysis of interventions for somatosensory function (n=12 RCTs) found significant positive summary effect sizes for somatosensory function and muscle tone following sensory retraining, but did not find significant summary effect sizes for motor function of the affected

arm(Veerbeek et al., 2014). In summary, currently there is no high-quality evidence for any single sensory or motor upper limb intervention, except for constraint-induced movement therapy(Doyle et al., 2010; Pollock et al., 2014; Veerbeek et al., 2014).

A few studies on upper limb interventions in stroke rehabilitation have attempted to train somatosensation and movement together(Byl et al., 2003; Smania et al., 2003). Importantly, the somatosensory and motor interventions were delivered sequentially, not synchronously. These interventions resulted in no gain or only modest gains in functional independence, strength, somatosensory discrimination, and fine motor control(Byl et al., 2003; Smania et al., 2003). Also, these studies had small sample sizes ( $n = 1-76$ ) and low statistical power.

In order to more comprehensively address somatosensory and motor deficits, the potential exists to *combine* somatosensory and motor training and deliver them synchronously to improve upper limb function after stroke. We hypothesize that greater gains are likely with synchronous somatosensory and motor relearning and practice, on the basis that this would activate both the somatosensory and motor networks in the brain, as occurs in everyday skilled actions, than if somatosensory and movement interventions are delivered separately. In addition, stronger connections may be formed between the somatosensory cortex and the functionally-related motor cortex to boost neuroplasticity. No study has yet investigated the effects of combining somatosensory and motor training and delivering it synchronously. This lead to the design of the COMPoSE intervention.

The COMPoSE intervention draws on the best available evidence for somatosensory and motor retraining of the upper limb, and systematically applies the principles of training and conditions of training to achieve combined sensorimotor training of the upper limb. The COMPoSE intervention was developed for use by people with residual somatosensory and motor deficits in their upper limb resulting from stroke. The aim is to retrain goal-directed use of the arm after stroke, with a focus on integration of RTG movements and discrimination of somatosensory features of objects important for controlled use of the arm in daily activities. It is derived from and extends existing neuroscience-based therapies focused on reach and grasp (Cunningham et al., 2016; van Vliet et al., 2013) and somatosensory discrimination training in the upper limb (Carey, 2011; Carey et al., 2011). These therapies were selected as they have strong foundations in neuroscience and learning (Carey, 2012b; Cramer et al., 2011; Nudo, 2003; van Vliet et al., 2013), are designed to help people who have experienced stroke regain skills in reach, grasp (Turton et al., 2016) and somatosensory discrimination (Carey et al., 2011; Carey & Matyas, 2011), and have demonstrated statistically and clinically significant effectiveness in small randomised controlled trials (Carey et al., 2011; Turton et al., 2016). These interventions have also been operationalised into clinical practice protocols (Carey, 2012a; Carey et al., 2011; Turton et al., 2016).

### Item 3. What: Materials used in the intervention

The materials used in the COMPoSE intervention include objects to be grasped and a haptic device to provide feedback. The objects vary in size diameter, surface texture, surface friction, and crushability. Two dimensions of a cylindrical object (salt shaker) are used. The smaller cylinder is 5 cm in diameter and 12.5 cm high; the larger cylinder measures 7.5 cm in diameter and is 12.5 cm high. The mass of both cylinders is adjusted to 160 g. Four versions of each cylinder are provided, with different surface properties to stimulate somatosensory cues involved in texture differentiation (texture and friction). For texture, felt material is used as a smooth surface on one cylinder, and sandpaper (100 grit) is used as a rough surface on a contrasting cylinder. For friction, rubber is used as the non-slippery surface on one cylinder, and polytetrafluoroethylene (Teflon) is used as the slippery surface on the contrasting cylinder. Rubber and Teflon have different frictional properties (coefficients of friction, 0.35 and 0.96, respectively) while having similar macrostructures (Blennerhassett et al., 2007). For crushability, soft and hard plastic cups are used because they replicate drinking cups used in real-life (Carey, 2011). The cups measure 5.0 cm in diameter and are 9.2 cm high.

The Tactarray pressure distribution system is a haptic device used for providing feedback on selected grasp pressures (PPS). The Tactarray pressure distribution system is a tactile data acquisition method devised by Pressure Profile Systems (PPS). Two dimensions of Tactarray cylinders are used, closely related to the size of the task objects. The Tactarray cylinders are hard and covered with pressure sensor arrays (conformable Tactarray T4500 SN1104; sensor

SN5385,5438) constructed from a soft and flexible conductive cloth approximately 1 mm thick. Further details of the system will be elaborated in Item 4 below.

#### Item 4. What: Procedures, activities, and/or processes used in the intervention

##### *4.1 Critical components of the COMPoSE intervention*

The COMPoSE intervention has four critical components: 1) Matrix of specially designed somatosensory and motor tasks to permit progressive and systematic grading according to specific parameters (e.g. levels of difficulty progressing from easy to more difficult discriminations); 2) Performance of goal-directed somatosensory-motor tasks (reach-to-grasp and lift-and-hold) under two conditions of practice (i.e., with vision and without vision); 3) Targeted feedback about both motor and somatosensory performance; 4) Varied and intensive repetitive practice.

##### *4.2 Matrix of specially designed training tasks with progressive and systematic grading of somatosensory-motor tasks according to specific parameters*

###### *4.2.1 Somatosensory and motor parameters of the COMPoSE intervention*

There is a total of 36 combinations of somatosensory-motor tasks organised into a standardised training matrix (Figure 1). Two motor parameters (object distance and object width) are combined with three somatosensory parameters (texture, friction and crushability) and three selected grasp pressures (preferred, minimum

and maximum grasp pressure) (Figure 1). Each motor and somatosensory parameter has two variables. Motor parameter variables include object width (5 cm, 7.5 cm) and distance (15 cm, 30 cm). Somatosensory parameter variables include: surface texture (smooth, rough) and surface friction (slip, non-slip) and crushability (hard, soft). Object shape and weight (160 g) are kept constant throughout the intervention. All tasks are performed at preferred speed (Figure 1).

The training is organised in two blocks within a matrix in a fixed order (Figure 1). In the first block, object width (5 cm diameter cylinder) is kept constant, while object distance (15 cm, 30 cm) and all somatosensory parameters are varied. In the second block, object width (7.5 cm diameter cylinder) is kept constant, while object distance (15 cm, 30 cm) and all somatosensory parameters are varied. Additional somatosensory-motor variations are provided through selected grasp pressure training using preferred, minimum and maximum grasp pressure (Figure 1).

Insert Figure 1 here

#### 4.2.2 Graded levels of difficulty

Progressive difficulty for the motor and somatosensory variables is integrated within each somatosensory-motor combination and across the standardised training matrix (Carey & Matyas, 2005). Fitts' index of difficulty (ID) (Fitts, 1954) is used to quantify the difficulty of the motor tasks, calculated from  $\log_2 \left( \frac{2 \times \text{Object distance}}{\text{Object width}} \right)$ . For example, as object distance is doubled across the COMPoSE standardised matrix, the indices of difficulty are progressively increased. In the first block, training commences with easier tasks (e.g., smaller object width, closer object, non-slippery

surface) followed by more difficult tasks (e.g., smaller object width, further object, slippery surface). In the second block, repetitions with the larger object width and increasing distances are practised to progress the level of difficulty for hand opening. The indexes of difficulty in COMPoSE are summarised in Table 1.

Insert Table 1 here

### *4.3 Performance of goal-directed somatosensory-motor tasks (reach-to-grasp and lift-and-hold) under two conditions of practice (i.e vision vs no vision)*

#### 4.3.1 Participant position

The participant sits in an upright position on a height-adjustable padded chair, the back against the backrest of the chair and feet flat on the floor. The elbow is flexed to 90 degrees, aligned with the shoulder. The wrist rests at the edge of the table with a loosely closed fist (thumb in opposition to other fingers). Trunk movements are not constrained throughout the trials but participants are reminded to minimise trunk movement.

#### 4.3.2 Performance of reach-to-grasp and lift-and-hold tasks

The somatosensory-motor task involves reach-to-grasp and lift-and-hold of the stationary cylindrical object. The participant reaches forward by flexing the shoulder and extending the elbow. The participant grasps the cylindrical object with a '5-digit multi-finger precision grasp' (Napier, 1956; Zatsiorsky & Latash, 2008) and lifts it to a height of 2-5 cm for 5 seconds before lowering it back on the table. The 5

seconds is sufficient time for correct positioning of the fingers on the cylinder to ensure stable grasp and allows time for sensing and interpreting of tactile cues. The position of the fingers is not constrained on the target objects. Prior to starting the treatment trials, the task is first described to the participant, followed by two practice trials with the less affected hand for familiarization with object size and weight. A rest of 10 minutes is given after completion of the first block or whenever the participant feels fatigued.

#### 4.3.3 Conditions of practice: vision vs no vision

To maximise improvement in the stimulus discrimination being trained, attentive exploration of the stimuli is performed with vision and without vision (Carey, 1993; Carey et al., 1993; Napier, 1956; Zatsiorsky & Latash, 2008). These two conditions are standardised across the COMPoSE intervention. For *grasp pressure training*, the first three repetitions are performed *with vision* to facilitate use of visual feedback from the Tactarray pressure measurement system and the last three repetitions are performed *without vision* to foster transfer of skill and to increase somatosensory demands of the task (see Figure 2a).

For training of *stimulus discrimination of each somatosensory-motor combination*, vision is occluded every time an object with a different surface property is presented for the first time. In contrast to the grasp pressure training, the first three repetitions are performed *without vision* for the somatosensory training part to allow participants to focus specifically on the somatic sensations (Carey, 1993; Carey et al., 1993;

Napier, 1956; Zatsiorsky & Latash, 2008); otherwise vision may take over tactile and proprioceptive senses in some instances(Clark, 1986; Lederman et al., 1986). The last three repetitions are performed *with vision* for the motor training part since it is required to guide our motor actions in real time(Goodale & Humphrey, 1998) (see Figure 2b).

Insert Figures 2a and 2b here

#### *4.4 Targeted feedback about both motor and somatosensory attributes of the task and performance*

Intrinsic feedback processes are disrupted after stroke, so extrinsic feedback is important for people with stroke to learn a motor skill and improve movement efficiency and consistency of performance(van Vliet & Wulf, 2006). Therefore in COMPoSE, knowledge of results is provided about the outcome of the task, including movement errors and movement successes. Knowledge of performance is also provided in the form of verbal statements and are worded to facilitate an external focus of attention as this has been found to improve RTG performance(Durham et al., 2014). The Tactarray distributed pressure measurement system is used to give on-line sensorimotor feedback on tactile pressure relative to preferred, minimum and maximum grasp pressures. Somatosensory feedback is also provided on the sensory tactile parameters (crushability, texture and friction). Motor feedback is provided on kinematics of movement such total movement duration, total distance moved, start time of grasp aperture, peak aperture size.

Feedback is provided on all trials(Durham et al., 2014) for grasp pressures, somatosensory and motor parameters of the task.

#### 4.4.1 Tactile pressure feedback using Tactarray distributed pressure measurement system

On-line tactile pressure feedback is provided by the Tactarray system. It consists of matching the pressure exerted by the affected hand to a standard reference (i.e. the pressure used by the less affected hand)(Carey, 2011; Carey et al., 1997). The standard reference for tactile pressure feedback is determined by the measures of pressure exerted for 5 seconds during a 5-digit multifinger prehension with the less affected hand during 3 levels of grasp pressure: 1) preferred grasp; 2) minimal grasp, and 3) maximal grasp. A value and a graph (Chameleon TVR 2012 software) are displayed for each grasp pressure on a computer screen. The standard reference is determined prior to the start of each intervention session. To ensure calibration of the response with the affected hand, the pressure exerted by the affected hand is matched to that of the less affected hand for each level of grasp(Carey, 2012a; Carey et al., 1997). Knowledge of results is provided based on the value and graph display of the standard reference. Knowledge of performance concerns the opening/closure of hand and fingers to adjust the pressure exerted on the Tactarray cylinder. Tactile feedback addresses specific grasp deficits, such as on correct finger positioning on the object for optimal stability of object; development of appropriate grasp forces for safe grip; appropriate individual finger force production

with respect to its contribution to grasp force during a 5-digit multifinger grasping; consistency in application of grasp forces; appropriate scaling of forces on the object (not pressing too much or too little to prevent slip or tilt); and timely release of object being held(Hsu et al., 2012; Kurillo et al., 2005).

4.4.2 Somatosensory feedback on combined somatosensory-motor variables, with calibration of the altered sensation.

Somatosensory feedback improves tactile discrimination(Carey et al., 2011). Somatosensory feedback is provided on four main aspects of active exploration of the surface properties: 1) on the accuracy of response by allowing the client to see the correct response (e.g. smooth or rough object surface), the therapist telling the client what the actual texture is, or by exploration of the stimulus by the client with the other hand; 2) on the actual tactile sensation and critical difference of the somatosensory attribute being trained; 3) guidance on movements of the hand and exploratory finger movements that are most optimal to explore the tactile sensory attribute e.g. static contact, lateral motion, contour following; and 4) using calibration, which involves comparison of the tactile sensation felt by the affected hand with the less affected hand(Carey, 2012a; Carey et al., 2011).

4.4.3 Motor feedback on movement performances, with calibration of motor response

Motor feedback is essential to improve kinematic performances of RTG(Cirstea & Levin, 2007; Durham et al., 2014). Motor feedback is provided using attentive exploration strategies applied to kinematic performances and is based on matching the kinematic measures of the affected upper limb to a standard reference (less affected upper limb). The standard reference for online motor feedback is determined prior to the start of each intervention session. To ensure calibration of the motor response, the kinematic measures of the affected hand are matched to those of the standard reference (less affected hand) during reaching and grasping.

To facilitate active learning, motor feedback is provided on movement duration of hand transport (using a stopwatch) during the first training block and on grasp aperture (qualitatively) during the second training block. Feedback on movement duration was chosen because it is a prominent kinematic variable associated with motor impairment and functional capacity(Li et al., 2015). Moreover, task parameters that emphasise speed positively influence reaching strategies with the more-affected upper-extremity(Massie & Malcolm, 2012). Hence, encouraging the affected upper limb to perform RTG with the same movement duration as the less affected hand positively reinforces the affected arm to improve its preferred speed. Feedback on grasp aperture was chosen because the ability to actively extend the fingers and thumb post-stroke for grasping and releasing is a key criterion for participation in activities of daily living(Wolf et al., 2006). Therefore, increased grasp aperture as a result of improved digit extension is an important motor skill to enable effective object handling. Feedback also focuses on: speed of grasp formation; pre-shaping of hand

and fingers; maximum grasp aperture as soon as reach starts; efficient closing of fingers in a single smooth movement.

#### *4.5 Varied and intensive practice*

##### *4.5.1 Varied practice*

Varied practice is integrated in COMPoSE training to reduce anticipation effects and make the intervention more challenging to enhance learning and to encourage the transfer of skill to the different tasks (Krakauer, 2006). In the last five sessions, the two somatosensory variables within each somatosensory parameter are presented in a random order, e.g., for texture parameter, first the smooth texture is presented followed by the rough texture, then either the smooth or the rough variation (Figure 3). This varied practice keeps the participant engaged in the task in order to promote active learning.

Insert Figure 3

#### Item 5. Who provided: Description of the expertise, background, and training given to intervention provider

The COMPoSE intervention is expected to be delivered by one physiotherapist or occupational therapist, with expertise in neurorehabilitation and upskilling in the COMPoSE approach. For the Phase II study, the research therapist was upskilled in RTG training and SENSE therapy by the originators of those interventions.

Item 6. How: Mode of intervention delivery

The COMPoSE intervention is provided individually and face-to-face to participants.

Item 7. Where: Location of intervention delivery

The proof-of-concept COMPoSE study is being conducted in the motion analysis laboratory at the Hunter Medical Research Institute (Newcastle, Australia). It is anticipated that future delivery may be in a rehabilitation setting or specialist clinic. A quiet room is recommended to facilitate focused attention to the learning demands of the therapy.

Item 8. When and How Much:

Intensive practice with a high number of repetitions is provided through repeated performance (Birkenmeier et al., 2010; Pollock et al., 2014) of the *reach-to-grasp and lift-and-hold* task. Within a session the participant aims to complete 6 repetitions of each somatosensory-motor combination parameter within the training matrix. An example of the sequence and number of repetitions for combinations practiced throughout the matrix is illustrated in Table 2. The actual number of repetitions completed will vary with the capacity of the individual and where the individual lies in the learning continuum. For example, during early phases of learning the individual may be expected to take more time to integrate the feedback and thus the number of repetitions may be lower. Each session lasts approximately 1.5 hours (with rest) and participants are encouraged to perform up to 36

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combinations of somatosensory-motor parameters within a session, each with 6 repetitions (216 repetitions in total). Ten training sessions are proposed to be delivered over 3 weeks at a frequency of 3-4 sessions per week, consistent with skill based learning approaches and current sensorimotor interventions(Carey et al., 2011).

#### Item 9. Tailoring: Individualising the intervention

The COMPoSE intervention is a structured therapy that is designed to address the somatosensory and motor challenges a stroke survivor may experience in the fundamental reach-to-grasp and lift-and-hold tasks required to perform a wide range of daily activities. All participants will receive the intervention in the same order as per the standardised matrix. This is to establish the framework for the key parameters selected and the levels of difficulty. Although the training is structured to cover the key parameters of training important to this task, the emphasis on somatosensory and/or motor feedback given for each somatosensory-motor combination task has scope to vary according to the needs of the individual. The intervention is also individualised based on rate of progression and the number of repetitions achieved within and across sessions. It is expected that the pace of progression through the learning tasks provided in the matrix will vary with severity of impairment and learning capacity. If the scheduled section of the training matrix is not completed in a particular session, the participant starts the next treatment session where the intervention was previously stopped so that the participant is exposed to all of the somatosensory-motor combinations.

## DISCUSSION

Performance of complex tasks in everyday life requires successive and fast sensorimotor integration. However, strategies involving integrated somatosensory-motor retraining of the hand and arm have been poorly addressed by current stroke rehabilitation research. It could be argued that any manual task inherently involves the integration of both somatosensory and motor function. By combining and integrating several somatosensory and motor parameters within a task, and by frequently varying these parameters and the conditions of practice in the COMPoSE intervention, the sensory and motor pathways are continuously challenged to respond synchronously and more often to these changes. It is proposed that this integrated somatosensory-motor retraining approach could optimise processes that drive reorganisation of brain activation and neural connectivity to a greater extent leading to maximal functional improvement in the paretic upper limb compared to training somatosensory and motor function sequentially, which might be a suboptimal approach to relearn functional movements. Therefore, in order to maximise improvement of functional movements such as reach-to-grasp after stroke, it is considered essential to address key sensory systems involved in this task (Kato et al., 2015). It should be noted that even though the COMPoSE intervention does not directly target proprioceptive training, the latter is inherent in the reach and grasp aspects of the task and feedback is provided in part with the motor training. For

example, the proprioceptive demands are increased under no vision conditions and feedback is provided with feedback on movement distance and grasp aperture.

The TIDieR checklist was a very valuable tool facilitating the reporting of essential information on the content of the COMPoSE intervention that could be useful for researchers and clinicians, even though items 10-12 in the TIDieR checklist, which pertain to an exploratory trial are not reported here.

## **IMPLICATIONS FOR PRACTICE**

The COMPoSE intervention offers a learning based approach that involves processing of multisensory information from the tactile, proprioceptive and visual systems, which are simultaneously integrated with motor function. A novel aspect of this intervention involves using Tactarray as a means of re-training sensorimotor function for scaling of grasp forces, which is crucial for dexterity. This could encourage skill transfer for adaptive control of grasp forces at the fingertips in response to surface feature detection and discrimination. Therefore, COMPoSE might be more effective in optimising functional improvement of upper limb after stroke compared to an intervention involving a single sensory approach.

The standardised training matrix further facilitates the delivery of the COMPoSE intervention as it explicitly and systematically incorporates all the combinations of somatosensory-motor parameters, conditions of practice, feedback delivery focused on somatosensory and motor aspects as well as adaptive pressure

outputs. The matrix provides adequate standardisation so that the intervention could be replicated by clinicians and researchers.

## CONCLUSION

A “COMBined Physical and somatoSEnsory training” (COMPoSE) intervention to improve upper limb function after stroke has been described and a standardised training matrix has been developed to facilitate intervention delivery. The COMPoSE intervention *combines* somatosensory and movement training, delivered *synchronously, within the same treatment and within the same task.*

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### Title page

**Title:** COMbined Physical and somatoSEnsory training (COMPoSE) after stroke:

*Development and description of a novel intervention to improve upper limb function*

**Running title:** COMbined Physical and somatoSEnsory training after stroke

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**Table 1. Indices of difficulty in COMPoSE**

Object parameters varied		Parameters constant	Fitts' Index of difficulty
<i>Width (cm)</i>	<i>Distance (cm)</i>	<i>Speed</i>	
5	15	preferred	< 2.585
5	30	preferred	<3.585
7.5	15	preferred	2
7.5	30	preferred	3

Fitts's Index of difficulty quantifies the difficulty of the movement task: as the ID increases, the difficulty of the movement increases(Fitts, 1954)



**Table 2. Examples of operationalisation of part of the training matrix**

Object width/cm	Object distance/cm	Selected grasp pressure		Crushability		Texture	
				<i>Soft plastic cup</i>	<i>Hard plastic cup</i>	<i>Felt</i>	<i>Sand paper</i>
				<i>Tactarray device</i>			
5	15	Preferred					
5	15	Preferred					
5	15		Minimum				
5	15		Minimum				
5	30			Maximum			
5	30			Maximum			
5	30				Soft		
5	30				Soft		
5	30					Hard	
5	30					Hard	
7.5	15						Smooth
7.5	15						Smooth
7.5	15						
7.5	15						Rough
7.5	15						Rough
7.5	30						
7.5	30						
7.5	30						
7.5	30						

No. of reps: Number of repetitions

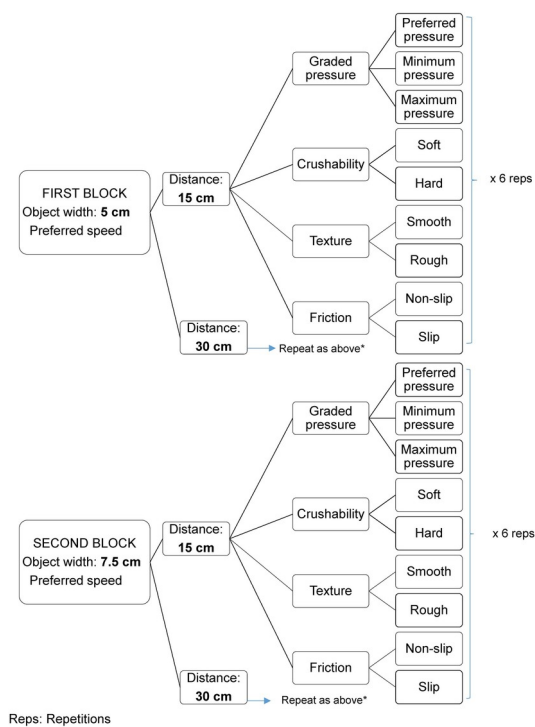
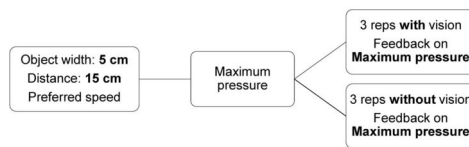


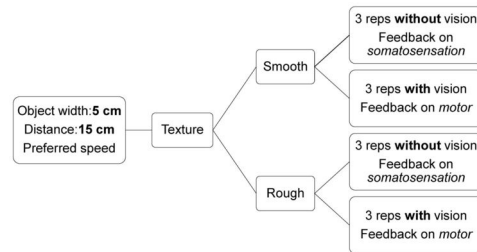
Figure 1. COMPoSE Standardised training matrix

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Reps: Repetitions

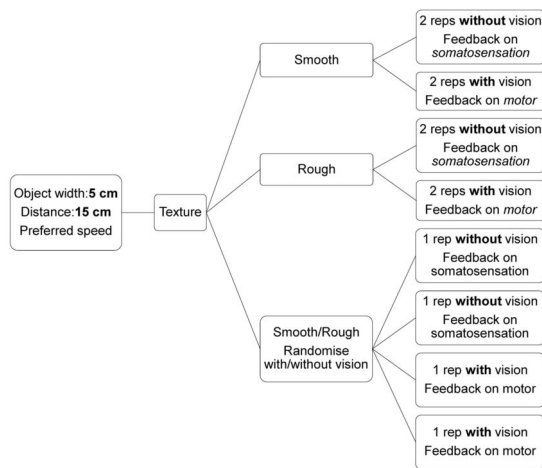
**Figure 2a:** Conditions of practice and number of repetitions with or without vision: Tactile pressure feedback task: Graded pressure - Maximum pressure variable



Reps: Repetitions

**Figure 2b:** Conditions of practice and number of repetitions with or without vision: Somatosensory-motor combination feedback task: Distance and Texture - Short distance parameter and texture

PRI\_1748\_f2.jpg



Reps: Repetitions

Figure 3. Varied practice for somatosensory-motor combinations: with or without vision e.g. short distance variable and texture

PRI\_1748\_f3.jpg