REVIEW REPORT

Augmented Feedback and Physiotherapy Practice

Adri Hartveld
John R Hegarty

Key Words
Physiotherapy, feedback, effectiveness, computers, review.

Summary
Research on aspects of feedback is reviewed. Movement science and neurophysiology literature shows that augmented feedback from a person or an object enhances performance and can improve motor learning. Physiotherapists systematically use augmented feedback in movement therapy and its effective use is considered. Different types of feedback are used during therapy. A greater use of feedback aids could improve treatment outcomes, particularly at the early stages of the treatment plan. Electronic computer-based feedback is increasingly available and can be an effective addition to movement therapy.

Introduction

Physiotherapists treating with exercises, for example children who have balance difficulties caused by cerebral palsy, frequently give feedback during their treatment. However, what scientific basis is there for the use of such feedback? Moreover, can the effectiveness of this feedback be improved? This article addresses these issues; in future editions of *Physiotherapy* an outline of newly developed tools and experimental data will be presented.

What is 'feedback'? Movement is a homoeostatic, or self-balancing, process. Neurological control of movements requires not only neural impulses to signal that muscles (or muscle groups) be contracted but also that information is received back by the appropriate control centres in the brain to give information on the resultant movement (fig 1). This is 'feedback'. At its simplest it can be seen as analogous to an electrical circuit, for example, controlling the domestic central heating, where heating is turned off or on by the action of a thermostat which senses room temperature. Unless there is central or peripheral damage which prevents feedback from occurring, all movement involves feedback; this may be termed 'intrinsic feedback'.

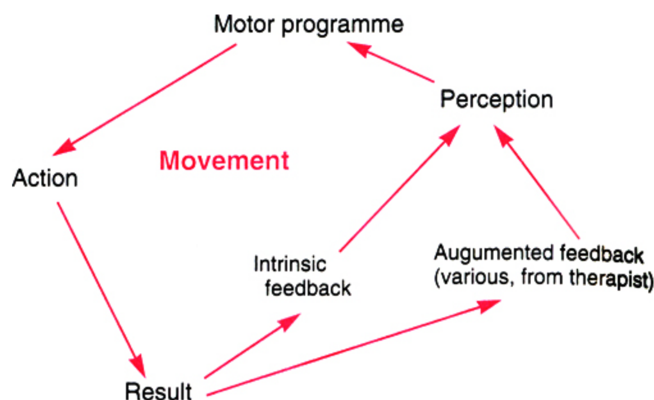

Fig 1: Movement – a dynamic interaction between action and perception with feedback a key component

Exercise therapy is provided by physiotherapists for people whose movements are considered insufficient, or abnormal. It essentially consists of instructions to patients to make movements and the provision to patients of feedback about the results of movements. This feedback may be given verbally or non-verbally (for example, by modelling), or by using equipment (such as video, exercise apparatus, computers, biofeedback machines, and so on). In all of these cases, feedback is being provided in a way which augments the naturally occurring, intrinsic feedback. Indeed, the provision of such 'augmented feedback' may be the essence of exercise therapy for patients – since they would not need to be treated if naturally-occurring, intrinsic feedback were sufficient for their condition to improve.

'Augmented feedback' is, therefore, information provided from an external source, which is additional to the perception of the mover. It can be verbal or non-verbal, and it can be provided concurrently, immediately following, or much later than the action.

The research literature uses a variety of terms with similar meanings. 'Extrinsic feedback', for example, equates with 'augmented feedback'. 'Biofeedback' is a form of augmented feedback, when electrical instruments are used to amplify physical parameters, such as electrical activity in muscle, which are then fed back to a patient. 'Knowledge of results' (KR) is information provided, after a response, that tells of the learner's success in meeting the environmental goal (Salmoni *et al*, 1984). In addition to helping

patients to see the results of their action (KR), therapists frequently give feedback about how they did it, or 'knowledge of performance' (KP). Newell *et al* (1985), and Newell (1991) give detailed discussions of these distinctions in terminology.

The long-established psychological theories of the reinforcement of behaviour can also be used in analysing adherence to exercise. Martin and Dubbert (1985) reviewed many different studies that show that feeding back information regarding the effects of the exercise and providing different forms of reward increases the likelihood of a person continuing the exercise programme.

Reviews of feedback from the movement science literature, which has built on nearly a century of research from such disciplines as psychology (see Annett, 1969 for a review), are given by Mulder and Hulstijn (1984), Salmoni *et al* (1984), Newell *et al* (1985), Thelen (1989), Winstein (1991), Mulder (1991), and Broker *et al* (1993). While these describe studies done in non-clinical settings, it seems safe to assume from them that feedback is essential to all co-ordinated movement, and to learning new movement patterns.

Sources of Feedback During Physiotherapy

Augmented feedback is given by therapists in three broad ways: personally either verbally or non-verbally; by strategically using equipment to enhance intrinsic feedback; and by using equipment which gives artificial feedback (such as information on a dial, or a tone).

Feedback from Therapists

Therapists frequently give verbal or non-verbal feedback during therapy. While this kind of augmented feedback appears not to have been analysed often in the literature, the comments that have been made about it highlight its weaknesses. Turnbull (1982) notes that this kind of feedback is based on subjective opinion so that its accuracy or consistency may vary. Mulder and Hulstijn (1984) suggest that it is not only subjective, but superficial and slow.

However, such feedback is versatile, and it may be assimilated more easily by a patient than other types of feedback. It is flexible. It can reflect qualitative aspects of performance which instrumentation may not be able to detect. It is part of social interaction and this aspect of the therapist-patient relationship can be used to motivate and encourage. Moreover, it requires no special equipment and so is portable and cheap.

Feedback from Objects

Frequently, physiotherapists actively organise the environment so that the patient receives additional feedback from the effect of his or her movement on an object. Van der Weel *et al* (1991) demonstrated this with cerebral palsied children. They compared the range of movement in the wrist on an abstract task to that on a concrete task. Children were asked to pronate and supinate their elbow either with or without the requirement to hit a drum with a drumstick. Movement range for the children with the more practical task was larger than for the abstract task.

The characteristics of this kind of feedback obviously depend on the nature of the task and its relationship to the object or equipment used to make it more concrete. However, as a general rule, it can be said that the feedback reflects only the end result of the movement. The patient does not get much information on the way the task is performed. However, it improves the functional realism of the task, and so may be helpful in fine-tuning movements to improve skills of daily living. And it has a motivational advantage when the task produces results which are desired by the learner.

Artificial Feedback from Equipment

Feedback from electronic or mechanical aids, many kinds of which have been developed for use in physiotherapy, is artificial in that it is an electronically (or mechanically) mediated representation of a physical process. Sensors are designed to detect physiological parameters and signals from them are amplified and converted into an analogue form such as a tone, lights or a meter reading. Patients can thus get precise, rapid and quantitative feedback on the specific parameter being measured.

This form of feedback has been characterised as quantitative, objective, accurate and immediate (Mulder and Hulstijn, 1984). However it must be pointed out that reliable, objective and accurate data can be obtained only with instrumentation that measures what it is intended to measure, that is well calibrated and that is correctly applied in relation to the human body. This depends greatly on the manufacturing process, the servicing and the manual application. The instrument readings need to be interpreted correctly in order to give patients valuable and not false feedback.

Feedback equipment can be inflexible and costly. It can malfunction. Most equipment is not readily portable, and the information has limited and

specific application, unlike that of a human therapist who can give feedback on a range of aspects of a variety of movements.

Neurophysiological Aspects of Feedback

Lesions of the central nervous system (for example, after strokes, or in cerebral palsy) can distort feedback loops and can result in balance difficulties and other motor impairments. Research in neurophysiology should therefore be taken into account in considering the importance of feedback in motor control.

It has long been debated how far the nervous system is able to compensate for lost function (plasticity). A variety of studies have shown that the brain has extensive capacity to utilise intact brain cells to compensate for brain areas that have been permanently destroyed – see, for example, Wall (1980), Bach-y-Rita (1980) and Tallis (1984). The adaptability of synapses has been known for many years and different theories of this process have been postulated (Changeux and Danchin, 1976). Synapses appear to open up with use of the neural pathway and close with disuse. This gives support to the assumption of physiotherapists, which is almost a fundamental rationale of their profession, that individuals can learn new skills even if they have severe neurological impairments. Evidence from research on what is happening when they do, however, is relatively sparse.

Harrison (1988) reviewed suggestions in the neurophysiology literature that abnormal and immature spinal inter-neuronal circuits play a role in spastic cerebral palsy. Although the number of relevant studies is very small, Harrison (1988) suggests there are indicators that long-term training can produce changes in segmental response, both by altering inhibition from the brain and by producing lasting changes in spinal inter-neuronal organisation and responsiveness.

Harrison and Connolly (1971) showed that people with spastic cerebral palsy could learn to recognise, isolate and produce on command fine degrees of neuromuscular activity for which augmented feedback was made available. However, they realised that this type of control would only carry over into functional movement tasks when the patients learnt to monitor, interpret and utilise the feedback information naturally available to them. This is a difficult challenge for therapists and patients: to encourage the development of intrinsic feedback cues in order to control more complex tasks and to decrease reliance on feedback equipment while at the same time providing just enough augmented feedback to maintain motivation and the desired movement pattern. It is possible that continuous augmented feedback discourages people from discovering their own intrinsic cues (Harrison, 1977). When they become reliant on this feedback they will not be able to use it for functional tasks outside the treatment environment.

It follows from studies showing that neural control pathways can change, that a particular movement pattern should become easier with the repetition of frequent practice. But undesirable reflex patterns could also increase through frequent stimulation. Particularly with spasticity (hyperreflexia), neuronal pathways for abnormal movement patterns are likely to be developed since a low-intensity stimulus can be enough to set off primitive reflex movements. Patients need to be able to select between desirable and primitive motor patterns. This emphasises the key importance of precise augmented feedback used in conjunction with the intrinsic feedback available to the individual.

When feedback is effective it may produce long-lasting changes in nervous system functioning, perhaps even to reduce abnormal reflex movement. On the other hand, ineffective feedback may reinforce abnormal movement patterns.

Feedback Aids

While there is a large literature on the role of feedback in learning and performance from the disciplines of psychology and movement science (see above), it does not refer to physiotherapy. Besides the more theoretical data from the social sciences, many reports on electronic feedback aids can be found the rehabilitation literature. It is to this body of research we now turn. We shall consider the range of applications studied and consider the research evidence for the effectiveness of this mode of feedback.

EMG-biofeedback

In the rehabilitation literature EMG-biofeedback is by far the most commonly presented artificial feedback aid. The electromyographic activity of a particular muscle group is presented in visual or auditory form to a patient, who uses the feedback signal to learn discriminative control of the muscle.

Basmajian (1981) reviewed a range of reports on EMG-biofeedback as therapy for stroke patients. Most studies showed good results with a particularly high success rate being reported with patients with a footdrop from three months to 6.5 years after their stroke. In contrast, in the brief review of Prevo *et al* (1982) the results from EMG-biofeedback appear much more limited. Functional changes seemed particularly small

with this type of treatment. It is obvious that stroke patients can decrease the activity in spastic muscles and increase the activity in weak muscles. However the clinical use of this is not proven because the relationship between an increased control over single muscles and the general functioning of the patients studied has not been investigated.

Wolf (1983) critically reviewed 33 studies on this form of feedback training with stroke patients. He concluded that this treatment could enhance function in stroke, but it was not clear which criteria needed to be applied to achieve success.

Sprenger *et al* (1979) and Lucca and Recchiuti (1983) reported on increased strength gains, compared to controls, when EMG-biofeedback was used in strength training programmes. Draper (1990) showed that a recovery rate of the quadriceps femoris muscle following anterior cruciate ligament reconstruction was quicker when strengthening exercises were aided by EMG-biofeedback. However, she discussed whether this was a direct result of the learning that is inherent with any information-based training technique or whether the more detailed assessment of performance and goal-setting led to increased motivation to produce more force during exercise.

Joint-angle feedback

Electrogoniometers are used to detect changes in joint angles and transmit that information to usually portable processors that give an auditory signal when a certain (adjustable) threshold of joint angle has been reached.

Basaglia *et al* (1989) reviewed studies on correction of hyperextension of the knees with electrogoniometry feedback and noted good results. In their research they found significant improvements in knee angle during walking at the end of treatment and at one year follow-up. However, they found no significant gains in walking speed. A big weakness in these studies is the lack of controls. Consequently one cannot be sure whether the feedback device induced the improvements.

Olney *et al* (1989) used a computer to give simple visual and auditory feedback of knee angle changes during gait. Although the results in this case study were good, the feedback and recording system needed development (see below).

Spatial Awareness

Halpern *et al* (1970), Wooldridge and Russell (1976) and Leiper *et al* (1981) reported on their devices to give cerebral palsied children precise auditory and visual information regarding the spatial position of the head. They found beneficial results with many of the children. Motivation, however, did seem to be a strong determining factor and one-to-one attention was often needed to encourage the children to try to reach the targets. The study shows that additional information is not always enough; feedback also needs to be directly or indirectly rewarding.

Feedback to Heelstrike in Walking

Different pressure-sensitive pads have been developed to feed back information on heelstrike to the patient. Conrad and Bleck (1980), Dalton (1987) and Seeger and Caudrey (1983) all noted improved heelstrike in children with equinus gait. However the long-term improvement in these children was either not evaluated or found to be not significant. Miyazaki *et al* (1986) developed a portable limb-load monitor to limit weight-bearing. In their trial the patients with lower-limb fractures were able to adjust the load on the affected limb to below the prescribed threshold only when the feedback tones were turned on.

Weight Transference in Standing

Centre-of-pressure, the vertical projection of centre-of-gravity on the supporting surface, is an important parameter of functional movements. In order to regain full mobility a person needs to be able to control a dynamic transfer of weight from one foot to the other and forwards and backwards.

Lord *et al* (1982) designed a video system in which the centre-of-pressure under the feet was shown to patients on a screen in front of them. With this equipment the subjects stood on a force platform which had a load cell under each of the four corners to register vertical force. The signals from the load cells were computed so that a cursor on the screen accurately represented the patients' centre of pressure. In this way postural sway and voluntary weight shift could be practised with tasks and games set by therapists. The authors felt that it was particularly successful in motivating patients to re-establish basic motor skills by repeated and directed practice.

Shumway-Cook *et al* (1988) used a very similar system in their trial with 16 hemiplegic patients who had had a stroke less than six months before to the experiment. Experimental and control groups received training of standing balance from their regular therapist for 15 minutes twice daily. The experimental group used a static force plate system to control their postural sway while the control group used only verbal, tactile and visual (mirror) cues from the therapist. The average lateral sway in standing had clearly reduced in both groups. The mean lateral displacement of sway was significantly more reduced in the experimental group than in the control group.

In a similar experiment Winstein *et al* (1989) compared 17 hemiplegic patients receiving conventional standing balance and weightshifting training with 17 matched hemiplegic patients practising balance and weightshifting with a visual feedback aid. All their patients, who only recently had had a stroke, also received a comprehensive daily physiotherapy regime. The feedback equipment included a force-plate linked to a screen that displayed the changing centre-of-pressure while the patients were exercising. Augmented feedback was withdrawn intermittently to aid learning – see Winstein (1991) for rationale. At the end of the training period (three to four weeks, five days a week, 30-45 minutes standing practice per day) the patients who had exercised with the visual feedback equipment had more symmetrical stance. However there was little group difference with regard to stability and gait parameters.

For most physiotherapy departments, force plates – mainly available only in laboratories – are too expensive to be used as a regular exercise aid. Less expensive and cumbersome equipment has been developed recently. Sackley *et al* (1992) described treatment with the 'SMS balance performance monitor', which is a lightweight portable unit that gives objective visual information on weight distribution and postural sway with different coloured lights and auditory signals. The authors outline how a variety of exercises and functional skills can be practised with a patient standing on the two footplates and receiving visual feedback from the movable monitor. They found that both staff and patients enjoyed working with the equipment, that it was easy to use, and that it gave accurate and quantitative information to both patients and therapists. The authors did note that, with the tool in the present form, the patients needed constant supervision by a physiotherapist to prevent the use of abnormal postures.

Sackley and Baguley (1993) reported on two single-case experiments in which weeks of visual feedback training with the SMS balance performance monitor was compared with weeks of conventional physiotherapy. After every week of visual feedback training, the balance of both patients had improved, in marked contrast to the development of balance after weeks of conventional therapy. Large functional improvements took place only after the weeks of training with the balance performance monitor.

Engardt *et al* (1993) used a portable force platform with an auditory feedback output, containing an electronic balance under each foot, as a training device. Forty stroke patients, one week to three months after a CVA, were randomly assigned to an experimental group or a control group all practising rising and sitting down for six weeks, five days a week, 15 minutes thrice daily. The experimental group using the auditory feedback force platform showed a considerably larger improvement in body-weight distribution than the control group. Both groups improved with activities of daily living without significant differences between the groups. From their report it is not clear how much physiotherapy input (time, instruction, oral feedback) was given to both groups of patients during this thrice-daily training.

Biofeedback in Pelvic Floor Re-education

Knight and Laycock (1994) reviewed the use of vaginal and rectal probes sensitive to pressure or EMG activity. The very few clinical trials on such aids show promising results in favour of using such equipment to increase the effectiveness of pelvic floor exercises.

Using Computers to Provide Augmented Feedback to Movement

Over the past years computers have become a common household item and are used in most physiotherapy departments. These versatile electronic aids are obvious and possibly convenient items to be used for visual and auditory feedback. With the commonly available input devices (keyboard, joystick or mouse) computers give feedback only to finger and hand movements. However, some input devices are being developed so that computers and the very wide-ranging software can be used to give feedback to weight shift and balance, and leg, arm and trunk movements. Surprisingly, very few physiotherapists have used home computers to provide augmented feedback to the exercises of their patients. Utilising microcomputers as therapeutic aids has been more common in occupational therapy (Pinnington and Brown, 1994). It has been shown to be an asset in employment, perceptual and cognitive training, communication and leisure (Stoneman, 1985).

Crofts and Crofts (1988) report on EMG with a BBC Microcomputer, the Myolink. Electrical activity of weak muscles is recorded and transferred to the computer. In this way a patient can cause display changes on the computer screen and even play games, receiving feedback from small and larger muscle contractions.

Mackey (1989) used a switch box linked into a BBC microcomputer on which cerebral palsied children pressed down with flat hands. The amount of pressure was represented by a visual display on the computer screen. The experiment showed that the children maintained the targeted pressure for much longer when they received

auditory and visual feedback from the computer.

De Weerdt *et al* (1988, 1989) used load platforms linked to a computer to train stroke patients' balance and weight shift with visual feedback from a monitor. The two single case experiments showed that their ability to shift weight on to the affected leg improved only when training with this device and not with conventional therapy or other feedback training of the arm.

Sackley (1991) used similar equipment in a controlled trial with stroke patients. After four weeks of training in stance symmetry, gross motor function and activities of daily living, a significantly greater improvement was found with those who received visual feedback from a monitor. However, these differences were no longer significant on follow-up.

Recently microcomputers have been used to achieve effective EMG biofeedback and joint angle feedback during walking. Colborne *et al* (1993) demonstrated that instantaneous feedback of muscle activity and joint-angular excursions during gait resulted in significant increases in stride length, walking velocity and gait symmetry with stroke patients. Colborne *et al* (1994) used this system with cerebral palsied hemiplegic children. EMG biofeedback was associated with improved gait symmetry and increased ankle power for push-off, but physiotherapy without biofeedback was more effective in changing other gait parameters.

The Compex board developed at Keele University (Hartveld, 1993a,b, 1995) is a centre-of-pressure feedback aid that is commercially available and can be used with a wide variety of computers.

Factors Affecting the Value of Feedback

It is important to consider whether the way in which physiotherapists use feedback during treatment is effective and if it can be improved. We will use evidence from the movement science and neurophysiology literature to evaluate treatment effectiveness and to give suggestions on how to improve therapy.

Since it has been shown that feedback is essential to movement control, it would be helpful if a way could be found of maximising the value of feedback given in individual treatment settings. However, giving precise and effective feedback to the appropriate underlying neural motor patterns may be difficult. For instance, feedback may not be precise enough to inform the motor programmes controlling particular movements; or it may not be forceful enough to be noticed by the learner. Ways in which feedback can be made more precise, or more noticeable, are therefore important to physiotherapists. Examples from the literature follow which show the effects of manipulating the frequency of feedback and the time-delay between the action and the feedback. Effects on 'motor performance' (the motor behaviour at the time) are clearly different from 'motor learning' (lasting changes in a person's movement, changes in motor behaviour that are maintained after treatment has been stopped).

In their critical review Salmoni *et al* (1984) highlighted that increasing the relative *frequency* of knowledge of results (KR) increases performance when acquiring a skill. However, a task is retained better with a less frequent KR. In other words, after training the learner will perform better when he has already been exposed to trials without this augmented feedback during the training sessions. He needs to learn to use his intrinsic feedback mechanisms. The same trend is emphasised in the review by Newell *et al* (1985) on 'augmented information'.

Decreasing the *time-delay* between the movement and KR tends to enhance the performance. However there are several indications that making the response immediate can be detrimental to learning and retention of a skill. Newell *et al* (1985) noted that augmented information during slow movements (with virtually no time-delay) was especially poorly retained by the subjects in a range of experiments. It may be that early in the learning phase, the patient needs more immediate feedback to 'get the idea of the task', but care should be taken to prevent over-reliance on the extrinsic feedback at the expense of the development of an internal reference of correctness (Winstein, 1991).

Other reviews of movement science data (Mulder and Hulstijn, 1984; Carr and Shepherd, 1989; Newell, 1991) highlight the following with regard to augmented feedback:

- Feedback should be *plentiful*. The more feedback available, the more effort will be put in, the more efficient are the processes of error detection and correction.
- Feedback should be *precise*. A strong motor programme can be developed only with feedback which gives precise information.
- Feedback should be given on *kinematic and kinetic aspects* of movement (how the person moves). This facilitates motor learning and performance better than just feedback on the end result of the movement.
- Feedback should be *functionally related*. The practice of meaningful, goal-directed 'action' (functional movement pattern) is superior to just

exercising an isolated movement in learning a skill.

- Feedback should be *available from errors as well as correct responses*. The learner achieves control over his environment through trial and error. He selects from a set of responses those that are followed by positive consequences. It means that in order to learn normal motor tasks, he needs to experience both correct and incorrect movements.
- Feedback should be *desirable*. The strength of the reinforcement available affects the movement behaviour; the more the learner wants to have the feedback, the more efficient are the processes of error detection and correction.

Choosing the Type of Feedback

The question arises as to how best feedback should be given. Feedback can be categorised along several dimensions. The table characterises oral, object and electronic feedback on a range of dimensions. The characteristics are not definite and depend on the user of augmented feedback. For example, oral feedback is not always subjective and superficial. A therapist's visual estimation of a joint angle might be quite accurate and might be conveyed to a patient with enough detail. However, biofeedback aids have the advantage of being able to obtain information on 'invisible' biological parameters. This information is fed back to the patient objectively and accurately if the equipment has been set up correctly and is working reliably.

Characteristics of three different forms of augmented feedback

Oral feedback (eg responses such as corrections and praise)	*Object feedback (eg toys, crafts, tasks)*	*Electronic feedback (eg centre of pressure. EMG, electrogoniometry. heelstrike)*
Responds to movement parameters (L/P)	Only shows *result* of movement	Most devices respond to movement parameters (L/P)
Qualitative	Qualitative + quantitative	Qualitative (L/P)
Subjective	Objective	Objective (L/P)
Superficial		Accurate (L/P)
Slow	Often quick	Quick/immediate (P)
Infrequent (L)	Often infrequent (L)	Frequent (P, some L)
Adaptable (L/P)	Hard to adapt to specific movement; client quickly reverts to compensatory movements	Time-consuming to set up +resistant to changes of need
Expensive over time	Can be inexpensive (L/P)	Mostly expensive
Can be applied to functional skills	Often applicable to functional skills (L)	Mostly not applicable to functional skills (L)
Social interaction – gives strong reward or incentive (P)	Tasks can be rewarding unless too hard (P/L)	Short term rewards, eg initial display of movement, computer games (P)

P = advantageous for motor *performance*
L = advantageous for motor *learning*

Augmented Feedback within the Treatment Plan

While general principles affecting the value of feedback can be set out, these need to be integrated into physiotherapy practice. Figure 2 suggests a general scheme for this.

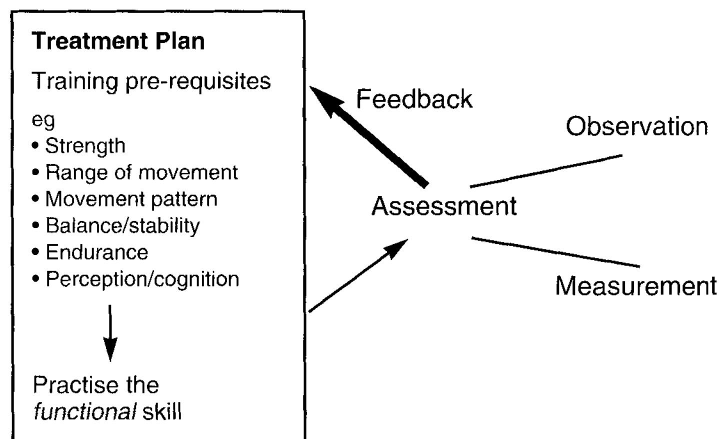

Fig 2: Feedback is integral to the treatment plan

A certain level of strength, range of movement, control of movement patterns, balance, endurance, perception and cognition is needed in order to have functional movement. The ultimate aim of physiotherapy is improved function. However, on assessment, the therapist might identify that certain of these pre-requisites for the desired functional skill are lacking. When these aspects of a patient's motor ability stop him or her from learning daily skills, they often need to be improved first before one can expect good results from functional training.

For example, a person with a very weak quadriceps muscle is unable to walk with a normal gait and at a satisfactory speed. The strength of the quadriceps will need to be improved with strength training before walking is practised.

Figure 2 indicates where different forms of feedback may be particularly useful (a) in the early stages of treatment where motor performance needs to be encouraged; and (b) in later stages where this performance needs to be retained and so motor learning is required.

Literature reviews of scientific research on

strength and endurance development by Matoba and Gollnick (1984), Sale (1987), Kraemer *et al* (1988), Szeto *et al* (1989), and Bohannon (1990) show that quantity and quality of movement are crucial to the development of such aspects of human movement.

Thus, in the early stages of treatment it is crucial to get good motor performance when training the pre-requisites of movement. Feedback with a short time-delay, that is given frequently, is more likely to facilitate a good quantity and quality of movement during the practice sessions. And here, the use of feedback aids, which give precise and frequent feedback, may be specifically beneficial.

However, to achieve the ultimate aim of function, skills need to be learned, ie permanently improved. People learn skills by trial and error. During practice they search through the numerous options of movement. They build up their perceptual motor programme on the basis of the natural and augmented information that they receive during the task. Consistent and frequent feedback to a variety of movement options needs to be given. Both the movement science and the neurophysiology research have shown that an increase in time-delay and a decrease of frequency of augmented feedback is required to ensure lasting changes in motor skills. In these later stages of therapy, progress may best be achieved without the continuous feedback of therapist or feedback aid.

Discussion

Evaluation

Feedback is essential to motor learning and is therefore an important aspect of the treatment process for physiotherapists to consider. There are scientific weaknesses in many of the studies reviewed which must make us cautious about claims for the value of any new therapy, but perhaps especially therapy which relies on equipment. Many of the studies of electronically mediated feedback suggest that positive benefits occur from using it. However, these studies sometimes provide only descriptive data, with no controls for co-varying treatment effects, such as other feedback from the therapist, increased motivation from the novelty effect of a new approach, and so on. Furthermore, they tend to be short in duration, with long-term follow-up not done. Improvements in everyday functional ability may not occur even when specific treatment aims have been achieved. Finally, studies have mostly been done with only one clinical group; similar gains may not be shown with patients who have different clinical conditions.

We should also be cautious in assuming that it is the equipment itself which is the 'active ingredient', as it were, in the therapy. As noted above, many studies show that the presence of the therapist is important, or that motivation to use the equipment may be a problem. The way in which the equipment is used is likely to be more critical a factor in therapy than the mere use of the equipment itself.

Bearing these methodological weaknesses in mind (which apply equally to many other treatment approaches) we nevertheless have a considerable body of evidence which is positive about the use of electronically mediated feedback in physiotherapy. This evidence points to the potential value of considering such devices further, especially for situations where existing therapy approaches are ineffective.

Augmented Feedback as Part of Physiotherapy

Augmented feedback to movement is only a part of the total treatment plan. The experiments on biofeedback have isolated the feedback from other aspects of therapy in order to analyse its effects. However, long-lasting functional improvements can be expected only from a total movement therapy programme, which addresses all individual impairments of a client's motor function.

Most of the reported experiments have been undertaken with stroke patients. Whether such aids are effective with other motor tasks and with other disabled people cannot be ascertained by reviewing only these experiments.

The above methodological weaknessess of the literature need to be kept in mind. The trials and reports on augmented feedback applications do not give us conclusive evidence on what would be the best method of feedback for an individual and how much this could change his or her movement ability. However, as we have seen, we can attempt to use the data from movement science and neurophysiology experiments to choose the optimum mode of feedback at the different stages of treatment. This choice will also depend on treatment settings and patients' individual responses.

Feedback given in person by a therapist must never be neglected. Therapists can respond to a large variety of movement parameters without spending any time on setting up equipment. Personal encouragement can be a strong facilitator to exercise throughout the treatment programme. However, the slowness and superficiality may retard improvement with some patients. They may not be able to perform certain movements and exercises without more immediate and precise augmented feedback. The amount of personal feedback that a physiotherapist can give to any one patient might not be

enough to achieve change in the muscles and nervous system, especially when workloads increase.

Feedback from a large variety of objects can make exercises much more appealing for patients. Movement targets and ensuring that they can reach them, thus giving positive feedback, will ensure greater motor performance than excluding such targets. However care needs to be taken that patients do not use undesirable movement patterns in their eagerness to reach the goal.

Electronic feedback aids can give immediate and continuous feedback to parts of the movement sequence and in this way they can act as powerful facilitators of the pre-requisites of function. However, they are rarely adaptable and mobile enough to be used at the last stage of treatment, that is in the training of functional skills. But they may have a specific role to play earlier in therapy, when frequent practice with specific feedback is needed to improve specific motor patterns.

There is very little research on the long-term everyday use of feedback aids. Most feedback aids are capable of giving only simple visual and auditory signals. For many patients, especially children, this will have appeal for only a limited time. Consequently these aids might not be motivating enough for people to practise for long periods. The expense of such feedback equipment also inhibits the use in physiotherapy departments and in patients' homes. Another obstacle can be the complication of setting up the equipment, which requires both time and expertise.

Future research may valuably consider the increased use of computers. Computers can provide immediate, continuous and exciting feedback to almost any movement parameter so long as the interfacing and the software have been developed for it. The same computer that might already be used for entertainment or administration, might function as a facilitator to a variety of body movements. The recent price reductions of home computers make feedback aids that link into computers an attractive and feasible option for therapists. More development of input devices and software is needed to make the common use of computers as feedback aids a reality.

In a following article in *Physiotherapy* the authors describe the development of an interface to allow home computers, with conventional and unadapted games software, to be used by patients while they practise physiotherapy exercises. Studies of the system show encouraging results, but also reveal the methodological and practical difficulties of applied research in this area.

Conclusion

Both theoretical and clinical research findings support the use of augmented feedback in different forms to improve people's physical abilities. Traditionally, physiotherapists have relied on their speech and touch to inform and encourage their clients. Experiments in movement science, neurophysiology and physiotherapy show that movements can be improved when other forms of augmented feedback are added rationally to the treatment programme. Computers with attractive software may prove beneficial to enhance motor performance.

Authors

Adri Hartveld MSc MCSP is a senior physiotherapist in the North Staffordshire Combined Healthcare NHS Trust, North Staffordshire.

John R Hegarty PhD CPsychol is a lecturer in the Department of Psychology, Keele University, Staffordshire.

Address for Correspondence

Mr Adri Hartveld, Senior Physiotherapist, Tunstall Health Centre, Dunning Street, Stoke on Trent ST6 5BE.

Contribution

This and the subsequent articles have been adapted from a Keele University MSc research thesis by Adri Hartveld with the supervision of Dr Hegarty. They were written jointly. They planned the research work together. Mr Hartveld undertook most of the literature search and carried out the experimental studies.

This article was received on September 7, 1995, and accepted on May 17, 1996.

Source of Funds

The West Midlands Regional Health Authority paid for MSc course fees. Some study leave was funded by the North Staffordshire Health Authority.

References

Annet, J (1969). *Feedback and Human Behaviour,* Penguin Books, Baltimore.

Bach-y-Rita, P (1980). 'Brain plasticity as a basis for therapeutic procedures' in: Bach-y-Rita, P (ed) *Recovery of Function: Theoretical considerations for brain injury rehabilitation*, Huber, Bern.

Basaglia, N, Mazzine, N *et al* (1989). 'Biofeedback treatment of genu-recurvatum using an electro-goniometric device with an acoustic signal', *Scandinavian Journal of Rehabilitation Medicine*, **21**, 125-130.

Basmajian, J V (1981). 'Biofeedback in Rehabilitation: A review of principles and practices', *Archives of Physical Medicine and Rehabilitation*, **62**, 469-475.

Bohannon, R W (1990). 'Exercise training variables influencing the enhancement of voluntary muscle strength', *Clinical Rehabilitation*, **4**, 325-331.

Broker, J P , Gregor, R J, and Schmidt, R A (1993). 'Extrinsic feedback and the learning of kinetic patterns in cycling', *Journal of Applied Biomechanics*, **9**, 111-123.

Carr, J H and Shepherd, R B (1989). 'A motor learning model for stroke rehabilitation.', *Physiotherapy*, **75**, 7, 372-380.

Changeux, J P and Danchin, A (1976). 'Selective stabilisation of developing synapse as a mechanism for the specification of neuronal networks', *Nature*, **264**, 23/30, 705-712.

Colborne, G R, Olney, S J and Griffin, M P (1993). 'Feedback of ankle joint angle and soleus electromyography in the rehabilitation of hemiplegic gait', *Archives of Physical Medicine and Rehabilitation*, **74**, 1100-06.

Colborne, G R, Wright, F V and Naumann, S (1994). 'Feedback of triceps surae EMG in gait of children with cerebral palsy: A controlled study', *Archives of Physical Medicine and Rehabilitation*, **75**, 40-45.

Conrad, L and Bleck, E E (1980). 'Augmented auditory feedback in the treatment of equinus gait in children', *Developmental Medicine and Child Neurology*, **22**, 713-718.

Crofts, F and Crofts, J (1988). 'Biofeedback and the computer', *British Journal of Occupational Therapy*, **51**, 2, 57-59.

Dalton, J O (1987). 'The REM unit with cerebral palsy', *Physiotherapy*, **73**, 6, 310.

Draper, V (1990). 'Electromyographic biofeedback and recovery of quadriceps femoris muscle function following anterior cruciate ligament reconstruction', *Physical Therapy*, **70**, 1, 11/25-17/31.

Engardt, M, Ribbe, T and Olsson, E (1993). 'Vertical ground reaction force feedback to enhance stroke patients' symmetrical body-weight distribution while rising/sitting down', *Scandinavian Journal of Rehabilitation Medicine*, **25**, 41-48.

Halpern, D, Kottke, F J, Burrill, C, Fiterman, C, Popp, J and Palmer, S, (1970). 'Training of control of head posture in children with cerebral palsy', *Developmental Medicine and Child Neurology*, **12**, 290-305.

Harrison, A (1977). 'Augmented feedback training of motor control in cerebral palsy', *Developmental Medicine and Child Neurology*, **19**, 75-78.

Harrison, A (1988). 'Spastic cerebral palsy: Possible spinal interneuronal contributions', *Developmental Medicine and Child Neurology*, **30**, 769-780.

Harrison, A and Connolly, K (1971). 'The conscious control of fine levels of neuromuscular firing in spastic and normal subjects', *Developmental Medicine and Child Neurology*, **13**, 762-771.

Hartveld, A (1993a). 'Computers as augmented feedback in gross movement training. Part 1: Motor skill acquisition', *Keynotes*, **2**,3,3.

Hartveld, A (1993b). 'Computers as augmented feedback in gross movement training. Part 2: The effects of frequent practice,' *Keynotes*, **3**,1,3.

Hartveld, A (1995). 'Computer-based Exercise for Children with Balance Difficulties', MSc Thesis, Keele University library, Staffordshire.

Knight, S J and Laycock, J (1994), 'The role of biofeedback in pelvic floor re-education', *Physiotherapy*, **80**, 145-148.

Kraemer, W J, Deschenes, M R and Fleck, S J (1988). 'Physiological adaptations to resistance exercise', *Sports Medicine*, **6**, 246-256.

Leiper, C I, Miller, A, Lang, J and Herman, R (1981). 'Sensory feedback for head control in cerebral palsy', *Physical Therapy*, **61**, 4, 512-518.

Lord, M, Kinnear, E, and Smith, D M (1982). 'Video aid to rehabilitation of standing balance', *Medical and Biological Engineering and Computing*, **20**, 281-285.

Lucca, J A and Recchiuti, S J (1983). 'Effect of electromyographic biofeedback on an isometric strengthening program', *Physical Therapy*, **63**, 200-203.

Mackey, S (1989). 'The use of computer-assisted feedback in a motor control task for cerebral palsied children', *Physiotherapy*, **75**, 3, 143-148.

Martin, J E and Dubbert, P M (1985). 'Adherence to exercise' in: Terjung, R L (ed) *Exercise and Sport Sciences Reviews*, **13**, 137-168, MacMillan, New York.

Matoba, H and Gollnick, P D (1984). 'Response of skeletal muscle to training', *Sports Medicine*, **1**, 240-251.

Miyazaki, S, Ishida, A, Iwakura, H, Takino, K, Ohkawa, T, Tsubakimoto, H, and Nayashi, N (1986). 'Portable limb-load monitor utilising a thin capacitive transducer', *Journal of Biomedical Engineering*, **8**, 67-71.

Mulder, T (1991). 'A process-oriented model of human motor behaviour: Toward theory-based rehabilitation approach', *Physical Therapy*, **71**, 2, 82/157-89/164.

Mulder, T and Hulstijn, W (1984). 'Sensory feedback therapy and theoretical knowledge of motor control and learning', *American Journal of Physical Medicine*, **63**, 5, 226-244.

Newell, K M (1991). 'Motor skill acquisition', *Annual Review Psychology*, **42**, 213-237.

Newell, K M, Morris, L R and Scully, D M (1985). 'Augmented information and the acqusition of skill in physical activity' in: Terjung, R L (ed), *Exercise and Sports Sciences Reviews*, **13**, 235-261, MacMillan, New York.

Olney, S J, Colborne, G R and Martin, C S (1989). 'Joint angle feedback and biomechanical gait analysis in stroke patients: A case report', *Physical Therapy*, **69**, 10, 77/863-84/870.

Pinnington, L L and Brown, A (1994). 'Ten years of computing in occupational therapy – the UK experience,' *International Journal of Computers in Adult Education and Training*, **4**, 8, 258 –265.

Prevo, A J H, Visser, S L and Vogelaar, T W (1982). 'Effect of EMG feedback on paretic muscles and abnormal co-contraction in the hemiplegic arm, compared with conventional physical therapy', *Scandinavian Journal of Rehabilitation Medicine*, **14**, 121-131.

Sackley, C M (1991). 'A randomised controlled trial of visual feedback after stroke', *Proceedings of the 11th Congress of the World Confederation for Physical Therapy*, London.

Sackley, C M, Baguley, B I, Gent, S and Hodgson, P (1992). 'The use of a balance performance monitor in the treatment of weight-bearing and weight-transference problems after stroke', *Physiotherapy*, **78**, 12, 907-913.

Sackley, C M, and Baguley, B I (1993). 'Visual feedback after stroke with the balance performance monitor: Two single-case studies', *Clinical Rehabilitation*, **7**, 189-195.

Sale, D G (1987). 'Influence of exercise and training on motor unit activation' in: Terjung, E R L (ed), *Exercise and Sport Sciences Reviews*, **15**, 95-151, MacMillan, New York.

Salmoni, A W, Schmidt, R A and Walter, C B (1984). 'Knowledge of results and motor learning: A review and critical reappraisal', *Psychological Bulletin*, **95**, 3, 355-386.

Seeger, B R and Caudrey, D J (1983). 'Biofeedback therapy to achieve symmetrical gait in children with hemiplegic cerebral palsy: Long-term efficacy', *Archives of Physical Medicine and Rehabilitation*, **64**, 160-162.

Shumway-Cook, A, Anson, D, and Haller, S (1988). 'Postural sway biofeedback: Its effect on re-establishing stance stability in hemiplegic patients', *Archives of Physical Medicine and Rehabilitation*, **69**, 395-400.

Sprenger, C K, Carlson, K and Wessman, H C (1979). 'Application of electromyographic biofeedback following medial meniscectomy', *Physical Therapy*, **59**, 167-169.

Stoneman, R (1985). 'The potential use of the microcomputer with patients suffering from cerebral vascular accident and head injury', *Occupational Therapy, June*, 163-166.

Szeto, G, Strauss, G R, De Domenico, G, Sun Lai, H *et al* (1989). 'The effects of training intensity on voluntary isometric strength improvement', *Australian Journal of Physiotherapy*, **35**, 4, 210-217.

Tallis, R (1984). 'Neurological rehabilitation: The next thirty years', *Physiotherapy*, **70**, 196-199.

Thelen, E (1989). 'The (re)discovery of motor development: Learning new things from an old field', *Developmental Psychology*, **25**, 6, 946-949.

Turnbull, G I (1982). 'Some learning theory implications in neurological physiotherapy', *Physiotherapy*, **68**, 38-41.

van der Weel, F R, van der Meer, A L H and Lee, D N (1991). 'Effect of task on movement control in cerebral palsy: Implications for assessment and therapy', *Developmental Medicine and Child Neurology*, **33**, 419-426.

Wall, P D (1980). 'Mechanisms of plasticity of connection following damage in adult mammalian nervous systems', in: Bach-y-Rita, P (ed) *Recovery of Function: Theoretical considerations for brain injury rehabilitation*, Huber, Bern.

de Weerdt, W D, Harrison, M, Smith, P, Hoodless, D and Pottage, I (1988). 'The Nottingham balance platform: A practical application of microcomputers in physiotherapy', *Physiotherapy Practice*, **4**, 9-17.

de Weerdt, W D, Crossley, S.M, Lincoln, N B and Harrison, M A (1989). 'Restoration of balance in stroke patients: A single case design study', *Clinical Rehabilitation*, **3**, 139-147.

Winstein, C J (1989). 'Standing balance training: effects on balance and locomotion in hemiparetic adults', *Archives of Physical Medicine and Rehabilitation*, **70**, 755-762.

Winstein, C (1991). 'Knowledge of results and motor learning – Implications for physical treatment', *Physical Therapy*, **71**, 2, 65/140-73/148.

Wolf, S L (1983). 'Electromyographic biofeedback applications to stroke patients', *Physical Therapy*, **63**, 9, 1448-59.

Wooldridge, C P and Russell, G (1976). 'Head position training with the cerebral palsied child: An application of biofeedback techniques', *Archives of Physical Medicine and Rehabilitation*, **57**, 407-414.

fellowships and awards

Medical Research Council

MRC Studentship Competitions

Applications are invited from heads of departments to compete for an allocation of the following postgraduate studentship awards:

- *Research studentships* for research training in medical or related biological subjects. Applications are invited from departments which were graded B1 or B2 in the last triennial studentship review or since. Departments which have not applied in the last two years should discuss any proposed application with the Medical Research Council (MRC) prior to submission.
- *Collaborative studentships* for research training in medical or related biological subjects jointly supervised by an academic institution and a collaborating organisation.
- *Industrial collaborative studentships* for research training in medical or related biological subjects jointly supervised by an industrial partner, from whom the initiative in establishing a link with a university should come, and an academic institution.
- *Advanced course studentships* for tenure on taught courses providing appropriate training in a field within the MRC's sphere of interest for which there is no provision at the undergraduate level. Applicants should note that awards will now be allocated on a triennial basis.

From the 1996 competition all departments will be required to self-nominate applications to one of the five MRC research studentships assessment panels (details will be available with application forms – see box opposite).

The closing date for all studentship competitions is September 27, 1996.

MRC Clinical Training Fellowships 1996/97

The Medical Research Council provides a range of training and career development opportunities for researchers at different stages of their careers. Recognising that members of the professions allied to medicine (PAMs) interested in pursuing a career in research must obtain both professional and scientific qualifications, Council has recently agreed that the PAMs may now apply for MRC clinical training Fellowship awards.

In order to encourage applications two clinical training Fellowship awards each year will be earmarked for the PAMs for a pilot period of two years.

MRC clinical training Fellowship awards enable applicants to undertake between six months and three years of specialised research training in the biomedical field within the UK. However, applicants are encouraged to register for a PhD which is based on research undertaken during the tenure of the award.

It will be a condition of the award that applicants from the PAMs must have completed their professional training and possess a good grounding in research methods by means of an MSc or equivalent postgraduate qualification.

As part of the Council's equal opportunities policy, consideration will be given to applicants returning to science following a career break.

Part-time awards are available for all MRC personal schemes and there are no age limits.

These opportunities will apply from the 1996/7 session (for awards taken up in 1997/8).

In view of this change, the PAMs will no longer be eligible to apply for the Council's non-clinical Fellowship schemes. Other MRC opportunities for PAMs are listed below.

MRC Development Schemes for Professions Allied to Medicine

Training Fellowships in Health Services Research

The Council wishes to promote research of direct relevance to the health service, and in particular to increase the workforce capacity in this area. Members of the PAMs may apply for special training Fellowships in health service research funded by the MRC or jointly by the MRC and the relevant health Region. Candidates from the PAMs are required to have an MSc and some research experience in a relevant discipline; candidates not already holding a PhD/DPhil are expected to integrate study for such a qualification with their programme of research training.