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4 authors:


Daniel Cury Ribeiro
University of Otago


Gisela Sole
University of Otago


J. Haxby Abbott
University of Otago


Stephan Milosavljevic
University of Saskatchewan

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Systematic Review

Extrinsic feedback and management of low back pain: A critical review of the literature

Daniel Cury Ribeiro [a,*], Gisela Sole [a], J. Haxby Abbott [b], Stephan Milosavljevic [a]

[a] Centre for Physiotherapy Research, School of Physiotherapy, University of Otago, 325 Great King Street, Dunedin 9016, New Zealand
[b] Orthopaedic Surgery – Medical and Surgical Sciences, Dunedin School of Medicine, University of Otago, Dunedin, 913, New Zealand

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Effective intervention for low back pain (LBP) can include feedback in one form or other. Although extrinsic feedback (EF) can be provided in a number of ways, most research has not considered how different EF characteristics (e.g. timing and content) influence treatment outcomes. A systematic search related to feedback and LBP was performed on relevant electronic databases. This narrative review aims to describe the forms of feedback provision in the literature regarding management of LBP, and to discuss these in light of previously recommended principles for the use of extrinsic feedback. The present review found support for the provision of EF that focuses on content characteristics including program feedback, summary results feedback, and external focus of attention. Temporal characteristics should enhance the use of intermittent or self-selected feedback. The literature does not support the provision of concurrent or constant EF. As much of the literature related to EF in the management of LBP has not considered content and timing characteristics we have identified future research directions that will clarify the use of content and timing characteristics of EF relative to the management of LBP.

1. Introduction

Motor control feedback can be defined as information provided by different sensory receptors as a consequence of a movement (Shumway-Cook and Woollacott, 2007). Such feedback informs about the effect of actions, and is designed to help improve the quality of adaptive responses (Schmidt and Wrisberg, 2008). Information provided by the sensory system is called *intrinsic feedback*, while the information provided via an external source (another person or instrument) can be described as *extrinsic feedback* (EF) (or, augmented feedback) (Schmidt and Wrisberg, 2008). Depending on the type of task, intrinsic feedback provides sufficient information to help execute or improve task performance. Nonetheless, there can be situations where motor improvements are very difficult to achieve without the support of EF (Guadagnoli et al., 1996), such as in individuals whose intrinsic feedback is impaired, in which case (re)learning of a task can be complex (Herbert et al., 2008).

EF has been used by physiotherapists in the management of patients with specific neuro-musculoskeletal conditions (Dozza et al., 2005; Magnusson et al., 2008; Durham et al., 2009), such as low back pain (LBP) and Parkinson disease. Different EF devices include verbal feedback (Durham et al., 2009), visual feedback for postural control and weight bearing symmetry (Brumagne et al., 2008a; Hlavackova et al., 2009), audio feedback (Dozza et al., 2005; Wong and Wong, 2008), and rehabilitative ultrasound imaging feedback (Teyhen et al., 2005). EF is argued to enhance: a) central nervous system facilitation of optimal sensory-motor loops; b) patient awareness, confidence and volitional control over specific physiological processes; c) motivation; and d) reinforcement for repetition of successful actions (Huang et al., 2006; Schmidt and Wrisberg, 2008).

Patients with LBP are thought to have an impaired intrinsic feedback system (Descarreaux et al., 2005; Panjabi, 2006; Brumagne et al., 2008b) with an alteration in muscular response (Sterling et al., 2001; Jacobs et al., 2009). The adverse alteration of proprioception is thought to play an important role in the maintenance of symptoms and motor impairments (O'Sullivan et al., 2003; Dolan and Green, 2006; Panjabi, 2006). The intrinsic feedback system can be altered due to disrupted paraspinal muscle spindle input, as well as, imprecise central processing, causing lumbar position sense deficits (Brumagne et al., 2000). In addition, partial ruptures of spinal ligaments leads to imprecise feedback input to the central neural system, causing reduced postural awareness and altered motor recruitment patterns (Panjabi, 2006).

* Corresponding author. University of Otago, Centre for Physiotherapy Research, School of Physiotherapy, University of Otago, PO Box 56, Dunedin 9015, New Zealand. Tel.: +64 3 479 5422, fax: +64 3 479 8414.
E-mail address: daniel.cury.ribeiro@gmail.com (D.C. Ribeiro).

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Examples reported in the literature are the delayed contraction of transversus abdominis muscle in subjects with LBP (Hodges, 1999), the localized atrophy and reduced capacity of actively recruit the lumbar multifidus muscle (Wallwork et al., 2009), as well as, increased spinal co-contraction (Newton-John et al., 1995; Marras et al., 2000) which increases spinal load (Marras et al., 2000). It is considered that EF is a useful procedure that facilitates or augments the information provided by the somato-sensory system (Henry and Teyhen, 2007).

The successful provision of EF depends on the selection of different features (Park et al., 2000; van Vliet and Wulf, 2006). Characteristics of feedback (e.g. when to provide EF, what type of information to be delivered) during motor learning have been discussed in depth (Newell, 1976; Hebert and Landin, 1994; McNevin et al., 1994; Smith et al., 1997; Park et al., 2000; Guadagnoli and Lee, 2004) and its implications for rehabilitation have been presented (Winstein and Knecht, 1990; Winstein, 1991; McNevin et al., 2000). These characteristics have been recently investigated during rehabilitation procedures for specific neuromuscular dysfunctions such as stroke (van Vliet and Wulf, 2006) and LBP (Herbert et al., 2008). However, the studies investigating the use of feedback towards managements of LBP are still limited (Henry and Teyhen, 2007). The aim of this narrative review is to describe the forms of feedback provision in the literature regarding management of LBP, and to discuss these in light of previously recommended principles for the use of EF.

2. Methods

The electronic search identified studies that have included the use of EF on the management of LBP. The following databases were used: Medline (1950–August 2010), CINAHL (1982–August 2010), PsycINFO (1967–August 2010), Embase (1947 August 2010). Additional searches used the PEDro database, as well as searches of rehabilitation journals including: Manual Therapy, Physiotherapy, Physical Therapy, Archives of Physical Medicine and Rehabilitation, Journal of Orthopaedic and Sports Physical Therapy (JOSPT). The search strategy was developed in consultation with a faculty librarian. The key words and the combination used for each database are described in Table 1. In addition, reference lists of retrieved articles were scanned for appropriate studies. Language restriction was not imposed.

Table 1
Results for electronic databases searches.

Database	Keywords	Number of studies
PsycInfo	(1) Back pain; (2) Biofeedback Training; (3) Biofeedback; (4) Feedback; (5) 2 or 3 or 4; (6) 1 and 5.	39
Embase	(1) Feedback system; (2) Low back pain; (3) Backache; (4) 2 or 3; (5) 1 and 4.	182
Medline	(1) Low back pain; (2) Feedback; (3) Feedback, Sensory; (4) Biofeedback, Psychology; (5) 2 or 3 or 4; (6) 1 and 5.	34
Cinahl	(1) Low back pain; (2) Feedback; (3) Biofeedback; (4) Extrinsic Feedback; (5) 2 or 3 or 4; (6) 1 and 5.	54

Studies were included if they involved a randomized control trial of subjects, with or without LBP, exposed to a period of training or treatment using feedback instruments (with or without the addition of verbal or tactile feedback) that focused on motor learning. Studies were excluded if they had any other study design, were narrative or systematic reviews, if the focus of the study was on behavioral feedback, or ergonomic training, or if it was not related to motor training.

The quality scores for those studies were assessed by the PEDro database (http://www.pedro.org.au). For studies not assessed by the PEDro database, we report our quality assessment findings using the PEDro instrument (http://www.pedro.org.au). Two reviewers (DCR, JHA) independently assessed each study. Differences were resolved by consensus. A third reviewer (GS) was available to adjudicate unresolved differences.

In order to establish the recommended principles for the use of EF, the following textbooks were reviewed (Magill, 2003; Shumway-Cook and Woollacott, 2007; Schmidt and Wrisberg, 2008), as were published articles related to motor learning and control. To identify these studies, an electronic search, through the same databases previously described, was conducted and the following key words used were: motor learning, motor control, feedback, extrinsic feedback, knowledge of results, and knowledge of performance.

3. Results

A total of 311 articles were found and 17 studies met the inclusion criteria. The identification, screening, eligibility and inclusion processes are described in Fig. 1. Main term definitions for content and timing characteristics of feedback provision are described in Table 2.

Study design description, as well as, main content and timing characteristics of EF found in the studies identified through the electronic search are outlined in Tables 3–5, respectively. From the 17 included studies, 6 studies (Henry and Westervelt, 2005; Teyhen et al., 2005; Van et al., 2006; Worth et al., 2007; Herbert et al., 2008; Magnusson et al., 2008) have compared use of EF with no use of EF in the intervention regime (Table 3); their main findings are presented in Table 6. The other 11 studies (Bush et al., 1985; Donaldson et al., 1994; Ferreira et al., 2007; Flor et al., 1983; Hides et al., 1996; Newton-John et al., 1995; Niemisto et al., 2003; Nouwen, 1983; Rasmussen-Barr et al., 2003; Stuckey et al., 1986; Vasseljen and Fladmark, 2010) have used EF as part of treatment/motor training management; however have not conducted a comparative effectiveness study of EF. As a consequence, all comments regarding the effectiveness of EF provision will be based on the former 6 studies. The latter 11 studies are presented and the way EF was provided is narratively described and compared to the recommendation summary for EF provision. The PEDro quality assessment results are reported in Table 3.

Before specifically describing the extracted data related to the use of EF in the management of LBP, a summary of existing recommendations related to EF in motor learning is presented in two domains: content feedback and timing feedback. LBP feedback characteristics are then reviewed and compared with this summary of existing recommendations.

4. Recommendations for the use of EF

The provision of EF can target different sensory channels (visual, kinesthetic, and verbal knowledge of results). Sarlegna et al. (2007) tested how adaptive control during reaching movements was

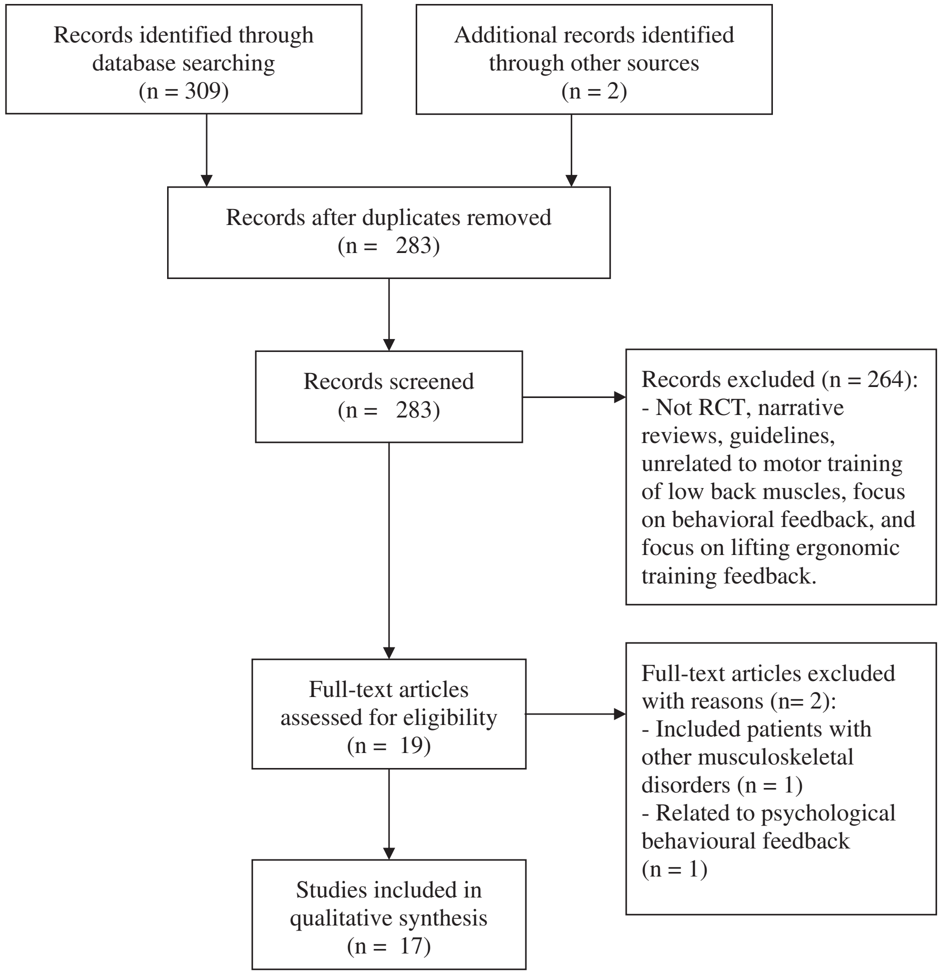

Fig. 1. Selection process.

affected by different sensory channels and found there were no differences in motor adaptation between the different feedback groups. This study supports the concept that sensory-motor adaptation is a multi-sensory flexible process and its efficiency seems to be independent of a specific sensory channel (e.g. Vision, audition, or kinesthesia) (Sarlegna et al., 2007). In spite of which sensory channel is targeted, clinicians must therefore decide the most effective way to provide EF for their patients.

Extrinsic feedback can be provided in two forms: knowledge of results and knowledge of performance (Schmidt and Wrisberg, 2008). Knowledge of results informs about the outcome or achieving the goal/target of a determined task, whereas, knowledge of performance feedback informs about the characteristics of a performed movement or task (Magill, 2000). The characteristics of such EF can have positive, detrimental or null influence on the motor learning outcomes (Wulf et al., 1994). For this reason, before providing EF, content and timing characteristics should be carefully selected (Butki and Hoffman, 2003; Guadagnoli and Kohl, 2001; Ishikura, 2005).

4.1. *Content characteristics*

In the present review, content characteristics are considered as features related to the focus of *intervention* of the EF (program or parameter), the way EF results are provided (summarized, averaged, or error magnitude – e.g. accepting some minor faults as a successful try), and the type of focus of *attention* associated with the feedback (Table 2). Skill complexity, feedback redundancy and subject experience have an important effect on learning outcomes from EF (Guadagnoli and Lee, 2004; Janelle et al., 1997; Park et al., 2000). When learning a new but easy task, EF does not necessarily result in enhancement of learning. While learning a complex task, provision of EF seems to enhance motor performance (Fredenburg et al., 2001). When there is sufficient intrinsic information, EF provision will not necessarily induce better learning outcomes (Guadagnoli et al., 1996). In this case, it is generally accepted that the therapist should direct and assist the subject to correctly identify and use the available intrinsic feedback information during task execution (Schmidt and Wrisberg, 2008). The more novel the task and less experienced the participant; the more useful EF is likely to be (Guadagnoli et al., 1996; Guadagnoli and Lee, 2004).

4.1.1. *Program and parameter feedback*

Learning a new task involves the acquisition of a generalized motor pattern followed by the refinement of specific execution parameters (Schmidt and Wrisberg, 2008). Different types of instruction feedback can be used to improve motor learning during these two phases. Program feedback provides information regarding the general movement pattern, while parameter feedback provides information of a specific component of the entire movement pattern (Schmidt and Wrisberg, 2008). Both forms of feedback can be provided prescriptively or descriptively. The former describes errors and suggests how to correct them while the latter only describes the errors (Schmidt and Wrisberg, 2008).

Table 2
Main term definitions for content and timing characteristics.

Content characteristics	
Program feedback	Feedback related to the general pattern of movement.
Parameter feedback	Feedback related to a specific component (part) of the whole movement pattern.
Summary feedback	Feedback is pooled and provided after a specific number of trials.
Average feedback	Feedback provided refers to mean values (mean error or performance score) of a group of trials.
Bandwidth (error magnitude)	The amount of error that is considered to distinguish between successful and unsuccessful trials.
Internal focus of attention	Feedback drives learner's attention to body movement characteristics.
External focus of attention	Feedback drives learner's attention to the effect of the movement.
Timing characteristics	
Concurrent feedback	Feedback is provided simultaneous to task execution.
Terminal feedback	Feedback is provided after task execution.
Immediate	Feedback is provided immediately after task execution;
Delayed	Feedback provision is delayed after the end of the task execution.
Frequency	
Constant	Feedback is provided at every trial.
Reduced	Feedback is provided for a fraction of trials (e.g. 30%).
Self controlled	Feedback provision depends on learner's decision.

Better results are often obtained when prescriptive feedback is provided.

4.1.2. Amount of information during feedback provision

The quantity and precision of EF can interfere in the learning process (Guadagnoli et al., 1996; Ishikura, 2005). Summary feedback, which provides information after a specific number of trials, has shown to be superior, when compared to EF provided after every trial (Gable et al., 1991). Average feedback provides mean values (mean error or performance score) of a group of trials (Wulf and Schmidt, 1996), it is considered to deteriorate movement parameter learning (Wulf and Schmidt, 1996), but to be superior to every trial EF. During every trial feedback, subjects ignore intrinsic feedback information and become excessively dependent on EF (Ranganathan and Newell, 2009a; Salmoni et al., 1984).

4.1.3. Performance bandwidth (error magnitude)

Another important issue is to determine the error magnitude (performance bandwidth) that should be followed by feedback (Butler et al., 1996; Lai and Shea, 1999; Smith et al., 1997). For example, isolated contraction for lumbar multifidus can be considered as successful when no pelvic tilt is performed concomitantly, and multifidus muscle thickening can be visualized on the rehabilitative ultrasound imaging screen (Herbert et al., 2008). In this example, the physiotherapist might consider a performance as successful even when small amount of pelvic tilt movement occur simultaneously to multifidus muscle contraction. Some studies support the idea that changing the bandwidth size during motor task trials does not alter motor outcomes (Goodwin and Meeuwsen, 1995; Lai and Shea, 1999). Conversely, Smith et al. (1997) found that a larger bandwidth (10%, when compared to 0 and 5%) has been associated with better retention outcomes. The use of bandwidth for EF provision enhances motor learning if qualitative knowledge of results feedback is provided when motor outcome is included within the bandwidth (Butler et al., 1996). In other words, subjects need to be aware that non-provision of EF means performance was considered either correct or within a predetermined error tolerance (Butler et al., 1996).

4.1.4. Focus of attention

EF can be applied in a form that drives learner's attention to body movement characteristics (internal focus of attention) or to the effect of the movement (external focus of attention) (Wulf et al., 2002). Better motor learning outcomes are related to the use of external focus of attention (Shea and Wulf, 1999; McNevin et al., 2000; Wulf et al., 2009). The reasons for this are unclear, however, it seems that attempts to control the movement itself would interfere in automatic motor control processes and, consequently, lead to deteriorated outcomes (McNevin et al., 2000). The use of an external focus of attention likely facilitates or sustains automatic pathways of motor control and improve motor performance (Wulf et al., 2009).

4.2. Timing characteristics

The excessive use of EF can lead to dependency and, consequently, promote detrimental or null effects on learning process (Winstein and Schmidt, 1990; Park et al., 2000; Butki and Hoffman, 2003). Concurrent or terminal (immediate or delayed) EF, as well as, the frequency of EF are critical features of application during motor learning (Magill, 2003; Schmidt and Wrisberg, 2008). EF can be provided during every trial (constant), concurrent to the task execution, immediately after task execution or, after a period of time following the end of the task (delayed).

4.2.1. Concurrent and terminal feedback provision

Whether to provide EF concurrent to or after task execution is a decision to be made by the physiotherapist. Published literature does not support the use of concurrent EF, unless there is impaired intrinsic feedback or insufficient information intrinsic to the task (Park et al., 2000; Magill, 2003; Ranganathan and Newell, 2009a). This might be the case for LBP patients, who were shown to have impaired intrinsic feedback (Newcomer et al., 2000). Otherwise, concurrent EF has a strong negative guidance effect (Winstein et al., 1996; Schmidt and Wulf, 1997). One possible reason might be related to EF obliterating the use of intrinsic feedback. Learners become dependent on EF during the acquisition phase and, consequently, when EF is removed, subjects are not able to perform the task correctly (Anderson et al., 2005). Even though concurrent *visual* feedback has been shown to be detrimental (Wulf and Schmidt, 1997), the provision of concurrent *audio* feedback is beneficial for motor learning (Konttinen et al., 2004). Concurrent visual feedback appears to induce a different neural pathway when compared to the execution of a task without visual EF. However, the reasons for the better retention results from learning with audio feedback are unclear.

Delayed EF improves motor learning outcomes (Magill, 2003; Anderson et al., 2005). It is possible that, by delaying the feedback provision for a few seconds or minutes after movement execution, subjects have time to better explore their intrinsic feedback and relate it to the motor outcome. When EF is provided, they can then compare the intrinsic feedback information to that provided by the EF (Anderson et al., 2005). However, the optimal delay interval for providing EF has yet to be determined (Magill, 2003).

4.2.2. Frequency of feedback provision

Additionally, providing EF after every trial (100% EF) appears to deteriorate motor learning, when compared to intermittent EF (e.g.

Table 3
Study description.

Author (Year)	Population	Intervention	Nature of EF (KP or KR)	Type of EF	Instrument/ Principle	PEDro Score
Vasseljen and Fladmark, 2010	109 chronic LBP patients	8-week intervention (8 sessions) G1: Low load exercise (stabilization focused on transverses abdominis) with USI ;G2: High load exercise; G3: General exercise.	KP	Visual	USI	6/10[a]
Magnusson et al. (2008)	26 LBP patients	5-week intervention (10 sessions) G1: Conventional physiotherapy; G2: Conventional physiotherapy + biofeedback	KP	Visual, auditory, success rates, reports	Postural	3/10[b]
Herbert et al. (2008)	30 healthy participants	4-week intervention (8 sessions): multifidus muscle exercise G1: constant USI; G2: variable USI	KR (verbal) KP (visual)	Visual Verbal	USI	5/10[a]
Ferreira et al. (2007)	240 chronic LBP patients	8-week intervention (12 sessions) G1: General exercise; G2: Motor control exercise + USI; G3: Manipulative therapy	KP	Visual	USI	8/10[b]
Worth et al. (2007)	19 LBP patients	Teaching abdominal hollowing exercise and retention test after 4 days. G1verbal and palpatory feedback; G2: USI	KP	Visual	USI	5/10[b]
Van et al. (2006)	25 healthy subjects	Teaching isometric contraction of multifidus muscle. G1: Knowledge of results; G2: Knowledge of results and performance.	KR (amount of increase in muscle thickness) and KP (visual observation of muscle contraction)	Visual, report	USI	4/10[a]
Teyhen et al. (2005)	30 LBP patients	G1: lumbar stabilization exercise; G2: lumbar stabilization exercise + USI; Both groups received 1 session followed short-term re-assessment (3 min after session). Retention test was carried out after 4 days (all patients received home exercises).	KP	Visual	USI	7/10[b]
Henry and Westervelt (2005)	48 healthy participants	Teaching abdominal hollowing exercise and retention test after 4 days. G1: minimal verbal feedback; G2: verbal and palpatory feedback; G3: verbal, palpatory and USI	KP	Verbal, tactile and visual	USI	6/10[a]
Rasmussen-Barr et al. (2003)	47 LBP patients	6-week treatment (one session/week). G1: Stabilizing group (PBU); G2: Manual treatment group	KP	Pressure	PBU	5/10[b]
Niemisto et al. (2003)	240 LBP patients	4-week intervention (one session/week). G1: Manipulation and stabilizing exercise (abdominal drawing-in maneuver); G2: Physician consultation	KP and KR	Pressure, visual and tactile	PBU	8/10[b]
Hides et al. (1996)	39 LBP patients	4-week intervention G1: Medical management; G2: Medical management and stabilization exercises	KP	Visual	USI	7/10[b]
Newton-John et al. (1995)	44 LBP patients	8-week intervention (2x/week). G1: Cognitive behavior therapy; G2: EMG Biofeedback; G3: Wait list control	KP	Not adressed	EMG	3/10[b]
Donaldson et al. (1994)	36 chronic LBP	G1: EMG Biofeedback, G2: Relaxation; G3: Education	Not adressed	Not adressed	EMG	5/10[b]
Stuckey et al. (1986)	24 chronic LBP	8 sessions (45 min each) G1: EMG feedback; G2: Relaxation training; G3: Placebo condition	KP	Visual and auditory	EMG	4/10[b]
Bush et al. (1985)	72 chronic LBP	8 sessions (period of intervention unclear) G1: Paraspinal EMG feedback; G2: Placebo; G3: No intervention	KP	Auditory	EMG	4/10[b]
Nouwen (1983)	20 LBP patients	3-week intervention (5x/week). G1: EMG Biofeedback; G2: Wait list control	KP	Visual and auditory	EMG	5/10[b]
Flor et al. (1983)	24 chronic LBP	G1: EMG feedback; G2: Pseudo therapy; G3: Conventional medical treatment	KP	Auditory	EMG	4/10[b]

G1: group 1; G2: group 2; G3: group 3; EF = extrinsic feedback; KP = knowledge of performance; KR = knowledge of results; PBU = pressure biofeedback unit; USI = ultrasound imaging; EMG = electromyopgrahic feedback.
[a] PEDro score assessed by the authors.
[b] PEDro score reported from www.pedro.org.au.

50%, 20% or 10% EF) (Salmoni et al., 1984; Winstein and Schmidt, 1990; Weeks and Kordus, 1998; Park et al., 2000). Weeks and Kordus (1998) found that uninjured learners, who received 33% relative frequency of knowledge of performance feedback, performed better when compared to 100% relative EF during a soccer throw-in task. The authors suggested that reduced frequency eliminates learner's dependence on the provision of EF (Weeks and Kordus, 1998). A possible explanation for reduced retention with 100% EF is that EF is a guide for motor execution and learners cannot guide themselves appropriately by task-intrinsic feedback when it is removed (Salmoni et al., 1984; Winstein et al., 1994; Anderson et al., 2005; Ranganathan and Newell, 2009).

Better outcomes were found if the decision for receiving feedback was controlled by the learner (Chiviacowsky and Wulf, 2002, 2005). Self-controlled feedback tends to be requested after performances learners believed to be successful (Chiviacowsky and Wulf, 2002, 2005, 2007). The reason why learners ask for EF after good trials and why it is more effective than a rigid schedule of feedback is unclear (Chiviacowsky and Wulf, 2002). However, recent results point to motivation, where knowledge about successful trials induces learners to reproduce the successful motor pattern (Chiviacowsky and Wulf, 2002, 2007). These findings indicate that providing feedback after good trials is superior than after incorrect trials, nonetheless, it is uncertain whether it can be applied to different motor tasks (Chiviacowsky and Wulf, 2007).

5. Feedback provision for the management of LBP

Different types of EF have been used during management of LBP using various conceptual frameworks (Table 3). Positive results from these studies are likely related to sensory-motor adaptation occurring independently of type of EF. Even though, the selection of optimal content and timing characteristics might influence motor adaptation. The provision of EF in the management of LBP is discussed in light of previously described principles for the use of EF.

5.1. Content characteristics

5.1.1. Program and parameter feedback

One study (Magnusson et al., 2008) provided program feedback, while all other studies focused on parameter feedback (Table 4). The reason may be that therapists believe that LBP patients need to improve specific features of movement patterns in order to enhance the quality of such performed movements. Examples reported in the literature, where parameter feedback was used, include delayed contraction of transversus abdominis muscle (Hodges, 1999), localized atrophy and reduced capacity to actively recruit the lumbar multifidus muscle (Wallwork et al., 2009), as well as, increased amount of spinal co-contraction (Flor and Birbaumer, 1993; Newton-John et al., 1995; Marras et al., 2000) increasing spinal loads (Marras et al., 2000). Nonetheless, it is considered that motor program training and, consequently, program feedback can enhance neural reorganization and motor control (Shepherd, 2001; van Vliet and Heneghan, 2006). Since motor control acquisition is task-specific, the isolated training of a component of the movement might not be as useful as the training of the functional task itself (Shepherd, 2001; van Vliet and Heneghan, 2006; Shumway-Cook and Woollacott, 2007).

5.1.2. Amount of information during feedback provision

Two studies have provided summary EF (Herbert et al., 2008; Magnusson et al., 2008). In addition, Herbert et al. (2008) results support the provision of variable feedback schedule for improvement of multifidus muscle recruitment. The literature supports the provision of summary EF for motor learning, indicating that it has a better influence on acquisition of a motor skill compared to EF provided at the end of every trial (Schmidt et al., 1990; Guadagnoli et al., 1996). However, other research suggests that there is an optimal number of performance attempts prior to provision of summary feedback (Schmidt et al., 1990). Theoretically, as the complexity of the task is increased, the number of trials to be included in the summary feedback is reduced (and consequently, the frequency of feedback is increased) (Guadagnoli and Lee, 2004; Schmidt and Wrisberg, 2008). Task difficulty will be related to personal previous motor experience and the task itself (Guadagnoli and Lee, 2004). However, for subjects with LBP, it is important to consider the disruption magnitude of the intrinsic feedback system (O'Sullivan et al., 2003; Brumagne et al., 2008b), since subjects with increased proprioceptive disruption might benefit from more frequent EF. Nonetheless, this has not been investigated in the LBP population.

5.1.3. Performance bandwidth (error magnitude)

Two studies (Henry and Westervelt, 2005; Magnusson et al., 2008) have used performance bandwidth during training of abdominal hollowing maneuvers in healthy subjects (Henry and Westervelt, 2005) and during rehabilitation program for LBP (Magnusson et al., 2008). The former has used it for the control group and the latter used it as a form of progression for rehabilitation spinal exercises. None of these studies have assessed the effect of different bandwidth magnitudes on clinical outcomes.

Table 4
Content characteristics.

Content Characteristics						
Author (Year)	Program	Parameter	Summary	Average	Bandwidth	Focus of attention (Internal or External)
Vasseljen and Fladmark, 2010	No	Yes	No	No	No	Not addressed
Magnusson et al. (2008)	Yes	Yes	Yes	No	Yes	External
Herbert et al. (2008)	No	Yes	Yes (VAR group)	No	No	Not addressed
Ferreira et al. (2007)	No	Yes	No	No	No	Not addressed
Worth et al. (2007)	No	Yes	No	No	No	Not addressed
Van et al. (2006)	No	Yes	Yes	No	No	Not clear (G1); External (for G2)
Teyhen et al. (2005)	No	Yes	No	No	No	Not addressed
Henry and Westervelt (2005)	No	Yes	No	No	Yes (Control)	Not addressed
Rasmussen-Barr et al. (2003)	No	Yes	No	No	No	Not addressed
Niemisto et al. (2003)	No	Yes	No	No	No	Not addressed
Hides et al. (1996)	No	Yes	No	No	No	Not addressed
Newton-John et al. (1995)	No	Yes	No	No	No	Not addressed
Donaldson et al. (1994)	No	Yes	Not adressed	Not adressed	Not adressed	Not adressed
Stuckey et al. (1986)	No	Yes	No	No	No	External
Bush et al. (1985)	No	Yes	No	No	No	Not addressed
Nouwen (1983)	No	Yes	No	No	No	Not addressed
Flor et al. (1983)	No	Yes	No	No	No	Not addressed

VAR = variable provision of EF group; CON = constant provision of EF group.

Table 5
Timing characteristics

Author	Concurrent	Terminal		Frequency		
(Year)		Immediate	Delayed	Constant	Reduced frequency	Self-controlled
Vasseljen and Fladmark, 2010	Yes	Not clear	Not clear	Not clear	No	No
Magnusson et al. (2008)	Yes	Yes	No	Yes	No	No
Herbert et al. (2008)	Yes (CON group)	Yes (CON group)	Yes (VAR group)	Yes (CON group)	Yes (VAR group)	No
Ferreira et al. (2007)	Yes	No	No	Yes	No	No
Worth et al. (2007)	No	Yes	No	Yes	No	No
Van et al. (2006)	Yes (G2)	Yes (G1)	No	Yes	No	No
Teyhen et al. (2005)	Yes	No	No	Yes	No	No
Henry and Westervelt (2005)	Yes (verbal & visual)	Not clear	Not clear	Yes	No	No
Rasmussen-Barr et al. (2003)	Yes	No	No	Yes	No	No
Niemisto et al. (2003)	Yes	No	No	Yes	No	No
Hides et al. (1996)	Yes	Not clear	Not clear	Yes	No	No
Newton-John et al. (1995)	Not addressed	No	No	Not addressed	Not addressed	Not addressed
Donaldson et al. (1994)	Yes	Not addressed	Not addressed	Not addressed	Not addressed	Not addressed
Stuckey et al. (1986)	Yes	No	No	Yes	No	No
Bush et al. (1985)	Yes	No	No	Yes	No	No
Nouwen (1983)	Yes	No	No	Yes	No	No
Flor et al. (1983)	Yes	No	No	Yes	No	No

VAR = variable provision of EF group; CON = constant provision of EF group.

5.1.4. Focus of attention

The use of external focus of attention on motor learning in patients with LBP has not been compared to internal focus of attention. Literature from the motor learning field suggests that EF should be provided with an external focus of attention (Shea and Wulf, 1999; Wulf et al., 2009). Similar results were found for subjects with Parkinson disease (Wulf et al., 2009), who presented a reduction on postural instability when instructed to perform a task with an external focus of attention.

Magnusson et al. (2008) used an external focus of attention in their trial of LBP treatment while Van et al. (2006) used external focus of attention in healthy subjects during isometric contraction of multifidus muscle. Their findings support the use of EF as an additional tool for rehabilitation of LBP and training of multifidus muscle contraction. However, other studies do not support better learning or clinical outcomes from using EF (Henry and Westervelt, 2005; Teyhen et al., 2005; Worth et al., 2007; Herbert et al., 2008). These four studies (Henry and Westervelt, 2005; Teyhen et al., 2005; Worth et al., 2007; Herbert et al., 2008) provided visual feedback to subjects and it is not clear what type of focus of attention was provided. The different findings between those of Van et al. (2006) and Worth et al. (2007) might be related, at least partially, to the type of focus of attention used. While results by Van et al. (2006) support the provision of EF (even during the retention test, the EF group performed better), Worth et al. (2007) found the feedback group performed better only during immediate assessment. At the retention test, no difference was found between groups (Table 6).

Table 6
Main findings for studies that compared the use or not of extrinsic feedback on training or rehabilitation management.

Author (year)	Main findings
Magnusson et al. (2008)	Patients allocated in the feedback group presented enhanced scores for VAS, SF-36 and kinematic measures.
Herbert et al. (2008)	Variable feedback provision resulted in better multifidus muscle recruitment, when compared to constant feedback provision. During the retention test, the variable feedback group also performed better.
Worth et al. (2007)	The provision of ultrasound imaging improved short-term performance for abdominal hollowing exercise, nonetheless, retention test results demonstrated no differences between the two groups.
Van et al. (2006)	Participants that received ultrasound imaging feedback improved motor recruitment for multifidus muscle and, also, performed better during retention test.
Teyhen et al. (2005)	Adding feedback did not improve contraction of transverses abdominis muscle. One possible reason could be insufficient training period.
Henry and Westervelt (2005)	The use of ultrasound imaging improved short-term performance for lumbar stabilization exercise (specific contraction for transverses abdominis). However, retention test results demonstrated no differences between the three feedback groups.

VAS = visual analogue scale; SF-36 = short form (SF) – 36 questionnaire.

5.2. Timing characteristics

5.2.1. Concurrent and terminal feedback provision

Rehabilitative ultrasound imaging (visual EF) has been used to enhance contraction of transversus abdominis (Worth et al., 2007). However, Henry and Westervelt (2005) and Teyhen et al. (2005) found provision of rehabilitative ultrasound imaging (visual EF) did not enhance the ability to perform the abdominal drawing-in maneuvre (Table 6). Although different explanations are presented by the authors (Henry and Westervelt, 2005; Teyhen et al., 2005), it is possible that the use of concurrent visual feedback influenced the results. On the other hand, the findings from Van et al. (2006) support the provision of concurrent feedback (Table 6). Due to the conflicting evidence, it is clear more research is needed to clarify this topic.

5.2.2. Frequency of feedback provision

Only one study tested how frequency of EF affected motor learning in LBP (Herbert et al., 2008) and found reduced EF frequency is better for motor learning purposes (Table 6). In the present review, rehabilitative ultrasound imaging feedback was considered as a form of parameter feedback (Table 2), aiming to improve the control over specific muscles (generally multifidus or transversus abdominis), instead of providing information about the general movement pattern. Interestingly, the findings from Herbert et al. (2008) are in contrast with other authors (Salmoni et al., 1984; Winstein and Schmidt, 1990; Weeks and Kordus, 1998; Park et al., 2000). Herbert et al. (2008) found reduction of EF frequency to be useful for acquisition of parameters of fundamental pattern of movement. Nonetheless, reduced frequency of EF appears to have only a small influence on the parameters of the fundamental pattern of movement (e.g. movement time, amplitude, speed), when motor learning related to manual tasks, such as striking keys in a board, was analyzed (Lai and Shea, 1998, 1999; Schmidt, 2003). Although this consideration is only based on the results of one study related to LBP (Herbert et al., 2008), further questions include: how does pain experience, in subjects with LBP, influence motivations and patterns of neural processing, when compared to healthy participants, when (re)learning a task?; and how does adaptive reorganization of motor cortex (Tsao et al., 2008), considered to be present in LBP subjects, influence motor learning?

Magnusson et al. (2008) provided constant EF during the intervention period. Even though that is argued to have a detrimental effect on motor learning (Lai and Shea, 1999), their results were favourable for the use of EF. It is important to highlight that the authors provided EF with the following recommended characteristics: program and parameter feedback, an external focus of attention, and summary feedback. It is possible that these characteristics have prevailed over the negative effect of providing constant EF. Moreover, the authors have used three different types of EF: visual, auditory and success rates reports, as well as, variable bandwidth (with increase in bandwidth precision as treatment progressed). Thus the use of bandwidth seems to be useful when followed by some form of instructional feedback (Butler et al., 1996).

Six studies (Flor et al., 1983; Nouwen, 1983; Bush et al., 1985; Stuckey et al., 1986; Donaldson et al., 1994; Newton-John et al., 1995) have used the pain–tension–pain cycle as the theoretical framework to support the use of electromyographic feedback for LBP (Table 3). Nonetheless, other recent conceptual pain models have been proposed and, it is clear that pain experience has a more complex interaction with motor control response (Hodges and Moseley, 2003; Moseley, 2003; Arendt-Nielsen and Graven-Nielsen, 2008). No studies were found that investigated the use of electromyographic feedback to improve specific muscle recruitment for individuals with LBP.

There are other types of feedback commonly used by manual therapists that were not included in the present review. One example is the use of adhesive medical tape (Selkowitz et al., 2007; Greig et al., 2008) as a feedback tool for rehabilitation. If tape is used with the aim of augmenting the intrinsic feedback, then, the same principles described above could be considered.

5.2.3. Future research directions

We found no evidence for a number of areas related to LBP and EF. Whether there are differences between knowledge of performance or knowledge of results EF on LBP outcomes; as well as, how parameter or program EF, different focus of attention, immediate or delayed terminal feedback and self-controlled EF influence LBP outcomes still need to be clarified.

Considering the significant and clinically relevant outcomes presented by Magnusson et al. (2008), the use of postural feedback requires further exploration. The way in which postural feedback influences motor control in subjects with LBP needs to be identified. Finally, it is possible that different LBP clinical presentations will respond in different ways to the provision of EF in its various forms. This is an area that has considerable scope for research where clarification of optimal responses has important clinical promise. Additionally, we suggest that future research could, also, investigate the use of electromyographic feedback in LBP rehabilitation.

6. Implications for clinical practice

Physiotherapists should consider the strong influence that feedback can have on motor learning as well as rehabilitation outcomes. Since the literature related to LBP and EF still needs to explore a number aspects related to optimal EF delivery, recommendations are based on the available literature primarily related to the motor learning field, which has focused mainly in healthy subjects. Generally speaking, physiotherapists should provide EF with the following *content characteristics*: program feedback, summary results feedback, and external focus of attention. With regards to *timing characteristics*, concurrent and constant feedback should be avoided. Reduced frequency or self-selected feedback has stronger support and should be provided.

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