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Research article

HEMODYNAMIC AND LACTIC ACID RESPONSES TO PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION EXERCISE

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ABSTRACT

The hemodynamic and metabolic responses to proprioceptive neuromuscular facilitation (PNF) exercise were examined in 32 male university students (aged 19-28 years). Ten repetitions of PNF exercises were applied to the subjects' dominant upper extremities in the following order: as an agonist pattern flexion, adduction and external rotation; and as an antagonist pattern extension, abduction and internal rotation. Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), double product (DP), and blood lactate concentration (La) were determined before, immediately after, and at 1st, 3rd, and 5th minutes after PNF exercise. A one-way ANOVA with repeated measures indicated significant differences in HR, SBP, DBP, DP and La immediately after PNF exercise. HR increased from 81 (±10) to 108 (±15) b·min^{-1} ($p < 0.01$), SBP increased from 117 (±10) to 125 (±11) mmHg ($p < 0.01$), DBP increased from 71 (±10) to 75 (±8) mmHg ($p < 0.01$), DP increased from 96 (±16) to 135 (±24) ($p < 0.01$), and La increased from 0.69 (±0.31) to 3.99 (±14.63) mmol·L^{-1} ($p < 0.01$). Thus PNF exercise resulted in increased hemodynamic responses and blood lactate concentration that indicate a high strain on the cardiovascular system and anaerobic metabolism in healthy subjects.

KEY WORDS: Heart rate, systolic blood pressure, diastolic blood pressure, double product, PNF.

INTRODUCTION

Proprioceptive neuromuscular facilitation (PNF) may be defined as "promoting or hastening the neuromuscular mechanism through stimulation of proprioceptors" (Knott and Voss 1968). PNF is widely used in physical therapy as a rehabilitation method especially in patients with cerebral palsy and multiple sclerosis but also used in rehabilitation of orthopaedic problems, arthritis and peripheral nerve injuries (Livanelioglu and Erden, 1998). PNF depends on the basic principle that human movements have rotational and oblique characteristics, and movements against maximum resistance result in greater muscular strength response. The amount of applied maximum resistance can change from patient to patient and also can vary within the same patient during different times of the day. The most important point is to find the optimal resistance for maximum effort. With maximal effort, motor unit firing rate increases which result in stronger muscular contraction (Livanelioglu and Erden, 1998). However, it is also very important that the resistance should not result in too much fatigue in patient groups so that the movement patterns can be followed.

It is known that repeated movements against resistance results in fatigue, such that patients can no longer continue the movement. To prevent or delay fatigue, different movement patterns are used during PNF application. The movement patterns and techniques can be alternated in a short period to prevent or delay fatigue (Voss et al., 1985). Currently, PNF techniques are commonly used for rehabilitation and in the area of athletic training to improve flexibility and thus improve function and performance respectively.

During PNF, maximal resistance through the range of motion is emphasized, using many motion combinations related to primitive movement patterns and postural and righting reflexes (Voss et al., 1985). These movement combinations include isometric, concentric, and eccentric contractions together with passive movements. However, there are limited studies examining the effect of PNF exercises on cardiovascular responses.

In an earlier study, Cornelius and co-workers (1995) investigated the acute effects of PNF stretching techniques on systolic and diastolic blood pressures and found that the first two trials of PNF did not result in any significant change in blood pressure; however, the third trial resulted in significant increase in systolic blood pressure. Others studies have found that compared with dynamic isotonic exercises, isometric contractions elicit marked increases in both systolic and diastolic blood pressures, while the rise in heart rate is less pronounced (Lind et al. 1966).

As noted, during PNF exercise patients usually fail to follow the contraction patterns as the number of contractions increases, which indicate local muscular fatigue in the working muscles (Livanelioglu and Erden, 1998). Muscular fatigue is defined as failure to maintain force or power output during sustained or repeated contractions (Newsholme et al. 1992). Fatigue also limits performance, produces a general feeling of discomfort and frustration, and interferes with well being (Kirkendall, 1990). The underlying mechanisms of fatigue have evoked much interest for a long time, and their significance lies not only in the function of normal skeletal muscle, but also in diseased muscle. Studies indicate that the cause of muscular fatigue could be central or peripheral (Gandevia, 1998; Westerblad et al. 1998). One of the causes of peripheral fatigue is the accumulation of lactic acid in the muscle that results in increased hydrogen ion concentration, which in turn results in decreased action potentials, changes in sarcoplasmic release of calcium, and decreased activities of muscle enzymes (Sahlin 1986; Kirkendall, 1990; Newsholme et al. 1992; Westerblad et al. 1998; Westerblad et al. 2002). No study related to PNF exercises and muscular fatigue has been found, although muscular fatigue plays an important role in being able to continue the exercise pattern(s).

Because limited research related to the effects of PNF exercises on the cardiovascular system and muscular fatigue has been found, this study was designed to determine the hemodynamic and blood lactic acid responses to PNF exercise.

METHODS

Subjects

Thirty-two healthy male university students (age 22.7 ± 2.2 years; height 1.78 ± 0.03 m; weight 74.4 ± 9.5 kg; BMI 23.4 ± 2.87 $kg \cdot m^{-2}$) voluntarily participated in this study. All subjects read and signed an informed consent form approved by the Faculty of Health Sciences project committee of Baskent University. The ethics committee of the University also approved the study. Subjects were moderately active as their physical activity level was 128.47 (±95.61) $MET \cdot w^{-1}$, which was determined by the Physical Activity Assessment Questionnaire (PAAQ), developed by Karaca and coworkers (2000) for the Turkish population. The reliability (r) and validity (r) of the PAAQ was 0.73 and 0.72 respectively (Karaca et al., 2000).

PNF Exercises

Repeated contractions were applied as facilitation techniques. The basis of this technique depends on the fact that repeated stimulation of CNS pathways reduces synaptic resistance and improves transmission of impulses (Voss et al., 1985).

Repeated contractions were applied to the subjects' dominant upper extremities. Agonist patterns of flexion, adduction, and external rotation, and an antagonist pattern of extension, abduction, and internal rotation were used. At the start of repeated contractions, the muscles of the dominant upper extremity were placed in the longest position. Starting with the antagonist pattern, fingers were placed into flexion and radial adduction, the wrist into flexion and radial deviation, the forearm into supination, the shoulder into flexion, adduction, and external rotation, and the scapula into rotation, abduction, and elevation. The rationale for selecting these particular PNF patterns was their frequent use in physiotherapy for patients demonstrating muscle weakness and poor co-ordination (Voss et al., 1985; Livanelioglu and Erden, 1998). During the arm movements that are performed over shoulder level flexion, adduction and external rotation were selected as agonist pattern to determine the hemodynamic loading of the exercise and its effect

Table 1. Heart rate (HR), systolic and diastolic blood pressure (BP), double product (DP) and blood lactic acid concentration (La) of subjects' prior to, immediately after and during recovery from PNF exercise. Data are means (±SD).

			Recovery		
	Before PNF	**After PNF**	**1st min**	**3rd min**	**5th min**
HR (b·min^{-1})	82 (10)	108 (15) [a]	82 (11)	81 (9)	80 (11)
Systolic BP (mmHg)	117.0(10.3) [e]	125.0 (10.8) [a]	116.0 (11.1) [d,e]	114.0 (9.9) [c]	112.0 (10.1) [b,d]
Diastolic BP (mmHg)	71.0 (9.6)	75.0 (7.7) [c,d,e]	72.0 (7.8)	72.0 (9.5)	70.0 (8.2)
DP	95.8 (16.4) [e]	134.5 (23.8) [a]	96.3 (17.8) [d,e]	92.8 (14.3) [c]	90.7 (16.5) [b,d]
Blood La (mmol·L^{-1})	.69 (.31) [c,d,e]	3.99 (14.63)	1.41 (.59) [e]	1.28 (.72)	1.10 (.65) [c]

[a] significantly different from measurements before PNF, and at 1st, 3rd and 5th min of recovery ($p < 0.05$).
[b] significantly different from measurements before PNF ($p < 0.05$).
[c] significantly different from measurements at 1st min of recovery ($p < 0.05$).
[d] significantly different from measurements at 3rd min of recovery ($p < 0.05$).
[e] significantly different from measurements at 5th min of recovery ($p < 0.05$).

on lactate concentration (Fletcher et al., 1995). The movements were performed from distal to proximal, during which isometric contractions were performed with the "hold" command at the proximal pivots. These PNF patterns were applied for 10 repetitions, and the same tester performed all applications.

Procedures

Subjects were familiarized with the experimental procedure 1 week prior to the experiment. Subjects performed a PNF exercise with their dominant hand with the help of a tester, and heart rate (HR), blood pressure (BP), double product (DP), and blood lactic acid concentration (La) were determined before, immediately after, and at 1st, 3rd, and 5th minutes after the PNF exercise.

Subjects' heart rates were monitored continuously throughout the test period and were recorded prior to, immediately after, and at 1st, 3rd and 5th minutes after the PNF exercise, using a Sports Tester Vantage (Polar Electro, Finland), short-range telemetry system.

Subjects' blood pressure was measured by auscultation of the inactive arm prior to, immediately after, and at 1st, 3rd, and 5th minutes after the PNF exercise, with an aneroid sphygmomanometer (Mac-Check, Japan). Systolic blood pressure (SBP) was determined as the initial appearance of sound, while diastolic blood pressure (DBP) was determined as the first change in sound from sharp to muffled. Double product (DP) (or the rate pressure product) value was calculated by the following formula: $DP = HR \times (SBP/100)$.

Blood samples were taken from the earlobe and were analyzed by using the YSI Sport 1500 L-Lactate Analyzer with a cell-lysing agent (Yellow Springs Instruments, Yellow Springs, OH, USA), prior to, immediately after, and 1st, 3rd, and 5th minutes after the PNF exercise.

Data analysis

Means and standard deviations were used as descriptive statistics. A repeated measures ANOVA was used to compare HR, BP, DP, and La, which were taken prior to, immediately after, and at the 1st, 3rd and 5th minutes after the PNF exercise. For each ANOVA that resulted in a significant F ratio, post hoc analysis was performed with Least Significant Difference. SPSS software (Statistical Package for the Social Sciences, version 10.0, SSPS Inc, Chicago, Illinois, USA) was used in statistical analysis, and the level of significance was set at $p < 0.05$.

RESULTS

Means and standard deviations and one-way ANOVA with repeated measures results for heart rate, blood pressure, double product, and blood lactate concentration are given in Table 1.

The results of a one-way ANOVA with repeated measures revealed significant differences in heart rate, systolic blood pressure, diastolic blood pressure, double product, and blood lactic acid concentration. LSD *post hoc* analysis indicated that HR, SBP and DP values obtained after PNF exercises were significantly higher than values obtained before PNF (for HR mean difference: 26.188, $p = 0.000$; for SBP mean difference: 7.500, $p = 0.000$; for DP mean difference: 38.759, $p = 0.000$) and during the 1st (for HR mean difference: 25.125, $p = 0.000$; for SBP mean difference: 8.438, $p = 0.000$; for DP mean difference: 38.230, $p = 0.000$), 3rd (for HR mean difference: 26.219, $p = 0.000$; for SBP mean difference: 10.938, $p = 0.000$; for DP mean difference: 41.697, $p = 0.000$), and 5th (for HR mean difference: 27.125, $p = 0.000$; for SBP mean difference: 12.500, $p = 0.000$; for DP mean difference: 43.853, $p = 0.000$) min of recovery period (HR: $F_{(4,28)} = 26.459$, $p = 0.000$; SBP: $F_{(4,28)} =$

14.539, $p = 0.00$ and DP: $F_{(4,28)} = 25.912$, $p = 0.00$). For DBP values LSD *post hoc* analysis indicated that DBP values obtained after PNF exercises were significantly higher than values measured at 1st (mean difference: 3.226, $p = 0.023$), 3rd (mean difference: 3.226, $p = 0.033$) and 5th (mean difference: 5.258, $p = 0.001$) min of recovery period ($F_{(4,28)} = 3.101$, $p = 0.032$) and for La, values obtained before PNF exercise were significantly lower than values obtained at the 1st (mean difference: -0.712, $p = 0.000$), 3rd (mean difference: -0.582, $p = 0.000$), and 5th (mean difference: -0.405, $p = 0.001$) min of recovery period ($F_{(4,28)} = 14.407$, $p = 0.000$).

DISCUSSION

In PNF exercise, repetition of activities is very important for motor learning, strength, and endurance development (Livanelioglu and Erden, 1998). Repeated contraction of weak components may result in fatigue. When the stretch reflex that appears at the initial phase of the movement is combined with the voluntary effort of the patient, the response is increased and fatigue is delayed (Voss et al., 1985). Isometric and isotonic contractions in PNF techniques may result in hemodynamic differences by affecting the cardiovascular system (Cornelius and Craft-Hamm, 1988).

In a study by Yakut and Arıkan (2001), hemodynamic responses to PNF techniques to upper and lower extremities were compared. Similar diagonal patterns of PNF exercise were applied to healthy subjects and heart rate, blood pressure, and double product values were measured at the first, fifth, and tenth PNF repetition (Yakut and Arıkan, 2001). As the number of repetitions increased, significant increases were found in heart rate, blood pressure and double product ($p < 0.05$). The latter study indicated that PNF applications provided an additional load to the cardiovascular system as evidenced by increased heart rate, blood pressure, and double product. In another study (Greer et al., 1980), changes in oxygen consumption, heart rate, systolic and diastolic blood pressures, and double product, were examined during PNF exercises in patients with coronary heart disease. Increases in double product values were higher in upper extremity exercise compared with lower extremity exercise. Other studies agree with this finding (e.g. Toner et al., 1983; Wetherbee et al., 1991).

Studies related to PNF exercise generally investigate hemodynamic responses to PNF exercises (Cornelius et al., 1995; Yakut and Arıkan, 2001), and no previous study has been found relating the effects of PNF exercise on blood lactic acid concentration. In the present study, significant increases were found after repeated PNF exercise in heart rate, systolic and diastolic blood pressures, double product, and blood lactic acid concentration. Increased lactic acid concentration to almost anaerobic threshold levels indicated that PNF exercises taxes the anaerobic energy supply systems as well as the cardiovascular system.

Muscle fatigue is defined as a loss of force and power output leading to reduced performance of a given task (Fitts, 1993). The nature and extent of muscle fatigue depends on the type, duration, and intensity of exercise, the fibre type composition of the muscle, individual level of fitness, and numerous environmental factors (Sahlin, 1986; Westerblad et al., 1998). During short duration, high-intensity exercise, fatigue could result from increased lactate accumulation and hence the increased H^+ concentration (Fitts, 1993; Sahlin, 1986). Concomitant with an increase in blood lactic acid concentration, there is a decrease in the ability of the muscle to perform work. Increased metabolic responses in the present study indicated that PNF exercise results in an increase in blood lactic acid concentration and may result in increased fatigue.

Increased lactate concentrations immediately after PNF exercise indicates the anaerobic contribution inherent during this type of exercise because of poor blood flow during PNF exercise (Powers and Howley, 2004). In the present study, an increased double product immediately after PNF exercises was similar to increased lactic acid concentrations immediately after PNF exercises. An increased double product values after PNF exercises indicates increased myocardial oxygen consumption. This in turn results in increased lactic acid concentration during anaerobic exercises, such as during PNF exercises in the present study since during isometric exercises blood flow is poor (Powers and Howley, 2004), because the heart has a limited ability to use lactic acid (Fletcher et al., 1995).

During PNF exercises, different movement patterns must be used. Duration, frequency, and intensity of the exercises must be arranged so that responses from PNF exercises can be increased. In addition, in patients at risk for the development of coronary heart disease, if PNF exercises are to be used together with isometric and isotonic contractions, care should be taken to monitor heart rate, blood pressure, and double product values at regular intervals to prevent untoward responses.

CONCLUSION

In conclusion, the present study resulted in increased hemodynamic responses and an increase in lactic acid concentration, indicating that PNF exercises resulted in a strain on the cardiovascular system and led to increased anaerobic metabolism in healthy subjects. Given that PNF exercises are also applied to patients and injured athletes, hemodynamic responses and lactic acid accumulation should be monitored carefully and intermittently during the rehabilitation period to prevent comorbid conditions and fatigue from developing during PNF exercises.

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KEY POINTS

- PNF exercises resulted in increased hemodynamic responses.
- Repeated PNF exercises resulted in an increased blood lactate concentration.

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