EFFECTS OF DIFFERENT FORMS OF EXTRINSIC FEEDBACK ON THE ACCURACY OF FORCE PRODUCTION AND TO DIFFERENTIATE THIS FORCE IN THE SIMPLE CYCLIC MOVEMENTS OF THE UPPER AND LOWER LIMB

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ABSTRACT

Background: This study aimed to assess the accuracy of force production by the limbs and to identify the ability to differentiate this force during a progressively increasing value, in response to different types of extrinsic feedback.
Material and methods: The study involved nineteen healthy and physically active boys and girls aged 12.82±0.34 years, body height 157.05±9.02 cm, and body mass 44.89±7.89 kg. The tasks were to perform a series of right and left upper limb pulls and pushes with increasing force using the levers of the kinesthesiometer and a series of lower limb presses on the pedal of the kinesthesiometer. The tasks were completed in three feedback conditions: no feedback, sound feedback, verbal feedback, and the retention test was used. To assess the level of accuracy of force production, the novel index of force production accuracy (FPAIndex) was used.
Results: The outcomes expressing the value of FPAIndex on the point scale indicated that the highest level of kinesthetic differentiation was observed when no feedback was provided (1.17 points), and the lowest kinesthetic differentiation was recorded when verbal feedback was provided (3.33 points). However, they were devoid of statistical value. The repeated-measures analysis of variance ANOVA with the Tukey post-hoc test (HSD) indicated a significant lowest ($p=0.0402$) level of accuracy of FPA ($\bar{x}$36.12±18.29 [N]) only for the act of left lower limb press (LL PRESS) in the retention test, while no feedback was provided to the subjects.
Conclusions: The results of this study showed that verbal and sound extrinsic feedback did not affect the accuracy of force production by the upper and lower limbs and the ability to differentiate this force in simple movements among children.
Keywords: verbal feedback, sound feedback, force production accuracy, kinesthetic differentiation.

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INTRODUCTION

Improvements in motor control are based on several motor strategies that enhance performance. Extrinsic-derived feedback provides the performer with strategies for modifying the position and velocity of the limbs, direction of movement, or the amount of exerted force [1]. It has been widely discussed various aspects of selecting the most appropriate type of feedback as well as its quality, quantity, and temporal characteristics [2]. It is interesting if changes in the intensity of verbal or sound feedback may significantly affect the precision and optimization of the forces inputted for movement.

The feedback that influences motor activity can be derived from exteroreceptors (i.e. vision or hearing) or proprioceptors (sensory receptors of proprioception) [3]. They include extrinsic (augmented) verbal, sound, and visual feedback derived from external sources e.g. teacher or coach [4] while intrinsic (integral) kinematic and kinetic feedback from internal sources, i.e. proprioreceptors (the vestibular system or muscle and joint receptors) [5]. According to several authors (representing psycholinguistic perspectives), verbal feedback is a determinant in the effective acquisition of motor skills [6,7]. The most common form of verbal feedback provides knowledge of results (KR) or knowledge of performance (KP) [8,9]. Sound feedback has also been used successfully in motor learning and control [10,11]. Research has also been performed on motor control and movement perception processes associated with visual modalities, in which there is significant evidence attesting to the importance of visual feedback on motor control [12,13].

It must be underlined that motor behavior is a multimodal phenomenon, in which movement is perceived by the sense of hearing, observed by the sense of sight, and controlled by the sense of touch. For this reason, many behavioral and neurophysiological studies have employed a multisensory approach in enhancing motor teaching and learning processes and performing motor tasks [14,15,16]. The increasing number of studies in this field highlights the significance of feedback on the improvement of motor performance in a wide range of tasks [17].

Kinematics refers to the effect of movement without consideration of the forces that generate them [18]. Hence, kinematic feedback provides information on the characteristics and patterns of movement. This type of information includes various quantified measures of movement, such as the position of the body in the environment and joint angulation (spatial component), the time and velocity of movements (temporal component), and coordination patterns (coordination component) [19]. While kinematic are variables that describe the characteristics of the movement, kinetic variables are descriptors of the forces that are the source of these kinematic variables. Muscle force (torque) and the time it is generated are the main results of activities, the structures that organize movement on the level of the central nervous system [18]. Kinematic and kinetic feedback is created and transmitted by the sensory organs. The vestibular system quantifies posture and balance, the muscle spindles provide information on muscle velocity, and the Golgi tendon organs and skin receptors (cutaneous mechanoreceptors) provide information on the forces developed in different parts of the muscle [20]. The sensory organs (at a neuromuscular level) and the afferent system transmit kinematic and kinetic information to the spinal cord that results in efferent reactions [21,22].

One external symptom of reflex actions originating from the central nervous system is the kinesthetic differentiation of movement [23,24]. Kinesthetic differentiation is a motor ability in the coordination (information) domain that quantifies the perception of force, timing, and position of a motor task in consideration of the most efficient movement strategy [23,25]. It depends on the reception, processing, and transmission of kinematic and kinetic feedback regarding joint angulation, the spatial positioning of the limbs relative to each other and to the body, the direction and velocity of the limbs, and the value of muscle force that is exerted to overcome resistance during movement execution [26,27].

Kinesthetic differentiation allows the performer to adjust muscle tension in variable conditions and modulate it when executing various motor tasks [28]. This ability is also responsible for mechanical efficiency and movement precision [29]. The results of current studies suggest that ability of kinesthetic differentiation plays the important role in daily life [30], physiotherapy [31], leisure [32,33,34], and also in the motor learning process [35,36,37]. Furthermore, the sensitivity of the kinesthetic sense is particularly crucial when performing motor tasks in competitive sports [38,39].

The neuroplasticity of the central nervous system [40] is particularly important, that is manifested in the specific sensibility for the stimuli received from different environments e.g. from water in artistic swimmers [41]. The ability to differentiation by means of the repeatability of the generated force is crucial in cyclic sports [42,43]. Examples are the "feeling" of water on the propulsion surfaces among swimmers [44,45,46,47], or on the surface of a monofin in swimmers using it for propulsion [28]. Sensibility for dynamic changes in the applied force is important for athletes, whose use of sports equipment, e.g: feeling of a ball [48], a javelin [49], table tennis paddle [50], a golf club [51], or feeling of air flow in ski jumpers [52], and a ski edge in alpine skiers [53].

The term kinesthetic differentiation, as the ability to sense limb and body movement, is often used interchangeably with terminologies such as kinesthetics, kinesthetic sense, kinesthetic (muscle) memory, kinesthesia, haptics, kinesthetic feeling, the feeling of movement, the perception of muscle strength, or the differentiation of force [54,55,56].

Teachers and coaches have various methods at their disposal for presenting information to students and athletes across the verbal, visual, and sound domains [5,57,58,59]. It is known that appropriately prepared extrinsic feedback (verbal, visual, or sound) can complement intrinsic feedback (kinematic or kinetic) [1] and even enhance intero and exteroreceptors sensation [1,60]. However, it is unknown what types of extrinsic feedback are most useful in the improvement of the accuracy of force production by the limbs or to differentiate this force during a progressively increasing value. An improvement in the accuracy of force production and the ability to differentiate this force (kinesthetic differentiation) via a suitable method for delivering extrinsic feedback could improve the teaching process in motor skills learning, enhance motor control, and improve motor efficiency. Determining which method, whether verbal or sound, is responsible for the improvement in the accuracy of force production and the ability to differentiate this force, would allow physical education teachers and coaches to use such methods in daily practice. The above considerations show the innovative nature of this type of research and may prove to be an interesting approach in the realm of physical education and sports.

AIM

This study aimed to assess the accuracy of force production by the limbs and to identify the ability to differentiate this force during a progressively increasing value, in response to different types of extrinsic feedback. The following research question was posed: how does the accuracy of force production and the ability to differentiate this force change in response to verbal or non-verbal extrinsic feedback of changing intensity?

MATERIAL AND METHODS

PARTICIPANTS

The study involved nineteen healthy and physically active participants (7 males and 12 females) aged 12.82±0.34 years (V2.64%), body height 157.05±9.02 cm (V5.74%), body mass 44.89±7.89 kg (V17.33%), and BMI 28.58 kg·m–2 (V11.50%). A low coefficient of variation (V) confirmed the developmental homogeneity of the sample [61]. All participants and their coaches were informed about the purpose of the study and procedure which would be used and had decided to voluntarily participate in the data acquisitions. Their parents or guardians provided the written informed consent for involvement in the study. The study protocol was approved by the University Research Ethics Committee (No. 16/2019) and was performed in accordance with the ethical standards of the Declaration of Helsinki.

DESIGN AND PROCEDURES

The task for the participants to perform was basic movements – pushing and pulling the lever of the device with the right and left upper extremities separately and analogous to the lower extremities that – press the pedal. This device named the kinesthesiometer (Figure 1) is designed for measuring, with the strain gauges located in the levers, the reaction force of torque generated as a result of the limb movement. The measurement system was located in an adjustable chair built out of a metal skeleton and was calibrated with 1, 5, and 10 kG loads prior to testing. The device was patented (Polish patent PL 213 505 B1) and validated as a measurement device [62].

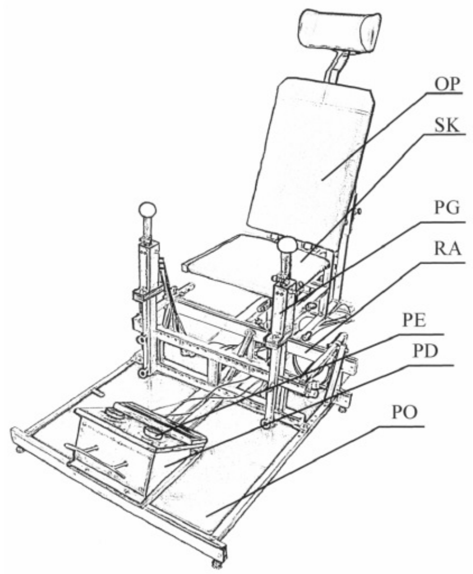

Fig. 1 The kinesthesiometer for measuring the accuracy in force production by the upper and lower limbs [62].
OP – the back of the chair; SK – seat for a chair; PG – upper limb research platform; RA – frame; PE – pedals; PD – lower limb research platform; PO – base of platform.

The subject of the research was the accuracy and the ability to differentiate force by the limbs during its cyclic production with a progressively increasing value in subsequent repetitions. The participants were sitting on a kinstesiometer without back support. The lack of additional support negated the effects of additional feedback from exteroreceptors to the cerebral cortex responsible for the sensory modality of touch as they could impact the findings of the study [62,63].

Upper right and left limb force production accuracy was measured in each participant during the forward and reverse operating with a lever held with one hand. The arm of this limb was still in contact with the trunk in order to keep the movement along the sagittal plane. The second hand rested freely on the thigh. Lower right and left limb force production accuracy was measured also with both legs separately. During the foot movement, the force was applied in one direction - to press the pedal only in the sagittal plane (the knees of both legs were touched themselves). The pedal was positioned obliquely to the base of the kinesthesiometer (allowing a right angle to be maintained between the foot and tight). During the test, the participants maintained their arms crossed over the chest. The procedure was based on approved testing protocol [64].

Before testing began, the participants were familiarized with the device and with the experimental tasks. Then they were asked to perform the maximal force output on the kinesthesiometer. Each participant performed this maximal trial with the right and left upper and lower limbs according to the following order: right upper limb push (RU_PUSH), right upper limb pull (RU_PULL), left upper limb push (LU_ PUSH), left upper limb pull (LU_PULL), - right lower limb press (RL_PRESS) and left lower limb press (LL_PRESS).

In the experimental session, the participants performed five separated trials according to the aforementioned order (RU_PUSH, RU_PULL, LU_PUSH, LU_PULL, RL_PRESS, LL_PRESS). The first trial should be performed at 50% maximal force (T1=50%). In the each next repetition the force would be proportionally increased as the following: T2 50% + 10%; T3 60% +10%; T4 70% +10%; T5 80% +10%. In all the trials the participants were asked to pull, push or press the device for one second. Each repetition was separated by a 4-second interval. A 5-min rest was provided between testing each limb.

In each of the aforementioned attempts, the accuracy of the cyclical force generation by the limbs in response to the different forms of extrinsic feedback was investigated: 1) no feedback (NF); 2) the sound feedback (SF), and 3) the verbal feedback (VF). Feedback concerning the quality or quantity of the performance is believed to be one of the most important factors in guiding the process of learning motor skills [5].

In the first (NF) trial the frequency of movements in subsequent repetitions was not imposed for the participants. In the second (SF) trial, a digital sound (single piano note) - five 2-second beeps were generated by the computer Ableton Live 10.0.6 software (Ableton, Germany) with a sampling frequency of 1 beeps/4-second. The sound intensity was increasing in each beep by 5 dB in the range of 20 dB. In the third (VF) trial the computer Ableton Live 10.0.6 software (Ableton, Germany) played an audio file in which the numbers from one to five were talking verbally by the speaker in the native language of the participants. The sound intensity was also increasing in each digit by 5 dB with the same frequency of the signal emission.

The feedback conditions (sound and verbal) with changing (increasing) sound intensity were used to indicate the amount of force that the participant was supposed to produce by their upper and lower limbs. The force generated by the participants was a motor response to the feedback they received.

A retention test (R) was administered 10 min. after completing all the mentioned trials in the same order. The retention test (R) usually involves retesting people on the same task or conditions [65]. Following Schmidt et al. [66], it was assumed that the results of the test tell us about the persistence of the acquired capability for performance (motor habit). If performance on the retention test is as proficient as it was immediately after the end of the experimental session, then we might be inclined to say that no motor memory loss has occurred. If performance on the retention test is poor, then we may suppose that a motor memory loss has occurred.

The magnitude of the force registered by the strain gauges was amplified and processed to the digital signal and then recorder on the PC. The output data in the form of time-depending series of the reaction force represented the sensitivity of the sensory system in the area of the accuracy of force production by the limbs and the ability to differentiate this force during its cyclic (progressively increasing) repetition, in response to different types of extrinsic feedback.

It was assumed that the recorded change in the value of the force produced in each trial indicates information about the accuracy of force production of this process in every repetition (with increasing force) is information about the ability to differentiate produced force.

Hence, we considered the difference in force between successive repetitions (T2-T1, T3-T2, T4-T3, T5-T4).

For the resulting four variables (differences), the statistics of the unbiased estimator of the variance was used, expressed the formula (1):

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (\mathrm{x_i} - \bar{x}) \tag{1}$$

where

$\bar{x}$ is the average of the sample (2)

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

Afterward, a novel index – named the force production accuracy index FPAIndex - was created, comparing the variability of force differences in respective five repetitions. Thus, four force production accuracy index values (one for each condition) were obtained for each participant in the form of the formula (3):

$$FPA_{Index} = \frac{1}{3} \sum_{i=1}^{4} (T_{i+1} - T_i - \bar{T}) \text{ [N]} \tag{3}$$

where

T is the next repetition in the task

The novel index allowed to estimate the differences in the numeric value of the increase in force produced in the next repetitions T2-T1, T3-T2, T4-T3, and T5-T4. Hence the lower FPA_{index}, the higher ability to control the accuracy of force production and therefore the better the ability to kinesthetic differentiation. For comparative purposes, a point-based scale was created that expressed the value of the force production accuracy index. The lowest index magnitude received 1 point and the highest 4 points. This ranking assessed the effects of the feedback conditions on kinesthetic differentiation among all the different tasks.

STATISTICAL ANALYSIS

Basic descriptive statistics were determined by calculating the mean ($\bar{x}$), standard deviation **(±)**, and variance for all variables. Multifactorial analysis of variance for independent samples (ANOVA) was used to assess the differences in the ability to differentiate the amount of force produced in the different feedback conditions. Tukey's test for multiple comparisons (HSD) was used to determine if differences exist between the means. The normality of the data distribution was assessed using the Shapiro-Wilk test (see Levene's test for confirming the homogeneity of variance p>0.05). For planning purposes, a four-dimensional approach was used (alpha, power, sample size, and effect size) [67]. Analysis of variance was performed at the significance level of $\alpha<0.05$. All calculations were performed with the Statistica version 13.1 software package (StatSoft, Tulsa, USA) and the IBM SPSS Statistics version 26 software package (IBM Inc., Chicago, USA). The sample size was calculated using G*Power 3.1.9.2 power analysis software (University of Kiel, Germany) [68] with a small effect size ($f^2 = 0.29$) for within-group variables, an alpha level of 0.05 (95% confidence), $-\beta = 0.80$ (80%), and $\beta = 0.2$. This determined a sample size of 20.

RESULTS

In table 1 are showed the results of descriptive statistics and differences between trials of the forces recorded with the kinesthesiometer in simulated feedback conditions provided to subjects during trials, assessing the accuracy of the cyclical force generated by the limbs.

The estimated values of the force production accuracy index (FPAindex) (Table 2) indicated that during: RU PUSH, PULL and LU PUSH, the participants showed the highest level of force production accuracy (the lowest value of the index) in the no feedback conditions. They obtain the lowest (the highest value of the index) when verbal feedback was provided. For LU PULL the lack of feedback resulted also in the highest level of force production accuracy, whereas the lowest level of accuracy was observed in the sound feedback condition. For RL PRESS the highest level of force accuracy was observed when sound information was provided whereas the lowest level of accuracy in the retention test. For LL PRESS the highest level of force production accuracy was when no feedback was provided and the lowest level of accuracy in the retention test.

The results expressing the value of force production accuracy index (FPAIndex) on a point scale (Table 2) indicated the highest ability to differentiate of force production was observed when no feedback was provided (1.17 points). In trials with sound feedback provided, the result was higher and equal to 2.33 points, and in the retention test was 3.17 points. The lowest level of the ability to differentiate of force production was recorded when verbal feedback was provided (3.33 points).

Repeated-measures analysis of variance ANOVA with post hoc Tukey's (HSD) test indicated a significantly lowest (p=0.0402) level of accuracy of force production FPAIndex ($\bar{x}$36.12±18.29 [N]) only for the left lower limb pressing action (LL PRESS) in the retention test, while no feedback was provided to the participants. Comparisons of the FPAindex values determined for trials performed under simulated feedback conditions did not indicate any other changes.

Tab. 1

The mean values ($\bar{x}$), the standard deviation (±) and differences between trials (Δ) of the forces recorded with the kinesthesiometer [N] in simulated feedback conditions (no feedback (NF); sound feedback (SF); verbal feedback (VF) and retention test (R)) provided to subjects during trials, assessing the accuracy of the cyclical force generated by the limbs.

Task	Testing condition																			
	No feedback					Sound feedback					Verbal feedback					Retention				
	Trial					Trial					Trial					Trial				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
RU_PUSH	63.78	77.29	89.40	97.93	106.50	64.63	79.69	93.08	102.84	117.52	47.96	63.22	74.20	89.56	101.49	62.36	74.47	88.98	102.43	122.42
RU_PULL	65.58	92.47	109.89	115.74	134.68	77.32	96.84	117.42	133.95	156.79	63.74	84.42	95.89	111.53	123.21	68.63	87.16	108.21	133.42	153.95
LU_ PUSH	68.84	87.47	99.63	106.16	114.63	60.37	78.63	95.00	107.37	125.74	48.21	68.84	82.42	92.58	105.84	70.58	81.47	100.37	118.74	129.21
LU_PULL	74.21	89.84	103.74	117.84	130.32	78.53	100.32	108.05	126.95	146.68	64.63	81.79	100.95	119.58	139.21	85.32	106.26	122.26	137.84	148.79
RL_PRESS	76.21	96.68	114.53	128.89	133.11	87.32	108.16	123.05	146.53	157.84	78.53	92.68	110.32	127.00	135.89	90.53	114.26	133.63	145.47	154.47
LL_PRESS	79.16	95.16	104.89	116.58	124.42	71.47	95.95	112.89	118.37	146.79	82.89	100.00	121.42	133.00	128.84	84.84	114.42	113.89	133.11	149.74
x̄	71,30	89,82	103,68	113,86	123,94	73,27	93,26	108,25	122,67	141,89	64,33	81,83	97,53	112,21	122,42	77,04	96,34	111,23	128,50	143,10
±	6,16	7,00	8,69	10,64	11,23	9,85	11,75	12,09	16,50	16,60	14,66	13,92	17,44	17,91	15,61	11,31	17,49	15,83	15,46	13,74
Δ	18,52	13,86	10,18	10,09	-	19,99	14,98	14,42	19,23	-	17,50	15,71	14,67	10,21	-	19,30	14,88	17,28	14,59	-

U – upper limb, L – lower limb, R – right, L – left

Tab. 2

The mean values ($\bar{x}$) and the standard deviation (±) of the force production accuracy index [N] FPA_{Index} with subordinated point values (*pts.*) quantifying the ability to kinesthetic differentiation of the force generated by the limbs in simulated feedback conditions (no feedback (NF); sound feedback (SF); verbal feedback (VF) and retention test (R)) provided to participants during trials.

Task		Testing conditions			
		NF	SF	VF	R
RU_PUSH	x̄	10.58	12.00	13.00	12.83
	±	5.60	7.84	9.67	11.97
	pts.	1	2	4	3
RU_PULL	x̄	17.17	18.87	21.84	19.39
	±	8.99	9.95	12.23	10.80
	pts.	1	2	4	3
LU_ PUSH	x̄	14.88	15.73	17.95	17.28
	±	11.34	10.29	9.32	12.28
	pts.	1	2	4	3
LU_PULL	x̄	12.39	16.27	16.21	14.44
	±	5.08	8.74	8.32	9.09
	pts.	1	4	3	2
RL_PRESS	x̄	23.92	21.35	25.45	32.53
	±	15.98	16.10	12.49	22.01
	pts.	2	1	3	4
LL_PRESS	x̄	21.52	34.70	25.98	36.12
	±	9.84	20.96	15.02	18.29
	pts.	1	3	2	4
	pts. x̄	1.17	2.33	3.33	3.17

U – upper limb, L – lower limb, R – right, L – left
NF – no feedback, SF – sound feedback, VF – verbal feedback, R – retention

Tab. 3

Results of ANOVA (*p*) with repeated measures and Tukey's HSD test post hoc for the force production accuracy index (FPA_{Index}) in simulated feedback conditions (no feedback (NF); sound feedback (SF); verbal feedback (VF) and retention test (R)) provided to participants during trials.

	Task																							
	RU_PUSH				RU_PULL				LU_ PUSH				LU_PULL				RL_PRESS				LL_PRESS			
Condition	NF	SF	VF	R	NF	SF	VF	R	NF	SF	VF	R	NF	SF	VF	R	NF	SF	VF	R	NF	SF	VF	R
NF	-	0.963	0.843	0.870	-	0.959	0.526	0.916	-	0.995	0.820	0.904	-	0.441	0.455	0.857	-	0.966	0.992	0.406	-	0.076	0.840	0.040*
SF			0.986	0.992			0.822	0.998			0.922	0.971			1.000	0.893			0.879	0.187			0.371	0.993
VF				0.999				0.890				0.997				0.902				0.576				0.242
R				-				-				-				-				-				-

U – upper limb, L – lower limb, R – right, L – left
NF – no feedback, SF – sound feedback, VF – verbal feedback, R – retention
*statistically significant difference ($p<0.05$)

DISCUSSION

Classical motor control theories assume that feedback (extrinsic/intrinsic) influenced on performance and mechanical efficiency and plays a significant role in the acquisition and improvement of motor activities [69]. It has been recognized that verbal feedback is an important element towards improving motor skills and that several researchers consider it to the most effective modality [7,60]. Sound feedback has also been used to improve motor performance [12,13]. The role of visual feedback in these processes is also widely described [70,71]. Thus, there are many works devoted to the issue of feedback in motor teaching and learning, but there is no clear evidence attesting to the advantage of one source of feedback over the other. It is nonetheless certain that extrinsic feedback supplements intrinsic feedback. Intrinsic feedback derived from the sensory organs (intrinsic) plays a significant role in motor control including precision (movement accuracy) or sensing the magnitude of exerted force [22,27].

The ability to differentiate force production, as a measure of kinesthetic differentiation is important not only in daily activities (e.g. gripping or squeezing objects) but also in physical activity (when soccer player kicking the ball, basketball player throwing the ball, a swimmer “catching the water”). Having the proper “feeling” of force often determines the accuracy of a motor task and plays a decisive role in competitive sport [22]. Hence, searching for methods and tools for improving the accuracy of force production and the ability to differentiate this force seem to be an interesting scientific endeavor. In the current references, there is a lack of studies on ways towards improving the accuracy of force production and the ability to kinesthetic differentiation via verbal or sound feedback. This signifies the need for research in this domain. Knowledge concerning the the effect of different forms of extrinsic feedback on the effectiveness of motor task in the context of the accuracy in force production and its kinesthetic differentiation could provide direct benefits in motor movement) control. Hence, in this study, we attempted to investigate how the accuracy of force production and the ability to differentiate this force change when performing a simple task with the limbs with progressively increasing value of force in response to various forms of extrinsic feedback (no feedback and sound feedback, or verbal feedback with increasing volume). This idea was created on the basis of the outcomes of Docherty and Arnold [29], Błacha [25], and Mustafa et al. [31], for whom the ability to reproduce a pre-specified force magnitude by the upper and lower limbs under static conditions was a measure of kinesthetic differentiation.

The results indicated (Tables 2 and 3) that verbal and sound feedback did not significantly affect the accuracy of force production and the ability to differentiate this force. These results can be accepted, especially in reference to the inconsistency of other findings on the issue under consideration. Takeuchi [12]; Sigrist et al. [13] had similar doubts, trying to determine the most effective forms of feedback that can improve motor control. This inconsistency resulted from the multitude of variables that affect the performance in motor activity (including feedback quantity, and, frequency and the types of motor tasks under analysis).

Arguments explaining the objective dimension of the results obtained in this study can also be found in the theory of motor control.

From a physiological point of view, muscle strength depends on the number of activated motor units, that are determined by the number of involved motor neurons, the contraction of muscle, and rate of change in this contraction (velocity) [72]. Furthermore, these neurons receive signals from the brain (controller) and peripheral sensory nerve endings (receptors). Peripheral skin receptors, joint receptors, and receptors found in other muscles provide information on muscle length, velocity, strength [72]. The most active receptors that monitoring muscle tone are Golgi tendon organs located at the end of muscle fibers [22]. The majority of Golgi tendon organs sense a change in muscle tension in a select group of motor units and could be treated as local sensors of force that send signals to the cerebral cortex [73]. Hence, in order to ensure movement with an adequate force, the peripheral controller must consider peripheral information (from the receptors) and produce the expected result (proper value of muscle strength) [72]. For this reason, we considered that the proprioceptive feedback (kinematic and kinetic) used to create a predicted value of change in muscle length and contractile velocity could be supplemented by extrinsic feedback (verbal and auditory).

The movements performed as a task in study (pulling, pushing and, pressing) can be classified as relatively short duration tasks (1-second). In this kind of task the programming processes in the open-loop system are more strongly involved and in which precise motor control is very disturbed [69,74,75]. Hence, motor control was most likely based on a general (previously acquired) motor program and was performed in advance (prior to processing any sensory feedback). Admittedly, there is known that feedback (from closed-loop processes) may occur in tasks of approximately 1-second [76], but tasks in closed, stable, and predictable environments, are usually performed in advance. Hence, a suggestion seems to be reasonable, that movement tasks performed herein were based on open-loop processes in which extrinsic feedback was not involved in motor control. This presumption is consistent with Gritsenko et al. [77], who reported that the prediction of a change in position or a force value during movement execution is based on efference copy, which is combined with sensory feedback that is delayed by conduction and processing time. The short duration of the movements (1-second) could have prevented the processing of additional extrinsic (verbal/sound) feedback.

In the retention test, we observed the lowest ability of kinesthetic differentiation in the pull of the left lower limb (Table 3). It could have been caused by the previous trials with extrinsic feedback (verbal and sound). While these are only speculations, verbal and sound feedback may have had an adverse effect on the ability to differentiate force production. This is confirmed by the studies by Schmidt and Wulf [76], who found that while feedback improved performance during exercise, it caused a decrease in performance during retention testing when feedback was not provided.

In light of the discussion, it is clear that the results of this study should be interpreted with caution due to several limitations. Our findings are limited to children and research on the effects of various types of feedback on the accuracy of force production and ability of kinesthetic differentiation has not yet been performed in this age group. Additionally, the use of a 2-s sound signal with increasing volume every 5dB may have been not enough stimulus to produce the expected outcome. As it was mentioned before the movements performed during the trials took only 1-second in duration, hence programming processes related to them were probably based on an open-loop control without error correction (non-feedback system). Also, the choice of the 4-second interval between repetitions was not confirmed as the sufficient duration in order to eliminate the effects of fatigue. Furthermore, the length of time from the last trial to the retention test (10 min) could not allow us to fully assess the robustness of the ability to exert force by the limbs. In addition, the retention test - the test that individuals perform motor activities - it is susceptible to the influence of intermediary variables. Thus, it could be that performance is poor on the retention test for some temporary reason (fatigue, anxiety) or a problem with the retrieval processes may arise I consequence it could falsely conclude that a motor memory loss has occurred [66]. We also did not check how the type of feedback we applied could affect the accuracy of force production and ability of kinesthetic differentiation when performing more complex motor activities than simple activity (push, pull, and press). Finally, we did not determine which is the preferred sensory modality for the participants which may have strongly impacted how feedback was received.

Further research is needed as many questions in reference to the accuracy of force production and to differentiate this force remain unanswered. Due to the multifaceted nature of the problem, future research should definitely encompass aspects on the motor control of muscle force, the adjustment of movement by proprioceptive information (kinematic and kinetic), and the role of extrinsic/intrinsic feedback in these mechanisms. It is also suggested that future research should take into consideration all aforementioned limitations. The results obtained can serve as a reference point and provide a theoretical and methodological basis for future research.

Conclusions

The results of this study showed that verbal and sound extrinsic feedback did not affect the accuracy of force production by the upper and lower limbs and did not affect the ability to differentiate this force in the simple movements among children. The significantly lowest level of accuracy of force production only for the act of left lower limb press in the retention test, while no feedback was provided to the subjects was statistically confirmed.

While these are only speculations, we can claim that there were limitations in the experiment that may have disturbed information processing and, at the same time negatively affected the accuracy of movement (accuracy of force production), and the robustness of the ability to differentiate this force. Hence, based on the experience resulting from this study, we postulate to search for methods, forms, and means of managing extrinsic feedback, as they can probably serve to increase the level of kinesthetic differentiation. A better understanding of the causes conducive to shaping the ability to accurately generate force and its differentiation may improve the control of the performed movement.

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