

THE EFFECT OF SONIFICATION OF VISUAL MODELING ON RELATIVE TIMING: THE ROLE IN MOTOR LEARNING

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Abstract

It has been shown the auditory channel associated with the task, transmits relevant information with movement and it can influence positively on perception and motor outcome athlete. But the combination of auditory patterns (Sonification) with common visual patterns in order to develop movement patterns, is still controversial field of study. Twenty subjects were randomly divided two groups: visual and visual-auditory. Visual groups watched pattern skilled basketball player and visual-auditory group in addition to watching pattern skilled basketball player, heard Elbow angular velocity as sonification. In training sessions, the subjects in each group received the desired pattern for each 5 trials. They received 32 times the desired pattern of a total of 160 trials. Selected kinematic variables (elbow joint angular distance and velocity) were evaluated in the pre-test, acquisition test and retention test. Six variables were identified that are: Relative Timing Error of angular distance (RTEad), Relative Timing Error of flexion angular velocity (RTEfav), Relative Timing Error of extension angular velocity (RTEeav), Maximum flexion angular velocity Error (MfavE), Maximum extension angular velocity Error (MeavE) and Error of Maximum Range of flexion (EMRf). The results showed that in all of the variables in the acquisition and retention test with the exception of "total time of elbow motion" between two groups there is a significant difference. The results show that audiovisual integration led to the development of temporal patterns of motor task in audiovisual group compared to the visual group. This results is explainable based of Common Coding Theory and modality appropriateness hypothesis.

Key words: sonification, audiovisual integration, audiovisual modeling, relative timing, motor learning

Introduction

Human beings are directed mainly by visual information, but it should not lead to ignoring other information resources related to human movement. Unfortunately, studies in the field of learning, particularly perceptual learning, focus on learning through a single sensory dimension (Shams & Seitz, 2008). Shams and Seitz (2008) suggested that single sensory training protocols that avoid the use of multi modal Learning will not probably have to look for optimal learning. Majority of studies regarding acquisition and learning of motor skills have focused on the areas of vision and dedicated less attention to other sources of information (Newell & Corcos, 1993; Ste-Marie, et al, 2012; Sors, Murgia, Santoro & Agostini, 2015). But the acquisition of motor skills cannot be reached only by vision and includes other senses as hearing, touch and proprioception as well. Among the senses, recent studies on hearing sense, have shown promising results in both acquisition of simple rhythmic movements and motor complex patterns (Sors, et al, 2015).

Research in this area shows that interventions based on sound (as modeling or feedback) include

both simple auditory warnings for physical and motor performance (Petrofsky, 2001; Batavia, Gianutsos, Vaccaro & Gold, 2001; Fernery, Moretto, Hespel, Thevenon & Lensel, 2004; Riskowski, Mikesky, Bahamonde & Burr, 2009; Helmer, 2011; Eriksson & Bresin, 2010) and acquisition rhythmic movements (Doody, Bird & Ross, 1985; McCullagh & Little, 1989; Glenberg & Jona, 1991; Keele, et al, 1985; Lai, Shea & Little, 2000; Shea, et al, 2001). These interventions also include more complex interventions such as providing hearing graphs of kinetic and kinematics features of human movement (which is called sonification) for feedback (Chollet, Madani & Micallef, 1992; Hummel, Hermann, Frauenberger & Stockman, 2010; Effenberg, 2007; Chollet, Micallef & Rabischong, 1988; Roth & Rocchesso, 2005; Schaffert, Gehret, Effenberg & Mattes, 2008; Hermann, Höner & Ritter, 2006; Schaffert & Gehret, 2013; Schaffert & Mattes, 2012; Schaffert, Mattes & Effenberg, 2011; Dubus, 2012; Schmidt, et al, 2013; Hermann & Zehe, 2011) or modeling (Effenberg, 2005; Effenberg, Feshe & Weber, 2011; Agostini, Righi, Galmonte & Bruno, 2004; Murgia, Hohmann, Galmonte, Raab & Agostini, 2012; Ramezanzade, Abdoli, Farsi &

Sanjari, 2014) for more complex motor tasks such as sports skills.

Sonification is the conversion of human kinetic or kinematic characteristics into auditory patterns and unlike simple auditory warnings that are important only from time dimension, considers, like vision, both temporal and spatial dimensions of human movement patterns and therefore they are important. A comprehensive review of research literature in this area shows that there are still many unanswered questions about different aspects of the impact of sound-based interventions on performance and learning. Furthermore, research on auditory modeling effect on performance (and in particular motor learning) is limited and does not have much empirical support. In complex motor tasks such as sports skills, while providing auditory patterns, this pattern should be provided with a visual pattern in order to make correction reference and develop the concept of movement for learners. But as previously mentioned, in sport science research and perceptual-motor processing and motor control and learning studies, the focus is on vision (Brock, Schmitz, Baumann & Effenberg, 2012; Williams, Ward & Smeeton, 2004; Abernethy & Zawi, 2007; Sors, et al, 2015) and visual-auditory integration effect on the perception (Kaiser, Medeiros, Wanderley & Schonwiesner, 2014; Effenberg, 2005; Schmidt, et al, 2013; Schmidt & Effenberg, 2012; Ramezanzade, et al, 2014; Ramezanzade, et al, 2017) and reproduction (Effenberg, 2005; Effenberg, 2007; Effenberg et al, 2011; Ramezanzade et al, 2014; Ramezanzade et al, 2015; Effenberg, Fehse, Schmitz, Krueger & Mechling, 2016) has been rarely studied or it was investigated in the form of concurrent feedback. On the other hand, among the studies that have investigated the effect of audio-visual modeling, a limited number of research have studied learning in addition to performance (Effenberg, et al, 2011; Effenberg, et al, 2016; Ramezanzade, et al, 2014). Effenberg et al (2011) studied the benefits of visual-auditory convergence to motor learning. In their study, three groups of participants as vision, visual-auditory (natural sound movement) and visual-auditory (sonification of kinetic and kinematic variables) rehearsed indoor rowing task. The results of their study showed that visual-auditory (sonification), had quicker and more accurate learning than the other two groups. Also, Ramazanade et al (2014) sonified elbow and wrist angular velocity in basketball jump shot. The two groups, vision group and visual - auditory group (elbow's sonified angular velocity), participated in retention after attending acquisition sessions. Results showed that visual-auditory group was better than the vision group in both the acquisition and the retention test.

The limited researches conducted to assess the impact of audio-visual convergence (as visual-auditory modeling) on motor learning on the one hand and lack of attention to the impact of infrastructure processes on the other hand, prompted researchers to study the impact of audio-visual modeling on learning of the relative timing of

elbow motion. Hermann and Zehe (2011), believe that in some areas, for example in the diagnosis of time or integrating consecutive sounds in a rhythm, ears act more accurate than eyes. Therefore, it is likely that the use of ears in motion-related perception could lead to a wider range of information and improves the accuracy of received information to support motor learning. Other studies have also found that the time resolution of vision can develop or deteriorate by sound due to time relation between vision and auditory stimulus (Scheier, Nijwahan & Shimojo, 1999).

Based on Schmit's Generalized Motor Program Theory, one of the immutable characteristics of motor programs, is the relative timing of movement. But by taking that vision is good in recognizing the spatial features (not timing features) one may ask: Can the Visual Pattern alone be enough for the development of relative timing of the movement? Does the use of auditory pattern with visual pattern can lead to better learning in relative timing of the movement? In simple rhythmic movements, a lot of research has confirmed the development of movement relative timing through auditory patterns. For example Lai, Shea and Little (2000), studied the impact of Sonification pattern on both absolute and relative timing of a simple rhythmic motion. The results showed that participants who experienced hearing model during the acquisition phase, showed more accuracy in timing, regardless of physical exercise, relative to the control group. However, the absolute timing in people who had physical exercise, was more accurate and even it was more accurate for those who had experienced auditory model.

Many other studies have shown the positive effects of sound-based interventions on time diagnosis in simple rhythmic movements and they confirmed that sound-based interventions compared to vision interventions are more effective in identifying, differentiating, creating a memory and reproducing movement with simple timing (Collier and Logan, 2000; Grondin & McAuley, 2009; Han & Shea, 2008; Repp & Penel, 2004). The results can be explained by modality appropriateness hypothesis (Welch, Duttonhurt & Warren, 1986). This hypothesis asserts that the sense which is the most appropriate or reliable in a special task is the sensory perception that is dominant in the perception of that task. Vision has higher spatial resolution and as a result is more dominant in spatial tasks while hearing has higher temporal resolution and consequently is more dominant in timing tasks.

But can auditory patterns in addition to the visual pattern be effective in creating better learning and memory in complex motor tasks (motor skills)? Will the development be better in the relative timing of movement parts with the addition of audio pattern to visual one?

Methods

Participants

20 subjects (aged 20.2 ± 1.8) were selected and they were randomly divided into two groups of visual modeling and audio-visual modeling. All participants were right-handed (self-reported by participants), had no previous basketball jump shot experience, and signed informed consent forms. All methods used in the study were approved by the Ethics Committee of Shahid Beheshti University.

Tasks and Tools

Kinematic Parameters

In the performance of the basketball jump shoot are involved many joints and all kinematic parameters (for example angular distance, angular velocity and angular acceleration etc.). Nevertheless, in this study, we choose the elbow joint and the angular velocity parameter for sonification. Of course, we analyzed both angular distance and angular velocity variables in results section. Elbow joint was chosen for two reasons: 1- Based on a study by Rojas, Cepero, Ona and Gutierrez (2000), who believed that the motor patterns of elbow joint would play a fundamental role in the final outcome and attainment of the goal. 2- Consult with two coaches. Angular velocity was chosen because we believe that understanding it is difficult through sight. Although the angular distance and angular velocity can both be detected by sight but the angular velocity is harder. Since velocity is the variation of distance per unit time and time changes are well recognized by the ears, we decided to present the elbow angular velocity through specific type of sound (sonification).

Visual Pattern

For visual pattern is used from a basketball player with at least 15 years of experience. Skilled pattern was recorded from the front and with angle of 20° to the frontal plan. Selected pattern consist of three features: 1- Had led to point 2- It was approved by the skilled player himself and 3- It is was approved by two basketball player and two basketball coach. Visual pattern was presented by a video projector on the wall in front of the subjects.

Audio Pattern

Before performing jump basketball shot by skilled player, were installed markers on certain areas of the hands, wrist, elbows, arms and shoulders. Information related to movement model was collected by Motion Analysis (version 2.5, manufacturing company Motion Analysis, eight camera) and analyzed by software Cortex. Finally, the elbow joint angular velocity was used to create audio pattern. Sandbox Sonification software (version 6) was used in order to sonify the data related to the elbow joint angular velocity. The Sonification Sandbox provides a cross-platform, flexible tool for converting tabular information into a descriptive auditory graph. This description includes

data representations of pitch, timbre, polarity, pan, and volume, along with graph contexts analogous to visual graph axes (Davison & Walker, 2007).

Figure 1 shows elbow joint angular velocity in relation to different stages of implementation of basketball jump shot.

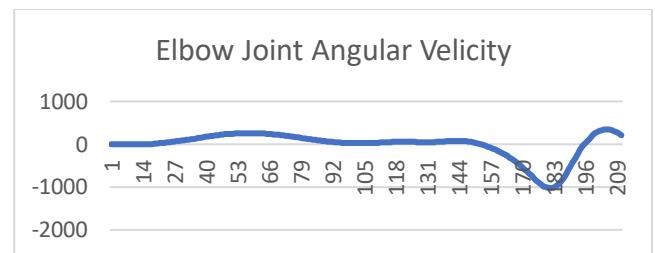


Figure 1. Charts the elbow angular velocity associated with the various stages of implementation.

Procedure

Vision and hearing health assessment

Before starting work, the participants' vision and hearing accuracy were evaluated. To assess vision, Snellen test was used. Subjects who had 10/10 vision, were selected for the study. To measure the hearing, audiometer screening software (Starkey Hearing Technologies) was used. This application is a hearing screening tool in four frequencies 500, 1000, 2000 and 4000 Hz in both ears. The application screens people in three steps (a) Asking questions (5 questions) b) Calibrate and c) The main test (play sounds in four frequencies)). People who did not have hearing problems based on the results of this test were selected for the study.

Furthermore, using a software installable on a mobile phone (supported by the android system), the frequency of hearing in subjects was determined. This application plays sounds at different frequencies and determines the minimum and maximum frequency audible by a person. The minimum and maximum audible frequency in the subjects (on average) was 38 Hz and 18950 Hz respectively. Both tests carried out in a quiet environment using headphones.

Practice Protocol

Each group after the pre-test, during the acquisition phase, performed four sessions of 40 trials on four consecutive days, and at the end of each session, they were evaluated by acquisition test. Retention test was conducted 48 hours after the last acquisition session. During the acquisition and retention tests, all participants performed skill jump

shot without modeling. The number of acquisition and retention were six trials in each of the tests.

In training sessions, the subjects in each group received the desired pattern for each 5 attempts. They received 32 times the desired

pattern of a total of 160 attempts. Selected kinematic variables (elbow joint angular distance and elbow joint angular velocity) were evaluated in the pre-test, acquisition test and retention test. Table 1 fully shows the training protocol.

Table 1. Training and test stages of the experimental groups.

Retention Test	Fourth Stage	Third Stage	Second Stage	First Stage	Pre Test	Stage
						Group
6 trial	40 training trial 6 test trial	40 training trial 6 test trial	40 training trial 6 test trial	40 training trial 6 test trial	6 trial	Visual Modeling
6 trial	40 training trial 6 test trial	40 training trial 6 test trial	40 training trial 6 test trial	40 training trial 6 test trial	6 trial	Audio -Visual Modeling

Data Analysis

In order to compare the relative timing of angular distance of the elbow joint and relative timing of elbow joint angular velocity in two groups with skilled player, a comprehensive program was written by Maple software, version 15. This program specified movement temporal features after determining the exact starting point and end of the run. Schmidt's Generalized Motor Program Theory (1974) was applied in order to compare the temporal features. Thus, the relative timing of the participant's performance, as one of the invariant aspects of generalized motor programs, was analyzed. The elbow joint angular velocity and angular Distance were divided into sections and timing of each was calculated and then it was divided in the whole time of elbow move. The level of statistical significance of differences for all variables was considered 0.05.

Angular Distance Analysis

To assess the relative timing of angular distance, the performed pattern was segregated into 2 parts as flexion and extension. And the timing of each section was determined, it was divided on the whole time of the movement and the relative timing of each section were calculated. Then the calculated timing was compared with the timing of the skilled player. Since the first and second part of movement (flexion and extension) are interdependent in terms of time (negative covariance), any changes during the first part leads to a change in the second part, but with an opposite trend. For example, if the first part movement (flexion) in one of the subjects is 1/0 seconds longer than the first part of a skilled player, the second part (extension) of this person would be 1.0 seconds shorter than the second movement of a skilled player. This number was considered as the timing error of angular distance. Figure 2 shows how this division is implemented for the elbow joint.

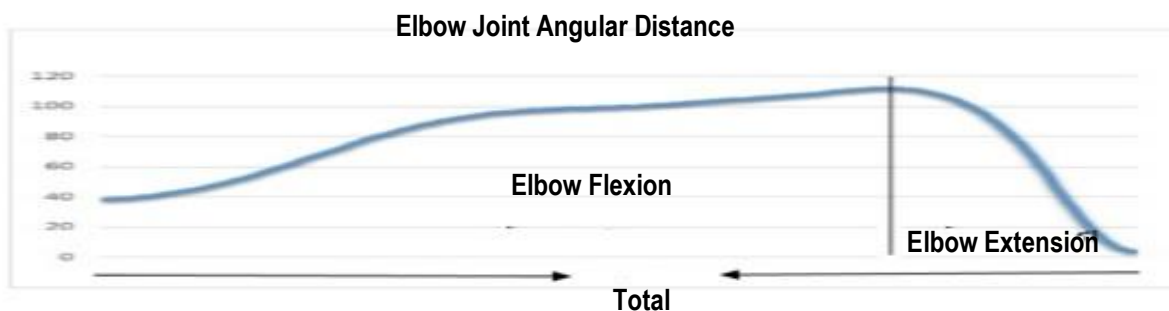


Figure 2. Timing analysis of angular distance pattern

Angular Velocity Analysis

In order to assess the relative timing of the elbow joint angular velocity, the performed pattern was divided in 4 parts: 1) from zero speed (starting) to maximum speed on the flexion movement 2) From the maximum speed of movement to zero speed in flexion in addition to the delay time between the change from flexion to extension 3) from zero speed to maximum speed in the extension and 4) from the maximum speed to zero speed (full opening of arm) in the extension. After the timing of each section was determined it was divided on the whole time of

the movement and the relative timing of each section were calculated. Then, the calculated timing was compared with the timing of a skilled player. Thus, for each participant four numbers were obtained that indicated the relative timing of any parts of movement. Similar to Part A (angular distance) for each of the first parts (speed-up flexion, speed-down flexion) and second parts (speed-up extensions and speed-down extensions) an error of timing was calculated. Finally, for every person on this stage two timing errors of angular velocity were calculated. Figure 3 shows this division for the elbow joint.

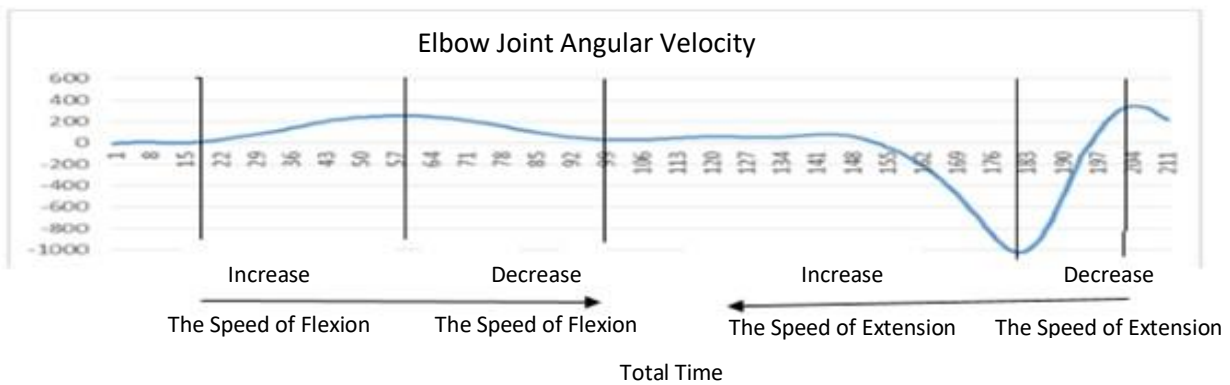


Figure 3. Timing analysis of the angular velocity pattern

Besides the three above error, the error of maximum range of elbow flexion, the error of maximum elbow flexion angular velocity and the error of maximum elbow extension angular velocity was calculated by comparing the performance subjects with skilled player.

Multivariate Analysis Variance Test was used in order to compare the two research groups in relative timing error of angular distance, the relative timing error of flexion angular velocity and the relative timing error of the extension angular velocity in acquisition and retention tests. All analyses were performed at the significance level of 0.05 using SPSS version 22.

Results

Table 2 shows the mean and standard deviation of the elbow joint performance errors (compared with elbow joint skilled performance) in acquisition and retention tests. As can be seen, in both acquisition and retention test, the level of three timing errors in visual group is more than visual-auditory one. The people in the visual group are at the maximum range of movement, the maximum flexion angular velocity and in particular in the maximum angular velocity of extension there was more errors than the people in visual-auditory group.

Table 2. Mean and standard deviation of the elbow joint function compared to a skilled person in acquisition and retention tests.

Group	Test	relative timing error of angular distance	relative timing error of flexion angular velocity	relative timing error of extension angular velocity	Maximum range Error of flexion	Maximum flexion angular velocity Error	Maximum extension angular velocity Error	Total Time Error
Visual		0.129	0.139	0.132	17.1	147.58	253.49	0.985
		± 0.029	± 0.035	± 0.032	± 4.23	± 37.70	± 54.96	± 0.092

Audio-Visual	Acquisition	0.088	0.101	0.099	12.20	106.15	134.70	0.929
		±	±	±	±	±	±	±
		0.031	0.021	0.025	4.12	17.84	52.00	0.081
Visual	Retention	0.123	0.122	0.125	12.70	110.67	171.41	0.937
		±	±	±	±	±	±	±
		0.017	0.022	0.030	3.06	21.68	69.97	0.122
Audio-Visual	Retention	0.092	0.100	0.097	9.50	91.78	111.82	0.895
		±	±	±	±	±	±	±
		0.025	0.022	0.022	3.54	13.36	22.56	0.088

Before performing multivariate analysis of variance Test, (in both acquisition and retention test), its assumptions, including the natural distribution of data in each of the dependent variables in each group, homogeneity of variance-covariance matrix of the compared samples and lack of univariate and multivariate outliers data were investigated. Shapiro-Wilk test result showed that the data in each of the dependent variable and each group has a normal distribution ($p > 0.05$). The result of M Box test showed that there is the assumption of homogeneity of variance-covariance matrix among the dependent variables ($p > 0.05$). According to Levin test, there was homogeneity of variance in all dependent variables between the two groups ($p > 0.05$). The assumption of lack of univariate outliers (by analyzing dependent variables individually) and no multivariate outliers (Mahalanobis test) was approved.

Before comparing the two groups in dependent variables on acquisition and retention tests, the performances of the participants in the pre-test were analyzed using multivariate analysis of variance. The test result showed that the effect of group was not significant in the modified model and therefore there was no significant difference between the two groups for the dependent variables ($p > 0.05$). Table 3 shows the output of multivariate analysis of variance for the acquisition and retention tests. As can be seen, the effect of group is significant in both acquisition ($\lambda = 0.183, F_{7,12} = 7.669, p = 0.001$) and retention test ($\lambda = 0.367, F_{7,12} = 2.959, p = 0.048$). The difference is that in case of acquisition, the size of effect is larger (0.817 for the acquisition test compared to 0.633 for the retention test). Great Eta coefficient for both acquisition and retention test shows the intervention (visual-auditory modeling) has a significant impact on performance compared with the visual modeling.

Table 3. Output of MANOVA test to examine the group effect of the acquisition and retention tests

Effect	λ	F	df	sig	Eta
Group Effect (Acquisition)	0.183	* 7.669	7	0.001	0.817
Group Effect (Retention)	0.367	* 2.959	7	0.048	0.633

P value = 0.05

Due to a significant effect in both acquisition and retention tests, between-group effects tests were carried out between groups for each of the dependent variables and the results showed that in all the variables in the acquisition test with the exception of "parameter of total time of elbow movement" between the two groups there is a significant difference and the effect size for the variable of maximum error of angular velocity (extension) was higher (0.633) relative to effect size of other variables (in the range of 0.266 to 0.354). In the retention test for all variables a significant difference was observed between the two groups except for the "parameter of total time of movement".

Discussion and conclusion

The results showed that both the acquisition and the retention tests, in all variables (timing error of angular distance, timing error of flexion angular velocity, Timing error of extension angular velocity, The error of maximum range of movement in flexion, The error of maximum flexion angular velocity) apart from the parameter of overall time

variable, there was a significant difference between the two groups in favor of audio-visual group. According to the results, the audio-visual group showed little difference to the pattern of skilled player compared to the visual group. In connection with the acquisition test results, one assumption is that the unconscious perception of the displayed movement characteristics, has a high information potential to understand and perform motor tasks

(Kibele, 2006). There is a significant amount of information related to the encoding of sound that supports the processes of motion perception, motor control and motor learning and is understood by the auditory system in conjunction with multisensory integration places (Vinken, et al, 2013). On the other hand, it seems multisensory integration, provides mechanisms to detect sensory and special flaws so that when the primary visual weakness occurs due to the lack of information, this weakness could be compensated with other senses (hearing) (Ladavas, 2008). The information provided in each of the primary sensory systems is largely influenced by the other senses (Calvert, Spence and Stein, 2004). Schmidt and Colleagues (2013) proposed that special regions of the brain (STS, mirror neuron system) that are involved in visual perception of movement, will be enabled during the hearing perception of dummy sounds of movement as part of multisensory integration (Lahav, Saltzman & Schlaug, 2007).

Common coding principle also states that some places in the vicinity of the location of STS responded to visual and auditory stimuli and turn them to a general code which are transmitted to multi-sensory intervention areas and consequently this may lead to neural responses (Van Ee, van Boxtel, Parker & Alais, 2009). A recent study has shown that the presence of a sound can change the interpretation of a vague visual movement (Sekuler, Sekuler & Lau, 1997). The sense of hearing is much more accurate than the sense of vision operation in terms of time. In addition, based on modality appropriateness hypothesis, hearing is the best sense for sensory perception of angular velocity of joints, therefore, it is dominant on visual perception. In addition to the timing, it has been shown that sound is especially effective for the duration and arrange of movement. On the other hand, the researchers believe that multisensory nerve activation threshold can be obtained much easier by multimodal learning rather than single modal learning. Multisensory stimuli, typically is received more accurate and faster than single sensory stimulus. Here, elbow joint angular velocity pattern has been made easier by both senses as audio-visual convergence. Researchers have assumed that after practicing with multisensory stimulus, multisensory processing is activated even if a single sensory stimulus to be provided. In fact, after training with visual-auditory feedback, perceptual-motor learning of assignments was at a high level even when the auditory feedback was removed. In line with these data, a new study compared visual-auditory and visual practice for perceptual learning with a task of recognition and motion detection. Comparison between the visual groups (V) and auditory-visual (AV) showed more learning at the first training session and during 10 sessions for audio-visual group (Krigestin & Girand, 2006). It seems that multimodal integration provides mechanisms to detect Spatial and sensory flaws so that in an initial sense of weakness or lack of information (e.g. visual), this weakness can be compensated with other senses (hearing and proprioception) (Vinken, et al, 2013) and

information provided on each of the primary sensory systems is widely used by other senses (Calvert, et al, 2004). Effenberg & colleagues (2011), studied the benefits of visual-auditory movement sonification on motor learning. The task used was indoor rowing. Data analysis revealed differences for visual-auditory group in learning as they were more accurate and faster than both other groups and the results of the present study is consistent with their results. These differences also remained for retention test which showed that learning has occurred. The main difference between them is that in Effenberg's research (2011), audio-visual patterns were executed concurrent feedback.

Many researchers believe that the positive effect of multimodal learning is the result of reducing cognitive load due to the distribution of information processing. For example, Burke and Colleagues (2006), stated that people have different cognitive resources to process information even if none of these resources to be used simultaneously without interference (Burke, et al, 2006). This is the theory of multiple sources by Winckens (2002). This theory states that the distribution of information to different aspects has preference compare to providing the same amount of information at only one aspect. Multiple Resource Theory is in accordance with the theory of working memory by Baddeley (1992). Visual-spatial information is stored in a working memory area and auditory verbal information is stored in another area of working memory. It is believed that both of these single-sensory processors are controlled by the central executive, but in terms of function they remain widely independent. This allows the working memory to be developed by providing multi-sensory inputs information (Baddeley, 1992). In fact, users prefer multi-modal interaction to a single sensory when task complexity increases. It shows that users manage working memory resources by switching from single sensory interaction to multimodeling by increasing their cognitive needs (Oviatt, Coulston & Lunsford, 2004). All of these findings on memory and cognitive load imply that when the workload is high in one dimension (e.g. visual), information should be provided to other aspects of multisensory method. This avoids overloading and thus may enhance motor learning. The visual and auditory information has provided evidence that different forms of auditory stimuli not only result in to different auditory information, but may also change multisensory integration which in turn indicates the need to the appropriate sensory stimuli.

On the other hand, presenting audio patterns in addition to the visual pattern, provides unique information to the participants. In visual-auditory, people in addition to the angular velocity of the elbow, receive information about the extension moment of the elbow in connection with the moment of separation of the ground and the peak of movement and the maximum speed of the extension of elbow in relation to the peak which is difficult to understand by the visual pattern alone. Although this perception may not happen explicitly, they are in a regulated environment and that is

repeated regularly. They probably gain structural rules related to environmental stimuli unconsciously without being able to describe these rules (Masters, Poolton, Maxwell & Raab, 2008). Accordingly, Schmidt and Colleagues (2013) concluded that movement sonification reinforces human activity monitoring that includes subcortical structure of motor loops.

The results of this research can be justified by some of the assumptions and hypotheses related to learning motor skills. Also, the results of this study are in accordance with Adams's closed-loop theory (1971), the hypothesis of cognitive effort by Lee, Swinnen and Serrien (1994) and challenge point hypothesis of Lee and Guadagnoli (2004). Adams believed that all movements are performed by comparing feedback gained during the movement and Correction resource that are obtained during training (he called it perceptual trace). When a person performs a movement, receives internal feedback as a result of limb position in space. This stimulus leaves a trace on the central nervous system (hence its name is perceptual trace). With continued practice and after much effort, one can slowly approach the intended movement and any attempt creates a separate trace that finally leads to a general one of all traces. A set of perceptual traces result in promotion of the quality of feedback due to correct movement. Then, in later attempts the person learns to move his body in such a way in space that he will be able to lower the gap between the gained feedback and the perceptual trace. It is likely that the performances in the reproduction stage, immediately after viewing pattern, leave more accurate and more precise rule on the motor memory due to similarities with skilled pattern. This proper perceptual trace (and also due to the efforts of perceptual traces training) in group of two sensory creates a correction resource. Thus, in group of two sensory feedback quality gained by proper movement is more as their move is compared with a more precise correction resource. Due to the more precise correction resource,

subjects in group of two sensory showed more consistency and finally more learning happened.

Based on the hypothesis of cognitive effort by Lee, Swinnen and Serrien (1994), training should promote the implementation of the movement and cognitive processes involved in it. Cognitive effort depends on the level of involvement of one's mind in making the correct decision. Sherwood and Lee (2003) defined the cognitive effort as decisions made by mental processing and motion processing required to perform the task. This hypothesis states that the more cognitive processing occurs during practice, the more learning happens. It is likely that in group of two sensory, accompanying audio pattern with a visual pattern, can lead to more cognitive effort because people were forced to process information on both models and adapt them over time and this has made people to have more mental conflict. Also based on the assumption of Lee's challenge point and Guadagnoli (2004), which is closely related to the theory of cognitive effort, cognitive processing during exercise depends on the challenging during the course exercise. The nature of the task, training positions and experience levels learner interact all together in order to determine the level of challenge is in training efforts. Therefore, different variables such as planning training, feedback, etc. are useful as long as they are to challenge the cognitive processes of learner. It is likely in group of two sensory (visual-auditory) due to more cognitive processing, more challenging has been created during the training course and this has been benefit for motor learning.

The results clearly show that the use of visual-auditory patterns improves the performance of the person as a result of the learning of relative timing of the elbow joint in basketball jump shot. Therefore it is recommended to implement the convergence of auditory and visual information in practice sessions and in the training of motor skills in order to improve performance.

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UČINAK SONIFIKACIJE VIZUALNOG MODELIRANJA NA RELATIVNO PODEŠAVANJE VREMENA: ULOGA U MOTORIČKOM UČENJU

Sažetak

Prikazano je kako slušni kanal povezan s zadatkom, prenosi relevantne informacije o pokretu i može pozitivno utjecati na sportaševu percepciju i motorički ishod. Ali kombinacija slušnih uzoraka (Sonifikacija) s uobičajenim vizualnim uzorcima kako bi se razvili uzorci kretanja, još uvijek je kontroverzno područje istraživanja. Dvadeset ispitanika slučajnim uzorkom podijeljeno je u dvije skupine: vizualno i vizualno-auditivno. Vizualne skupine gledale su vještog košarkaša i vizualno-auditivnu grupu koja je uz gledanje vještog košarkaškog igrača, čula i kutnu brzinu lakta kao sonifikaciju. U treninzima, subjekti u svakoj skupini primili su željeni uzorak za svakih pet pokušaja. Primili su 32 puta željeni uzorak od ukupno 160 pokušaja. Odabrane kinematičke varijable (kutna udaljenost i brzina zgloba koljena) procijenjene su u testu predtestiranja, testiranja i retencije. Utvrđeno je šest varijabli koje su: Relativno vremensko ograničenje Pogreška kutne udaljenosti (RTEad), Relativno vremensko ograničenje Pogreška prilagodne kutne brzine (RTEfav), Relativno vrijeme Pogreška širine kutne brzine (RTEeav), Maksimalna kutna brzina savijanja Greška (MfavE) kutna brzina pogreške (MeavE) i pogreška maksimalnog raspona savijanja (EMRf). Rezultati su pokazali da je u svim varijablama u testu stjecanja i zadržavanja, s iznimkom "ukupnog vremena pokreta lakta" između dvije skupine, značajna razlika. Rezultati pokazuju da je audiovizualna integracija dovela do razvoja vremenskih uzoraka motoričkog zadatka u audiovizualnoj skupini u odnosu na vizualnu skupinu. Ovi rezultati mogu se objasniti temeljem teorije Zajedničkog kodiranja i hipoteze prikladnosti modaliteta.

Ključne riječi: sonificiranje, audiovizualna integracija, audiovizualno modeliranje, relativno vrijeme, motoričko učenje

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