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Tap harder: Cognitive abilities, subjective factors, and musical properties that predict tapping force in young and older adults.

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Abstract

Research examining movement to music typically examines dance, or the less demanding task of finger-tapping along to a rhythm. Previous studies have focused on timing accuracy of finger-taps, largely neglecting the force aspect of tapping, which is both important for understanding rhythmic movement, and relevant to clinical applications. In two experiments on healthy young and older adults, we examined the role of i) cognition, ii) subjective factors, and iii) properties of music that influence the force of finger-tapping to music of varying genre, tempi, and complexity. Our results revealed that switching/inhibition ability *inversely* predicted tapping force, whereas liking of the music, and music expressing positive emotions predicted *greater* tapping force. Despite known declines of motor and cognitive functions in aging, we found that older adults were no different than young adults on these factors, suggesting that mechanisms of tapping force may be spared in healthy aging. We examined other relevant factors based on previous findings, including working memory, familiarity with the music, and whether the music was activating, but none were predictive of applied force. Clinical implications are that for increased effort or engagement, developers and practitioners of music therapy may seek to assess aspects of cognition that influence participation, tailor the music to the patient's preference, and pre-select musical samples that express positive emotions.

Keywords: music-induced movement, music cognition, finger-tapping force, emotional arousal, music preference

Introduction

There has been a recent surge in the development and use of music-based interventions to treat a variety of cognitive and movement disorders (e.g., Schaefer, 2014; Thaut, 2010), however, our understanding of underlying mechanisms is fragmented and the scientific evidence for the effectiveness of these now commonly used interventions remains sparse. While several theories have been proposed from various disciplinary perspectives, experimental as well as clinical research must clarify who may benefit from such interventions, and whether aspects of cognition, subjective factors, and musical properties need to be considered as factors that impact the effectiveness of music-based interventions.

Music-based movement therapies often make use of rhythmic auditory stimulation (RAS; Thaut, 2010). While much of the focus on the effects of RAS on movement has been on motor timing, the spontaneous force of movement is a sparsely examined factor that can inform us about effort, and potentially also the motivational aspects of moving to music. When explicitly cueing force, an early experimental study found that greater variability of a finger-tapping sequence led to longer reaction times, and cueing greater force modulated the timing of taps around the target tap in a sequence (Semjen & Garcia-Colere, 1986). Cueing force and timing simultaneously revealed that performance on either task is internally consistent, but one does not predict performance on the other (Balasubramaniam et al., 2018), contrary to the view that periodic entrainment fixates other kinematic aspects of movement (Thaut et al., 2015). Moreover, the timing of taps appears most accurate not at initial contact, but at a point of peak force, a fraction of a second thereafter (Du et al., 2017). This poses a fundamental problem, as the common finding that cued movement tends to be predictive (e.g., Repp & Su, 2013) may be affected by measuring

time earlier than the more accurately synchronized point of peak force. Thus, to elucidate the nature of entrainment, tapping force must also be considered in RAS tasks.

A better understanding of the predictors of tapping force is of relevance to both clinical populations and healthy older adults (HOA). People with cognitive decline or dementia show greater tapping timing variability, associated with poor performance in working memory (WM) and attention (Rabinowitz & Lavner, 2014), as well as difficulty in selecting fingers on a multi-finger tapping task, even when controlling for age, which is interpreted as a sign of diminished visuomotor learning. Aging itself is related to motor slowing and difficulties of motor inhibition, irrespective of cognitive decline. HOA are also more error-prone and make fewer taps compared to young and middle-aged adults, indicative of declining sensorimotor integration (Carment et al., 2018). These findings highlight the importance of force in understanding music-entrained movement in aging, and its relevance to clinical populations. Here, we aim to examine factors that may influence tapping force. Aspects of cognitive function, musical preferences, and musical properties have all been found to differentially influence cued tapping, and we will discuss them in turn here.

Executive functions such as cognitive flexibility and attention have been associated with kinematic indices of periodic movement e.g., gait, whereas working memory has been associated with tapping synchrony (Colley et al., 2018; George & Coch, 2011; Roden et al., 2014; Yogev-Seligmann et al., 2008). While the relationship between musical training and cognitive ability has received ample research interest, the direction of causality remains contested (Costa-Giomi, 2015; Degé et al., 2011; Schellenberg, 2011; Swaminathan et al., 2017). Whereas, music training may lead to more accurate music-synchronized movement (cf. Aschersleben, 2002; Bailey & Penhune, 2010) as well as cognitive benefits, there are also examples outside the musical domain where

cognition predicts more efficient periodic movement (Yogev-Seligmann et al., 2008). There are, to our knowledge, no previous findings examining the effects of cognitive factors on movement force in the context of music-cued movement.

Other subject-dependent factors of interest when examining music-synchronized movement concern the individual's preference or previous experience. Music preference has been associated with movement output (Luck et al., 2014), where people made the greatest movement displacement to music they preferred (or disliked) the most, and the authors attributed this to emotional, arousal-driven response to highly preferred or non-preferred music. Emotions and arousal are typically rated on a valence scale (Kron, et al., 2015) from negative to positive emotions, and from relaxing to activating on the arousal scale. The factors contributing to the subjective experience of music are further complicated by the association between familiarity and preference (Peretz et al., 1998). Increased walking speeds have been reported for walking to familiar music in Parkinson's Disease (PD) (Leow et al., 2015), however only when the music was also preferred (Park et al., 2019), indicating complex interactions between these factors on movement performance. A theoretical account of the effects of subjective experience on movement force or vigor in moving to music was offered by Schaefer & Grafton (2017), also predicting a positive effect of motivation and arousal on additional energy expenditure.

A third element to consider is the variety in the types of music used to cue movement, such as tempo, or the emotion perceived in music separately from what is induced in the listener. Previous research indicates that musical characteristics (e.g., timbre) and rhythmic structures were associated with different types of movements, whereas tempo was not (Burger, Thompson, et al., 2013), and distinct types of movement reflect emotional properties of music (Burger, Saarikallio, et al., 2013). For instance, people's walking pace tends to vary depending on sonic features, even

when tempo is held constant (Leman et al., 2013), indicating that some musical features are more important than tempo in perceiving music as activating (i.e., recognized arousal). Older adults more accurately categorize emotionally positive music (Vieillard et al., 2012), and perceive music as more positive than middle aged and young adults, attributed to an inclination for “pro-hedonic motivation” in old age (Cohrdes et al., 2018). While older adults have shown a stronger association between emotion and arousal (Vieillard et al., 2012), they conversely reported lower rates of perceived arousal compared to middle-aged adults, purportedly as an aversion to high-arousal states, from which longer time is needed to recuperate in old-age (Cohrdes et al., 2018).

Based on these three domains of predictors of tapping force, several hypotheses can be formulated. In terms of the role of cognition in tapping, we hypothesize that executive functions of working memory, attention, and cognitive inhibition and flexibility would positively predict tapping force, while controlling for known effects of age on cognition (West & Alain, 2000). Based on findings showing older adults scoring lower on cognitive tests than young adults, we expect cross-sectional differences between age-groups on cognition will account for differences in tapping force. Next, we aim to disentangle effects of subjective experience of music, hypothesizing that preference for specific musical cues will predict a greater portion of the variance in tapping force above and beyond familiarity, again controlling for age. Moreover, the speculation that preference effects on music are emotional and arousal-driven will be addressed by hypothesizing experienced positive emotions and higher self-reported arousal to be predictors of tapping force. Based on the findings that certain sounds (timbre), and rhythms correspond to unique movement types (Burger, Thompson, et al., 2013), and sonic features regardless of tempo affect movement differently (Leman et al., 2013), we hypothesized that perceived positive emotional content and higher arousal in the music will lead to greater exertion of force, while tempo does not. We also

hypothesize that older adults are more likely to rate music as emotionally positive, and are expected to report lower rates of arousal (Cohrdes et al., 2018; Vieillard et al., 2012).

Our findings promise to provide supporting evidence to an expanding, and fast-accelerating field of music-based interventions for movement impairments. By determining whether cognitive ability affects engagement in such interventions, clinicians may select who may thrive in or even benefit from such interventions. Understanding subjective factors that can enhance music therapy will help determine the basis on which music may be tailored to the participant, and the knowledge that certain musical properties affect movement differently, may be used in treatment interventions to increase patient engagement while decreasing experience of effortfulness.

Methods

Participants

Two experiments were carried out. In Experiment 1, sixty-six healthy adult participants between the ages of 18-87 years ($M = 23.86$; $SD = 9.44$) including 34 females (52%) were recruited through Leiden University facilities and online social media. Three participants were excluded from analysis due to technical errors, but no outliers were otherwise identified. Participants opted for either Dutch or English versions of the experiment; as well as a right or left-handed set-up, as per their preference. To further assess questions about aging, experiment 2 involved two groups, fifty healthy young adults between the ages of 18-35 ($M = 22.17$, $SD = 3.39$) including 27 females (54%), recruited through social networks, and Leiden University bulletin, and a cohort of 46 healthy older adults (HOA), 55 years and older ($M = 67.78$, $SD = 6.70$) of which 31 are female (67%), recruited through social networks and an online participant recruitment platform (Hersenonderzoek.nl). Exclusion criteria for both experiments were uncorrected impairments of

hearing or vision, a history of neurological, motor or psychiatric disorders, including attention deficit/hyperactivity disorder (ADHD), and for the HOA cohort in group 2 an additional dementia screening was performed (all older adults scored ≥ 25 on the Mini-Mental State Exam, Folstein et al., 1975). The musical training subscale of the Goldsmith Musical Sophistication Index (GMSI), a self-report measure ranging from 7 - 47 from lowest to highest musical training, was calculated for participants overall ($M = 21.47$, $SD = 9.93$, $Range = 40$), younger adults ($M = 22.74$, $SD = 10.07$, $Range = 40$), and older adults ($M = 18.58$, $SD = 9.10$, $Range = 31$). Participants in both experiments were compensated in either cash payment or student credit. The experiment was carried out in accordance with the principles stated in the Declaration of Helsinki. The Psychology Research ethical committee of the Institute of Psychology at Leiden University approved both experiments, under application numbers CEP 18-0312/146 and CEP18-1016/386.

Measures and Materials

Tapping task Experiment 1 involved a multi-finger tapping task, using all four fingers from index to little finger in synchrony with the musical beat, and guided by a visual red light flashing on the tapping pad in sequence corresponding to each finger, so as not to increase the task's memory load; the direction of the light was reversed for left-handed individuals (Mudarris, 2019). The finger-tapping task in Experiment 2 was similar to the task in Experiment 1 except it involved tapping with only a single finger (index finger) of the dominant hand, and the red light sequence was removed, as there was no order of movement as in the multi-finger task. The tapping was registered on a 64-pad MIDI Controller, the Novation Pro Launchpad (Focusrite Audio Engineering Ltd., High Wycombe, UK). Velocity is also registered by the same device (ranging from 0 - 127 arbitrary units), as an indication of applied force, and the data were recorded through

Max7: a visual programming language for music (Cycling' 74, Walnut, CA). The stimuli were presented through Creative A60 stereo desktop speakers (Creative Labs, Milpitas, CA)

Stimuli

Forty music samples were selected across four genres, with and without lyrical content, in nearly equal parts: Classical, Rock, Pop, and Jazz, encompassing tempos ranging from 100-150 (Beats per minute; BPM), and of a 4/4 time signature. The length of each stimulus was 64 musical beats in total, averaging approximately 30 seconds. The stimuli were piloted on a small sample ($N = 10$) to ensure a representative distribution of rhythmic and harmonic complexity, as well as perceived emotional valence on a bipolar scale. Two stimuli were eliminated for varying in tempo across the sample, rendering their timing inconsistent. The same 38 samples were used for both experiments (a full list of stimuli and their characteristics as determined in the pilot can be found in the Supplementary Materials S1).

Subjective Ratings

After each finger-tapping trial, the participants rated the musical stimulus using visual sliders (ranging from 0-100 arbitrary units) on the following aspects: liking, familiarity, emotional valence (induced and recognized), arousal (induced and recognized), and the extent of associated autobiographical memories.

Cognitive Measures and Questionnaires

In both experiments participants were assessed on working memory using the Digit Span Backwards (DSB) of the WAIS-IV (Wechsler, 2008). The second study included additional neurocognitive assessments: the MMSE (Folstein et al., 1975) was administered only to the HOA cohort to screen for cognitive impairment. Both young and older cohorts of Experiment 2 were additionally tested on auditory attention using the Digit Span Forward (DSF; Wechsler, 2008), the

Trail Making Test (TMT; Tombaugh, 2004), and the Color-Word Interference (CWI) task of D-KEFS (Delis, et al., 2001). Participants in both studies have also completed the GMSI (Müllensiefen et al., 2014). For the current analyses, the scores were calculated as follows: for the DSB the total trials correct were used, where higher score indicates better performance, for the CWI, the difference between incongruent and congruent conditions ((Time on Trials (3+4)) - (Time on Trials (1+2))), where a higher score indicates worse performance, allowing for comparison across age groups as prescribed in previous studies, with the addition of interference/switching (condition 4 of D-KEFS) (Van der Elst et al., 2006)). For the TMT, the difference between the second (TMT-B) and first trial of (TMT-A) was used, to capture the cognitive switching rather than the psychomotor aspect of the TMT, where a higher score indicates worse performance (Arbuthnott & Frank, 2000).

Procedure

Participants were first asked to complete the consent form, and then carried out the cognitive measures. In Experiment 1 participants were only administered the DSB, while in Experiment 2, the HOA cohort were first administered the MMSE, as it may preclude inclusion in the experiment, then both age-groups of Experiment 2 received the remaining cognitive assessments described above in counterbalanced order. Each participant was then led into a soundproof booth, where the finger tapping task was administered. The experimenter first demonstrated the task for the participant. In Experiment 1, lights guided tapping sequence so as not to increase the task's cognitive load, but this was not necessary in Experiment 2 as it only involved a single finger. Participants in both experiments then completed a practice trial with a metronome, before proceeding with the actual task. Music stimuli were presented in randomized order, and

participants rated each stimulus after the tapping task. After all trials concluded, participants completed the GMSI, they were then debriefed and received compensation, as appropriate.

Analysis

MATLAB R2012b (The Mathworks, Natick, MA) was used to extract the velocity data from text files generated from Max7. To calculate the force, the average over all taps collected in a single trial was taken over only the index finger taps from the multi-finger and the single-finger tapping tasks based on the MIDI keys that were used, taking into account hand-preference.

Three multilevel models (MLM) were built using SPSS 24 (IBM Corp., 2016) to test each hypothesis on cognition, subjective factors, and musical properties as predictors of tapping force. In the first model, only Experiment 2 participants were included as they had completed all cognitive measures (DSB, TMT, and CWI), their scores on these tests and the interaction between TMT and CWI due to their correlation, as well as participants' age groups (young v. old adults) were included as predictors of tapping force. In the second and third models, participants in Experiment 1 and 2 were combined as they had completed all the relevant outcome measures to answer the research questions. In the second model, the predictive value of preference, familiarity, and their interaction, along with self-reported experienced emotional valence and arousal are included as fixed-effect estimates, accounting for age-group and tapping-task as predictors of tapping force. In the third model, perceived musical properties of emotional valence and arousal, and tempo, including the age-group and tapping task are included as predictors of tapping force. In all models, participants are modeled at level-2, and included as a random effect, to account for individual variance. *Maximum likelihood* is the estimation method used to test model fit (Maximum iterations = 1000; Maximum step-halvings = 10), as well as to allow for the comparison of fixed and random effects. The significance of fixed effects is tested at 95% ($\alpha=0.05$). For each

model, a comparison of model fit was estimated by assessing whether including each planned factor as a predictors, or their interaction, accounted for a meaningful proportion of the model variance by comparing minus twice the log-likelihood (-2LL) based on critical values of the chi-square distribution, the model yielding the best fit was used in the interpretation. The intra-class correlation coefficient (ICC) is calculated as a ratio of group error variance over total error variance, using the following formula: $\rho = \frac{\tau_{00}}{\tau_{00} + \sigma^2}$, where τ_{00} represents between variance, and σ^2 resembles within cluster variance (McCoach, 2010).

Results

The age and gender of all retained participants are detailed in Table 1, both for the participants in Experiment 2 who received all cognitive tests and were thus included in Model 1, and the combined dataset used to assess the subjective and musical predictors in Models 2 and 3, which all participants in Experiment 1 and 2 completed. Table 2 provides an overview of the descriptives of all variables included in the subsequent analyses.

Table 1.

Final participant sample by gender, and age group.

N	Combined Experiments 1 & 2						Experiment 2						Total
	Young Adults			Older Adults			Young Adults			Older Adults			
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	
Female	57	21.7	3.55	32	66.8	7.13	27	21.4	4.52	31	66.1	6.19	89
%	51			67			54			67			56
Male	54	22.9	2.60	16	69.1	7.28	23	23.2	2.64	15	69.7	7.12	70
%	49			33			46			33			44
Total	111	22.3	3.16	48	67.5	7.19	50	22.3	3.83	46	67.3	6.65	159

An overview of the descriptives for the main relevant variables is shown in Table 2.

Table 2.

Means, and standard deviations of independent and dependent variables by age group.

Age Group	Combined Age Cohorts		Young Adults		Older Adults	
Measure	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
DSB	7.38	2.34	7.96	2.20	6.04	2.07
CWI	55.63	22.40	43.37	11.27	67.89	23.00
TMT(B-A)	32.90	23.19	22.95	13.33	43.29	26.50
Tapping Force	36.85	27.46	34.12	26.46	42.95	28.64
Preference	51.11	29.15	51.51	28.16	50.19	31.28
Familiarity	35.18	35.05	32.80	34.51	40.63	35.66
Induced Valence	56.41	25.32	56.10	24.79	57.12	26.50
Induced Arousal	58.70	26.82	57.99	27.36	60.32	25.47
Perceived Valence	55.98	26.57	56.30	25.48	55.25	28.92
Perceived Arousal	53.90	26.67	52.59	27.26	56.90	25.01

Role of Cognition in Applied Force

The multi-level model (MLM) includes five factors: DSB working memory score, CWI cognitive interference score, the TMT(B-A) switching score, and its interaction with CWI as these are moderately correlated ($r(89) = 0.573, p < .001$), while controlling for age group (young vs. older adults), which led to a better model fit (exceeding the chi-square cut-off for the difference in df at 0.001 level). The MLM revealed a high ICC rate of 85.49%, which indicates a highly nested data structure, and between-subject level (level 2) effect of 614.679 ($Wald Z = 6.137$). Performance on CWI task (where a higher score indicates more interference) inversely predicts tapping force

(estimate = 0.935, $SE = 0.31$, $p < .01$, 95% CI = 0.315, 1.55), whereas DSB, TMT, TMTxCWI interaction, did not predict tapping force, and there was no difference between age groups. To rule out indirect effects of age on force, mediated by cognition, a simple regression analysis of age as a predictor of force was not significant ($p = .832$), precluding the need for a mediation analysis of cognitive performance on the effect of age on force. The results of the MLM are listed in detail in Table 3.

Table 3.

Model 1 - Cognitive predictors of tapping force: Fixed, and random effects parameter estimates, standard errors, and p-values.

Parameters	Estimate	SE	p
Fixed (Level-1) Effects			
Digit Span Backwards	1.390	1.425	0.333
Color-Word Interference	0.935	0.311	0.004**
Trail-Making Test	0.028	0.278	0.919
CWI*TMT Interaction	- 0.005	0.004	0.180
Age Group (young v. old)	9.866	7.485	0.191
Random (Level-2) Effects			
Participants	614.679	100.159	< 0.001***

Significance level is indicated by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Effect of Subjective Factors on Applied Force

Here, an MLM of six factors was estimated, including preference, familiarity, and their interaction as they are moderately correlated ($r_s(6002) = .520$, $p < .001$), as well as ratings of induced valence, and induced arousal, while controlling for tapping task and age. The MLM of six factors revealed an ICC rate of 86.92%, indicating a highly nested data set, with most of the variance due to individuals' variability (estimate = 561.904, $Wald Z = 8.36$). Liking for the musical cue positively

predicts tapping force (estimate = 0.018, $SE = 0.008$, $p = .02$), in contrast to all other predictors. A statistically significant difference was found between the two tasks ($p < .001$), with the multi-finger task (Experiment 1) leading to significantly lower force than the single finger task (Experiment 2). A model fit comparison yielded the model including the above variables to be the most parsimonious at the 0.001 level of the Chi-square distribution. The results of this model are listed in Table 4.

Table 4.

Model 2 - Subjective predictors of tapping force: Fixed, and random effects parameter estimates, standard errors, and p-values.

Parameters	Estimate	SE	p
Fixed (Level-1) Effects			
Liking	0.018	0.008	0.023*
Familiarity	-0.009	0.011	0.380
Induced Valence	0.002	0.007	0.765
Induced Arousal	0.003	0.005	0.619
Liking x Familiarity	-0.0001	0.0001	0.529
Age Group (young v old)	3.545	5.104	0.490
Tapping Task	-22.621	4.737	< 0.001***
Random (Level-2) Effects			
Participants	561.904	67.213	< 0.001***

Significance level is indicated by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Musical Properties' Effect on Applied Force

This MLM includes six factors: participants' ratings of recognized emotional valence, recognized arousal, tempo of the stimuli, while accounting for participants' age and the tapping task. The analysis yields a high ICC rate of 86.94%, which reveals a highly nested data structure, and a high contribution of participant variance (estimate = 563.713, $Wald Z = 8.36$). Recognized

valence significantly predicts tapping force when controlling for age group and tapping task (estimate = 0.013, $SE = 0.005$, $p = 0.019$). The difference between tapping tasks was again statistically significant ($p < .001$) with lower registered force for the multi-finger task (Experiment 1) than the single-finger task (Experiment 2). Table 5 details the results of this model, with musical properties as predictors of tapping force.

Table 5.

Model 3 - Musical predictors of tapping force: Fixed, and random effects parameter estimates, standard errors, and p-values.

Parameters	Estimate	SE	p
Fixed (Level-1) Effects			
Recognized Valence	0.013	0.005	0.019*
Recognized Arousal	-0.005	0.005	0.322
Tempo	0.004	0.010	0.691
Age Group (young v old)	3.566	5.11	0.487
Tapping Task	-22.474	4.744	<0.001***
Random (Level-2) Effects			
Participants	563.713	67.426	< 0.001***

Significance level is indicated by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Age Effects on Ratings of Emotional-Valence and Arousal

Examining the difference between age groups in ratings of recognized or induced emotional valence and arousal, we found that only recognized arousal was moderately higher in older adults ($t(36) = -2.72$, $SE = 1.60$, $p < .01$; Cohen's $d = -0.47$), than that reported by young adults. Notably, ratings of induced arousal were no different between groups ($t(36) = -1.43$, $SE = 1.63$, $p = .157$, Cohen's $d = -0.28$).

Discussion

In two experiments, we investigated predictors of tapping force (a novel factor) in a music-cued task in young and older adult cohorts, specifically, whether cognitive ability, subjective factors, and musical properties are predictive of applied force in a music-cued finger-tapping task. For the sample that received more elaborate cognitive testing it was found that switching/inhibition ability inversely predicts applied force regardless of age, whereas neither working memory or mental tracking predicted tapping force. Liking for the music stimuli was found to predict tapping force across age groups, but familiarity, experienced emotional valence, and experienced arousal did not. Lastly, perceived positive emotional valence in the music was found to predict tapping force in both healthy young and older adults, but the music tempo and perceived arousal of the music did not. Notably, age did not account for any of the effects examined above, or indeed predict tapping force at all. Overall, differences between individuals accounted for most of the variance in all models, however, small but significant contributions of attention, musical preference, and perceived emotions in the music on tapping force were found.

Effects of Cognition on Applied Force

In line with previous research associating executive functions with periodic movement such as gait (Yogev-Seligmann et al., 2008), we found that switching/inhibition *inversely* predicted tapping force. Impairment in executive functions leads to movement inefficiency, for instance, lack of inhibition may lead to walking too fast, which increases fall risk. Performance on the Stroop task has been inversely linked to greater gait, and swing time variability, which in turn increases likelihood of falls. Moreover, those who fell while walking performed significantly lower on the Stroop task compared to those who did not (Springer et al., 2006; Yogev-Seligmann et al., 2008). Similar findings of movement inefficiency have been shown in the timing of tapping tasks, where those with cognitive decline or dementia showed a prolonged and more variable finger-tapping

than cognitively intact older adults (Carment et al., 2018; Rabinowitz & Lavner, 2014). In pediatric populations, adolescents with ADHD were more variable on a tapping task, and less accurate on an anticipation task compared to their neurotypical counterparts, and these differences were attributed to cognitive-presentation and motor-production impairments in those with ADHD (Toplak & Tannock, 2005). The results of the current study extend these findings to healthy young and older adults, showing that lower switching and inhibition ability predicts greater tapping force in a rhythmic-auditory cued task. Reduced ability of cognitive inhibition and switching attention may impair movement efficiency with an external auditory cue (e.g., music), as greater tapping force can be an indication of inefficient motor output, by expending more effort than necessary. One surprising finding is that performance on the switching and inhibition task predicted tapping force even when controlling for participants' age, despite known age-related decline in attention (West & Alain, 2000). This may be an indication of how sensitive cued-movement tasks are even to minute differences in attention, not just stark differences between older and young adults, but also to smaller variances within each age group. We did not corroborate findings of working memory as a predictor of motor control, however, this may be due to differences in the way working memory is measured, as Colley et al. (2018) measured WM in association with a dynamic measure of sensorimotor synchronization, which may be more sensitive to minute fluctuations as opposed to our static measure of working memory, to predict an average score of tapping force across each stimulus, possibly leading to the discrepancy between the studies' results. It is possible, however, that WM is not as sensitive as inhibition/switching to movement efficiency, and as such would not be indicated as relevant in force of tapping.

Subjective Predictors of Tapping Force

Based on a previous study that found that people made greater movement displacement to music that they either liked or disliked the most (Luck et al., 2014), the current study examined how preference of and familiarity with music can predict tapping force. We also examined self-reported induced emotional valence and induced arousal state after exposure to each musical stimulus, due to their suspected involvement as the mechanism driving the effects of preference. The results indicated that preference was a predictor of tapping force even when controlling for age of participants, tapping task, and an interaction between preference and familiarity, added due to their previously demonstrated association (Peretz et al., 1998). The results of this study, contrary to the previous proposition by Luck et al. (2014), were not explained by an emotional response to preferred music that is driven by psychological arousal, as the effect of preference here persists even when accounting for self-reported experienced emotions valence, and experienced arousal. This does not rule out physiological arousal as a proposed mechanism to explain greater movement relation to preference to the music, however, as emotional arousal was reported to be moderately associated with musical preference but not with physiological arousal, which in turn was only weakly linked to music preference (Schäfer & Sedlmeier, 2011). Moreover, we found that only perceived arousal level of the music differed between groups, with older adults reporting higher perceived arousal. While this may seem contrary to previous findings that showed older adults reported lower perceived arousal than middle-aged adults, purportedly to avoid higher arousal states that may be disturbing in old age (Cohrdes et al., 2018), this may still be the case in our study if you take into account that despite greater perceived arousal in older adults there was no difference in ratings of experienced arousal between the age groups. Thus, while older adults may have recognized higher arousal in music, they did not report experiencing this presumed aversive

high-arousal state. Our study did not include a middle-aged group, however, and thus may not show the variance observed in the previously reported study. The current findings support the tailoring of music to the person's preference in a cued-movement task, suggesting that engagement with the task may increase vigor of movement. Using preferred music may motivate greater effort, thereby reversing the natural tendency to conserve energy when executing a goal-directed action (Diedrichsen et al., 2010; Schaefer & Grafton, 2017), and making movement less efficient.

Musical Properties Predicting Tapping Force

Previous studies have shown that certain musical properties can affect induced movement, such as rhythm, use of different musical instruments (Burger, Thompson, et al., 2013), the perceived emotions in the music (Burger, Saarikallio, et al., 2013), and whether the music induces activation or relaxation (Leman et al., 2013). The current findings support previous work that indicate that musical properties affect vigor of music-induced movement (Lakoff, 2012; Schiavio & Altenmüller, 2015). Perceived emotions were shown to predict tapping force in music-synchronized movement, and that this effect holds even when accounting for the tempo, and perceived arousal and controlling for the age of participants. This shows that how the participant perceives the music may affect motor engagement, in line with a previous finding that showed certain genres to be more movement-inducing (Burger, Saarikallio, et al., 2013), and supports the general motivational quality of music on movement, as motor output increases were observed when people exercise to music even without synchronizing their movement to the music (Karageorghis & Priest, 2012). The evidence of the effect of musical properties beyond temporal structure is supported by the fact the differences in the output of music-cued movement arise without varying tempo across music samples, wherein participants' perception of sonic features (e.g., loudness, pitch) and whether the music was "activating" predicted movement output (Leman

et al., 2013). Synchronizing movement to music, therefore, is not the only means by which music can increase motor output. Although the current findings did not find support for the effect of perceived arousal (Leman et al., 2013), it supports previous findings of perceived emotional valence on movement vigor in terms of applied force (Burger, Saarikallio, et al., 2013). The relationship between different aspects of subjective experience may be complicated, but this study aimed to dissociate the various effects of these closely associated factors. The results highlight the importance of selecting music that is perceived to express positive emotions, which can increase engagement with the selected music, by motivating greater vigor of movement.

Limitations and Future Directions

Although we expected to observe aging effects, based on robust findings of age on cognition (West & Alain, 2000), this was not observed, and the current findings are more in line with a recent paper that found certain aspects of movement, such as motor planning ability, was spared in healthy older adults (Ruitenberg & Koppelmans, 2020). However, our sample of older adults may not be representative of a community sample, as those who participated performed exceptionally well on cognitive testing, which may be explained by the recruitment method, as participation required some level of independence, as well as being technologically adept to be able to register through an online portal. Future studies may examine the current findings in healthy older adults in a community setting, and subsequently in clinically relevant populations who may benefit from movement interventions including Parkinson's disease, dementia, or stroke patients (Carment et al., 2018; Schaefer, 2014). While the participants in this study have a wide range of musical ability, we did not control for variability in previous musical training, however, there are established differences between musicians and non-musicians, as well as between amateur and professional musicians, on sensorimotor synchronization tasks (Repp & Su, 2013). Musical training differences

may elucidate characteristics that preclude or enhance the benefits from music-based interventions, and are an important next step in this line of research.

The two experiments employed the same musical stimuli, and rating questions, however, they differed in the finger tapping task, with either a single or multi-finger tapping paradigm. The multi-finger tapping task was initially selected to be more representative of naturalistic tapping, however, as studies showed greater finger enslavement in older adults (Mirakhorlo et al., 2018), and difficulties selecting fingers in cognitively impaired individuals (Carment et al., 2018), we used a single-finger task in the subsequent experiment involving older adults. It may be argued that with the widespread use of smart-phones in recent years, single-finger tapping has also become a part of daily activities. As previous studies have explored dance or free movement to music (Burger, Saarikallio, et al., 2013; Luck et al., 2014), and findings show motivational aspects of exercising with music that is not synchronized with movement (Leman et al., 2013), future studies may explore these aspects with respect to movement force.

Clinical Implications

Our results suggest that cognitive assessment of switching/inhibition can help predict which patients are prone to inefficient motor control that may lead to fatigue in music-synchronized tasks, and therefore may benefit from shortening the duration of their intervention for example. Clinicians designing musical interventions may seek to tailor the music to the individual's preference, as our findings revealed that liking the music is more important for movement vigor than familiarity, arousal state, and self-reported emotions. It is also important to examine how people perceive the emotional content of music, which our results show can increase participants' engagement as indicated by greater movement vigor. Extending these findings to clinical populations is imperative prior to its application in interventions.

Conclusions

The results of the current study show that aspects of cognition, subjective experience, as well as musical properties can influence tapping force. Switching/inhibition, but not mental tracking or working memory, inversely predicted tapping force regardless of age. Liking the music positively predicted tapping force, in both young or old adults, whereas familiarity, induced emotions and arousal did not. Moreover, music expressing positive emotions, but not music perceived as activating or the tempo of the music, predicted tapping force across age groups. Aging effects were not present in any of the examined factors, as age it seems was not at all associated with tapping force. Although differences between individuals accounted for most of the variance, there were small but significant contributions of cognitive inhibition, musical preference, and recognized emotions in music on tapping force.

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No potential conflict of interest was reported by the authors.

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Appendices

Table A1.

List of Musical Stimuli, Song Title, Artist and/or Composer, Lyrical Content, Genre, BPM, and Pilot Ratings (N = 10) of Rhythmic/Melodic Complexity.

Stim- ulus No.	Song Title	Artist and/or Composer	Lyris	Genre	Tempo BPM	Rhythmic Complexity		Harmonic Complexity	
						<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1	The End of Time	Beyonce	Y	Pop	116.75	5.5	1.8	3.6	1.1
2	Odessa	Caribou	N	Pop	117.85	5.5	1.3	6.6	1.1
3	Beat It	Michael Jackson	Y	Pop	137.72	4	1.4	5.1	1.6
4	Four Seasons; Fall	Vivaldi	N	Classical	116.85	6	1.4	6.2	1.8
5	Imaginary	Brennan Heart	N	Pop	149.99	2.8	1.9	2.9	1.9
6	He's a Pirate	Hans Zimmer	N	Classical	140.44	5.3	1.2	5.6	1.9
7	Concerto for Strings in B Minor	Vivald	N	Classical	119.99	5.9	1.3	7.1	0.9
8	Swing is Here to Stay	Gene Krupa	N	Jazz	141.48	7.2	1.6	7.9	1.5
9	Samba Triste	Baden Powell	N	Jazz	115.84	6.7	1.3	6.8	1.3
10	Tea for Two	Ella Fitzgerald & Count Basie	Y	Jazz	137.00	4.9	1.8	6.4	1.4
11	Enter Sandman	Metallica	Y	Rock	125.31	3.6	1.6	6	2.1
12	Sunshine of Your Love	Jimi Hendrix	N	Rock	135.23	7.2	1.9	6.5	1.5
13	Sparrow	Mastodon	N	Rock	124.26	5.3	1.4	5.5	1.1
14	Paris	MSTRKRFT	N	Pop	135.85	6	2.0	5.7	1.8
15	Anesthesize	Porcupine Tree	N	Rock	110.11	5.7	1.5	5.6	1.4
16	Agostina	Puscifer	N	Rock	124.99	4.9	2.5	4.3	1.2
17	Figure it Out	Royal Blood	Y	Rock	107.93	5.4	2.2	5.8	1.4
18	Played-A-Life	Safri Duo	N	Pop	137.89	3.2	1.9	3.4	1.3
19	My Baby Just Cares for Me	Nina Simone	Y	Jazz	117.81	3.9	2.1	5	1.4
20	How Insensitive	Astrud Gilberto	Y	Jazz	121.89	5.9	1.4	6.7	1.9

21	Umray	Avishai Cohen	N	Jazz	100.54	5.9	1.3	7	1.4
22	Let Go	Ennja	Y	Pop	134.98	5.9	0.8	4.1	1.5
23	Genesis	Justice	N	Pop	117.03	4.8	2.3	3.9	2.0
24	You Don't Know What Love Is	Kurt Elling	Y	Jazz	111.95	5.2	1.7	6	1.1
25	The Beautiful People	Marilyn Manson	Y	Rock	143.45	5.3	1.2	5.1	2.3
26	Der Hölle Rache (Queen of the Night Aria)	Diana Damrau, Mozart	Y	Classical	140.62	6.3	1.6	6.1	1.7
27	Salve Regina XI: Inflammatus en Accensus	Emma Kirkby, Pergolesi	Y	Classical	102.29	5.3	1.5	6.1	1.3
28	Messiah, HWV 56	Stephen Cleobury, GF Händel	Y	Classical	101.87	5.2	2.0	6.6	1.2
29	The Crest of the Wave	EYOT	N	Rock	135.60	4.7	1.7	5.6	2.1
30	Una Mattina	Ludovico Einaudi	N	Classical	140.26	6	2.2	5.6	2.0
31	Double Double	Atta Boafu	Y	Jazz	124.89	3.9	1.9	4	1.7
32	Can You Get to That?	Parliament Funkadelic	Y	Pop	141.48	4.4	1.4	5.1	2.2
33	Fly Me to the Moon	Frank Sinatra	Y	Jazz	118.16	4.2	1.1	4.7	1.8
34	Dreams	Fleetwood Mac	Y	Rock	121.09	2.6	1.7	3.8	2.2
35	Kiss	Prince	Y	Pop	111.19	3.5	0.9	4.1	1.4
36	Carmina Burana_ II. In Taberna, In taberna quando sumus	Carl Orff	Y	Classical	141.07	6	1.1	6	1.6
37	Inta Omri	Umm Kulthum, Mohammed Abdelwahab	N	Classical	119.13	6.3	1.2	6.1	1.3
38	Jambone	Snarky Puppy	N	Jazz	145.97	7.9	1.5	6.7	1.6

Table S2.

Range of stimuli based on genre by lyrical content, and positive/negative emotional valence.

	No Lyrics Positive-Valence	No Lyrics Negative-Valence	Lyrics Positive-Valence	Lyrics Negative-Valence	Total
Pop	3	2	4	1	10
Rock	1	4	2	2	9
Jazz	3	1	4	2	10
Classical	3	2	3	1	9
Total	10	9	13	6	38