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Effects of cognitive load on expressive musical performances

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“ If the ears hear the truth, they become eyes”

Mevlana Rumi

List of acronyms

F: F ratio in ANOVA

M: Mean

N: Total number in a sample

p : Probability

SD: Standard deviation

t : Value of t-test

S1: primary somatosensory cortex

IPL: Inferior parietal lobule

DLPFC: Dorsolateral prefrontal cortex.

Summary

In this dissertation, we report the results of empirical studies on the effects of cognitive load on performing musicians. The main aim of these studies was to investigate to what extent an additional working memory task might affect the timing of musicians' performance. To test this argument, musical performances, with and without a secondary task have been tested. Experiments' results revealed that cognitive load leads to a decrease in musical expressiveness. Thereby, we focused on musicians' tendency to speed up, or slow down their performance of musical phrases and pauses. We expected that, in general, timing in expressive performance would be affected by the concurrent working memory task. The results of the experiments suggest that additional cognitive load dramatically affect~~s~~ perceived time perception in musicians with regards to the development of performance strategies and planning before the start of a phrase. We discuss the role of sensorimotor control and feedback processes in musical timing to explain these findings. While there is only a few examples of empirical work addressing gender differences in multitasking and cognitive attention, none of these have focused on gender inequality in skilled musicians. To explore the question whether gender could be a determining factor in multitasking during music performance, a mixed strategy empirical study was conducted. First an experiment was carried out that examined whether gender plays a critical role in time perception in music playing under increased cognitive load with multitasking. Only few significant differences between men and women were found. Our study suggests that differences between women and men are not due to biological but to cultural conditions.

Overall, it can be suggested that, with well-practiced pieces, musicians use cognitive resources for handling the control of expressiveness. Moreover, it is quite plausible to assume that with an additional cognitive load, performances will become less expressive due to the occupied cognitive resources. The main assumption that musicians can rely on self-generated sensory feedback and sensorimotor control to regulate temporal coordination of muscle activity seemed to be confirmed with a special profile: "Operatic singers". Operatic singers often encounter heightened cognitive load situations and therefore they are better equipped to handle dual tasks.

Gender seemed to be an insignificant parameter pertaining to the effects of cognitive load. In this dissertation three critical research questions were discussed through a body of literature review (chapters 1 and 2). Three different experiments were conducted (chapter 3, 4 and 5) and overall results discussed at the end of this dissertation (chapter 6).

Nederlandse Samenvatting

In deze dissertatie presenteren wij de resultaten van empirische studies naar de effecten van cognitieve belasting op uitvoerende musici.

De hoofddoelstelling van deze studies was het onderzoeken in welke mate een bijkomende werkgeheugen-taak de timing van de uitvoering bij muzikanten beïnvloedt.

Om deze stelling te testen werden muzikale uitvoeringen met en zonder dergelijke secundaire taak getest.

Experimentele resultaten hebben aan het licht gebracht dat cognitieve belasting leidt tot een afname in muzikale expressiviteit.

Wij legden hierbij vooral de focus op de neiging van muzikanten om hun uitvoering van muzikale zinnen en pauzes (rusten) te versnellen of te vertragen.

Onze verwachting was dat, algemeen gesproken, de timing van expressieve uitvoering beïnvloed zou worden door een gelijklopende werkgeheugen-taak.

De resultaten van de experimenten suggereren dat bijkomende cognitieve belasting de ervaren tijdsperceptie bij muzikanten dramatisch beïnvloedt, betreffende het ontwikkelen van uitvoeringsstrategieën en planning voor de start van een muzikale zin.

We bespreken de rol van sensorimotorische controle en terugkoppelingsprocessen in muzikale timing om deze bevindingen te verklaren.

Hoewel er een beperkt aantal empirische studies zijn die genderverschillen in multitasking en cognitieve aandacht bestuderen, besteedden deze geen aandacht aan genderverschillen bij geschoolde musici.

Op de vraag of gender een bepalende factor kan zijn bij multitasking tijdens een muzikale uitvoering werd een mixed strategie empirische studie uitgevoerd.

Eerst werd een experiment uitgevoerd dat onderzocht of gender een kritieke rol speelt in tijdsperceptie bij muzikaal spel onder verhoogde cognitieve belasting met multitasking.

Slechts weinig significante verschillen tussen mannen en vrouwen werden vastgesteld.

Onze studie suggereert dat verschillen tussen vrouwen en mannen niet aan biologische condities te wijten zijn maar aan culturele.

In het algemeen kan gesuggereerd worden dat, bij goed ingestudeerde stukken, musici cognitieve reserves gebruiken om de controle over expressiviteit te sturen.

Bovendien is het plausibel te veronderstellen dat met een toegevoegde cognitieve belasting, muzikale uitvoeringen minder expressief worden ten gevolge van deze in beslag genomen cognitieve reserves.

De veronderstelling dat musici kunnen terugvallen op zelf-gegenereerde sensorische feedback en sensorimotorische controle om de temporele coördinatie van musculaire activiteit te reguleren, lijkt bevestigd door een specifiek profiel: "Operazangers".

Operazangers worden vaak geconfronteerd met verhoogde cognitieve belasting en zijn derhalve het best uitgerust om dubbele taken te verwerken.

Gender bleek geen significante parameter te zijn met betrekking tot de effecten van cognitieve belasting.

In deze dissertatie werden drie kritieke onderzoeksvragen besproken door een literatuurstudie (hoofdstuk 1 en 2). Drie verschillende experimenten werden uitgevoerd (hoofdstuk 3, 4 en 5) en algemene resultaten besproken aan het einde van deze dissertatie (hoofdstuk 6)

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Introduction

Music is ubiquitous and its influential power is well appreciated, even by a layman. Acoustical features of musical stimuli are known to convey expressive features that trigger behaviors in a powerful way. Much research on the power of music acknowledges the role of musical expressiveness as its ubiquitous influence. Therefore, this research aims at better understanding of the relationship between these acoustical features and human behavior.

Over the course of two decades, research on musical expressiveness got renewed attention thanks to the development of the embodied music cognition paradigm (Leman, 2008). In this paradigm, one considers musical expressiveness from the viewpoint of enactment. The central idea is that the translation of expressive intentions into acoustical patterns (during the encoding of expression), or the translation of acoustical patterns into expressive intentions (during the decoding of expression) is guided by corporeal principles related to sensorimotor mechanisms and action-perception couplings. In former work on expressive encoding and decoding, the focus was mainly on information transfer and emotions (e.g., Kendall and Carterette, 1990; Juslin, 2005), and corporeal principles were often not explicitly taken into account. This changed over the course of two decades. Current research builds on previous achievements by identifying the acoustical features that influence the human mind and body (e.g., Fabian et al., 2014). In addition, it focuses on interaction principles that support these expressive influences (e.g., Leman, 2016). Overall, the goal is to understand the expressive power of music and the effects it has on human behavior. The research trends reveal that the role of the human body in the encoding and decoding of musical expressiveness has become an important research topic.

In this thesis, we will focus our attention on the encoding of musical expression, leaving aside aspects of decoding. In particular, we aim at understanding the role of cognition in the encoding process. Different musicians, while playing exactly the same notes, can interpret the same written score very differently. Their expressive interpretation can be encoded in the sounds, leading to highly different expressive musical powers. The listener can then decode these powers and perhaps reconstruct the expressive intentions of the musician, or construct new expressive intentions based on the expressive musical features heard. In focusing on the encoding part, we aim at investigating how cognition works in relation to motor abilities. After all, a music performance draws upon the relationship between planned actions and given action skills: playing the guitar requires particular technical motor skills that need to be controlled in function of the intended expressive power. Our research question aims at understanding how music cognition is related to these motor skills, in particular those that control expression.

However, the precise role of cognitive resources (addressed by mental effort, attention, working memory) and motor skills (addressed by technical challenges) in relation to the musician's encoding of musical expression is not very well comprehended. Can these two important components of music making (namely cognitive resources and motor skills) be separated from each other when it comes to musicians' (mental) intentions and bodily actions? Does one of these components affect the other?

It has been suggested (Leman, 2008) that the practicing of music, such as the arpeggio part of a guitar piece, is crucial to automate the musical actions needed to perform. This practicing would reduce the cognitive load of playing, so that the musician would have residual cognitive resources that can be used for expressiveness. Differences in performance level of a piece might therefore result in the need for more or less cognitive resources. A not well-practiced piece, for instance, would require more cognitive resources to be performed than a well-practiced piece. The lack of automatized actions would leave less cognitive resources for playing expressively because attention is needed to execute these actions. Alternatively, the performance of a well-practiced piece could be played leaving residual cognitive resources that can be harnessed for the control of expression. Less attention (as being one of the most important component of cognitive resources) or perhaps less mental effort is needed to execute the actual playing actions because these actions are automatized (and under sensorimotor control). In other words, this theory (also put forward in Leman, 2016) assumes that expressiveness is hard to automatize by the brain because of the continuous feedback that is needed to control timing (necessary deviations in time). Cognitive resources are needed to maintain its control, no matter how well the piece is mastered from a technical point of view.

Can we design an experiment in which this hypothesis is tested? Can we show that a well-practiced musical piece leaves place for cognitive resources, and that the control of expressiveness requires cognitive resources?

In this thesis, we manipulated the cognitive load of the musician who is performing and we considered the effect of cognitive load on the musician's encoding of musical expression. Thus, we applied a dual-task interference paradigm, meaning that two different tasks are performed simultaneously. This method allows an identification of the role of cognitive and sensorimotor resources during the encoding of musical expression.

While the primary task consists of performing a piece of music, the secondary task deals with an on-going working memory task (together with the performance), in which participants count the number of shapes appearing on a computer screen. Thus, a well-practiced piece will be performed twice: a condition without dual task (playing) and a condition with a dual task (playing + counting). If the encoding of expressiveness is indeed mediated by cognitive resources, then these resources will be affected in the dual task condition. This happens because this dual task will also consume cognitive resources, and this will interfere with the cognitive resources needed for the encoding of expression. If the encoding of musical expressiveness is not mediated by cognitive resources, then this encoding will not be affected in the dual task condition. This happens because the dual task's consumption of cognitive resources will not interfere with the motor skills needed to encode musical expressiveness. The latter may be assumed to be controlled by sensorimotor predictive processes that largely escape cognitive attention. Rather than continuous feedback control (which we assume for expressiveness), attention for motor skills may occur at regular times and less intensive, due to motor programs that control the activity by means of sensorimotor forward models (Maes et al., 2014; Leman, 2016).

As a matter of fact, the crux of this study depends on the ability to measure differences in encoded musical expressiveness. That measurement should be based on the recorded audio performance after the task has been completed. During the course of our study, we explored whether different expressive cues of the musical performances were affected by cognitive load. However, we soon found that the most important cue is probably the temporal control over the piece of music, known as "expressive timing". This timing parameter is in an important way connected with cognitive load as will be explained the first chapter of this thesis.

To summarize, the thesis aims at investigating to what extent cognitive load (induced by an additional working memory task) influences the encoding of expressiveness in (semi-) professional musicians: graduated conservatory students, symphonic orchestra musicians and professional opera singers. We also wanted to know whether gender plays a role. The result of these investigations should give an answer to the question whether control of musical expressiveness is a matter of cognitive resources. The outcome of our research might have important uses beyond the confines of musicology. It may well throw important additional light on our understanding of mind body interactions from the point of view of various other disciplines such as neuroscience psychology, systematic musicology and gender studies. Moreover this research may a positive affect on music education, especially for the development of pedagogical principles that address musical expressiveness.

1

Theoretical Framework

This chapter presents a theoretical framework for the experiments that are reported in the following sections. This framework builds upon a number of concepts, which we will introduce in this chapter. Starting with the concept of embodied music cognition, we introduce: musical expressiveness, expressive timing, time perception, and cognitive load. Finally, the gender issue will be taken into consideration in order to clarify if gender is a predominantly effective when it comes to expression encoding.

1.1 Embodied Cognition

Modern neuroscience findings and behavioral studies claim that the mind is embodied, meaning that mental processing is strongly influenced by corporeal activities. Descartes' dualism, which assumed different substances for mind and body, cannot longer be maintained. The famous quote "cogito ergo sum- I think therefore I am" which implied the existence of mental activity without a body no longer serves as a guide for research. As Damasio (1994) argued, together with many other scientists and philosophers (e.g., Metzinger, 2003), there is no non-physical mind in the brain. Accordingly, a pure focus on mental processing misses a major part of what happens in human interaction with its environment. Cognition is embodied because it arises from bodily interaction with environment. Cognition thus depends on the experiences that come along from having a body with particular perceptual and motor capacities that are inseparably connected with each other. Together these connections form the matrix within which memory, emotion, language, and all other aspects of life are meshed (Thelen et. al. 2001). In short, cognition is influenced by the corporeal mediation of all experiences.

1.2 Embodied Music Cognition

Music playing is known to rely on high-level skills involving cognitive schemata, fine motor control, as well as emotional regulation. Research in embodied music cognition aims at understanding these skills by considering the body as a natural mediator between musical intentions (mind) and musical sounds (matter) (Leman, 2008). Thereby, the body is not only used to perceive sounds, or to produced them, but also to transform these patterns (by means of an enactment process) into something that can be interacted with at the intentional level (Leman, 2016). According to the embodied music cognition paradigm, musical meaning-formation is corporeal rather than cerebral (Leman, 2008). While playing a piece of music, a musician maintains an action-perception loop in which he or she uses the sound of the music as feedback for the process of performing or singing. Three fundamental motor functions of this action-perception loop are timing, sequencing, and spatial organization of movement (Zatorre *et al.,* 2007). To master these motor functions requires many years of practice and training.

It has been suggested that skillful (technical) playing is an important prerequisite for expressive musical performance (Palmer, 1989). A cognitive concept with special relevance to advanced musical skills is motor programming, or the idea that there exist schemes for the control of skillful playing. This concept offers a structure appropriate to the demands of skilled performance and it can encompass properties of creativity, fluency and expression. Evidence from studies of piano performance (Shaffer 1981), for example, suggests that the skilled performance draws upon cognitive and motor schemes that lie outside the scope of the unskilled performer. Given that the combination of difficult cognitive tasks requires that a significant amount of information is processed at the same time, it can be assumed that expressive playing poses a significant load on the musician (e.g. Chandler & Sweller, 1991).

In a recent theoretical work on action-perception coupling and music playing (Leman 2008) it has been suggested that the practicing of motor actions such as the arpeggio part of a guitar piece is crucial to automate the motor patterns, reducing the cognitive load of playing, so that the musician has residual cognitive resources that can be used for expressiveness, rather than on the sound-producing gestures. Among all musicians, professional opera singers undergo the highest cognitive load while performing. They not only have to act and know where to move around on the stage, to know when to sing something, and to interact with others, but also they have the added language, which involves correct pronunciation, natural inflection, clear diction, and genuine comprehension in as many as four different languages beside one's own (Helding, 2012). According to Kleber et al. (2010), operatic singers develop specialized neural networks for enhanced somatosensory processing as well as motor sequence attention when compared to laymen and even other singers. This is certainly a reason to pay attention to this specific group of musicians. If they are used to work with cognitive load, then perhaps their encoding of expressiveness will be less influenced by additional cognitive load than other musicians that are not used to work with cognitive load.

To sum up, research in embodied music cognition is strongly linked with the pragmatic turn in cognitive science (Engel et al., 2013). It stands as a subfield within the field of cognitive science because it pays a lot of attention to sensorimotor interactions in which expression plays a central role (Leman, 2016). We believe that this field offers the right epistemological and methodological background for our research on expressive encoding during music playing. Our central question about cognitive resources needed for expressive control is directly related to the embodiment of musical intentions and to sensorimotor skills that automatize the actions that execute the intentions.

1.3 Musical Expressiveness, “timing” as a mean of Expressiveness

Musical expressiveness has been characterized as a main property of musical and social cognition (Hodges, 1996; Malloch & Trevarthen, 2009), and it is likely that expressiveness has roots in the mirror neuron system (Molnar-Szakacs, 2011). However, the precise role of cognitive resources (such as mental imagery, structural organization, memory of musical schemata), motor resources (fine and coarse motor control) and emotional resources (stress control, experienced and intended mood) in relation to musical expressiveness is not well understood. Leman (2016) suggests that expressiveness may be hard to automatize completely, because, during a given musical interaction, it may require constant monitoring of the gestural sensory outcome. Given that musical expressiveness is enacted gesturally (in the sense that intentions are acted out in overt behaviors), timing is essential in any convincing performance, which involves expressive intentions on different time scales such as note articulations, note co-articulations (slurs, staccato), and phrase-related expressive arcs. From different perspective, the question is whether musically expressive timing can be fully encoded by means of automated motor programs, or whether that encoding requires dedicated cognitive resources. Even when a given performance is mastered technically (e.g., control of finger patterns that execute the arpeggio), it is possible that cognitive resources (e.g., attention) are required to monitor the sensory effects and implications of those gestures on different expressive time scales, and within rapidly-changing interactions. At the same time, we should keep in mind that the rehearsal of musical sequences, such as playing arpeggios on the violin, can never be fully disconnected from expressiveness. Articulations and expressive arcs can be rehearsed and learned and it is likely that their corresponding expressive gestures can also be brought under the control of dedicated sensorimotor schemes. This implies and assures a certain degree of automaticity in their performance. The question, therefore, is one of degree: to what extent does the gestural control of expressiveness require cognitive resources, even when technical control is fully mastered, and when the there is no “pressure” to interact with accompanists or other musicians (when playing solo).

Music playing is said to be expressive, or musical, if somehow, the performer succeeds in invoking certain (emotional) responses in the listener by intentional manipulation of the written score (e.g. Palmer, 1989). Musical expressiveness can also be linked to different musical parameters, such as dynamics like crescendo or decrescendo, timbre, energy, timing and articulations (De Poli, 1998, Bresin, 1998). Based on measurements of acoustical features such as amplitude or brightness, it is possible to model and synthesize musical expressiveness up to a certain degree (Camurri et al., 2005; Bresin & Friberg, 2000). Musical expressiveness is often linked with musical structure (e.g. Gabrielsson & Lindström, 2010), which suggests that the generation of musical expression is based on a planned cognitive structuring of musical phrasing in combination with the fine-grained control of motor commands that manipulate the music instrument (see also Fabian et al., 2014 for a review of empirical approaches). The effect of rehearsing is that playing gestures become partly automated because they are controlled by forward predictive models (Leman, 2016, chapter 6; Maes et al., 2015; Wolpert, Diedrichsen, & Flanagan, 2011). Automated gestures consume fewer cognitive resources than non-automated ones because they are governed by sensorimotor schemes that control motor activity continuously, until motor activity is checked (hence ‘forward predictive models’). Accordingly, prediction errors are only calculated at particular points with a view to adapting the sensorimotor schemes and their desired action outcomes. The prediction error is the difference between the expected motor outcome and the actual motor outcome. The important point here is that actions controlled by sensorimotor schemes can be executed automatically until verification is needed, at which point a prediction error might be identified, requiring a newly adapted forward predictive model. This adaptation is assumed to happen on a discrete basis, as the forward predictive models ensure the execution of actions “in the dark”, for a short time at least. The main point is that due to sensorimotor schemes, gestural control requires far less cognitive resources than when gesture would need continuous updating.

A musician can always convey emotions through his or her performance without knowing or taking less care on how he or she is interpreting a piece of music. Yet, the musical piece itself can be technically so easy for the musician that the expressiveness can still be present without mastering the piece in question. Although it seems that it is hard to formally conceptualize ones musical expressiveness, Juslin et al. (2002) provide a valuable model known as ‘The GERM model’ that drives from four components of expression: (1) Generative rules, which mark the structure in a musical manner; (b) Emotional expression, which serves to convey a particular mood; (c) Random fluctuations, which reflect human limitations in timing precision; and (d) Motion principles, which postulate that tempo changes should follow patterns of human movement. These components were simulated in synthesized performances, and tests revealed that all of these components contribute to the perceived expressiveness of a performance. This study suggests that expressiveness is an empirically tractable problem (Juslin, 2002).

In the context of this dissertation, it is important to mention the work of Bruno Repp (1995, 1997), who suggested that expressive timing may be a crucial factor in the control of expressiveness. The term “expressive timing” refers to continuous modulations of the performer’s tempo. This tempo can be measured in terms of the time intervals between successive tone onsets of the recorded performance. A silent pause in between musical phrases can therefore also be argued to be part of expressiveness because its timing will be of crucial importance to the overall tempo feel (see also Palmer, 1989).

In short, given the same melodic and harmonic ingredients, musicians can generate very different musical expressions. They manage to do this through the control of the aforementioned sonic properties; in this control, variations in timing play an important role.

1.4 Time Perception Models and Musical Performance

Expressive music performance requires a fine-grained temporal coordination of muscle activity to control one’s musical instrument, or vocal chords in the case of singing performance. Thereby, musicians often perform under conditions of heightened cognitive load due to various reasons. Previous research demonstrated that a cognitive load impairs regular timing production, suggesting the role of a cognitively controlled system for the temporal control of body movements (Krampe et al., 2010; Rattat, 2010; Fischinger, 2011; Çorlu et al., 2014; Maes et al., 2014).

The basic idea here is that a dedicated internal clock is used to keep track of time. The most influential account of this “timekeeper” approach is the pacemaker-accumulator model (Gibbon, 1977). In this model, a clock, or pacemaker emits pulses that enter an accumulator via an attention-controlled switch. The number of accumulated pulses is stored in working memory, and compared with a criterion interval in reference memory.

Working memory can be described as a process by which information is stored and processed (Baddeley, 1966). A typical effect that is observed in experiments investigating timing production under heightened cognitive load is a tendency to speed up (Krampe et al., 2010; Rattat, 2010; Çorlu et al., 2014; Maes et al., 2014). This effect is explained by memory-based models of estimated time duration, such as Ornstein's storage-size hypothesis that states that the experience of duration is related to the amount of stored information: as the storage size increases, duration experience increases (Ornstein, 1969). Accordingly, in situations of heightened cognitive load, cognitive storage size will increase more rapidly, leading to an overestimation of interval durations, and correspondingly to the production of shorter temporal intervals. This cognitive timekeeper is highly vulnerable to cognitive load and therefore relatively inefficient in situations that require heightened cognitive load. Accordingly, this approach is presumably incomplete to fully explain timing behavior.

Research also suggests an alternative account in which perceptual and motor systems guide the temporal control of body movements through interaction with the external environment (Jones and Boltz, 1989; Hopson, 2003; Mauk and Buonomano, 2004; Ross and Balasubramaniam, 2014). A basic idea is that the course of coordinating body movements, (repeated) patterns in spatial trajectory and energy expenditure (e.g., muscle contractions/relaxations) arise that can be used to "index" time in a continuous way. Accordingly, it is suggested that temporal control may emerge from the control of movement dynamics itself, without the need for a central timekeeper. This "emergent" timing approach is supported by empirical research investigating the mechanisms underlying the temporal control of continuous and discrete rhythmic movements. In this context a distinction is made between an emergent-based timing and an event-based timing (Robertson et al., 1999; Zelaznik et al., 2002, 2005, 2008; Delignières et al., 2004; LaRue, 2005; Torre and Balasubramaniam, 2009; Studenka et al., 2012). To clarify, the distinction between event-based and emergent-based timing can be found in the finger tapping task (Repp, 2005) where participants tap in synchrony with a metronome. An example of an emergent-based timing task however, could be the circle drawing task where participants continuously trace the synchrony.

Other research, focusing on the role of sensory information in timing production tasks, suggested that sensory information coming from the external environment, as well as self-generated sensory feedback may contain temporal cues that guide temporal behavior in a more or less direct way (Rodger and Craig, 2011; Varlet et al., 2012; Roerdink et al., 2013; Bravi et al., 2014). By repeated experience, and general (associative) learning mechanisms, people learn how patterns of dynamic change in sensory information provide an index of the passage of time (Dragoi et al., 2003; Hopson, 2003; Addyman et al., 2011). Correspondingly, proper timing may then be realized by "anchoring" muscle activation to these sensory patterns.

In short, we may assume that expressive timing in music performance is based on the control of timing. The two basic models to be considered here are cognitive and embodied. The cognitive timing is based on internal events generated by a clock mechanism (event-based timing). The embodied timing is based on interactions of movements with the environment and on cues from the environment that are used for timing.

1.5 Cognitive Load Theory

Another concept on which our study is based is called “cognitive load”. This concept is based on the idea that the amount of information processed by the working memory is a load for cognitive functions. However, this cognitive load may depend on the ability to chunk or group the amount of information. George Miller's information processing research (Miller, 1956) showed that this working memory is limited in the number of chunks that can be processed and he suggested that this memory could only hold seven (plus or minus two) chunks of information.

The cognitive load theory draws upon the idea that the processing capacity of the working memory is limited and that this limitation determines abilities in processing information (Sweller, 1988). In order to increase the information transfer towards working memory and from working memory, cognitive load has to be reduced. Since working memory (alternative term for working memory would be short term memory) is used to organize, contrast, compare and work on the information in question, humans can barely process two or three information simultaneously. Therefore, human cognition relies more on the ability of long-term memory (instead of short-term or working memory), which can store seemingly unlimited amount of information (Kirschner, 2002). Chi et al. (1982), argues that knowledge is categorized in long-term memory in schemata. According to this schema theory, a schema consists of immense amount of information and that can be processed as a single unit in working memory. Furthermore, schemata can integrate information elements and production rules and become automated (higher-order schemas) and thus, schema construction helps the organization of the information in long-term memory and reduces working memory load (lower-order schemas), (Sweller et al. 1998, Kirschner, 2002). It is also very important to distinguish the three types of cognitive load. According to Sweller (1988), one of the types, namely, intrinsic load, is directly related to the task or learning material. Learner's level of expertise plays also a role here since the more experienced he or she is, the more they will be able to shrink information on high-order schemata that minimize the cognitive cost of maintaining elements in working memory (Debue & Leemput, 2014). Extraneous load refers to the load that is not related to the information presented and therefore increases the cognitive load without improving the learning. From educational psychology point of view or more precisely, from instruction design point view, it is important to keep the extraneous load as low as possible. Isolation and elimination of redundant sources is therefore indispensible in designing the information (Chandler & Sweller 1991). Germane load, on the other hand, means the mental (or cognitive) resources that are devoted to acquiring and automating schemata in long-term memory (Sweller et al. 1998). In this regard, it is obvious that the germane load is beneficial and must be promoted to enhance learning (Ayres, 2006). It is quite interesting and yet very straightforward to our assumption that Sweller et al. (1998) argues that automation is an important factor in schema construction which can free working memory capacity for other activities. With automation, they claim, familiar tasks are performed accurately whereas unfamiliar tasks can be learned with maximum efficiency because maximum working memory capacity is available. Apart from instructional perspective, this idea is rather parallel to our assumption in the sense that professional musicians automate their pieces of music to free their cognitive resources. It would be conceivable therefore, use of dual-task paradigm (secondary task procedure) can give more insights in terms of the affect of cognitive load on musicians.

A known objective measure to assess cognitive load is a secondary task procedure (Bruenken et al., 2003). In that procedure, a secondary task poses an additional cognitive load, which affects the performance of a primary task. In our study we use this method to investigate the role of cognitive load on performing musicians. As far as we know, the use of additional cognitive load during music playing has not yet been used as a method for studying music cognition.

We assume that the control of expressiveness depends more on cognitive resources. Actually, years of formal education and rehearsals lead to a schemata construction (germane load) that can enhance to comprehend a piece of music apart from its own challenges (intrinsic load) during performing. With additional cognitive load (extraneous load) we create a situation where these cognitive resources are challenged. Our assumption is based on the idea that the encoding of expressiveness during music playing requires a constant sensory feedback control that consumes attention and therefore cognitive resources. The alternative assumption is that the encoding of expressiveness during music playing draws upon a motor program that probably requires less cognitive resources. That program would be established through the musical learning process. If our hypothesis about the cognitive dependency is true, then cognitive load should affect the control of expressiveness, but not the technicalities of playing. If our hypothesis is false, then cognitive load should not affect the control of expressiveness. Our approach allows the experiment to be executed using the same piece in both conditions, and thus circumvents potential problems of using two different pieces, for example, a well practiced piece and a less well practiced piece. In our dual task condition a modified oddball paradigm (Huang et al., 2005) was used as a secondary task. In this paradigm, we asked participants to count the number of infrequently occurring triangles and circles amongst frequently occurring squares that appeared on the computer screen while they were performing their musical pieces by heart.

1.6 The Gender Issue

At first, the gender topic may appear as a topic aside of our core research. However, the gender issue is highly relevant in terms of multitasking and consequently in dealing with cognitive load. More importantly however, it would be a missed opportunity if we did not ask the question whether the affect of cognitive load could be generalize on every musician regardless of the gender. Therefore, we included it in our approach.

The complexity of the variables affecting the cognitive functions in terms of gender differences has been widely discussed over the last years. Constant media attention has created debates on whether gender is a crucial issue on intelligence and cognitive functions. In that context, it has been argued that for some cognitive functions females are superior over men and for other functions the case is vice versa (Weiss et al., 2003). In terms of memory, for instance, studies show that the advantage is for females whereas men tend to outperform women on visual–spatial tasks (Hampson and Kimura, 1992, Weiss et al., 2003). The limited amount of studies, both on animals and humans, portray difficulties in determining the mechanisms underlying gender differences in behavioral responses (for the review see: Kelly et al., 1999). However, thanks to functional magnetic resonance techniques (fMRI), the debate on gender differences has recently focused on brain studies, revealing that gender differences depend on different cognitive styles of encoding, rehearsing, and thinking about emotionally laden personal experiences in males and females (see Piefke and Fink 2005 for review on fMRI and memory studies). Some studies, therefore, suggest that the gender-related differences in brain function are neurobiological determined, rather than culturally (Cahill et al., 2001; Piefke et al., 2005).

Multitasking is of particular interest in the study of gender-related cognitive functions. Multitasking is the scheduling and interleaving of multiple parallel tasks. Women seem to excel in episodic memory tasks in which a verbalization of the material is possible (Lewin et al., 2001). However, recent findings (Mäntyla, 2013) suggest that these popular assumptions and actual differences between men and women in time-use patterns do not directly translate to a superior female capacity to handle multiple tasks.

At that point, it is of interest to look at gender differences in musical performance. Music is of interest here because both men and women are known to be capable of developing musical skills and there are no gender differences in music performances ever reported. This means that neither the cultures people are living in, nor biologically determined sex, are useful analytic tools in providing explanations for differences between females and males (Maidlow and Bruce, 1999). To our knowledge, such multitasking experiments with music have never been used in studies of gender-related cognitive abilities. In short, we devote one study to this issue in order to see whether it affects cognitive load during music performing.

1.7 Conclusion

In this chapter we introduced the basic concepts that play a central role in our study. The main research approach adopted is based on the paradigm of embodied music cognition. We have reasons to believe that the expressive cues (intentions, ideas and feelings) of a musical performance depend on how music is embodied, or bodily realized/encoded in space and time during the performance. We have reasons to assume that one of the most crucial elements of this embodiment of expressiveness is timing. As a piece of music consists of technical demands as well as musical ideas, a musician is usually confronted with a huge cognitive load. Therefore, the practicing of motor actions (such as the arpeggio part of a guitar piece, as mentioned earlier) is indispensible, in order for motor actions to become automated. In principle, this practicing could also apply to expressiveness, because the control of expressiveness also relies on actions, similar to the actions needed to perform the arpeggio. However, there are reasons to believe that expressiveness, due to its high demands in accurate (deviations) timing (at millisecond level), requires more attention and therefore continues to consume cognitive resources, even when the actual playing of the arpeggio is already technically mastered (in terms of an automated motor program). On top of that, we are interested in knowing whether the capability of dealing with cognitive load (multitasking) is gender specific.

2

Problem Identification and Methodology

2.1 Research Questions

Based on the above framework of concepts, the main research questions can be summarized as follows:

We hypothesize that with well-practiced pieces, musicians use cognitive resources for handling the control of expressiveness. Then:

1. *Is it correct to assume that with an additional cognitive load, performances will become less expressive due to the occupied cognitive resources?*

We assume that musicians can rely on self-generated sensory feedback and sensorimotor control to regulate temporal coordination of muscle activity. Operatic singers often encounter heightened cognitive load situations and therefore they are best equipped to handle dual tasks. Therefore:

2. *To what extent does cognitive load (dual task) affect their expressive timing of the singers' performance?*

It is of interest to focus on this special group of musicians to vindicate the interaction between expressiveness and cognitive load.

In Çorlu et al. (2014), we found that cognitive load tends to shorten the performance of pause durations. The question is whether this effect is gender-related. If women are indeed superior in multitasking, they should be better in handling cognitive load, and this should be reflected in the timing of their performance: the female timing of pauses should be different from the male timing of pauses.

3. *Can we generalize our finding to all musicians, is there a gender related differences?*

Since our hypothesis is to observe how expressive playing (or the encoding of expression) is affected by cognitive load, our strategy was first to let a jury assess the level of expressiveness of pieces played under normal and cognitive load conditions. If the assessments would indicate a change in expressiveness, the next step was to identify consistent differences in acoustical parameters that correlate with these changes in expressiveness using audio analysis.

2.2 Experimental Design

To answer the questions listed above, we developed a simple experimental design that we could apply to several of our studies. In this chapter we briefly describe the general design that has been used in the three experiments. Further details are given in later chapters: Experiment 1 is detailed in chapter 3, experiment 2 in chapter 4 and experiment 3 in chapter 5.

2.2.1 Participants

In the first experiment (chapter 3) twenty-one musicians (singers and instrument players) participated. Their mean age was 26 years and the instruments they used were guitar, violin, clarinet, trombone, trumpet, viola da gamba and viola. All participants had at least eight years of formal musical education. In the second experiment (chapter 4) twelve operatic singers (six female, mean age = 29,2 years) participated. All participants had at least eight years of stage experience besides their formal operatic education. In the third experiment (chapter 5), there were two different participant categories, for audio recordings, and for questionnaires. Participants for audio recording: 29 musicians (Mean 25,5) participated in the music performance experiment. Their performances were recorded for audio analyses. The participants had between 8 and 24 years of musical experience. Participants for on-line questionnaire: A representative sample of 194 respondents was collected. After elimination of a number of subjects (they were not eligible for our target group), 182 responses were available for data analysis. They were aged between 15 and 65 (mean age 32,91), 50% are women; they come from 14 different countries. Participants had between 6 and 56 years of experience in music performance.

2.2.2 Ethical Standards

For the participants there were no risks involved in the studies and confidentiality was guaranteed. During each experiment, the Ethics Committee of Ghent University approved each of the three studies' methodology. Moreover, participants signed a form at the start of every experiment, declaring that their participation was voluntary; that they had received sufficient information concerning the tasks, the procedures, and the technology used; and that they were aware of the fact that recordings will be used for scientific and educational purposes only.

2.2.3 Procedure

Participants were asked to perform music, with and without an additional cognitive task. Participants were asked to play or sing a short piece of music that they knew by heart. The pieces were at least 2 minutes long and the participants stopped playing or singing after the two-minute task ended. For the secondary working memory task, participants were placed at a computer monitor. Different shapes (squares, circles, and triangles) were presented for 800 milliseconds each, before a next shape appeared. They were instructed to count the shapes during playing. Afterwards, they were asked how many triangles and squares they counted. Note that, shape counting was the most affective secondary task during our pilot studies. Mathematical equations (appeared on the computer screen) were too difficult to execute musical performance. Shape counting seemed more doable for the musicians especially when we set the intervals of the appearing shapes to 800 milliseconds. Since we have not come across any dual task examples done to test musical expressiveness, we come up with the idea 'shape counting' after couple of pilot test.

It is always possible to argue whether cognitive resources were shared or, instead, cognitive tasks were executed by shifting the attention from one to another. Counting shapes needed constant attention presumably because they were not just counting the shapes but also they had to keep in their minds the number of shapes counted which needs continuous 'update' to remember the correct number. Yet, the durations of the pauses vary from 100 millisecond to 3000 millisecond therefore it would be rather difficult to use the interval of the appearing shapes as a reference (covert counting) for their performance (during pause).

In the following chapters (from chapter 3 to 6), the procedure is described in more detail for each experiment.

2.2.4 Data Acquisition

2.2.4.1 Heart rate Variability

The heart rate variability was measured in the first experiment. The goal was to measure whether an additional cognitive load causes a significant change in heart rate variability, as one of the stress indicators. ECG recordings were made for this purpose.

2.2.4.2 Questionnaire

From every participant we gathered an information sheet in which they gave information about the gender, age, left or right-handedness, years of experiences and other types of information. There were two main questionnaires:

Post-experimental questionnaires: With post-experimental questionnaire, we tried to probe subjective feelings about the experienced difficulty, the experienced stress, and the satisfaction of the performance.

Online survey: The online survey was used only in the third experiment (chapter 5). This validated questionnaire was administered online using Google Docs web survey we could reach large samples (see above).

2.2.5 Data analysis

In order to analyze the data we used jury evaluation, audio analyses, analysis of heart rate variability and questionnaire analysis.

2.2.5.1 Jury Evaluation

The audio recordings of each performance in the two conditions were listened to by three music scholars (the jury). The jury was unaware that certain recordings were performed with a secondary task. For both performances, each jury member determined whether one of the two recordings was musically less expressive, and in which of the performances there were rhythmic hesitations, wrong phrasings, and tempo instability, if any (see chapter 3, jury evaluations in the methodology and result section for the details). The idea is to concentrate more on the time aspect of musicality. All parameters are directly related to the timing feature of the acoustical cue. Audio analysis aimed at finding those differences by using audacity program to be sure. Jury judgments gave information more on a subjective level about expressiveness.

2.2.5.2 Audio analysis

By using audacity program we calculated overall duration of the performance in each condition. We wanted to investigate whether the durations of musical phrases and pauses were differently affected by the working memory task. For that purpose, we calculated the total accumulated durations of both the musical phrases and pauses in the baseline condition (see chapters 3 and 4 for detailed procedure of audio analysis from sections 3.1.2.5 and 3.2.5).

2.2.5.3 Analysis of heart rate variability

Heart rate variability was measured only in the first experiment (chapter 3). Heart rate data was analyzed by calculating the heart rate variability for each participant and each condition. The heart rate variability was calculated based on the intervals between the peaks in the heart rate data. Peaks were detected using a peak detection algorithm with a threshold value of 0.7 after normalization of the data between 0 and 1.

2.2.5.4 Analysis of the questionnaire

The validated questionnaire was administered online using Google Docs web survey. This method was chosen because it can be easily implemented to large samples (see chapter 5 section 5.2.5 for detailed explanation).

2.2.6 Statistics (repeated measures) Reporting Results

The results of our empirical research are presented as journal papers (see chapter 3, 4 and 5). We have underlined the following statistics when reporting them in a manuscript:

F (F ratio in ANOVA)

M (mean)

N (total number in a sample)

p (probability),

SD (standard deviation)

t (value of t-test).

Two papers have been published. The third paper is currently still under review. Some results of our studies were also presented during conferences.

2.2.7 List of Publications

Çorlu, M**.,** Maes, P., Muller, C., Kochman, K. & Leman, M. (2015). “The Impact of Cognitive Load on Operatic Singers’ Timing Performance.” *Frontiers in Psychology, Auditory Cognitive Neuroscience* 6:429. doi: 10.3389/fpsyg.2015.00429.

Çorlu, M., Muller, C., Desmet, F. & Leman, M. (2014). “The Consequences Of Additional Cognitive Load On Performing Musicians.” Psychology of music Published online before print February 6, doi: 10.1177/0305735613519841.

Çorlu, M., Lesaffre, F. & Leman, M. (2016). “A Gender-Specific Analysis in Multitasking Behavior and Time Perception During Performance of Professional Musicians with Additional Cognitive Load (under review).

Çorlu, M., Maes, P.-J. & Leman, M. Cognitive and sensorimotor resources for the encoding of expressiveness during music playing. A Book Chapter, Routledge (in press).

3

The effect of cognitive load on expressive musical performances

3.1 Introduction

In line with our first research question (specified in chapter 2), we hypothesize that with well-practiced pieces, musicians use cognitive resources for handling the control of expressiveness. We therefore predict that with an additional cognitive load, performances will become less expressive. We discussed the literature overview in the chapter 1.

3.2 Methodology and Experimental Design

3.2.1 Participants

Twenty-one musicians (singers and instrument players) participated in the experiment (9 females and 13 males). Their mean age was 26 years, ranging from 18 to 40 years, with a standard deviation of 6,41. Two of the participants were left-handed. All participants had at least 8 years of formal musical training. The instruments used were guitar, violin, clarinet, trombone, trumpet, viola da gamba and viola. The participants were not recruited on the basis of their instrument. However, the piano was excluded for practical purposes (its shape did not allow us to adjust the screen). Written informed consent was obtained from all participants. Each participant received a 20 Euro gift voucher for participation.

3.2.2 Task

Participants were asked to play or sing a short piece of music that they knew by heart while looking at a computer screen. There were no restrictions placed on the musical piece that the participants could choose. The pieces were at least 2 minutes long and the participants stopped playing or singing after the piece ended. Participants were placed at approximately one meter from a 15-inch flat computer screen. They sat on a chair or stood, depending on what was the most comfortable playing position for them. The height of the screen was adjusted accordingly, so that it was always at a comfortable viewing height. They were instructed to look only at the screen. The experiment took place in a quiet room.

3.2.3 Conditions and Procedure

The experimental procedure was organized as follows; two minutes of rest, two minutes task performance, and again two minutes of rest. The rest periods before and after the performance were intended to measure heart rates in a resting state. These resting state measurements were necessary for the analysis of the heart rates during the performance. Furthermore, the rest periods allowed the participants' heart rates to return to normal between conditions. This three-block design (see figure 1) was used in both conditions.

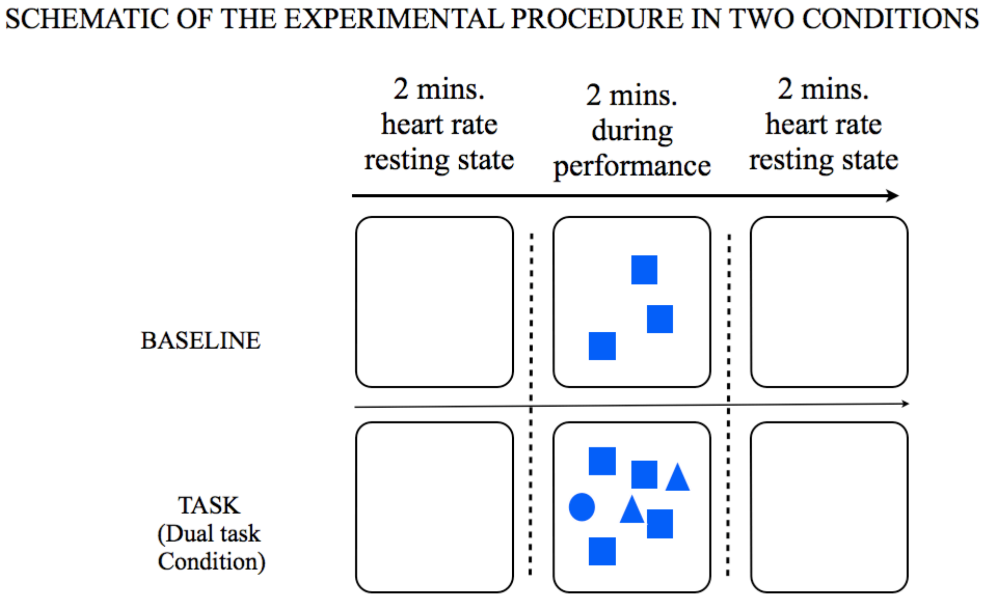


Figure 1 Schematic of the experimental procedure in two conditions.

During the two minutes before and after the task, the screen was white and participants were asked to keep their eyes on it. During the middle part of the procedure, the two minutes of task performance, shapes appeared on the screen. The shapes were presented for a duration of 800 milliseconds each, with 800 millisecond intervals in between. The words “start” and “stop” appeared on the screen at the start and the end of the middle part to instruct the participants when to start and stop playing. There were two different conditions. In the baseline condition, during the task performance, the screen showed a two-minute movie in which blue squares appeared on the screen in random locations, one square at a time. In this condition, participants were instructed to look at the screen while playing their piece. In the experimental condition, three different blue shapes randomly appeared one by one. The shapes in the experimental condition were squares, circles and triangles. In this condition, the participants were instructed to count the number of circles and the number of triangles, independently, while playing their piece. They were instructed to play the piece exactly the same way in both conditions. Participants performed each condition once, and one condition lasted a total of about six minutes. In between conditions they were given a short resting period of approximately two minutes. The conditions were not performed in counterbalanced order because the instruction for the secondary task condition was to play the piece in exactly the same way as in the baseline condition. This was only possible if they played in the baseline condition first. Furthermore, two minutes of music performance would not be tiresome in any way that would affect the second performance. In addition, the pieces were already fully known by heart and therefore, we could exclude the possibility of a learning effect.

After the experimental condition was completed, participants were asked how many circles and triangles they had counted. They were also asked to fill out a brief questionnaire regarding their personal information, musical background and experienced subjective feelings about the experiment.

3.2.4 Data Acquisition

During performances, heart rates and video footage (using a Canon Legria digital camera) were recorded. The heart rate monitor was an IcubeX BioBeat v1.2 sensor. The entire procedure was automated using a custom programmed computer patch in Max/MSP (Puckette, 1980), which ran on a Mac Book Pro. The patch displayed written instructions for the participants to start and stop playing on the computer screen, played the movies with the shapes, and automatically handled synchronized recording of the audio and the heart rate data. The heart rate sensor was attached to a Bluetooth transmitter that enabled wireless transmission of the data to the computer running the Max/MSP patch.

3.2.5 Evaluation Methodology

Data analysis consisted of two different methods. First, a jury of three professional musicians and music scholars compared the performances in the two conditions in terms of musical expressiveness (section 3.3.1). Second, the audio files and corresponding heart rate data from the two conditions were imported in Matlab and analyzed (section 3.3.2). Next, in the audio analysis, two components of musical expressiveness were analyzed: Energy of the sound (root mean square), and phrase durations (section 3.3.3). Finally, The Post-experimental questionnaire has been analyzed (section 3.3.4).

Jury Evaluation: Three expert music scholars listened to recordings of performances in pairs (randomized order of the performances of baseline and experimental condition of a musician) without knowing that one of the performances was performed with a secondary task. Jury members were asked to determine the differences between performances of each participant. If they were unsure (either because of the piece or performance), then they were given the option not to vote. They answered four questions listed below:

> In which of the following performances are there rhythmic hesitations (if there are any)?
>
> In which of the following performances are there wrong phrasings (if there are any)?
>
> In which of the following performances is there tempo instability (if there is any)?

Which of the following performances is less expressive than the other (if there is any difference)?

In order to avoid jury members from voting less expressively for a musician who has rhythmic hesitations, tempo differences and/or wrong phrasings compared to baseline condition, we separated these parameters from each other.

Heart Rate Variability: Heart rates were recorded for 15 of the 21 participants. Heart rate data was analyzed by calculating the heart rate variability for each participant and each condition. The heart rate variability was calculated based on the intervals between the peaks in the heart rate data. Peaks were detected using a peak detection algorithm with a threshold value of 0.7 after normalization of the data between 0 and 1.

Audio Analysis: Given the diverse nature of the pieces and the instruments that were used in this study, the audio analysis was constrained to general audio features, rather than detailed acoustical analysis. Two parameters were selected as indicators of musical expressiveness, namely, sound energy (corresponding to dynamics) and durations of the phrases (sound production in between pauses-corresponding to timing).

First, for the sound energy, audio files were imported in Matlab using the music information retrieval (MIR) toolbox (Lartillot & Toiviainen, 2007). For each participant/condition combination, the root mean square (RMS) values of the entire extracted segments were calculated as one single mean value each. These means were compared between conditions.

Secondly, the audio excerpts were segmented into musical phrases and the length of the pauses between phrases was calculated with Audacity (Crook et al., 1991). For each performance recording, musical phrases were segmented and then compared in two conditions. By using Audacity's onsets and silence detector, the precise starts and endings of musical segments were determined. Subsequently, the length of each musical phrase and the pause were calculated for each performance. The pause durations were normalized by taking the percentages of each pause length in proportion to its related musical phrase. Normalization allowed a comparison between the pause durations in the two conditions.

Post Experimental Questionnaire: Apart from gathering personal information of the participants (name, age, gender, years in experience, handedness, whether a participant was on any performance related medication), our post-experimental questionnaire particularly aimed at finding out subjective feelings over experienced difficulty, experienced stress, and satisfaction of the performance, in the dual task condition. During the pilot experiments, participants declared that while they were performing with a secondary task they felt restricted in terms of body movements. In addition to that, they also, noticed that by the dual task paradigm it is possible to foresee potential weak parts in their knowledge of the piece before the actual performance. A post-experimental questionnaire was conducted to find out these subjective evaluations of the participants.

3.3 Results

3.3.1 Jury Evaluation

The audio recordings of each performance in the two conditions (with and without a secondary task) were listened to independently by three music scholars (the jury). The jury was unaware that certain recordings were performed with a secondary task. The jury listened to the two recordings of each participant in a random order. For both performances, each jury member determined whether one of the two recordings was musically less expressive, and in which of the performances there were rhythmic hesitations, wrong phrasings, and tempo instability, if any.

The jury results were processed as follows: If all jury members voted that the performance in the experimental condition (with a secondary task) was musically less expressive, a plus (+) was marked in the corresponding box (table 1).

In case there was no consensus among jury member a minus (-) was marked for that parameter even if two members out of three marks were the same. For example, for participant number one, all jury members judged that the excerpt with the task was less expressive than the other excerpt. A plus (+) indicates that there is total consensus on those parameters. If the jury members believe that both performances contain rhythmic hesitations, wrong phrasing and tempo stability a minus (-) was marked. As a result, after jury evaluations, 17 out of 21 of the performances with a secondary task were found to be less expressive compared to the baseline condition performances. However, for three participants' counting task scores (2nd, 7th and 12th on the list in table 1) the numbers of counted circles and triangles were far from the actual numbers. This was taken as an indication that these participants did not perform the counting task correctly, and their data was therefore excluded from further analysis. Ultimately, 16 counting task performances out of 18 (89%) were found musically less expressive compared to their baseline performances.

Table 1 Jury evaluations. A plus (+) means that the indicated item (e.g. wrong phrasing) occurred in the performance of the dual task condition. A minus (-) means that the jury found no difference between the two performances. Actually there were 13 triangles and 21 circles.

Subject	∇ =13 o=21	Rhythmic hesitations	Wrong phrasing	Comparably flat (less expressive) interpretation	Tempo differences
1	16 – 20	+	+	+	+
2	7 – 10	-	-	-	-
3	13 – 20	+	+	+	-
4	19 – 24	+	+	+	+
5	18 – 15	+	+	+	-
6	12 – 22	+	+	+	+
7	6 – 8	-	-	-	-
8	15 – 25	+	+	+	+
9	20 – 25	+	+	+	+
10	16 – 21	-	-	+	+
11	15 – 18	+	+	+	+
12	31 – 44	-	+	+	+
13	14 – 22	+	+	+	+
14	12 – 20	-	-	-	-
15	16 – 24	+	+	+	+
16	15 – 24	+	+	+	+
17	14 – 23	+	-	+	+
18	16 – 25	-	-	+	+
19	11 – 22	+	+	-	+
20	10 – 26	-	-	+	+
21	13 - 25	-	-	+	+

3.3.2 Heart Rate Variability

From the questionnaire data, it was found that one participant used medication that affected heart rate. This participant was excluded from heart rata data analysis. For the remaining 14 participants, the heart rate variability was compared between the two conditions. The heart rate variability analysis did not show a significant difference between the two conditions as determined by ANOVA *F(1, 27)=0.1, p = 0.88.*

3.3.3 Audio Analysis

An overall RMS value for sound energy was calculated for each performance. It was found that there was a great variability between the participants and that the resulting comparison between the baseline and experimental condition did not show any significant difference as determined by an ANOVA F(1,38)= 0.02, *p = 0.76.* between the conditions in terms of sound energy (RMS).

Pause durations in experimental conditions, however, were significantly shorter than those in the baseline condition. This was tested with a Friedman's two-way ANOVA analysis (*p <.002*). The lengths of the phrase durations were not significantly different (p >.090).

Note that, one musician (the electric guitar player) was excluded from inter onset interval analyses due to the fact that the audio data did not allow us to determine the pause durations because there were no silences. After excluding this participant, 16/17 musicians had shorter pause durations in the dual task condition. Only one participant did not have shorter pause durations among those who were judged as less expressive. In contract, it turned out that phrases durations did not show any significant difference (figure 2). In other words, there were only significant differences for pause durations. Figure 2 illustrates differences between the baseline and the dual task condition for one musician.

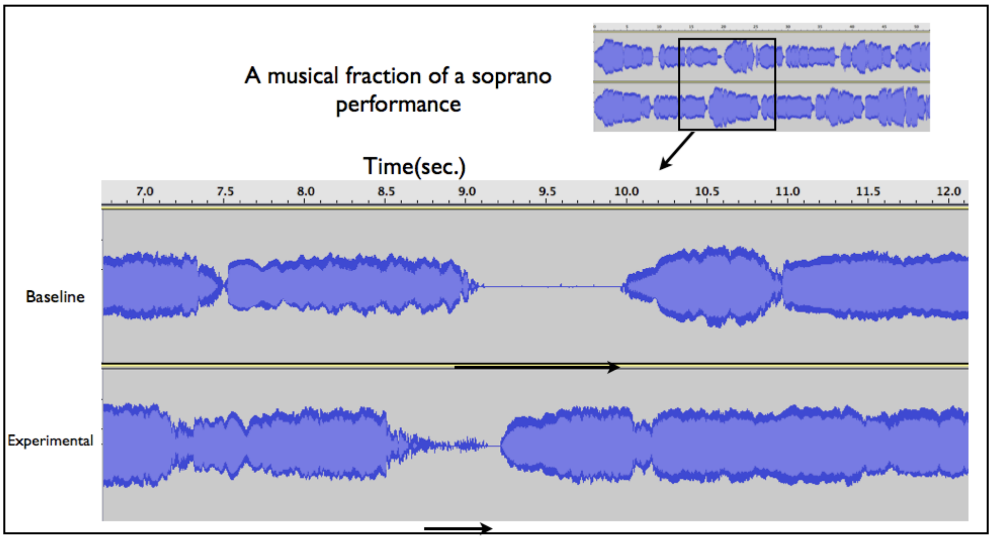


Figure 2 Pause durations between base line condition and dual task condition for one musician. The top layer is an audio waveform excerpt of a performance without a counting task whereas the lower is an audio waveform excerpt of a performance with a counting task of the same phrase. The arrows indicate the durations of the pauses.

3.3.4 Post Experimental Questionnaire

Participants' answers to post-experimental questionnaire revealed that 87% of them felt that in the dual task condition, playing was more difficult than in the baseline condition, 80% of them felt that the dual task condition was more stressful than the baseline condition, 74% felt increased restriction of their body movements during the dual task condition than during the baseline condition, and 67% felt less satisfaction with their musical performance in the dual task condition than in the baseline condition. Finally, 60% of the participants believed that using dual task paradigm would be useful to foresee potential mistakes before concerts.

3.4 Discussion

The increase in cognitive load, elicited by the counting task, leads to a decrease in musical expressiveness, as judged by expert evaluation. In addition, answers to the questionnaire show that musicians have difficulties to think about the music they are playing during the counting task.

In this study, well-practiced pieces of music were used, and they were all different. This forced us to focus on a type of acoustical parameter that is present in all the pieces.

The identification of the(se) acoustical feature(s) was based on manual analysis. The musical excerpts were analyzed phrase by phrase, in order to find out those unique features that are significantly different between the two conditions. Several features such as root mean square (energy) and time durations of phrases have been analyzed but they were not invariant over the pieces. However, the durations of the pauses were found to be affected in all pieces. Although the participants' total playing or singing durations did not show significant difference between conditions, the pause durations were significantly shorter in the dual task condition. It could be argued that mistakes (such as additional or missing notes) have affected the durations of the musical phrases. However, these mistakes were of such short duration that they had no significant effect on the durations of the performances.

Despite the fact that 80% of the participants reported that playing with a secondary task was stressful, heart rate variability analyses (HRV) did not show significant differences between the two conditions. This result suggests that musical differences did not happen due to stress. However, although HRV is one of the most important stress indicators (Taelman et al. 2003), it is not the only one. Additional physiological and psychological tests could be used to evaluate the stress factor in a dual task paradigm.

4

The impact of cognitive load on operatic singers' timing performance

4.1 Introduction

In line with the body of research mentioned in the first part (chapter 1), there are reasons to believe that people can rely on self-generated sensory feedback and sensorimotor control to regulate their temporal coordination of muscle activity. In the current study, we tested this hypothesis in the context of expressive music performances, more in particular singing performances by professional musicians. A singing performance is a naturalistic task that requires auditory-motor coordination and expressive timing control, often under conditions of heightened cognitive load. We recruited operatic singers, as they often encounter situations in which they have to perform under heightened cognitive load; they have to act and know where to move around on the stage, to know when to sing something, to interact with others and so on. Also, singers have the added charge of language, which involves correct pronunciation, natural inflection, clear diction, and genuine comprehension in as many as four different languages beside one's own (Helding, 2012). According to Kleber et al. (2010), operatic singers develop specialized neural networks for enhanced somatosensory processing and performance monitoring, as well as motor sequence attention when compared to laymen and even other singers. The findings suggest that changes in the primary sensorimotor cortex (S1), inferior parietal lobule (IPL), and dorsolateral prefrontal cortex (DLPFC) allow for more accurate fine-tuning and feed-forward motor commands. From a methodological point of view, it is known that pauses of singers are slightly easier to identify than pauses of other instrumentalists. The reason is that respiratory behavior in vocal performance is rule based. Therefore, singers should only breathe at predefined areas between phrases, rests, and punctuation.

For the purpose of the study, we applied a dual-task interference paradigm (Pashler, 1994). This paradigm assumes that when two tasks rely on similar processing resources at the same point in time, interference will occur due to the inherent limitations of the processing resources. This approach allows pinpointing the role of cognitive and sensorimotor resources in the expressive timing of a singer. The primary task consists of singing an operatic aria, and the secondary task is a working memory task, in which participants count the number of shapes appearing on a computer screen.

The main aim of the study was to investigate to what extent the counting task affected expressive timing of the singers' performance. Thereby, we focused on the performers' tendency to speed up, or slow down. The operatic arias that the participants of our study sang contained both musical phrases and pauses. We expected that, in general, musical timing would be affected by the counting task. More in particular, we expected a tendency of singers to speed up their performance. However, based on the above-mentioned theories, we hypothesized that phrases and pauses would be affected differently.

By phrase we mean; musical sentences that involve a series of notes, and by pauses we mean the silent regions that usually occur between musical phrases or sometimes within the phrases (see figure 3).

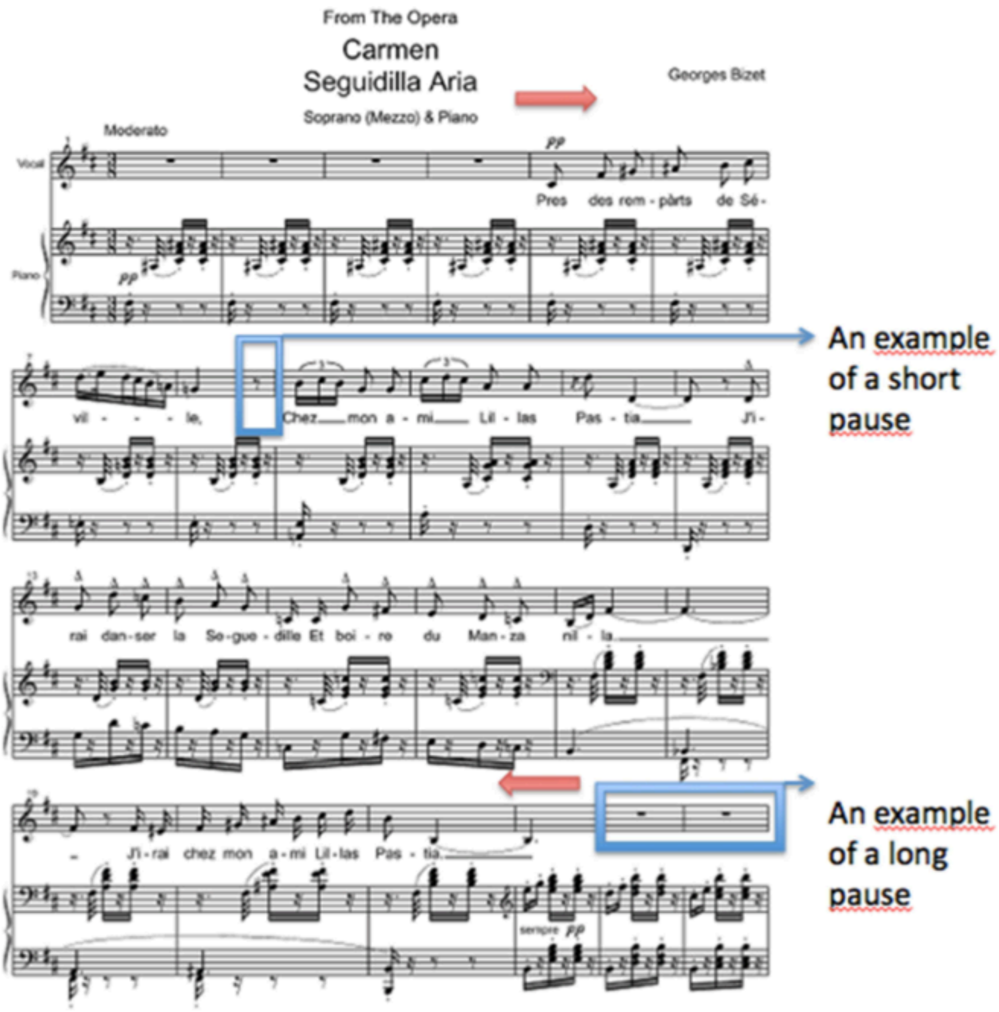



Figure 3 The entrance passage of “ Carmen”, an opera by Georg Bizet. An example of a short pause and a long pause is given. A musical phrase is in between the red arrows.

As can be observed, there are pauses in between phrases that define the musical structure. These pauses are long enough to breath and to count for the next phrase (usually a whole rest or double whole rest). In addition, there are shorter pauses where musicians can breathe within the phrases (usually an eight rest or sixteenth rest).

During pauses—in particular longer pauses that are not used solely for breathing—we expected singers to rely on cognitive timekeeper resources, as there is no sensory and sensorimotor feedback to rely on. In contrast during phrases, sensory feedback and sensorimotor control may function as a “scaffold” in support of temporal control of the singing voice. Also, respiration in shorter pauses could possibly function as somatosensory scaffold in support of musical timing. In short, we expected that increases in cognitive load would affect longer pauses more, compared to phrases and shorter pauses used solely for breathing.

4.2 Methods

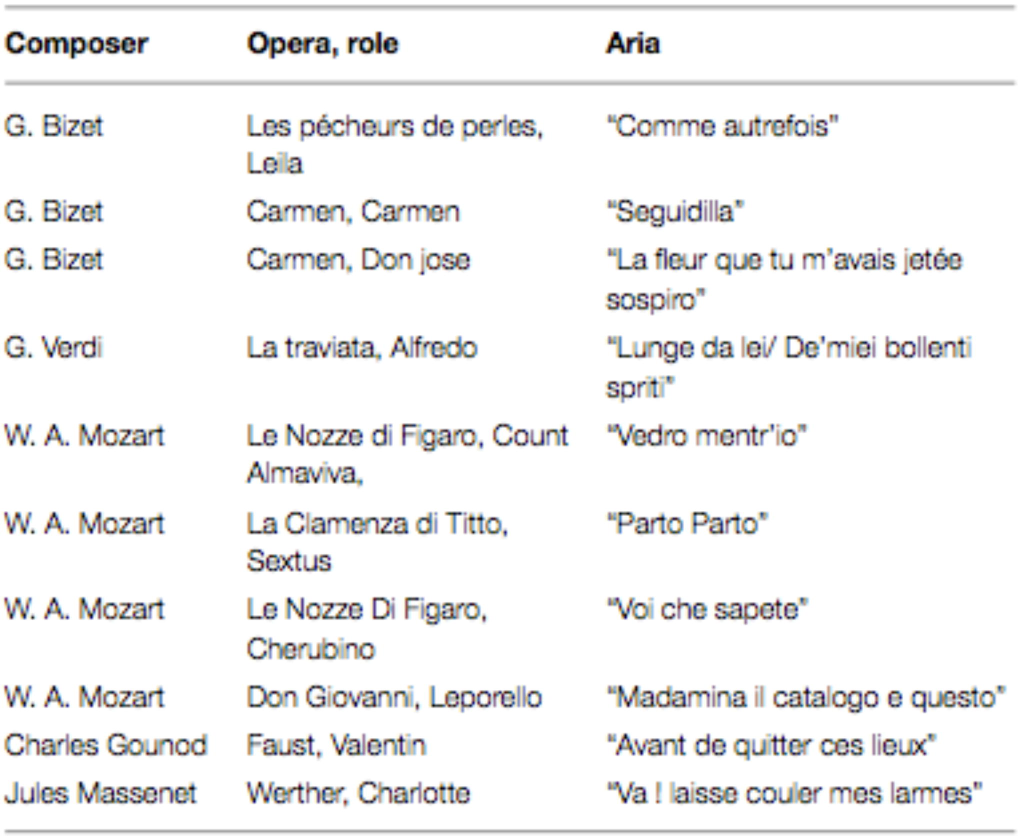
4.2.1 Participants

Twelve operatic singers (six female, mean age = 29.2 years; range = 29–33 years) participated in the experiment. All participants were right-handed. They had at least 8 years of formal musical training, and at least 8 years of stage experience. All were Turkish native speakers (also Turkish maternal speech). Written informed consent was obtained from all participants prior to participation, and the Ethical Review Committee of Ghent University approved the experiment.

4.2.2 Stimuli

Operatic Arias: For the primary musical task, the operatic singers were asked to sing an operatic aria from their repertoire (see table 2). The arias were at least 100 seconds in duration. Males sang arias for males and females sang arias for female. The arias were selected based on the repertoire with which they were acquainted and felt comfortable singing. Two sopranos chose the aria “Voi che sapete” from Le Nozze di Figaro by Mozart (table 2).

Table 2 Operatic arias chosen by the singers.



Composer	Opera, role	Aria
G. Bizet	Les pécheurs de perles, Leila	“Comme autrefois”
G. Bizet	Carmen, Carmen	“Seguidilla”
G. Bizet	Carmen, Don jose	“La fleur que tu m'avais jetée sospiro”
G. Verdi	La traviata, Alfredo	“Lunge da lei/ De'miei bollenti spriti”
W. A. Mozart	Le Nozze di Figaro, Count Almaviva,	“Vedro mentr'io”
W. A. Mozart	La Clamenza di Titto, Sextus	“Parto Parto”
W. A. Mozart	Le Nozze Di Figaro, Cherubino	“Voi che sapete”
W. A. Mozart	Don Giovanni, Leporello	“Madamina il catalogo e questo”
Charles Gounod	Faust, Valentin	“Avant de quitter ces lieux”
Jules Massenet	Werther, Charlotte	“Va ! laisse couler mes larmes”

Classical singers are governed strictly by a fach system to assist in the categorization of instruments (light or dramatic, range, etc.) This is important due to the physical parameters and capabilities of the voice. As it was necessary to avoid confounds resulting from imposed repertoire, singers were allowed to sing the material that was typical for their voice. Later on, studies can compare singers using the same repertoire, but we opted in this study to be as ecological as possible. The individual compositional features of the music will always have an impact in these cases, but an overall statistical trend may still be initially identified.

Working Memory Task: For the secondary working memory task, different shapes (squares, circles, and triangles) were presented for a duration of 800 milliseconds each, until a next shape appeared. In condition one (no additional load condition) a 100 s movie was displayed in which blue squares appeared on the screen at random locations, one square at a time. In condition two (working memory task condition with low load), again a 100 s movie was displayed where squares, circles and triangles randomly appeared. The exact number of triangles was seven and the exact number of squares was eight. Condition three (working memory task condition with high load) was the same as condition two, only the number of shapes differed: 12 triangles and 16 squares had to be counted.

In no load condition participants were asked to look at the visual objects, but not to count anything. In all conditions, singers were observed as they were looking at the computer screen.

4.2.3 Materials and Apparatus

Participants were placed at approximately 1 m from a 15-inch computer screen. The experiment took place in a professional sound recording studio. The entire procedure was automated using a computer patch programmed in Max/MSP (http://cycling74.com/products/max/), which ran on a MacBook Pro. The patch displayed written instructions for the participants to start and stop playing, it played the movies of the working memory task, and it automatically handled synchronized recordings of the audio. During performances, video footage (using a Canon Legria digital camera) was recorded.

4.2.4 Design and Procedure

Upon arrival, participants were given a short explanation about the experiment, they read the information sheet that explained the whole procedure, and they signed the consent form. The experimental procedure was organized in three different conditions (no/low/high cognitive load) that were counterbalanced across participants. Participants performed each condition once. Between conditions, participants were given a short resting period of approximately 1 minute.

No metronome was used. Singers were instructed to sing their pieces exactly the same way three times. Counterbalanced experimental order was used to eliminate the possibility that tempo changes, due to the experimental manipulations, had not occurred randomly.

At the beginning of each condition, the word “start” appeared on the screen indicating to the participants to start singing, while the 100 seconds movie (see 4.2.2) started concurrently. Participants were instructed to sing their aria in exactly the same way in each condition. In the no load condition, participants were asked to sing while only looking at squares appearing on the computer screen. In the other conditions (low/high load), participants were asked to sing while concurrently counting the number of circles and the number of triangles appearing on the screen. So, participants had to store and manipulate two separate numbers in memory. After 100 seconds, the word “stop” appeared on the screen indicating to the participant to stop singing. The total singing duration was measured as follows: the starting point was always when a singer starts to sing (visually determined based on the waveform). Some singers took some time before starting their performance, which accounted for the fact that the total duration of their performance was less than 100 seconds. Afterwards, participants were asked to report the number of circles and the number of triangles they counted. In between conditions there were 2 minutes of resting period. In all conditions, singers were observed as they were looking at the computer screen. In order not to interfere, the observer sat a bit behind the singers.

The participants filled out a brief questionnaire regarding their personal and musical background after they performed in all three conditions.

4.2.5 Audio Analysis

Raw audio data (recorded performances) were imported into Audacity (http://audacity.sourceforge.net/). For each singer, the three audio tracks (one for each condition, figure 4) were displayed and extraneous noise was removed below −40dB (figure 5), using the noise removal function of Audacity.

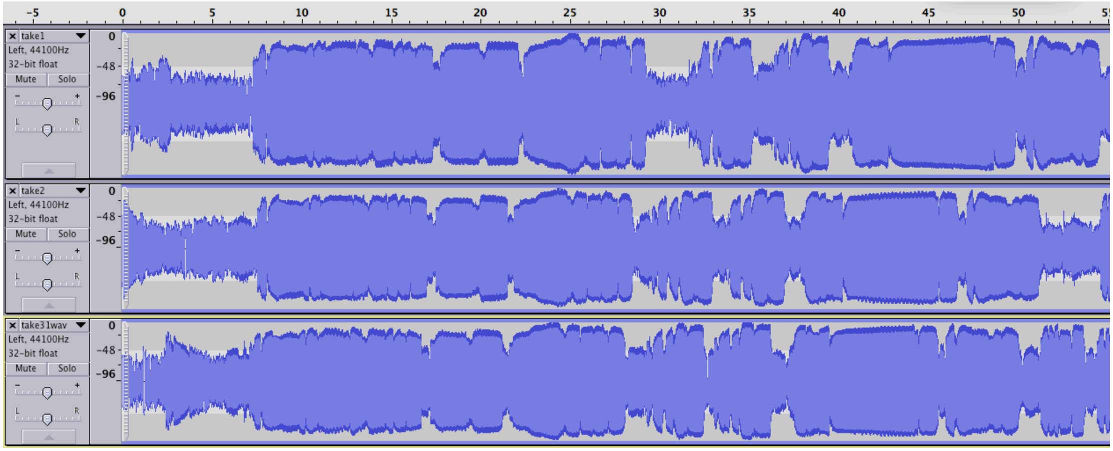


Figure 4 Raw audio data sample of one singers, for Condition 1 (top), Condition 2 (middle), Condition 3 (bottom).

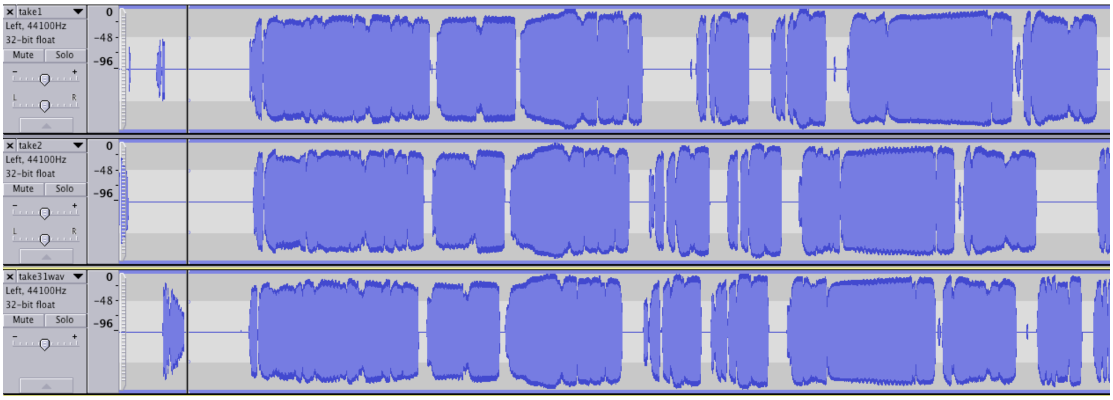


Figure 5 Audio track samples after the noise below -40 dB was removed from the three signals of figure 2.

The silent regions detector of Audacity was applied to segment the recorded performances into musical phrases and pauses, as a basis for further manual analysis (figure 6). In addition, changes in expressiveness were taken into account.

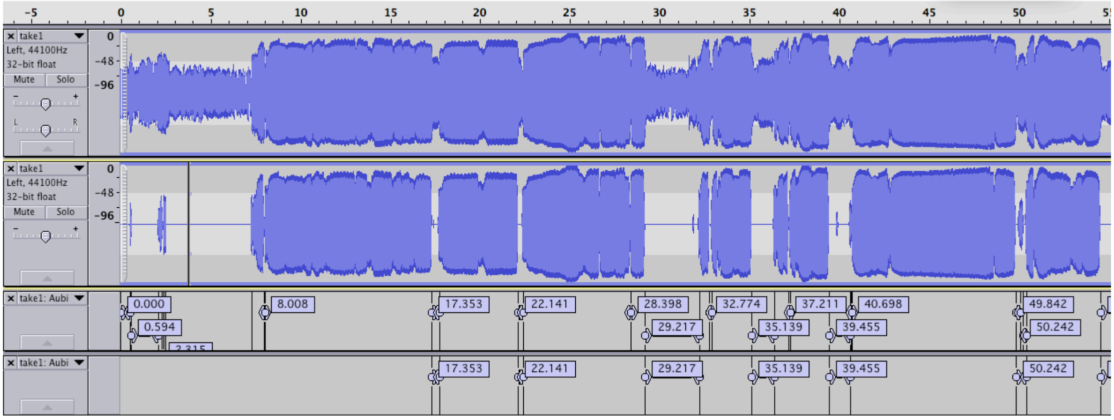


Figure 6 An example of raw audio (the first layer corresponds with first layer of figure 3) and after noise removal (the second layer corresponds with the first layer of figure 4), with the silent regions extracted (the third layer is based on the data of the second layer). Finally, the fourth layer shows the silent regions that are taken into account after a manual inspection of the analysis.

For example, if a musician sang legato in one performance but non-legato in the other performance, pauses between non-legato notes were not considered silences. Based on the obtained audio performances, we calculated two dependent variables.

First, we were interested in changes in the overall duration of the performance in each condition (no/low/high load). In the no load baseline condition, singers stopped after 100 seconds. After inspection, it was found that the baseline condition (no load) for each participant was always performed at the slowest tempo compared to the low and high load conditions. Then we identified the positions in the audio recordings of the counting conditions (low/high load) that corresponded with the position in the audio recording of the baseline condition. Accordingly, we obtained three values for each participant that represented the total duration of their performances in each condition.

Second, we wanted to investigate whether the durations of musical phrases and the durations of pauses were differently affected by the counting task. To find that out, we calculated the total accumulated durations of both the musical phrases and pauses in the baseline condition. For each participant, these two values were taken as a reference to compare the durations of musical phrases and pauses in the counting conditions (low/high load). Accordingly, we calculated for each counting condition the difference in duration in reference to the baseline, expressed as a percentage. Additionally, to further investigate whether effects of cognitive load were influenced by pause duration, we divided pauses into two categories (long/short) using a split-median analysis for each participant.

4.2.6 Results

All effects are reported as significant at an alpha level of 0.05. *Post-hoc* tests for interactions were conducted with alpha levels corrected for multiple comparisons using Bonferroni's method. For the repeated-measure ANOVA tests, we tested for the assumption of sphericity using Mauchly's test. When the assumption of sphericity was violated, we corrected degrees of freedom using the Greenhouse-Geisser procedure.

Total Duration (s): We performed repeated-measures ANOVA with Condition as within-subjects factor (no/low/high load). The results showed (see figure 7) a significant main effect, $F_{(1,\ 11)} = 10.08$, $p < 0.01$, $\eta^2_p = 0.48$. *Post-hoc* comparisons yielded a significant difference between the no load condition ($M = 93.67$, SEM = 0.90) and low load condition ($M = 89.64$, SED = 0.99), $t_{(11)} = 5.11$, $p < 0.001$. Also, we found a significant difference between the no load condition ($M = 93.67$, SEM = 0.90) and the high load condition ($M = 88.88$, SEM = 1.28), $t_{(11)} = 3.25$, $p < 0.05$. No significant difference was found between the low load condition and the high load condition.

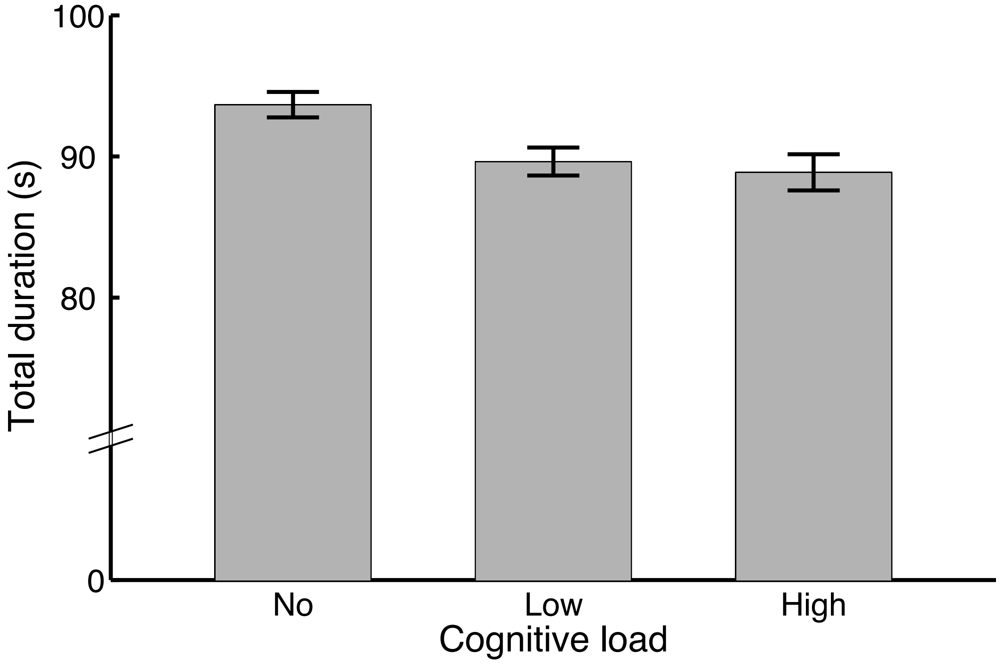


Figure 7 Total singing durations of each condition. Bars indicate the total durations of the performances in each condition in seconds. In other words how performances speed up with conditions.

Working Memory Task: In low load condition singers had to count seven triangles and eight circles. In the low load condition, performance typically fell in the range of ±2 from the veridical amount, 12 triangles and 16 circles had to be counted. Singers counted roughly (±5).

Duration (s) of Musical Phrases and Pauses: Distributions of pause durations for each participant are shown in figure 8. Average duration difference (in %) of the phrases in the no/low/high load conditions, and of the pauses in the no/low/high load conditions are shown in figure 9.

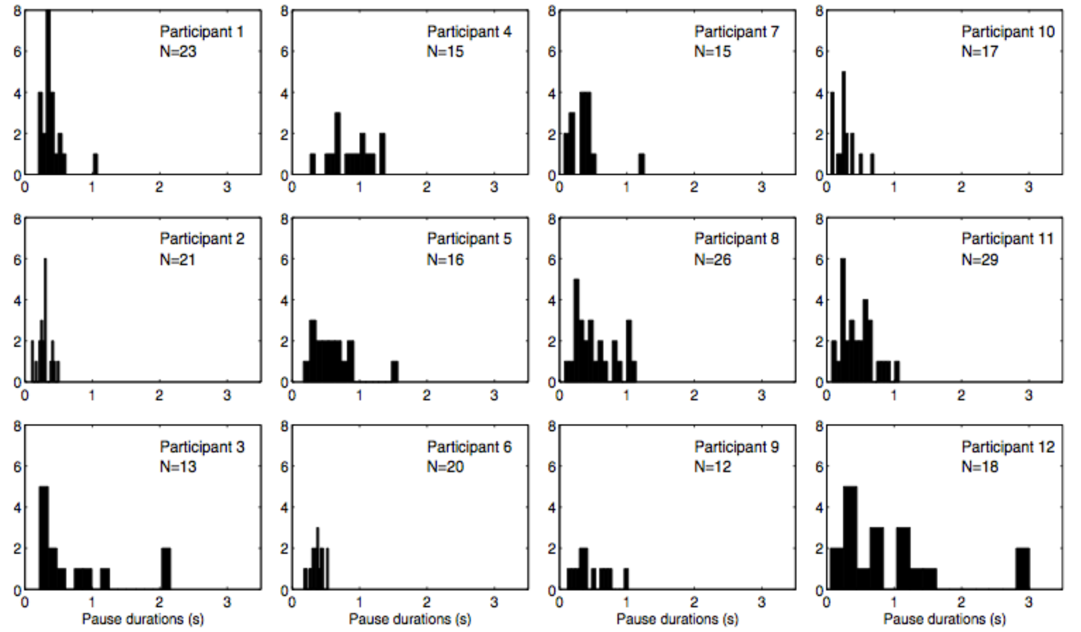


FIGURE 6 | Histogram shows pauses in no load condition per participant.

Figure 8 Histogram shows pauses in no load condition per participant.

We performed Two-Way repeated-measures ANOVA with Performance type (Phrase/Pause) and Condition (no/low/high load) as within-subjects factors. The analysis yielded a significant main effect for the factor Performance type, $F_{(1,\ 11)} = 48.61$, $p < 0.001$, $\eta^2_p = 0.81$, with Phrases ($M = -2.10$, SEM = 0.78) having a significantly different difference in percentage (the dependent variable) compared to Pauses ($M = -10.73$, SEM = 1.37). Also, we found a significant main effect of Condition, $F_{(2,\ 22)} = 25.66$, $p < 0.001$, $\eta^2_p = 0.70$. *Post-hoc* comparisons revealed significant differences between the no load condition and the low load condition ($M = -9.90$, SEM = 1.38), $t_{(11)} = 7.09$, $p < 0.001$, and between the no load condition and the high load condition ($M = -9.34$, SEM = 1.75), $t_{(11)} = 5.36$, $p = 0.001$. Additionally, a significant interaction effect was found between Performance type and Condition, $F_{(2,\ 22)} = 11.86$, $p < 0.001$, $\eta^2_p = 0.52$. *Post-hoc* comparisons indicated that the interaction was driven by the significant decrease of the duration of pauses in the low load condition ($M = -17.15$, SEM = 2.65), $t_{(11)} = 6.47$, $p < 0.001$, and high load condition ($M = -15.05$, SEM = 2.59), $t_{(11)} = 5.82$, $p < 0.001$.

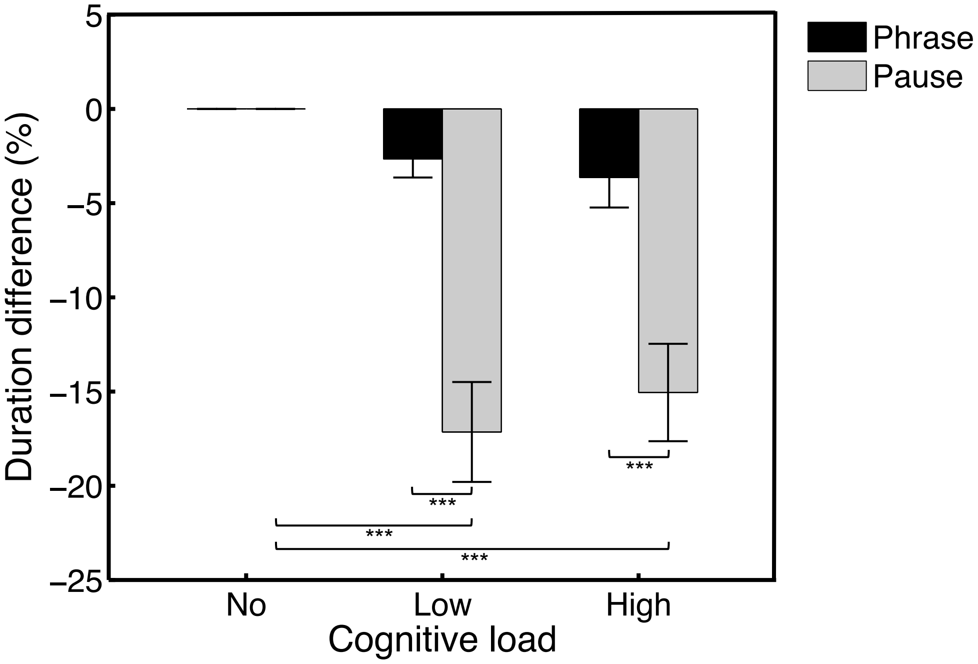


Figure 9 Average duration difference (in %) of the phrases in the no/low/high load conditions, and of the pauses in the no/low/high load conditions. A significant interaction effect was found driven by a significant decrease of the duration of pauses in the low and high load conditions.
$***p \leq 0.001$.

Effects of Pause Duration (s): In order to assess whether effects of heightened cognitive load on the shortening of pause durations were further influenced by the initial duration of the pauses, we conducted an additional analysis. In that analysis, we divided the pauses of each participant into two categories—i.e., long and short pauses— based on a split-median analysis. Categories were made per participant, based on the pauses that occurred in the single Task condition. The medians per participants were respectively 418, 707, 260, 399, 460, 382, 368, 547, 882, 418, 292, 348 milliseconds, (*M* = 456.75milliseconds, SEM = 51.43). Average duration difference (in %) of the phrases/short pauses/long pauses in the no/low/high load conditions are shown in figure 10.

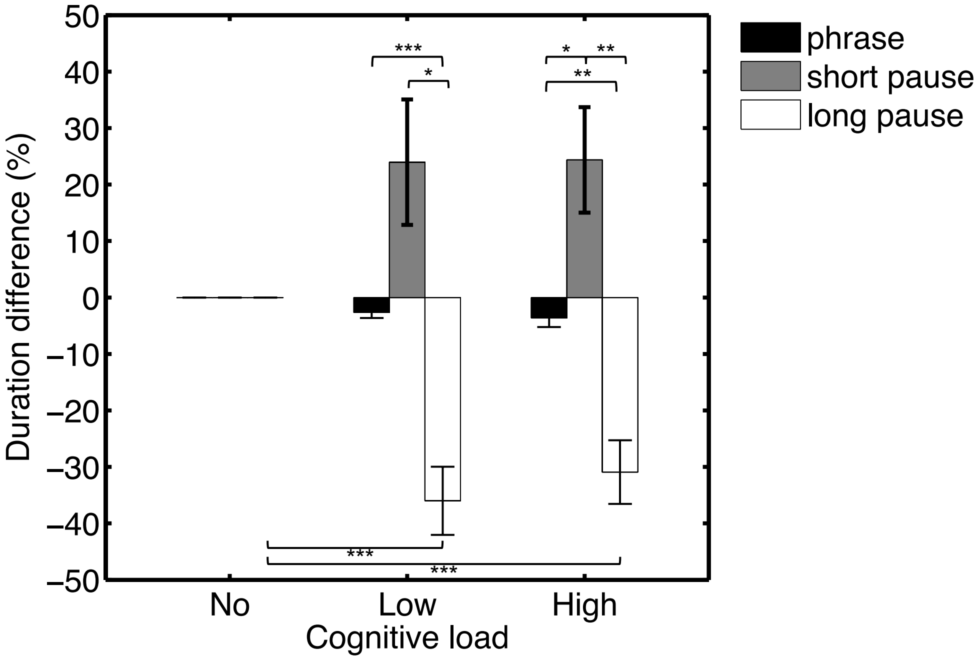
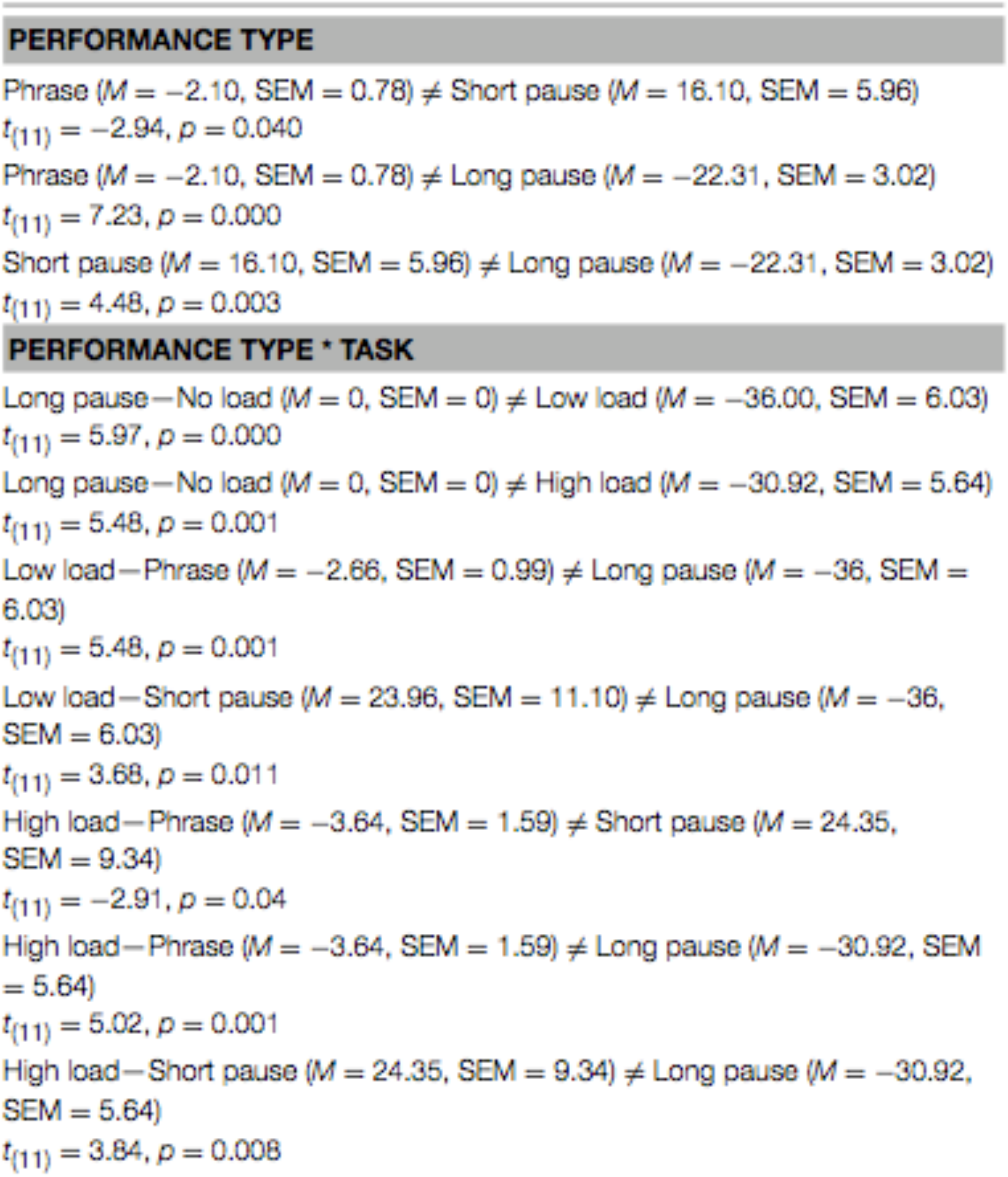


Figure 10 Average duration difference (in %) of the phrases/short pauses/long pauses in the no/low/high load conditions. Results show that long pauses are significantly more affected by an additional cognitive load compared to phrases and short pauses. *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.

A Two- Way repeated-measures ANOVA was conducted with Performance type (Phrase/Short pause/Long pause) and Condition (no/low/high) as within-subjects factors. We found a significant main effect of Performance type, $F_{(1.05,\ 11.55)} = 18.53$, $p = 0.001$, $\eta^2_p = 0.63$. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity, $\varepsilon = 0.53$, as Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(2) = 23.49$, $p < 0.001$. Additionally, we found a significant interaction effect between Performance type and Condition, $F_{(2.05,\ 22.57)} = 18.53$, $p = 0.002$, $\eta^2_p = 0.43$. Again, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity, $\varepsilon = 0.51$, as Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(9) = 44.52$, $p < 0.001$. Results of the *post-hoc* tests can be found in table 3.

Table 3 Results of the *post-hoc* comparisons of the repeated-measures ANOVA (Performance type, Phrase/Short pause/Long pause; Condition, no/low/high), adjusted for multiple comparisons using Bonferroni's method (SPSS).



PERFORMANCE TYPE

Phrase ($M = -2.10$, SEM = 0.78) ≠ Short pause ($M = 16.10$, SEM = 5.96)
$t_{(11)} = -2.94, p = 0.040$

Phrase ($M = -2.10$, SEM = 0.78) ≠ Long pause ($M = -22.31$, SEM = 3.02)
$t_{(11)} = 7.23, p = 0.000$

Short pause ($M = 16.10$, SEM = 5.96) ≠ Long pause ($M = -22.31$, SEM = 3.02)
$t_{(11)} = 4.48, p = 0.003$

PERFORMANCE TYPE * TASK

Long pause—No load ($M = 0$, SEM = 0) ≠ Low load ($M = -36.00$, SEM = 6.03)
$t_{(11)} = 5.97, p = 0.000$

Long pause—No load ($M = 0$, SEM = 0) ≠ High load ($M = -30.92$, SEM = 5.64)
$t_{(11)} = 5.48, p = 0.001$

Low load—Phrase ($M = -2.66$, SEM = 0.99) ≠ Long pause ($M = -36$, SEM = 6.03)
$t_{(11)} = 5.48, p = 0.001$

Low load—Short pause ($M = 23.96$, SEM = 11.10) ≠ Long pause ($M = -36$, SEM = 6.03)
$t_{(11)} = 3.68, p = 0.011$

High load—Phrase ($M = -3.64$, SEM = 1.59) ≠ Short pause ($M = 24.35$, SEM = 9.34)
$t_{(11)} = -2.91, p = 0.04$

High load—Phrase ($M = -3.64$, SEM = 1.59) ≠ Long pause ($M = -30.92$, SEM = 5.64)
$t_{(11)} = 5.02, p = 0.001$

High load—Short pause ($M = 24.35$, SEM = 9.34) ≠ Long pause ($M = -30.92$, SEM = 5.64)
$t_{(11)} = 3.84, p = 0.008$

The interaction effect between Performance type and Condition was mainly driven by a significant decrease of the duration (in %) of long pauses in the low ($M = -36.00$, SEM = 6.03) and high load conditions ($M = -30.92$, SEM = 5.64), compared to the duration (in %) of phrases and short pauses. In contrast, in the high load condition, there was an increase (in %) in the duration of short pauses ($M = 24.35$, SEM = 9.34), relative to the duration of phrases ($M = -3.64$, SEM = 1.59).

As a final step, we wanted to investigate how individual performances related to the general pattern displayed in figure 8. As observed in figure 9, that plots individual duration differences across Conditions (no/low/high) per participant, the increase in tempo (i.e., negative percentages) of the longer pauses (plus labels) in the low/high load conditions is generally consistent across the different participants. A further visual inspection indicates that short pauses (diamond labels) in general are becoming longer (positive percentages) in the low/high load conditions. In summary, these observations indicate consistency across participants, reflecting the general pattern displayed in figure 11.

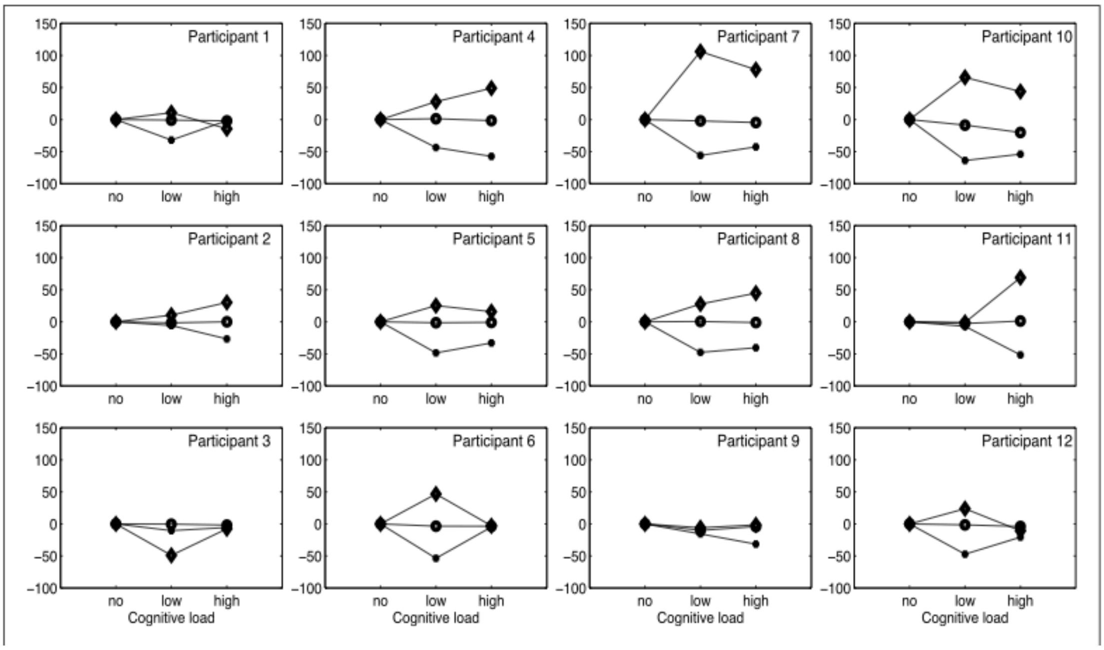


Figure 11 Graphs show percentage changes of phrase and pauses in three conditions for each participant. Note that, circles are phrases, diamonds are short pauses, and plusses are long pauses.

4.2.7 Discussion

Opera singers are believed to perform well under heightened cognitive load situations. The main question was to what extent an increased cognitive load (by dual task of counting) affected expressiveness of the sung operatic arias. The singers' tendency to speed up, or slow down was analyzed. The results showed that singers have a general tendency to speed up their performance under counting conditions. Speeding up was more obvious in pauses compared to phrases. This finding is discussed in detail in chapter 6.

5

A Gender-specific analysis in multitasking behaviour and time perception during performance of professional musicians with additional cognitive load

5.1 Introduction

The cognitive functions in terms of gender differences have been widely discussed over the last decades. This attracted media attention upon whether gender is a crucial issue on intelligence and cognitive functions. It has been argued that for some cognitive functions females are superior over men and for other functions males are advantageous. As the experiments suggested in chapter 3 and 4, musicians tend to speed up due to the additional cognitive load especially during the pauses (in between phrases). The aim of this study is to investigate whether this effect is gender-related. If one of the genders is better in multitasking, that gender should be better in handling cognitive load, and this should be reflected in the timing of their performance. Related literature is reviewed in chapter 1.

5.2 Methods and Set-up

To compare male and female musicians, 29 musicians (16 male, 13 female) were instructed to play or sing the same piece of music twice in counterbalanced order. Musician's timing was measured by means of audio analysis looking into pause durations. Based on the results of audio content analysis that showed no significant difference between men and women in performing music with extra workload, we felt the urge to investigate this further. Therefore the experiment was subsequently complemented with a survey. In order to provide an additional understanding of the phenomenon, the survey instrument was a self-administered questionnaire that aimed at involving a larger group of professional musicians (N=194), so that the topic could be framed in a broader context of how multitasking behavior is perceived, In the next sections we first discuss the method used for audio analysis of the music performances and second we explain the design of the questionnaire, validation, data collection and the target population sample.

5.2.1 Experimental Procedure

For the audio analysis, performances of the musicians were recorded. The two-block experimental (figure 12) procedure was as follows: 1. Hundred-seconds performing music without any additional task (condition one), 2. Hundred-seconds performing the same piece of music while counting shapes that appeared on the computer screen (condition two). Between conditions, there was one minute of resting time.

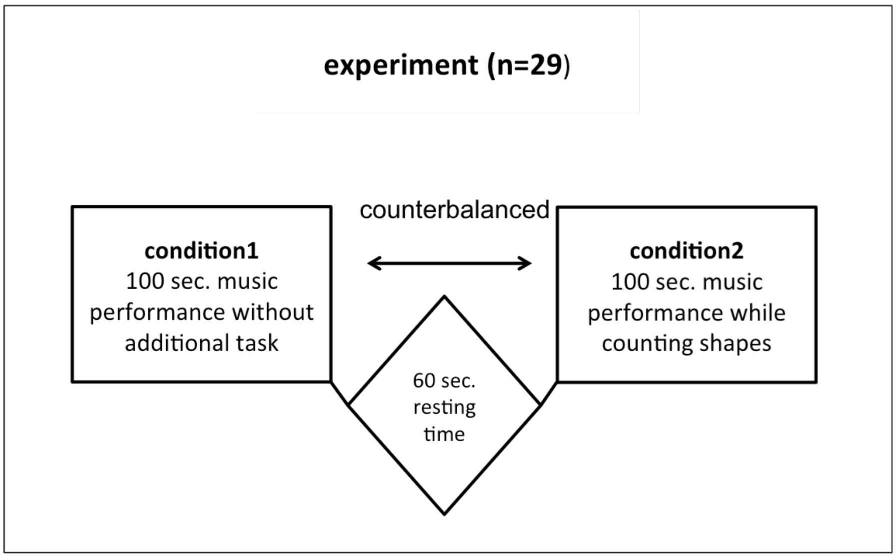


Figure 12 Experimental set-up.

The shapes were displayed for 800 milliseconds each, with 800 millisecond intervals. In our pilot study, longer or shorter than 800 milliseconds of duration between shapes was rather confusing for the musicians. Therefore, we decided to keep the intervals as 800 milliseconds. The words “start” and “stop” appeared on the screen at the start and the end of the hundred-second performance time to instruct the participants when to start and stop playing or singing. In condition one, during the performance of the task, the screen showed a hundred-second movie in which blue squares appeared on the screen in random locations, one square at a time. In this condition, participants were instructed to look at the screen while performing their piece. In condition two, three different blue shapes (i.e. squares, circles and triangles) randomly appeared one by one. Participants were asked to count the number of circles and the number of triangles, independently, while performing their piece. At the end of the experiment they were asked how many triangles and circles they had counted. Participants performed each condition once. Between conditions, participants were given a short resting period of approximately one minute. The conditions were performed in counterbalanced order.

After the experimental condition was completed, participants were asked to recall how many circles and triangles they had counted. They were also asked to fill out a brief questionnaire regarding their musical background to obtain their years of experience. The ethical committee of the Ghent University provided an approved research protocol.

5.2.2 Data Acquisition

The entire procedure was automated using a programmed computer patch in Max/MSP (Puckette, 1980), which ran on a Mac Book Pro. The patch displayed written instructions on the computer screen for the participants to start and stop playing, played the movies with the shapes, and automatically handled synchronized recording of the audio. During performances, video footage (using a Canon Legria digital camera) was recorded to control and specify unclear points.

5.2.3 Analysis of Phrase and Pause Durations

Raw audio data (recorded performances) were imported to Audacity (Crook et al., 1991). For each singer, the three audio tracks (one for each condition) were displayed and extraneous noise was removed below -40dB, using the noise removal function of Audacity. Then, a silent regions detector was used and applied to the signal at -80dB. Labeled tracks were exported as text files, as a basis for further analysis.

5.2.4 Participants Audio Recordings

There were 29 musicians, 16 male and 13 female, (Mean 25,5; St. Dev. 6,03), who participated in the music performance experiment. The participants had between 8 and 24 years (Mean 12,60; St. Dev. 4,59) of musical experience.

5.2.5 Questionnaire

A self-report questionnaire was designed that investigates (1) to what extend self- reported cognitive skills during music practice are gender dependent and (2) whether there are gender differences in the multitasking behavior of skilled musicians.

5.2.5.1 Questionnaire Design and Validity

As our special target group consisted of musicians and naturally trained as multitasking experts, we did not make use of existing instruments that measure multitasking such as the Media Multitasking Index (MMI) (Ophir et al., 2009). These instruments address broad populations and other goals. Therefore, a new survey instrument was designed focusing on professional musicians. In this study they are defined as musicians that have at least 6 years of performing experience. This selection criterion was specified to guarantee that the respondents are musicians who can have optimal control over their performance. In addition to acquiring demographic information, the questionnaire includes questions pertaining to health and personality, musical background, perceived cognitive abilities during music practice, and self-reported multitasking behavior during music practice and in daily life. Figure 13 shows the questionnaire modules.

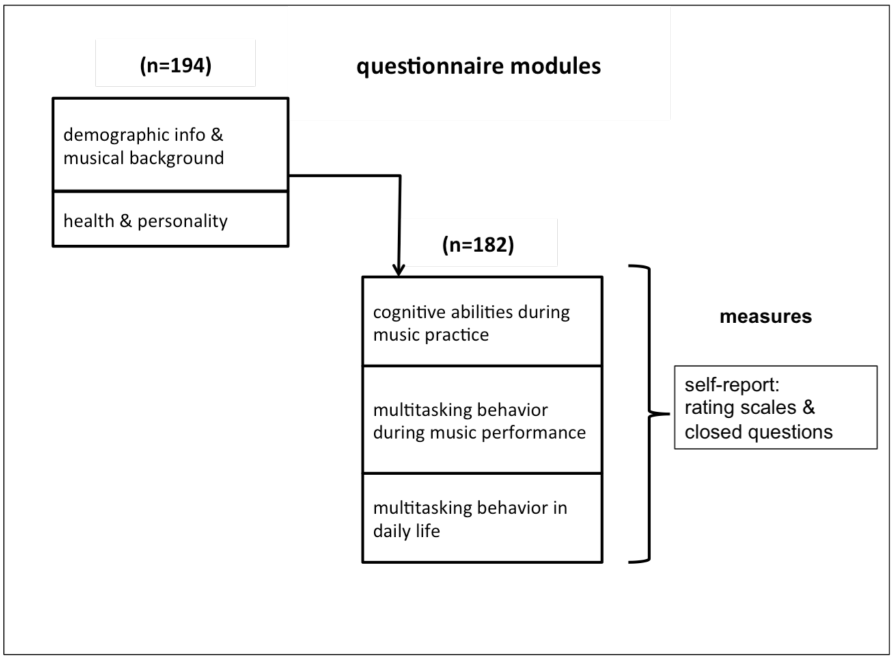


Figure 13 Questionnaire modules.

Because we conducted an exploratory study involving an in house designed questionnaire, it was necessary to check the questionnaire's validity. Therefore, it was systematically examined whether the aspects of the construct as we have defined it were captured in our measures. First, a couple of small sample tests were executed with peers at our institute. It was assessed whether our measures seemed reasonable to them. Based on multiple brainstorm sessions, the questionnaire has been systematic redesigned to reduce measurement errors. Then the questionnaire was tested in a pilot study involving 12 musicians who were not included in the sample.

5.2.5.2 Data Collection and Cleaning

The validated questionnaire was administered online using Google Docs web survey, and took approximately ten minutes to complete. This method was chosen because it can be easily implemented to large samples. A call through Social Media (including Facebook and Twitter) was posted to reach the intended population of experienced musicians. Moreover, the musicians who participated in the experiment were also encouraged to fill in the questionnaire. In that way, a representative sample of 194 respondents was collected. First it was checked whether all participants met the requirements of health and performing experience. As it is well known that Attention Deficit Hyperactivity Disorder (ADHD) and related conditions can affect cognitive abilities, a question was included that tested the occurrence of inattentive symptoms in the respondents. 8 subjects who confirmed that there are medical reasons that might inhibit their attention were omitted. After elimination of another 4 subjects with less than 6 years of experience playing their instrument or singing, 182 responses were available for data analysis.

5.2.5.3 Questionnaire Participants

The demographics revealed the following information on the participants: they are aged between 15 and 65 (Mean 32,91; St. Dev. 12,18), 50% are women; they come from 14 different countries (19,8% are Turkish, 67% are Belgian and 13,2% is a mixture of 12 other countries). Participants have between 6 and 56 years of experience in music performance (Mean 21,42; St. Dev. 11,27). More than half of them (58,2%) mainly perform classical music. They play between 1 and 8 instruments (Mean 2,37; St. Dev. 1,13). Almost half of them (45,6%) performs at least four times per year for an audience, 27,5 % at least once per month, 8,1% once per week and 18,4% less that four times per year.

5.3 Results

5.3.1 Audio Analysis

The audio analysis revealed that there are tempo differences for different load conditions. Overall, participants tended to sing or play faster in the load condition. Therefore, in order to be able to access the timing differences between pause and phrases over the two conditions, we normalized the time by takes percentages of pause and phases into account, rather than absolute time measurements. The goal of the analysis is to see whether there are differences in pauses between the two conditions. Because of the rather small sample size, a Shapiro-Wilk test was used to test normality. A Shapiro-Wilk (p>.05) indicates that the data is approximately normally distributed with a skewness of .663 (SE=550) and kurtosis of -.596 (SE=1063) for the males and a skewness of .535 (SE=616) and a kurtosis of -.377 (SE=1191) for the females. One-way analysis of variance (ANOVA) was performed to determine the statistical significance between groups. The difference in pause duration percentage turned out not to be statistically significant: F(1,28)=3,563, p=0.069.

5.3.2 Questionnaire Data Analysis

Pearson's chi-square test is used to examine gender dependencies for the questionnaire modules on cognitive abilities, multitasking during practice and during daily life. Only significant results are mentioned, for a complete overview see table 4.

Questions regarding participants' *perceived cognitive abilities* investigated following aspects: concentration time, self estimation of avoiding distraction, avoiding errors, reacting quickly, adapting, and maintaining focus, and the number of tasks participants can perform simultaneously. Almost half of the participants reported that they can stay up to 1 hour concentrated (48,9%) and a bit more than half of the participants can stay more than one hour concentrated (51,1%). For self-estimation of cognitive abilities participants had to report, on a 5-point Likert scale from very bad to very good. Because very bad and bad were never or rarely chosen, to meet the requirement of the chi-square test the results the data had to be rescaled from 5 to 3 steps. For the majority of participants their cognitive abilities during practice are good to very good: avoiding distraction (59,3%), reacting quickly (66,4%), adapting (69,3%), and maintaining focus (70,3%). Only 39,5 report to be good or very good at avoiding errors. No significant dependencies were found.

Participant's *perceived ability to multitasking* was measured as well. They were asked how many things they can do at once and still feel like they are being efficient in each task. More than half of the participants (52,2%) report that they can do at least 2 tasks at the time, 29,2% can do one task at the time and 18,6% at least 3. Within gender 40,7% of men can do only one task at the time whereas 59,3% of the women can do at least 2 tasks at once. In this case there was evidence against the null hypothesis of no association between the variables. This is in line with the general assumption that women are better multitaskers than men.

Table 4 Gender dependencies for the questionnaire modules on cognitive abilities, multitasking during practice and during daily life, chi-square test result.

Cognitive Abilities

Gender*	Pearson's chi square	df	Sign.
Concentration time	3.716	1	.054
Avoiding distractions	1.207	2	.547
Avoiding errors	0.107	2	.948
Adapting	1.976	2	.372
Reacting quickly	2.094	2	.351
Maintaining focus	4.132	2	.127
Number of simultaneous tasks	13.093	3	**.004**

Multitasking during practice

Gender*	Pearson's chi square	df	Sign.
Stop practicing	8.570	4	.073
Interrupt practicing: reading email	10.697	1	**.001**
Interrupt practicing: answering email	2.786	1	.095
Interrupt practicing: taking a phone call	0.441	1	.507
Interrupt practicing: texting	0.465	1	.495
Interrupt practicing: web search	3.595	1	.058
Interrupt practicing: use Facebook	1.861	1	.172

Multitasking in daily life

Gender*	Pearson's chi square	df	Sign.
Drive and talking on the phone	12.037	4	.017
Check emails while doing something else	1.624	4	.804
Use Facebook while doing something else	8.412	4	.078
Laptop open in meetings	3.118	4	.538

The *multitasking during practice module* investigated reasons to stop practicing and types of activities causing practice interruption. The main reason to stop a practice session is physical exhaustion (26,37%). By ticking items in a list of reasons why they would interrupt practice, participants reported on their sequentially tasking behavior during practice. 14,8% does not interrupt practice, whereas main reasons for doing so are taking a phone call (72, 5%), texting (25,3%) and reading email (18,1%). For the latter there was evidence against the null hypothesis of no association between the variables. Within reading email 75,8% are men.

The *multitasking in daily life module* explored what types of media was used during multitasking, such as cell phone usage while driving, checking emails while doing something else, using Facebook while doing something else, and having a laptop open in a meeting. Participants reported their behavior on a 5-point Likert scale from never to very often. 82,4% reports that they never or rarely drive and phone and 78,7% never or rarely has a laptop open in meetings. What they often to very often do is emailing while doing something else (41,2%) and using Facebook while doing something else (36,8%). For this module, no dependencies of gender were found.

5.4 Discussion

Music is an excellent domain for testing cognitive abilities of multitasking, especially in relation to gender. Music is indeed played equally well by men and women and it forms therefore an excellent baseline for testing possible biological proclivity in multitasking conditions. Based on earlier studies, we assumed that cognitive abilities in multitasking should be reflected in the handling of pause durations during a multitasking music performance. However, the results of this experimental study with twenty-nine musicians did not show any difference between the performances of males and females, neither women nor men are better in avoiding shortening under cognitive load. An additional questionnaire, through which a larger audience was addressed, did not reveal much difference either, except for the perception of multitasking. Females seem to think of themselves that they do manage multitasking, while males have a more modest opinion about this issue. This difference in perception may be influenced by social and cultural factors related to gender roles, rather than biological gender differences involving multitasking during music playing. The observation that in the multitasking condition pauses are played shorter than phrases, compared to the non-multitasking condition, is in line with the literature on timing. Experimental findings (e.g. Zakay & Block 2004) reveal that the estimation of a time interval depends on the length of the interval, and on the additional cognitive load that diverts the attention from the elapsing time (Migliore et al., 2000). According to the attentional theory (Frankenhauser, 1959) the cognitive timer counts subjective time units. Given the fact that this timer demands attentional resources, time estimation should be a direct function of the amount of attention devoted to it (Migliore, 2000). This literature explains why the entire music performance (phrases and pauses) is overall faster in the multitasking condition. However, to explain the difference between phrase and pause, reference must be made two different timing strategies for phrases and pauses. It can be assumed that phrases rely on emergent timing, while pauses rely on discrete timing. The rationale behind this assumption is that phrases require movement that elapses over time, providing a footing for timing. In contrast, pauses do not involve movement and therefore the timing mechanism cannot use movement as footing. Instead, it will use an internal brain clock as basis. Recent studies show that discrete timing is more affected by cognitive load than emergent timing because the timing of the latter can be based on ongoing movements during playing (i.e. timing is outsourced), while the timing of the former relies on an internal brain. Timing that is outsourced to the human body is less affected by cognitive load than timing that is internal (Çorlu, 2014). This theory of timing is in line with the embodied music cognition theory that stresses the role of the body as mediator for cognitive functions (Leman, 2008). The present study thus shows that men and women perform equally for this type of multitasking and it can be assumed that their performance relies on the same mechanisms.

These findings are discussed in details in chapter 6.

6

General Discussion and Conclusion

In this doctoral dissertation, we first examined the theoretical framework in relation to our research questions. Then we presented the overall methodology and we reported three empirical experiments about the interaction between musical expressivity and cognitive load. Overall, the result showed that cognitive load (realized by means of a counting task during music playing) has an impact on musical expressivity. It was possible to identify a key parameter known as "expressive timing". Gender differences turned out to be insignificant.

6.1 General Discussion

To the best of our knowledge, the present experiments introduced in this dissertation were the first ones in which the influence of cognitive load on expressive encoding has been investigated. The first study (chapter 3) indicated that during the dual task condition, the main findings are: less expressive playing (from jury judgments) and shorter pause durations (from audio analysis). This result suggested that cognitive resources for musical interpretation are reduced when working memory processes are occupied, so that expressiveness is affected (as argued by Leman 2008; 2016). In other words, this means that the encoding of expressiveness (mainly timing aspect of it) relies on cognitive resources. This finding is also consistent with the idea that the availability of cognitive resources during music playing can be therefore used to the benefit of the musical expressiveness. When additional cognitive load is added to the playing of a well-practiced musical piece, some amount of cognitive resources is no longer available for the encoding of expressiveness. As a result, the control of the encoding gets affected, leading to a less expressive performance. On the other hand, the automated sound-producing gestures (e.g. correct playing of notes and their durations) will basically remain unaffected while the music is played in a less expressive way during the counting task. This is in line with the assumption that the technical skills are controlled by sensorimotor programs that require less continuous feedback monitoring. Through rehearsal, musicians not only automate technical components of a piece but also they enhance the higher level cognitive schemata (germane load). Parallel to this, the evidence from studies of piano performance claims that an unskilled participant or a participant with limited training cannot exhibit more than a rudimentary version of these properties of skill (Shaffer, 1981).

In addition, the results reveal that there is one salient parameter that recurs in all pieces played, that is the pauses between musical phrases get shorter in the cognitive load condition. Other parameters of expressiveness such as dynamics (RMS) were affected as well, however, these were not consistent across pieces. Pauses can be considered to be a main aspect of musical expressiveness (Palmer, 1989). Analyses in Repp (1995, 1997) revealed that experienced musicians' timing vary much more than that of student musicians. Having practiced more, these professional musicians 'embody' their pieces in a sense, this would be in line with our finding that more practice allows for more expressiveness reflected in more variability in timing.

Figure 14 gives a summary of a model that could explain our findings: practicing sound-producing gestures leads to automatic motor actions, which results in residual cognitive resources. Both automatic motor actions and cognitive resources are needed to play expressively. The music is thereby typically based on musical phrases, with pauses in between.

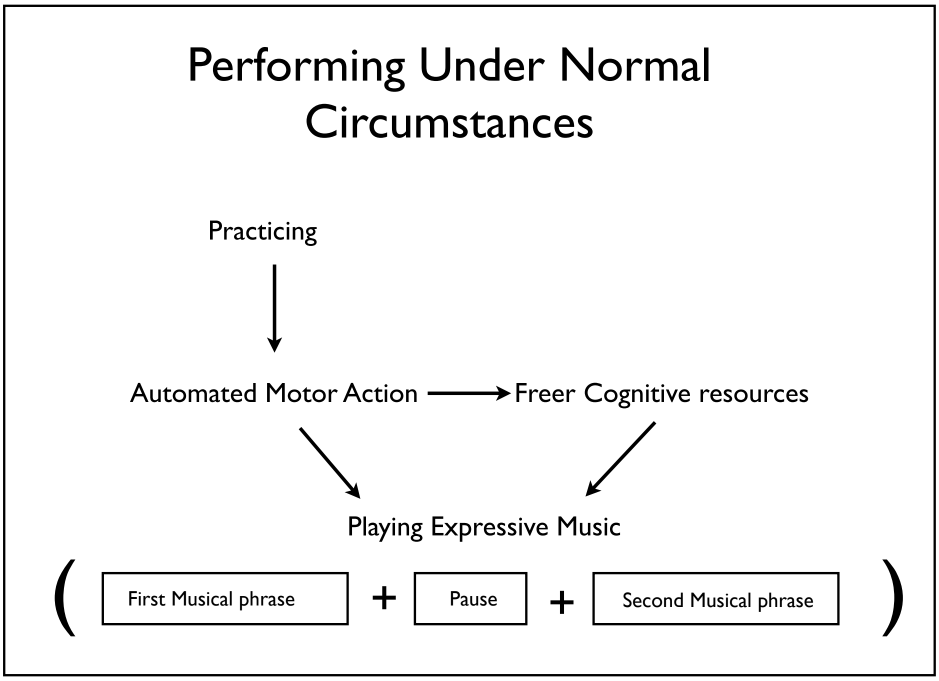


Figure 14 A model illustrates playing under normal circumstances.

As we looked into those durations separately, we found that pause durations were significantly shorter in the presence of an additional cognitive load, whereas played phrase durations did not differ significantly. Therefore, in what follows, we discuss how we could interpret the finding that additional cognitive load leads to shortened pause durations, but does not affect phrase durations for the first experiment explained in the third chapter.

First of all, it is important to mention that cognitive load is known to affect the perception of duration. There are several theories about the influence of cognitive load on duration perception. Ornstein (1969) predicts that increased attention leads to more stored information and hence to longer time estimates. Ornstein's storage size hypothesis assumes that two equal time intervals are perceived to be different durations if one time interval contains more complex information and therefore requires more storage space in memory. As storage size increases, duration experience lengthens. Underwood and Swain (1973) postulate that duration judgments are affected by attentional effort. Block's (1978) contextual change hypothesis on the other hand, suggests that experienced duration increases as a linear function of the number of contextual changes occurring in both the environmental situation and in the organism. According to this contextual change model, neither attentional effort nor storage size hypotheses fully explain judged durations properly. The theories above have in common aspect that elapsed time is judged differently under different cognitive states. We may assume that additional cognitive load during music playing increases attentional effort and storage size, and that contextual change is increased as well. Therefore, in line to these theories, we can assume that musicians judged elapsed time in the cognitive load condition differently from that of without cognitive load. In fact, they should indeed judge elapsed time to be longer in the cognitive load condition, leading them to unknowingly judge short pause durations as sufficiently long for a particular expressive purpose.

However, musicians did not judge duration after the task, rather they performed a task during which passive duration judgments are made throughout the performance. These judgments during a pause and during active playing differ in the amount of extra information available to judge duration. It seems that bodily interaction and corporeal properties should be taken in to consideration as well when it comes to judge perceived durations. We assume that when a musician is actively playing music, additional information is available which makes estimating elapsed time more robust against cognitive loading. A good candidate for such a timing reference is the body of the musician itself. For example, musicians' arms, hands and fingers are constrained by their biophysical properties that do not depend on cognitive circumstances. These more or less constant properties, such as how fast a finger can move, can provide the musician with an unconscious frame of reference for duration. This is in line with Gabrielsson (1999), who described how "the motor system itself acts as timekeeper by translating a given interval into a movement trajectory with the corresponding duration". Moreover, the well-practiced sound-producing gestures have likely reached an optimal set of spatiotemporal characteristics, which are further supported by sound-accompanying gestures (Jensenius et al., 2010), which further constrain the physical possibilities of the musicians playing. These embodied constraints, both in purely biophysical properties of the body, as well as in the way a musician has practiced the movements, can provide a robust frame of reference that a musician can use to estimate elapsed duration.

A possible explanation for the shorter pause durations in the dual task condition is thus that there is no embodied reference during the pause, so that the perception of duration is affected.

Figure 15 gives a summary of the model of a music performance with additional cognitive load. Again, in the model, we assume that practice leads to automated motor actions and residual cognitive resources. However, during playing with an additional cognitive load, part of the cognitive resources are now devoted to a second task and can no longer be devoted entirely to expressiveness. The general principle is that additional cognitive load leads to the judgment that elapsed time is longer, which indeed results in shorter time duration for the pauses (probably because they are believed to take longer then they actually are). However, playing is not affected by shortening because the musician can rely on body movement (sound-generating gestures, sound-accompanying gestures) as a reference for timing.

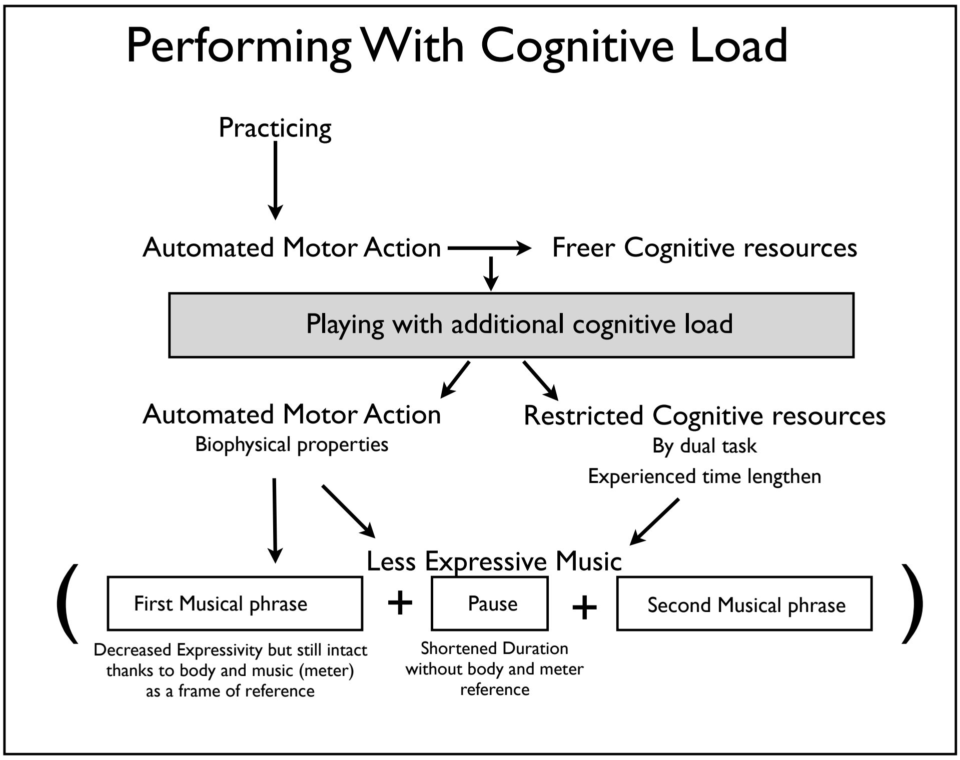


Figure 15 A model illustrates the consequences of playing with additional cognitive load.

In short, the execution of motor actions during a music performance implies a spatiotemporal deployment, which can be used as a reference for the perception of elapsed time. We assume that during the pause this reference disappears to a large extent and, consequently, the estimation of the duration of time becomes more vulnerable to the effects of cognitive load or perhaps other mechanisms such as stress or anxiety (i.e. subjective time perception may rely on different cognitive and emotional processes). Bar-Haim *et. al*. (2010) indicate that relative to non-anxious individuals, anxious individuals subjectively experience time as moving more slowly. Our findings suggest that pauses in between musical phrases are experienced as longer by the participant in the absence of reference (i.e. playing) under an additional cognitive load. In the first experiment reported in the third chapter, we measured the heart rate variability as it is considered as one of the stress indicators (Taelman et al., 2003), however results did not show any significant difference between the two conditions in terms of HRV.

The fact that in both cases the perceived duration increases could indicate that cognitive load is a useful tool for studying performance stress. In the post-experiment questionnaire, musicians in the study described in the third and fourth chapters, reported that during their concert performances they feel the need to accelerate during pauses in between musical phrases. Before starting any musical phrase, (also between two phrases), it is essential to breathe and be prepared for the musical intentions of that phrase. If this time is shortened there may be direct effects on respiration, as well an effect on expressiveness during performance. Parallel to this argument, in a case study (Kochman *et. al*., 2011), there were consistent differences in breathing between the rehearsal and public performance. In this specific case, the singer used pauses more briefly when performing with an audience, which was believed to be the reason of dramatic change in the expressiveness.

In questionnaires, the participants claimed that they could have played better if they had practiced more. Moreover, the participants reported that the secondary task condition was quite useful to foresee the potential mistakes before the actual performance, that is, concerts or competitions. This may suggest that relatively more difficult sections or phrases of a piece that are vulnerable to mistakes could be more obvious or perceivable for the musicians in a dual task environment. In a study conducted by Brandmeyer et al. (2011), conservatory percussion students performed imitations of recorded teacher performances while receiving either high-level feedback on the expressive style of their performances, low-level feedback on the timing and dynamics of the performed notes, or no feedback. They concluded that, while potentially disruptive to timing processes involved in music performance due to extraneous cognitive load, high-level visual feedback could improve participant imitations of expressive performance features. Furthermore, these results highlight both the benefits and the difficulties that come along with the various manners in which knowledge of results can be given to learners. They claim that this is may be especially true in learning situations involving complex tasks such as expressive drum performance, which requires the combined use and sequencing of multiple effectors at short, precisely timed intervals, and with subtle manipulations in force in order to achieve the desired performance (Brandmeyer et al. 2011). From an educational psychology point of view, further studies might reveal valuable outcomes such as new practicing paradigms for learners with which they can test their performance quality.

Another point worth mentioning is that in some of the cases musicians performed the same note repeatedly in the dual task conditions. Besides significantly shorter durations of pauses, some musicians tended to play a single note or a short sub-phrase repeatedly as if they were stuck into a loop, which can be named as musical stuttering. In fact, these false notes and /or unexpected repeated notes (as in this case) do not have an effect on the length of the played phrases. Involuntarily repeated notes in music with high working memory load can be linked with research in working memory and its role on various communication disorders. The sustained interest in phonological encoding and attention-related processes in stuttering provides the rationale to explore the extent to which phonological and attention-based working memory elements are involved in the disorder (Bajaj, 2007). In the present study, increased working memory load resulted in stuttering like playing in half of the participants.
The second experiment (chapter 4) positions ongoing cognitive load research into the domain of music performance, more in particular singing performance. Music performance offers us a naturalistic context in which the relationship between timing and cognitive load can be studied. The central question was to what extent a heightened cognitive load is going to affect expressive music performance of the opera singers that are known as they are better in coping strategies with cognitive overload. For that purpose, we looked at performers' tendency to speed up, or slow down. Previous research demonstrated that timing production generally speeds up in the presence of an additional cognitive load (Krampe et al., 2010; Rattat, 2010; Fischinger, 2011; Çorlu et al., 2014; Maes et al., 2014). Therefore, we expected a general tendency of singers to speed up their performance under cognitive load. Additionally, we made a distinction between the performance of pauses and phrases to test whether an additional cognitive load similarly affects both performance aspects. The results of the study showed indeed that singers have a general tendency to speed up their performance under cognitive load conditions. However, when making a distinction between pauses and phrases, we found that this speeding up was more pronounced in pauses—in particular longer pauses—compared to phrases. This finding suggests that different timing mechanisms underlie the temporal control of pauses and phrases. The fact that the longer pauses are significantly affected by an additional cognitive load as compared to the shorter pauses, suggests the role of a cognitively controlled timing system (Church, 1984; Allman et al., 2014). We expected longer pauses to be more affected by the cognitive load because we expect that there is some more time elapsed apart from respiration. Arguably, during short pauses singer could only breath, which might mean that respiration could function as somatosensory scaffold. The results are in line with our expectations, during longer pauses the

devastating effect of an additional cognitive load is significantly higher. When singers breathe they are often trained, for example, to activate the support and raise the palate to prepare for the next phrase. It can be that less preparation is taken when cognitive load increases. For short pauses, where musicians can only breathe, respiration can serve as a motoric cue to enhance cognitive planning and preparation for the next phrase, becoming part of the atomization process. This might account for the insignificant effect of additional cognitive load in short pauses. Consequently, because of they are shorter and singers were may only be able to breathe, therefore motor and somatosensory feedback were still present. Maes et al. (2015) found evidence that gestures can invoke either an emergent, or an event-based timing principle depending on whether the articulation is legato or staccato. In staccato articulation, there are moments where the body does not move very much. Thus it seems that a cognitive counter comes in to play, maintaining the appropriate time intervals between staccato articulation onsets. This idea is supported by the observation that regular timing is disturbed when an additional cognitive load task is applied. Since all participants were professional opera singers and they all performed their pieces previously with piano accompaniment as well as with the original scores played by the orchestra. We cannot know exactly whether they imagined the accompaniment or not, however, it is conceivable to deduce from the data that they were rather hasty to start to the new phrase probably because of the need for bodily and musical cues. Moreover, in both conditions they had to sing without accompaniment.

In contrast, the relatively lower impact of an additional load on the timing of phrases suggests that another system supports the timing of phrases. In line with other research, we suggest that the perceptual and motor system—and correspondingly sensory feedback and the control of movement parameters—may directly contribute to temporal control (Jones & Boltz, 1989; Hopson, 2003; Mauk & Buonomano, 2004; Ross & Balasubramaniam, 2014). Through extensive rehearsal and practice, technical aspects of sound production, such as the correct production of singing tones and their durations, become more fluid and ingrained in motoric memory, thus leaving more cognitive resources available for other tasks. Similarly, self-generated auditory feedback, incorporating dynamical patterns of sounds changing over time, may provide temporal cues guiding a singer’s performance. The dissociation between a cognitive controlled timing system, and a timing system that is inherently linked to the perceptual-motor system is reflected in the dissociation between *event-based* timing, and *emergent* timing, often mentioned in studies on temporal control of respectively discrete, and continuous rhythmic movements (Robertson et al., 1999; Zelaznik et al., 2002, 2008; Spencer et al., 2003; Huys et al., 2008; Elliott et al., 2009; Lorås et al., 2012; Studenka et al., 2012; Maes et al., 2014). It can be argued that during pause durations—which were made substantially shorter under cognitive load—singers relied on event-based timing. In contrast, research suggests that the temporal control of continuous rhythmic body movements relies on an *emergent* timing system. In that regard, temporal regularities emerge from the motor system's dynamics with a minimum of explicit, cognitive control (Zelaznik et al., 2008). Accordingly, during the singers' performance of musical phrases, continuous activation of phonatory muscles could have functioned as dynamical framework for emergent timing.

The secondary task we choose was shape counting which was perceived visually. Therefore selective attention was needed to execute the secondary task. To perceive the shapes appearing on the computer creates additional load on perception. One important concept namely, perceptual load theory (Lavie, 1995), postulates that perception has limited capacity but operates automated, involuntary manner on all the information within its capacity. Perceptual load poses an important role in determining the efficiency of selective attention. The different manipulations of load converged to show that interference from irrelevant distractors was found only under conditions of low perceptual load in the relevant processing and was eliminated under conditions of high load. Thus, the ability to ignore irrelevant information is directly related to the load in the processing of the relevant information (Lavie, 1995). In our dual-task paradigm, participants had to keep the number of shapes counted in their minds that needs constant working memory involvement during the experiment. The idea was not respond immediately after perceiving different shapes (here triangles and circles). They had to memorize (by updating the number of different shape counted) and hold the increasing number of shapes in order to be able to tell the correct amount of shapes appeared. Nevertheless, it is quite plausible to consider that in our dual-task paradigm secondary task involves visual perception and working memory load whereas the first task involves sensorimotor and audio perception. In a recent study, (Molloy et al., 2015) provides crucial insight into the mechanism of sensory processing in the brain. With numerous sources of sensory information, perceptual resources can be limited thus may cause that cognitive system become overloaded, leading to reduced processing of stimuli that are not directly relevant to the current task and resulting in inattentional blindness and deafness. Since in our experiments participants had to tell the number of shapes at the end of the procedure so that methodologically possible 'blindness' affect believed prevented. In other words, rather than instant reaction to perceived stimuli, participants had to rely on other components of the cognitive resources than perceptual ones that are attention, memory and recall functions.

For the second experiment, we studied professional operatic singers. This category of musicians is especially acquainted with conditions of heightened cognitive load. Their performance does not only involve a musical component, but also an "acting" component in relation to other musicians and an audience. Hence, especially this category of musicians is assumed to develop timing strategies that capitalize on perceptual-motor abilities as an alternative for cognitive resources. Research demonstrated that the specific performance condition of operatic singers (performing under cognitive load, and the assumed development of perceptual-motor timing strategies) is reflected in specific brain architecture. Kleber et al. (2010) pinpointed specialized neural networks for enhanced somatosensory processing and performance monitoring in operatic singers, as well as motor sequence attention when compared to laymen and even other singers. The findings suggest that changes in the primary S1, IPL, and DLPFC allow for more accurate fine-tuning and feed forward motor commands.

An important question is to what extent lyrics could be a factor influencing our results. However, the lyrics were not likely to be the reason for different timing performances simply because they sang the same aria in each condition. Since all musicians shortened the pause durations in load conditions, we rather count on the fact that working memory load is the predominant factor for the differences. From the singers' point of view, singers may change breathing based on the expression of lyrics. However, this would be likely to remain the same between conditions.

The last experiment presented in the chapter 5 was conducted to test gender differences in multitasking, and the perception of multitasking, using a music performance study that tested the effect of additional cognitive load on music performance duration, and a questionnaire that tested perceived multitasking abilities. It was important to know whether we can generalize the outcome of the first two experiments to all musicians in terms of gender? The novelty of this study is related to the special target group, namely skilled musicians, but also the use of mixed methods, namely, a controlled experiment and a questionnaire. Another asset is the relatively large number of participants and the good gender balance therein.

The results show that professional musicians can multitask but that multitasking generates an additional cognitive load that affects the music performance. The audio analysis showed no significant differences between males and females; they are both affected by cognitive load and this is reflected in their shortening of the pause duration.

Our complimentary additional questionnaire reveals that there are no significant gender differences in concentration time, avoiding distractions, avoiding errors, adapting, reacting quickly and maintaining focused, except for number of tasks and interrupt practicing (see Table 4). From respondents' self reports, it is rather interesting to see that roughly 60% of the musicians were women who believe that they can perform two tasks at a time. However, this percentage is not outspoken. Moreover, the experiment does not support the belief that there would be fundamental differences between males and females regarding the cognitive abilities. Looking at the significance levels of the results of the audio analyses, we have no evidence that gender is an issue in multitasking. Our results suggest that actual differences between men and women in time-use patterns do not directly translate to a superior female capacity to handle multiple tasks (see also Mäntyla, 2013). The difference in perception, therefore, may be due to cultural and social circumstances that create this perception. In other words, it is not because females do more multitasking, that they are better equipped to do this multitasking than men. This suggests that the differences are not due to biology but to cultural conditions.

As this experimental design is the first attempt to understand whether gender is a critical variable in professional musicians under cognitive load, we strongly argue that these results might foster the research on gender studies with performing musicians. The estimation of time intervals is relevant for understanding music performance. However, investigating the effect of cognitive load on time perception during music playing is rather a new concept, especially since it involves both action and perception (i.e. judgments while playing music with additional cognitive load). Moreover, music is a rich source of information with a highly complex temporal structure. Like spoken language, music is structured into phrases and for the perception of those structures, the boundaries of phrases are very important (Knoesche et al., 2003). As previously put in the introduction part, understanding the cognitive mechanism and functions in male and female, our paradigm seems a promising starting point to investigate these phenomena and music performance provides an interesting baseline for gender-related multitasking studies.

However, it should be noted that studies that encompass multi-strategy research approach are not so common in the domain of music performance. With multi-strategy (i.e. Bryman, 2004) we refer to our use of different approaches to data collection and analysis. The third experiment for gender difference was not primarily designed as mixed method research but it was implemented in two distinct phases. The rationale for employing mixed methods was complementarity to the evidence found in the experiment: our study started with a strictly controlled experiment that investigates gender differences in musician’s time perception during performance and it was expanded with a survey about the perception of multitasking. However, our research strongly suggests that there is considerable value in using a multi- strategy approach. We believe that given our specific target group and our strategy of social networking among musicians the risk of bias was restricted.

In summary, the results add to the understanding of multitasking in male and female professional music performers. We found no gender differences in multitasking music performances. Besides, there are even few gender differences in the self-report of cognitive abilities and multitasking behavior during music practice.

6.2 Limitations and Future Work

The novelty of this dissertation is the use of a dual task paradigm for musicians. We asked participants to do two tasks simultaneously, namely a musical task, which was a piece of music that they performed and an additional task which was counting the shapes on the computer screen. The aim was to see the effect of the additional task on musical task. The reason why we asked them to count the shapes was to increase the cognitive load. Since this method has not been used for performing musicians so far, it keeps the door wide open to criticism whether any other additional task would have been more reliable. In our pilot studies we tried mathematical equations as a secondary task instead of counting shapes. However, as compared to the shape counting it turned out to be more difficult to execute the musical performance probably because of the cognitive overload. Assessing the data of the effect of cognitive load on performing musicians the methodology used here needs to be confirmed by future studies.

It is always difficult to say that exactly how many participants would be sufficient for a reliable data. We strongly believe that the experiments conducted for this dissertation should be vindicated by the future studies with larger groups. Especially for the second experiment presented here (chapter 4) due to the difficulty to find large number of professional opera singers we had only twelve participants of that kind.

Moreover we are not perfectly sure whether musicians used the shorter pauses solely for breathing. It is plausible to presume that the longer pauses are not only for breathing, but still, to avoid possible uncontrolled variables (such as lung size or capacity) more controlled methodology (using the breath measurer) might be of utmost importance for the validity of our results.

The link between musical expressiveness and movements has not been investigated in these experiments. However, responses in the questionnaire suggest that participants were not free in their movements while playing with the secondary task. Two-thirds of the participants stated that they felt inhibited during the experimental condition in terms of freedom in movements. This could not have been caused by the fact that they were instructed to watch the screen continuously, because the instructions were identical in both conditions. However, that might have been caused by the task demands. A perceived restriction of movements could be a part of the reason for the different musical performance between the conditions.

6.3 Conclusion

The research discussed in this dissertation is specifically based on the effect of cognitive load on performing musicians and whether gender is an important factor to that. Based on the theory of embodied music cognition and cognitive load paradigm, three experiments were presented here. Overall result shows that the occupied cognitive resources lead to a change in musical expressivity. Timing is very critical parameter here, which is responsible for the difference in expressive performances. Musicians have particularly shortened the pause durations in between musical phrases. Even among the opera singers who are better in coping with cognitive load showed the same behavior. We concluded that no embodied reference during the pause account for the shorter pause durations in the dual task condition. The main finding of the present research is that operatic singers speed up their performance, in particular pauses (to be more specific long pauses), in conditions of heightened cognitive load. We expected that this effect would increase proportionally to the level of cognitive load. Therefore, we included two experimental conditions varying only in the level of cognitive load (low/high). However, we found no significant differences between the low load and high load conditions. A possible explanation for this result is that a so-called ceiling effect occurred; the low load condition was already amply difficult so the additional cognitive load did not had any further effect on the timing performance. Gender differences seemed to be insignificant.

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