Circadian Preference and Amplitude

"Under Consideration of Physiological Markers, Activity and Sleep/Wake Timing as well as References to Attention, Mood and Motivation in Everyday School Life"

Dissertation

der Mathematisch-Naturwissenschaftlichen Fakultät
der Eberhard Karls Universität Tübingen
zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer. nat.)

vorgelegt von
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Tübingen
2019

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	19.12.2019
Dekan:	Prof. Dr. Wolfgang Rosenstiel
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2. Berichterstatter:	Prof. Dr. Katharina Scheiter

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Acknowledgement

I would like to thank everyone who supported me during my PhD. First and foremost, a big “Thank you” goes to my supervisors Prof. Dr. Christoph Randler and Prof. Dr. Katharina Scheiter, who have always supported, inspired and challenged me. They were always open and ready to discuss any issues that arose.

I would like to thank LEAD (Graduate School and Research Network) for providing me with an outstanding research environment. In particular, I would like to thank the "School Contacts" department, which supported and advised me in the communication with the schools.

Furthermore, I would like to express my gratitude to the schools, teachers, parents and students who participated. During my survey, I found a friendly and cooperative environment in the schools, which made my work easier and more inspiring.
I would also like to thank my student assistant Lara Täuber, who supported me with her efficient and reliable help.

Many thanks also to my two colleagues Nadine Kalb and Alena Rögele. Because of you, my PhD became an unforgettable experience. Without your support, advice and encouragement I would not be where I am today.

Finally yet importantly, I would like to say a few words to my parents and husband: I am grateful for your unconditional help and support, your persistent trust in me and your words of encouragement. Without you, it would not have been possible!

Danksagung

Ich möchte mich bei allen bedanken, die mich bei meiner Promotion unterstützt haben. Allen voran, geht ein großes Dankeschön an meine Supervisors Prof. Dr. Christoph Randler und Prof. Dr. Katharina Scheiter, die mich immer unterstützt, inspiriert und gefordert haben. Sie hatten stets ein offenes Ohr und waren immer bereit anstehende Themen zu diskutieren.

Ich möchte mich bei LEAD (Graduate School and Research Network) bedanken, indem mir ein herausragendes Forschungsumfeld zu Verfügung gestellt wurde. Insbesondere möchte ich mich bei der Abteilung "Schulkontakte" bedanken, die mich in Sachen Kommunikation mit den Schulen unterstützt und beraten haben.

Weiter möchte ich meinen Dank gegenüber den teilnehmenden Schulen, Lehrpersonen, Eltern sowie Schülerinnen/Schülern aussprechen. Ich stieß während meinen Erhebungen in den Schulen auf ein freundliches und kooperatives Umfeld, was die Arbeit erleichterte und beflügelte.
Ebenfalls möchte ich mich bei meiner studentischen Hilfskraft Lara Täuber bedanken, die mich mit ihrer gründlichen und zuverlässigen Hilfestellung unterstütz hat.

Ein ganz großer Dank geht hiermit auch an meine beiden Kolleginnen Nadine Kalb und Alena Rögele. Durch euch wurde meine Promotion ein unvergessliches Erlebnis. Ohne eure Unterstützung, Beratung und Fürsprache wäre ich jetzt nicht da, wo ich heute bin.

Zu guter Letzt, möchte ich noch ein paar Worte an meine Eltern und an meinen Mann richten: Ich bedanke mich für eure bedingungslose Hilfe und Unterstützung, euren ausdauernden Glauben an mich und die stets aufmunternden Worte. Ohne euch wäre es nicht möglich gewesen!

Abstract

Morningness-Eveningness can be understood as individual daytime preferences in different physiological, cognitive and behavioral parameters. Those differences can be summarized on the one hand as a dimension of Morningness-Eveningness (continuous) or on the other hand as circadian typology (categorical). Morningness-Eveningness is seen in this case as a uni-dimensional construct, with Morningness and Eveningness marking the two endpoints of one scale. Based on this continuum, the persons were categorized into different chronotype groups. In the meantime, research tends to let go of dividing persons into different chronotype groups. A multi-dimensional view of the construct Morningness-Eveningness is seen instead, whereas a certain type of circadian preference may be more or less pronounced within a person. Research suggests that at least Morningness and Eveningness should be considered as two separate dimensions and other aspects, such as circadian fluctuations over the day, should be include.

Assessing differences in daytime preferences is important, because they have a great impact on the human physiology and health. Especially in school context, adolescents struggle in adapting their inner circadian rhythm to the requirements of our school system. It is known, that morning-oriented adolescents have an advantage over evening-oriented adolescents in terms of sleep habits and school achievement. This is due to the fact that with increasing age, the adolescents tend to describe their selves as more evening-oriented. For this reason a reliable and valid measurement of circadian preference and its stability over the day (amplitude) is needed, which can also be used in an adolescent sample. The measurement used for this purpose in the present dissertation does justice to all of these requirements. The Morningness-Eveningness-Stability scale; improved (MESSi) by Randler et al. (2016a) determines the individual daytime preferences and their amplitude. Therefore, the aim of the present dissertation was to validate the measurement MESSi with the help of certain physiological parameters (like body temperature and cortisol) as well as other intervincing variables (like habitual sleep/wake times, activity and personality). On the other hand, the MESSi should be usable in a student population to investigate the influence of Morningness-Eveningness on school-

relevant achievement under consideration of important variables in school context (like motivation and mood).

First, the validation of the MESSi was carried out within one survey, which was divided afterwards into two studies. A total of 97 German students participated voluntarily in this survey. A subsample (*N*=42) of definite Moring and Evening types experienced actigraphic and body temperature monitoring, provided information about different sleep patterns as well as personality traits and sampled individually saliva probes. The results demonstrated that the MESSi could be seen as a reliable and valid instrument to measure circadian preference and amplitude. The circadian preference, given by the MESSi, is congruent to intervincing variables, like sleep/wake timing, activity and personality. The scale is comparable to existing scales and does justice to the multi-dimensional view of Morningness-Eveningness with the advantage of three distinguishable dimensions (Morningness, Eveningness and Stability). The validation of the MESSi with the help of physiological markers, like body temperature and cortisol levels, unfortunately did not provide fully satisfactory results.

Second, convergent validity of the MESSi with well-established measurements of circadian preference was analyzed in an adolescent sample. A third study resulted from three separate surveys with a total sample of *N*=215 adolescents. The results of this study supported the assumption that the MESSi is a valid instrument with a three-factor structure to measure circadian preference and amplitude in adolescents.

Lastly, the MESSi was used to investigate the impact of Morningness-Eveningness and stability on school-relevant achievement in a field setting with an adolescent sample. Relevant intervincing variables such as motivational aspects in learning and the emotional state were also taken into account. A total of *N*=30 students from two different Gymnasia participated in this survey. At two different test points at school the students provided information about their mood and motivational aspects of learning, additionally they edited a concentration and attention test. Further, the students experienced actigraphic and temperature monitoring. The results of this study suggested that in this age group, Morningness-Eveningness has less effect on school-relevant performance than time of day. It seems that motivational aspects and mood still play an important role in school achievement.

Zusammenfassung

Morningness-Eveningness kann als eine Art individuelle Tageszeitpräferenz angesehen werden, die sich in verschiedenen physiologischen, kognitiven und verhaltensbezogenen Parametern manifestiert. Diese Unterschiede können einerseits auf der Dimension Morningness-Eveningness (kontinuierlich) oder andererseits als zirkadiane Typologie (kategorisch) zusammengefasst werden. Morningness-Eveningness wird in diesem Fall als ein eindimensionales Konstrukt gesehen, wobei Morningness und Eveningness die beiden Endpunkte einer Skala markieren. Basierend auf diesem Kontinuum wurden die Personen dann in verschiedene Chronotypgruppen eingeteilt. In der Zwischenzeit neigt die Forschung allerdings dazu, die Einteilung von Personen in verschiedene Chronotypgruppen loszulassen. Stattdessen wird eine mehrdimensionale Sicht des Konstrukt Morningness-Eveningness präferiert, in welcher eine bestimmte Art von zirkadianer Präferenz innerhalb einer Person mehr oder weniger ausgeprägt sein kann. Die Forschung legt nahe, dass zumindest Morningness und Eveningness als zwei getrennte Dimensionen betrachtet werden und andere Aspekte, wie z.B. zirkadiane Schwankungen über den Tag, einbezogen werden sollten.

Die Erfassung von Unterschieden in den Tagespräferenzen ist wichtig, da sie einen großen Einfluss auf die Physiologie und Gesundheit des Menschen haben. Gerade im schulischen Kontext haben Jugendlichen Schwierigkeiten, ihren inneren zirkadianen Rhythmus an die Anforderungen unseres Schulsystems anzupassen. Es ist bekannt, dass morgenorientierte Schülerinnen und Schüler in Bezug auf Schlafgewohnheiten und Schulleistung einen Vorteil gegenüber abendorientierten Schülerinnen und Schülern haben. Dies liegt daran, dass die Jugendlichen mit zunehmendem Alter dazu neigen, sich selbst als abendorientierter zu bezeichnen. Aus diesem Grund ist eine zuverlässige und valide Messung der zirkadianen Präferenz und ihrer Stabilität über den Tag (Amplitude) erforderlich, da diese auch in einer Schülerinnen/Schülerpopulation verwendet werden soll. Das in der vorliegenden Dissertation zu diesem Zweck verwendete Messinstrument wird all diesen Anforderungen gerecht. Die Morningness-Eveningness-Stability Scale; improved (MESSi) von Randler et al. (2016a) bestimmt die individuelle

Tagespräferenz und deren Amplitude. Ziel der vorliegenden Arbeit war es daher, das Messinstrument MESSi mit Hilfe bestimmter physiologischer Parameter (wie Körpertemperatur und Kortisol) sowie anderer aussagekräftiger Variablen (wie gewohnte Schlaf-/Wachzeiten, Aktivität und Persönlichkeit) zu validieren. Zusätzlich sollte der MESSi in einer Schülerinnen/Schülerpopulation nutzbar sein, um den Einfluss von Morningness-Eveningness auf die schulrelevante Leistung unter Berücksichtigung wichtiger Variablen im schulischen Kontext (wie Motivation und Stimmung) zu untersuchen.

Zunächst wurde die Validierung des MESSi im Rahmen einer Erhebung durchgeführt, die anschließend in zwei Studien unterteilt wurde. Insgesamt 97 deutsche Studierende haben sich freiwillig an dieser Untersuchung beteiligt. Eine Teilstichprobe (*N*=42) von definierten Morgen- und Abendtypen wurde einer aktigraphischen und Körpertemperaturüberwachung unterzogen, lieferte Informationen über verschiedene Schlafmuster sowie Persönlichkeitsmerkmale und entnahm sich selbständig Speichelproben. Die Ergebnisse zeigten, dass der MESSi als reliables und valides Instrument zur Messung der zirkadianen Präferenz und deren Amplitude angesehen werden kann. Die zirkadiane Präferenz, die durch den MESSi bestimmt wird, ist kongruent mit andern intervenierenden Variablen wie Schlaf/Wach-Timing, Aktivität und Persönlichkeit. Die Skala ist mit bereits bestehenden Skalen vergleichbar und wird der mehrdimensionalen Sichtweise von Morningness-Eveningness gerecht, mit dem Vorteil von drei unterscheidbaren Dimensionen (Morningness, Eveningness und Stabilität). Die Validierung des MESSi mit Hilfe physiologischer Marker, wie Körpertemperatur und Kortisolspiegel, lieferte leider nicht ganz zufriedenstellende Ergebnisse.

Als zweites wurde die konvergente Validität des MESSi mit etablierten Messinstrumenten der zirkadianen Präferenz in einer Stichprobe bestehend aus Jugendlichen analysiert. Eine dritte Studie ergab sich aus drei separaten Erhebungen mit einer Gesamtstichprobe von *N*=215 Jugendlichen. Die Ergebnisse dieser Studie unterstützten die Annahme, dass der MESSi ein valides Instrument mit einer Drei-Faktor-Struktur zur Messung der zirkadianen Präferenz und Amplitude bei Jugendlichen ist.

Schließlich wurde mit dem MESSi der Einfluss von Morningness-Eveningness und Stabilität auf schulrelevante Leistungen in einem Feldstudien Design bei Jugendlichen untersucht. Relevante, intervenierende Variablen wie motivationale Aspekte beim Lernen und der emotionale Zustand wurden ebenfalls berücksichtigt. An dieser Erhebung nahmen insgesamt *N*=30 Schülerinnen und Schüler aus zwei verschiedenen Gymnasien teil. Zu zwei verschiedenen Testpunkten in der Schule gaben die Schülerinnen und Schüler Auskunft über ihre aktuelle Stimmungslage und motivationale Aspekte des Lernens, zusätzlich wurde ein Konzentrations- und Aufmerksamkeitstest durchgeführt. Weiterführend wurden die Schülerinnen und Schüler einer aktigraphischen und Körpertemperaturüberwachung unterzogen. Die Ergebnisse dieser Erhebung deuten darauf hin, dass in dieser Altersgruppe Morningness-Eveningness weniger Einfluss auf die schulrelevante Leistung hat als die Tageszeit. Es scheint, dass motivationale Aspekte und die momentane Stimmungslage nach wie vor eine wichtige Rolle bei der schulischen Leistung spielen.

List of publications and papers

Accepted papers

1. Faßl, C., Quante, M., Mariani, S., & Randler, C. (2019). **Preliminary findings for the validity of the Morningness–Eveningness-Stability Scale improved (MESSi): Correlations with activity levels and personality**. *Chronobiology International*, 36(1), 135-142.

2. Weidenauer, C., Vollmer, C., Scheiter, K., & Randler, C. (2019). **Weak Associations of Morningness-Eveningness and Stability with Skin Temperature and Cortisol Levels.** *Journal of Circadian Rhythms*, 17(8).

3. Weidenauer, C., Täuber, L., Huber, S., Rimkus, K., & Randler, C. (2019). **Measuring circadian preference in adolescence with the Morningness-Eveningness Stability Scale improved (MESSi).** *Biological Rhythm Research*, 1-13.

Manuscript

4. Weidenauer, C., Rögele, A., & Randler, C. **Circadian Preference and School-relevant Achievement: Implications for Skin Temperature, Emotional State and Motivation in Learning.**

1. **Introduction**

“*Be ruled by time, the wisest counsellor of all*.”

Plutarch (46-120 AD)

„Tick, Tock…Tick, Tock“…that is how the clock goes. Moreover, we are not talking about the watch you can wear on your wrist. We are talking about the inner biological clock. All organisms on this planet: humans, plants and animals; life under a certain rhythmic order. It is well known, that our life’s move in synchronicity with different clocks and calendars inside and outside of our bodies *(Koukkari & Sothern, 2007)*. Inside our bodies, a biological rhythm sets the clock for many events in daily life. Especially the time of active and rest phases through the day or sleep and wakefulness is determined by this conductor *(Randler, 2008a)*. Biological rhythms are essential for our life! They can even decide between life and death as it can be felt, heard or seen in the rhythm of a beating heart. Two biological scientists of the University of Minnesota (Willard Koukkari and Robert Sothern) named the biological rhythm as “A Primer of the Temporal Organization of Life, with Implications for Health, Society, Reproduction and the Natural Environment” *(Koukkari & Sothern, 2007, pp. 1)*. To correctly interpret the meaning of this definition, the most important framework conditions should be clarified.

In general, a rhythm is determined by four criteria. First, the biological system in which it was observed, second the type of process that generates the rhythm, third the function that the rhythm performs, or a specific criterion, such as the frequency with which the rhythm repeats itself *(Aschoff, 1981)*. In this case, the internal rhythm describes a recurrent event in a biological structure system at a regular interval – biological rhythm *(Kalmus, 1935)*. The interval, in which a biological rhythm repeats itself, is deciding for its description. Sunset and sunrise, sleep and wakefulness or even the opening and closing of flowers reflect the complex and connected system of the biological rhythms and is represented in a large network *(Koukkari & Sothern, 2007)*. While these examples only represent intervals of daily fluctuations, shorter and longer variations within the period of biological rhythms can also be present. There are three common domains of biological rhythms: *ultradian*, *circadian* and *infradian* rhythms. Biological rhythms are described as *ultradian* when their period is shorter than 20 hours. The range of ultradian rhythms is very large and extends from seconds (e.g. EEG activity in humans by Krippke, 1972) to minutes (e.g. cortisol secretion in the blood stream of horse *by Drake & Evans, 1978) to* hours (e.g. enzyme activity in the unicellular organism Euglena *by Blazer et al., 1989).* Biological cycles with periods repeated in intervals longer than 28 hours are called *infradian*. *Infradian rhythms* can be repeated in weeks (e.g. organ transplant rejection in humans by DeVecchi et al., 1981), months (e.g. menstrual cycle in women by Presser, 1974) or years (migration of birds by Gwinner, 1977). In between those two biological rhythms, there is the so-called *circadian rhythm*, which has a leading part in biology as also in this dissertation. A circadian rhythm has a period of about 24 hours due to earth's rotation and its resulting alternation of light and darkness. These rhythms got a special feature: they have also a nearly 24-hour period even when the organism is isolated from external/environmental influences. Circadian rhythms can therefore "free-run" in an organism independent of an external synchronizer (zeitgeber) *(Randler, 2008a; Koukkari & Sothern, 2007)*. These and other particularities of the circadian rhythm are described later in the part "**Theoretical background".**

The discovery of the presence of biological rhythms dates back to the 18th century to the former geophysicist and astronomer Jean Jacque De Mairan from France *(De Mairan, 1729)*. Even though he was not a biologist, he had enjoyed watching his mimosa plants in his garden and discovered that they opened and closed their leaves at a certain period of time in one day. The curiosity and desire for discovery lay in his blood and he wanted to know why his plants handled it that way. He first assumed that it could be due to the effects of light and put some of his plants in his basement to separate them from environmental influences. And lo and behold, his plants were still closing and opening their leaves for nearly the same period of time as before *(Schibler, 2005)*. At this time, however, it was not clear what exactly caused the biological rhythm. A few years later, the work of the German biologist Erwin Bünnig was to bear fruit. Bünnig discovered in gene mutation studies with bean plants that circadian rhythms might be inheritable *(Bünnig, 1932; 1935)*. For a long time intensive research was carried out to confirm the original assumption of Bünnig and to find out further which mechanisms are responsible for the inheritance. Then in the 70s, the breakthrough should come: the two researchers Konopka and Benzer discovered mutations in the genetic structure of the drosophila flies and observed dramatic variations in their rhythmic behavior concerning the internal biological rhythm. All causes can be located to one specific gen on the X chromosome. A few years later, Konopka and his research team can isolate the special “clock gen” and named it “period” (short “per”) and were able to show that the oscillator for the internal biological rhythm is due to a particular gen *(Konopka & Benzer, 1971; Zehring et al., 1984)*. At the same time, a second research team discovered a certain gen to be responsible for the biological clock *(Bargiello, Jackson & Young, 1984)*. Bargiello and his colleagues could also show that if “per” is integrated in the genetic structure of a drosophila flie with a problematic phenotype mutation, some rhythmic behavior variations can be restored. The two research teams competed head-to-head for whom to publish first this explosive and groundbreaking found. In the end, both articles appeared in the same year (1984) and culminated with the highest honor of three scientists (Jeffrey Hall, Michael Rosbash and Michael Young) from the teams: the Nobel Prize for Medicine in 2017 *(www.zeit.de[1])*. Outstanding in Hall, Rosbash and Young's life work was not only the finding that our internal clock is determined by genetics, but also the fact that it has a profound impact on our daily rhythm. Flies in which the mutations in "per" had a pathological phenotype were no longer able to produce a regular rhythm of active and resting phases and suffered terribly.

Not to that extent, but similar effects can be observed in the sleep/wake rhythm of long-time shift workers. Although the leading companies try to make shift work as comfortable and uncomplicated as possible for the body of the workers, they are constantly forced to fight against the inner, natural rhythm. In spite of the isolation of environmental influences, such as light and temperature, to create a "free-run" rhythm, it can lead to sleep disorders (problems to fall asleep and sleep through), an increased risk of stroke and disturbances in eating habits *(Wright, Bogan & Wyatt, 2013; Boivin & Boudreau, 2014; Li et al., 2016)*. However, not only in shift work, you always come across the relentless ignorance to fight against your inner rhythm. Even in everyday work, at university or at school, people are constantly coming up against their limits. At school, adolescents are forced to fight against their inner rhythm to perform in the early morning. However, a presumably hormonal change from “early birds” to “late risers” makes it even more difficult for adolescents to achieve adequate performance at school and results, for example, in worse grades *(Randler, Faßl & Kalb, 2017; Randler & Frech, 2009, Tonetti, Natale & Randler, 2015)*. Might it be shift work schedules, a school bell ringing too early or just a long night out dancing, the days when people went to bed at sunset and got up at sunrise are over. The demands placed on us and our inner rhythm by our daily lives must be mastered. In a world where it is about being available 24/7 and getting everything done now, faster and better, it is not always possible to live in conformity with our inner rhythm. In the short term, our body can handle this, but if our inner rhythm is ignored over a longer period of time, it can lead to serious health problems as is evident at shift work *(www.gesundheit.de[2])*.However, vegan lifestyles, yoga and Feng Shui refer to other intentions. The need within us grows to live in harmony with nature, our body and ourselves. Life-style and food bloggers live in a healthy way and you can watch them around the clock on Facebook, Twitter or Instagram. Never before had the relevance of our inner clock been greater for us. In conclusion, therefore, can only be said: It was a long journey to go for research witch is still going.

2. Theoretical background

2.1 Chronobiology

The concepts time, clock and rhythm are the key characteristics for the research field chronobiology. By union those three words, chronobiology deals with the systematic research of time processes *(Dunlap, Loros & DeCoursey, 2004)* and is known as the study of biological rhythms *(Koukkari & Sothern, 2007)*. The term chronobiology is composed together of the two words: Chrono (gr. "Chronos", engl. "Time") and Biology (gr. Bíos, engl. Live and gr. Lógos, engl. „Study“*[Randler, 2008a]*). In fact, chronobiology explores the individual differences in the biological rhythm of all living beings: from humans to animals and plants to the smallest cells in an organism.

To better understand the complex and cross-linked structure of chronobiology, one has to think outside the box and realize that this is a field of research with many links to other research disciplines. In 1937, it was recognized that chronobiology is an interdisciplinary field of research with growing enthusiasm and great importance for society. For this purpose, seven researchers met in Sweden to discuss the exploration of biological rhythms and examined three papers that were specialized in plant, animal and human rhythms and discussed this with a rather theoretical background. The group of researchers, then known as the “International Society for the Study of Biological Rhythms”, met several times. From meeting to meeting, the number of participants increased from 12 over 50 to several hundred in 1971 at the meeting in the USA. Here, the name was changed into "International Society for Chronobiology" *(Cambrosio & Keating, 1983; Sothern & Koukkari, 2007)*.

The research history of chronobiology dates back to the 18th century and is difficult to separate from the history of the biorhythm, because it forms the basis for chronobiology. As mentioned earlier in the introduction section, in 1729 a French scientist noticed the time-dependent opening and closing of petals in a 24-h rhythm *(De Mairan, 1729)*. In 1745, this phenomenon was recorded for the first time by the Swedish botanist Carl de Linné as the "flower clock". With the help of the “flower clock”, it should be possible to determine the time by the inclination and opening of certain types of flowers *(Randler, 2008a)*. As it has already been noted, there are individual differences in the biorhythm depending on the type of the flowers. Thus, there are also individual differences in humans. In 1901, O'Shea came to terms with this fact, reporting individual differences in the sleep duration of students. They needed different durations to be optimally rested and fit. 213 students reported to sleep eight hours, 58 students slept only seven hours and 34 students reported to need more than nine hours of sleep. Further years of research into individual differences in the human biorhythm followed and culminated with the isolation studies of Professor Jürgen Aschoff in the 1960s.

In his experiments, Professor Aschoff worked on finding out what synchronizes our inner biorhythm. For this purpose, he conducted studies in humans and isolated them completely from external influences for sometimes almost up to 4 weeks. The tst persons should be shielded from any external stimuli that could give those clues to the time. Initially served for this purpose, a former soundproof bunker from wartime. No sounds, no daylight and indications of the outside temperature were given to the test persons. Now, they were allowed to organize their daily routines by themselves. They could decide for themselves when they wanted to sleep and get up or when they wanted to eat and drink. Aschoff found that fluctuations in body temperature not only occur as a consequence of the change of light and darkness but are controlled by an endogenous synchronizer and have a rhythm of 25 h *(Aschoff, 1960; 1965 & 1967)*. With his research results, Aschoff coined that the internal rhythm, also known as circadian rhythm, can be determined not only by external factors but also by internal factors.

2.2 Circadian rhythm

Life, as we know it, is generated in cycles or rhythms with certain period lengths *(Randler, 2008a)*. One of the most important rhythms for the organization of life is the circadian rhythm. The circadian rhythm describes a specific type of our internal biorhythm with an approximate period length of 24 hours. Due to the change of light and darkness (due to the Earth's rotation), humans especially like to live according to a timetable in a constant change of sleep and wakefulness or rest/active phases *(Randler, 2008a)*. This change is essential for survival and provides an evolutionary advantage. During periods of rest, the organism can recharge its batteries and pass on the active phases. Furthermore, the circadian rhythm helps the organism to adapt to external conditions and thus offers an adaptive advantage. To put it this way, one knows what to do and when to do *(Dunlap et al., 2004)*.

The circadian rhythm is known as "internal clock" because it synchronizes certain biological processes within the 24-h rhythm. However, our internal clock does not work correctly all the time. Our internal clock has sometimes a spare number of hours. There may be rhythms with more or less than 24 h. Thus, if the circadian rhythm were controlled purely by internal/endogenous factors, our important biological processes would collide with the 24-h rhythm of Earth's rotation. An irregular, out of control life would be the result. Thus, the metronome of the circadian rhythm needs a small impulse from the outside (exogenous factors). These exogenous factors are also named as synchronizers or zeitgeber. The primary synchronizers on our planet are at first the change of light and darkness and second, the resulting temperature fluctuations. They are the necessary impulse from the outside and appear in a 24 h rhythm *(Koukkari & Sothern, 2007)*. For biological processes that fluctuate throughout the day, the term 24-h rhythm can sometimes be very misleading. Because this description would rather be based on a rhythm that has a period length of 24 h. This is not the case with the circadian rhythm, which is why the term "circadian" was introduced in 1959 by Franz Halberg. The root is composed of the words "circa" (lat. „circa", engl. about) and "dies" (lat. dies, engl. day), which means about one day. Halberg thus decided that all biological rhythms should be named as "circadian" if their period lengths were about 24 hours. A time shift between a few minutes to hours was taken into account (20 to 28 hours), depending on the type of process and species. The term circadian rhythm describes certain biological rhythms that got a period length of 24 h under the influence of exogenous synchronizers (change of light and darkness, temperature fluctuation), but only have a period length near 24 h when got isolated of the exogenous synchronizers. For example, the fluctuation of the body temperature renders a rhythm of about 25 hours (Wever, 2013). Halberg stated two conditions under which a biorhythm can be named as circadian rhythm: first, biological processes whose period lengths are synchronized by exogenous zeitgeber in a 24-h rhythm and second, biological processes whose period lengths under free-run conditions show a rhythm of about 24 h *(Halberg, 1959, pp. 235)*.

Circadian rhythms, like biorhythms, are generally determined by genetic factors and inherited from generation to generation. For this purpose, as mentioned in the introduction, the gene "PER" (short for period) on the X chromosome is responsible *(Konopka & Benzer, 1971)*. From a multitude of studies with insects (for example, fruit fly Drosophila, *Handler & Konopka 1979*) and rodents (for example, rats, *Richter 1967*), it has been found out that our internal clock has an exact seat in the brain. It could be located in the hypothalamus, a highly sensitive area of the brain where more than 20.000 neurons meet. The exact anatomical name for this area is suprachiasmatic nucleus, abbreviated SCN. Thus, the SCN could be determined as an endogenous synchronizer, but it works in concert with a number of other endogenous oscillators in the body (such as body temperature fluctuations) *(Koukkari & Sothern, 2007)*.

2.3 Chronotype

Although there is an empirically established predisposition to circadian preferences, differences in the expression of circadian rhythm may vary from individual to individual. Every person has this own preferences to organize their life within a day. Already in the year 1906, Marsh dealt with the repeating variations in different abilities over the day. For the first time, he characterized the classification of people into groups according to their time of day preferences. He was able to distinguish between so-called "morning-workers" and "evening-workers" *(Marsh, 1906, pp. 95)*. Over the years, research in circadian typology has been able to identify three significant types, so-called chronotypes: Morning types, Evening types and Neither types *(Adan et al. 2012)*. Depending on chronotype, specific behaviors can be identified with regard to the time of day preferences. Morning types like to start their day very early. They get up early, wake up early and reach their maximum mental and physical performance during the first half of the day. However, they soon get tired in the evening and like to go to bed early. Evening types, on the other hand, like to get up later and let the day begin calmly. Their maximum performance is more likely to be in the second half of the day. Unlike the Morning types, they can hold out for a long time in the evening and only go to bed late or early in the morning. Between these two extreme types are the Neither types. Their behavior shows parts of both types, but not that extreme *(Adan et al., 2012)*. The majority of the human population can be counted among the Neither types (60%). Only 40% can be divided into one of the two extreme groups. *(Adan et al. 2012)* Some research groups postulate an even sharper division into five subgroups: extreme Morning types, moderate Morning types, Neither types, moderate Evening types and extreme Evening types *(Horne & Östberg 1976)*. The Morning types are often compared with the day-active songbirds larks and the Evening types with the nocturnal owls. In the meantime, other names for the different chronotype classifications have been found. For example, the American psychologist Michael Breus embossed four types. According to him, there is the wolf, the lion, the bear and the dolphin. Depending on the characterization of sleep behavior, a special type can be assigned. With Breus, however, also other factors play a role for the subdivision. For example, personality traits and the need to sleep are taken into account. According to its classification, the wolf is a true Evening type with an extroverted personality and a moderate need for sleep. The lion, on the other hand, is an absolute Morning type and optimist. Bears are obviously characterized by an adaptable sleep-wake behavior. They should be regarded as open-minded people with good sleep quality. Last but not least we have the dolphins. They seem to be considered neurotic control freaks with a low need for sleep but a high need for safety *(Breus, 2016, pp. 15)*.

An important aspect in describing chronotype is its change over a person's span of life. Particularly with regard to sleep/wake behavior, relevant differences can be noted. In infancy there is a strong orientation towards Morningness *(e.g. Randler & Truc, 2013)*. At the age of 0–1 years, there are about 70% Morning types, and about 1% Evening types *(Randler, Faßl & Kalb, 2017)*. However, this morning orientation preference declines with increasing age and an evening orientation increases. At the age of 16 years, only 5% are Morning types and 19% are Evening types *(Randler, Faßl & Kalb, 2017)*. According to Roenneberg et al. (2004), evening orientation reaches its climax at an age of approx. 20 years. Here, adolescents describe themselves predominantly as evening-oriented, with girls (19 yrs.) having an earlier breaking point towards Eveningness than boys (21 yrs.). Roenneberg et al. (2004) described this age limit as a kind of marker to identify the end of adolescents. According to this marker, evening orientation decreases again and the adolescents would increasingly describe themselves as morning-oriented. For example at an age of 30 years, higher morning orientation (17%) can be recognized as compared to evening orientation (13%). This difference, of course, is small compared to early childhood. The majority show rather a typical Neither type behavior (70%) *(Randler, Faßl & Kalb, 2017)*. In this age range, life is strongly influenced by career and social contexts. A strong adaptation of the inner sleep/wake rhythm to the demands of everyday life is necessary to cope with it. A Neither type behavior therefore offers the best adaptation possibilities. Up to an age of 50 years, the age and gender related differences are to be registered. This also goes together with the typical age for menopause *(Hollander et al., 2001)*. From an age of 65 years and older, a broad picture of daytime preferences emerges. Roenneberg et al., (2004) argue that this can be due on the one hand by a less robust circadian system in older age *(e.g. Weinert, 2000)* or on the other hand on less regular social and light schedules. Furthermore, Roenneberg and his colleagues assume an endocrinological cause for the overall changes in chronotype during lifespan. Especially noteworthy, however, is the shift towards Eveningness among adolescents. Numerous studies confirm the shift of daytime preference during adolescent's age *(e.g. Bearpark & Michie, 1987; Kim et al., 2002; Randler, 2011)*. In addition, older adolescents report about getting up later at the weekend and going to bed later as well as about shorter sleep duration in general *(Mateo et al., 2012)*. In a study by Randler, Faßl and Kalb, this circumstance was investigated in a large age range (0-30 years). The break point towards Eveningness was found here to be earlier. In girls this was 15.7 years and in boys 17.2 years. These findings support the assumption of Roenneberg et al. that the change in daytime preferences has something to do with endocrinology and the onset of puberty.

As is already quite clear in puberty, there are gender differences regarding daytime preferences. Some studies have investigated gender-related differences in chronotype during childhood and did not find any significant differences *(e.g. Wickersham, 2006; Zimmermann, 2016)*. The gender differences then become clear in adolescents. Women and girls tend to describe themselves as more morning-oriented than men and boys *(Randler, 2007; Chelminski et al., 1997; Natale & Danesi, 2002)*. Lehnkering and Siegmund (2007) found out that this gender effect is prevalent in terms of chronotype, but that there is no difference between men and women in sleep efficiency. It should be noted, however, that women prefer to go to bed earlier and sleep longer than men *(Natale, Adan & Fabbri, 2009)*. Whether it is rationality or the desired "beauty-sleep" that motivates women to do this, it can be observed that in terms of sleep structure (such as sleep pressure or sleep phases) men are more influenced by their chronotype *(Mongrain, Carrier & Dumont, 2005)*. However, a study by Mateo et al. (2012) demonstrated that girls between the ages of 13 and 14 have higher Eveningness than boys. Further, girls reported earlier rising time on weekdays but later rising times on the weekend and longer sleep length on weekends. Some studies also found no significant gender differences at all *(e.g. Giannotti et al., 2002; Russo et al., 2007)*. As previously described in the Roenneberg study (et al, 2004), these differences manifest themselves up to an age of approx. 50 years. After that, larger fluctuations can be found.

As mentioned in the introduction, the genetic environment plays an important role in the development of the individual chronotype. Studies have shown that two particular alleles of the clock gene function as predictor for diurnal preference *(Katzenberg et al., 1998)*. This is probably a variation on the clock genes "Per1 and Per3", which is said to be responsible for an extreme diurnal preference *(Archer et al., 2003, Carpen et al., 2006)*. The clock gen "Per2" could so far be associated with Morningness *(Jones et al., 2016)*. In addition, twin studies have shown that the sum of all additive and non-additive genetic influences is up to 47% *(Vink et al., 2001).* In a report of Hur and his colleagues (1998) it is stated that in monozygotic twin studies the genetic variability accounted about 54% of the variance for chronotype. Hur, Bouchard and Lykken also pointed out that other factors such as gender (3%) and environmental influences might have an effect *(see also, Koskenvuo et al., 2007)*. These include social factors such as the current family situation. Morningness could be predicted by the presence of children in women *(Leonhard & Randler, 2009)*. Cultural and geophysical factors are also on the agenda *(Randler & Díaz-Morales, 2007, Roenneberg, Kumar & Merrow, 2007)*. People who are at home in subtropical regions are more likely to be Evening types *(Randler 2008b)*. Similar to the circadian rhythm, the expression of an individual chronotype is assumed to have an evolutive reason. A division into groups, which can be fit early in the morning to hunt at dawn when all red deer are on their way, and the night owls, which guard the camp all night, seemed to make sense more than 10,000 years ago *(Randler, 2008a)*.

In summary, chronotypology is concerned with investigating individual differences in human biorhythms and then attempting to classify them *(Randler, 2008a)*. Morningness-Eveningness is seen in this case as a unidimensional construct, with Morningness and Eveningness marking the two endpoints of one scale. For example, the Morningness-Eveningness Questionnaire *(Horne & Östberg, 1976)* only determines circadian preference on a specific phase of the day and categorizes the test person into groups by certain cut-offs. But classifying people has become a difficult task today. The general aim of a typology is to create categories and to classify people into them. However, there is no longer only "black or white", "one or the other". The "two-category system" had to give way. Instead, the test persons were also placed in categories between the extremes *(Roenneberg, 2015)*. In the meantime, research tends to let go of a division into groups. The standardized chronotypology gives way to a more daytime preference view where Morningness-Eveningness can be understood as a multidimensional construct. This allows considering the fact that a certain type of circadian preference may be more or less pronounced within an individual. Research suggests that at least Morningness and Eveningness should be considered as two separate dimensions and possibly other aspects, such as circadian fluctuations over the day, should be included *(Preckel et al., 2013; Oginska, 2011; Dosseville, Laborde & Lericollais, 2013)*.

2.4 Morningness-Eveningness-Stability Scale; improved (MESSi)

Morningness-Eveningness is usually determined by using different self-assessments, especially when conducting research in large samples. Depending on the purpose and context of the planed study, one can choose for example between the most commonly used Morningness-Eveningness Questionnaire (MEQ) by Horne and Östberg (1976), the Diurnal Type Scale (DTS) by Torsvall and Åkerstedt (1980) or the Munich ChronoType Questionnaire (MCTQ) by Roenneberg and his colleagues (2003) *(Adan et al., 2012, Di Milia et al., 2013)*. All these measurements have in common that they assess circadian typology as a one-dimensional trait, with Morningness and Eveningness marking the two endpoints of one continuum. Due to the work of other researchers *(e.g. Preckel et al., 2013; Oginska, 2011; Dosseville et al., 2013; Putilov ,2016)*, circadian typology should no longer be seen as a one-dimensional construct, but rather as a multi-dimensional circadian preference. Professor Randler and his colleagues (2016a) then considered the complex structure of the construct and created (from already three existing scales: Composite Scale of Morningness, Caen

Chronotype Questionnaire; CCQ, *Dosseville et al., 2013* and Circadian energy scale ;CIRENS, *Ottoni, Antoniolli & Lara, 2011*) the three-dimensional measurement: MESSi. The Morningness-Eveningness-Stability scale (improved), determines the individual daytime preference and its amplitude. The scale is a three-dimensional measurement and assesses Morningness-Eveningness with two dimensions and amplitude with one separate dimension. The dimension Morningness describes the affective facet of the morning orientation and takes for example into account how easy it is to get out of bed in the morning or how awake someone feels. The dimension Eveningness determines the affective facet of the evening orientation and evaluates activity aspects and mood in the evening. The third dimension Distinctness/Stability operationalizes the fact that circadian preferences fluctuate throughout the day. Subjective feelings, concentration and motivation play also an important role. The MESSi therefore consists out of three scales: Morning affect sub-scale (MA), Eveningness sub-scale (EV) and Distinctness/Stability sub-scale (DI). Each sub-scale is represented by five items with a 5-point Likert format. The sum-scores for each sub-scale reach from five to twenty-five. In terms of the MA and EV sub-scale, higher scores represent higher expressions in the representative trait. Concerning the DI sub-scale, a higher score represent greater fluctuations and therefore a lower stability. The MA sub-scale measures the affective facet of morningness-eveningness ("How easy is it for you to get up in the morning?") and the EV sub-scale determines the affective facet of the evening orientation ("After waking up, I feel sleepy for some time "). The DI sub-scale gives information about the stability of the orientation. It shows how much the expression of the facets fluctuates throughout the day ("I can be concentrated at any time of the day").

The MESSi does not categorize individuals into distinct chronotype groups (Morning types, Evening types or Neither types). The scale rather allows considering the fact, as mentioned earlier, that a certain type of circadian preference may be more or less pronounced within an individual. In addition, it reflects that individuals may show fluctuations in their circadian preference depending on other, contextual factors. So far, there is a cross-cultural study (Germany, Spain and Iran), a Spanish, Slovenian and Portuguese adaption of the MESSi and its validation among workers and students *(Rahafar et al. 2017, Diaz-Morales & Randler 2017, Tomažič & Randler, 2018, Rodrigues et al., 2018; Diaz-Morales et al. 2017)*. The three-factorial structure has been established by psychometric analysis *(Vagos et al., 2019)* and validations were done by using actigraphy as well as body temperature in a university student population *(Faßl et al. 2019; Weidenauer et al., 2019a)*. In order to be able to use the MESSi also in a school context this year the MESSi (adolescents) was validated in a sample size of 215 students *(Weidenauer et al., 2019b)*.

2.5 Physiology and health

The circadian rhythm is conditioned and influenced by a variety of biological/physiological markers. These markers help to investigate the circadian rhythms of an individual and, above all, to precisely determine them. For example, the exact internal circadian phase of a human can be determined using only one blood sample *(Wittenbrink et al., 2018)*. Gene expression analysis by epidermis samples are used to identify the accurately circadian phase to three hours from a single probe *(Wu et al., 2018)*. The circadian rhythm is in a kind of homeostatic balance with the biology of our body. If this is out of rhythm, serious consequences for health can occur. In the following, the biological/physiological markers of the circadian rhythm relevant for this dissertation will be discussed as well as other intervincing factors.

2.5.1 Morningness-Eveningness and sleep/wake behavior

Sleep can be understood as a state of rest that usually occurs periodically and serves recovery *(Becker-Carus[3], 2019)*. It is a complex biological process that plays a very important role in our lives. It can be often understood as a kind of counterpart to being awake and as a periodic interruption of the waking state. These periodic interruptions of the waking state are, however, indispensable for a healthy life *(Kleitman, 1963)*. The brain functions are limited to a minimum; the muscle tone is reduced to a maximum. The body temperature decreases...our body is shut down like a kind of computer. During sleep, our body can rest and recharge its batteries for the wake states. Past events are processed (dreaming), cells are renewed *(Kleitman, 1963, Becker-Carus[3], 2019)*. According to Borbély (1982), the human sleep is generated by two separate processes. In this "two-process model", sleep regulation is determined by a process S and a process C. Process S is determined by everyday sleep and wakefulness conditions, such as activity and sleep deprivation, which leads to sleep pressure and ultimately to the initiation of the sleep phase. Process C, on the other hand, is determined by the individual circadian phase of sleep and is initiated by a biological oscillator. Process C therefore runs independently of the daily conditions of sleep and wakefulness. The importance of circadian regulation of sleep is relevant and undisputed. This is particularly visible in the inheritance of different aspects in sleep wake timing *(e.g. Van Beijsterveldt et al., 1996; Andretic, Franken & Tafti, 2008; Adan et al., 2012)*. For example, Andretic et al., (2008) named sleep as a “complex phenotype” (pp. 362). In particular, twin studies have shown that various aspects of sleep can be inherited *(e.g. Linkowski, 1999; De Gennaro et al., 2008)*. With an inheritance rate of up to 96 percent, sleep aspects are the most inheritable trait in humans *(Andretic et al., 2008)*. Due to this heredity, certain individual phenotypic differences with regard to sleep wake timing occur. According to Roenneberg, differences in sleep characteristics can be generally traced back to individual differences in daytime preferences *(Roenneberg et al., 2007)*. Significant correlations between Morningness-Eveningness and sleep/wake timing as well as significant differences in sleep timing with regard to chronotype can be assumed. In general, it is known that Moring types tend to get up and go to bed earlier than Evening types *(Adan et al., 2012)*. This can also be proven by some studies *(e.g. Duffy et al., 2001; Horne & Östberg, 1976)*. In contrast, Eveningness for example is associated with later bed and wake times, a greater need for sleep, a greater morning sleepiness and shorter times in bed *(e.g. Taillard Philip & Bioulac., 1999; Taillard et al., 2004)*. As explained shortly before, sleep is regulated by two processes. The findings on the differences between Morning and Evening types refer purely to sleep/wake timing by process S. However, there is also evidence that the regulation of sleep by process C, which is regulated by the individual circadian phase, differs in chronotype. Duffy et al. (2001) explores that the internal circadian clock of Morning types is set to an earlier point as compared to Evening types. Mongrain et al. (2004) also proved that Morningness-Eveningness is associated with a difference in circadian period and phase.

If compare individual differences in sleep behavior from weekday to weekend, clear differences in terms of circadian typology are also evident here. During week, Evening types presented shorter times in bed and a shorter sleep duration. This lead to a greater need for sleep, greater morning sleepiness and higher caffeine consume in Evening types *(Taillard et al., 1999; Taillard et al., 2004)*. On the weekend, in contrast, Evening types show later bed and rise times compared to Morning types and longer times in bed *(Taillard et al., 1999, Roepke & Duffy, 2010)*. More irregular sleep/wake habits are the consequence *(Taillard et al., 1999)*. These and further results demonstrate that Evening types accumulate a sleep debt during week and try to compensate this on the weekend. This so-called "social jetlag" is common in our society because we are ruled by given time schedules at work, at university or in school *(Roenneberg et al, 2012; Roenneberg, 2012)*. A large discrepancy between internal biological clock and time schedules predetermined by social factors can lead to serious illnesses. For example, chronic sleep loss *(Wittmann et al., 2006)*, obesity *(Roenneberg et al., 2012)* or depressive symptoms *(Levandovski et al., 2011)*. Adolescents meet this circumstance, however, particularly hard because the individual circadian preference changes throughout the life span "from lark to owl". Previous research shows that evening-oriented students have a disadvantage in school relevant achievement compared to morning-oriented students *(Preckel et al., 2013, Randler & Frech, 2006)* and that these findings are also due to social jetlag *(Díaz-Morales & Escribano, 2015)*.

2.5.2 Morningness-Eveningness and body temperature

The human body temperature is controlled by a complex feedback system. The feedback system is to be understood in such a way that when sensory information from the environment reaches our body, it triggers a physiological process. The physiological processes that are set in motion then cause a difference between the prevailing temperature and the required one. The thermoregulation system must now balance and follow the action with a reaction. Put simply, the thermoregulation system keeps the body temperature in balance between heat gain and heat loss *(Hammel & Pierce, 1968)*. Similar to cortisol segregation, we also find circadian fluctuations in body temperature during the day. The body temperature has a very stable daytime rhythm, which has a nearly 25 h cycle even when controlling for environmental influences such as light and darkness *(Wever, 2013)*. Already in the 60s Prof. Aschoff found out that the circadian rhythm of body temperature can be seen as a kind of marker for the circadian rhythm in general *(Aschoff, 1960, Aschoff, 1965, Aschoff, 1967)*. The rhythm of body temperature under normal conditions (constant routine) shows an increase shortly before waking up and then increases continuously. Between 2 p.m. and 8 p.m. a kind of plateau is formed, where the body temperature shows a constant temperature level (approx. 37 degrees) and reaches its peak in the late afternoon (approx. 5 p.m.). From this time on, the body temperature drops again and is lowest in the early morning hours (approx. 5.00 a.m.) *(Waterhouse et al., 2005; Krauchi & Wirz-Justice, 1994)*. The fact that the body temperature is easy to measure and that it can be measured under normal conditions in daily life, makes it a pioneer in chronobiological research. Here the core body temperature, the oral temperature or the skin temperature can be determined. Usually, core body temperature is used, because its fluctuations are robust and less influenced by environmental issues. Nevertheless, to measure core body temperature, rectal probes are often to be used. Another possibility is that the participants have to wear small sensors over a long period of time or even to swallow small data-logger pills *(Kolka, Levine & Stephenson, 1997; O´Brien et al., 1998; Bryne & Lim, 2007)*. These methods are unpleasant and beyond that quite expensive. Furthermore, frequent controls and surveillance of the participants are necessary. In order to make it more comfortable for the participants, the rhythm of the skin temperature is nowadays used to determine. The skin temperature has also been proven to follow a circadian rhythm *(e.g. Krauchi & Wirz-Justice, 1994)*. However, it looks different to the body temperature that can be due to a special thermoregulatory cascade, which is possibly triggered by nocturnal melatonin segregation *(Cajochen, Krauchi and Wirz-Justice, 2003)*. The skin temperature drops rapidly after awakening and decreases over the rest of the day. The minimum is reached in the early evening hours (approx. 7 p.m.). During the night, the skin temperature increases again and peaks in the early morning hours (approx. 6.00 a.m.) *(Krauchi & Wirz-Justice, 1994; Sarabia et al., 2008; Martinez-Nicolas et al., 2013)*. The rhythm of the skin temperature can be influenced by environmental characteristics such as physical activity or environmental temperature. Above all, the amplitude is strongly influenced but the acrophase seems to be quite robust *(Martinez-Nicolas et al., 2013)*. The fluctuations during a 24-h period normally show a wide range (between 31 °C and 36 °C), which depends on the technique deployed by different sensors *(Sarabia et al., 2008; Martinez-Nicolas et al., 2013)*. These sensors are temperature data loggers, called iButtons. iButtons measure the skin temperature within a range of – 40 to +85 degrees Celsius with a possible deviation of 0.5 degrees Celsius. Originally, they were developed to keep track of the temperature of goods during longer transport distances. However, one can quickly understand their importance for research. The iButtons, which are now "misappropriated", consist of a temperature sensor, a computer chip with real-time measurement, storage space for the data obtained, and a lithium battery. All this is encased in a stainless steel cap. The iButton is placed directly on the skin and must be in contact with the skin for the entire measurement period. The possible measuring time intervals can range from a few seconds to hours and must be programmed before the first application. The usual interval is 1 or 10 minutes. Ultimately, this depends on the research question. The data then stored in the chip can be transferred to the respective computer via a USB connection and evaluated with the help of a software (1-wire). The iButtons used for the studies in this dissertation belong to the "Thermochron Temperature Data Loggers" of type DS1922L and are therefore among the latest models on the market. With a size of 16.25 x 5.89 square millimeters, they are small and handy (see **Picture 1**).

Picture 1: Front and back of an iButton (DS1922L)

Their advantage is, they are wireless and therefore it is not necessary to stay within the reach of a power source or router. Their biggest disadvantage is that they are not waterproof. Therefore, the test persons have to take off the iButton e.g. before taking a shower, to store it carefully and to put it back on the skin afterwards. This can lead to loss of data and equipment during daily use *(Van Marken Lichtenbelt et al., 2006; Smith et al., 2009)*.

Analyzing the circadian fluctuations in body temperature over the course of the day, individual differences become apparent. These individual differences can be related to circadian typology. Research has shown that Morning types tend to have earlier acrophase times (6 to 7 p.m.) in body temperature and their temperature minimum occurs also earlier (3 to 5 a.m.) compared to Evening types (acrophase: 8 to 10 pm, nadir: 5 to 6 am) *(Kerkhof & Van Dongen, 1996; Beahr, Revelle & Eastman, 2000; Waterhouse et al., 2001, Bailey & Heitkemper, 2001)*. Duffy et al. (1999) could show that Morning types have also an earlier circadian phase of the core body temperature compared to Evening types. Concerning oral temperature, Morning types tend to have earlier peak phases than Evening types *(Gupta & Pati, 1994)*. These individual differences can be seen determining in free-living subjects *(Beahr et al., 2000)* as well as under a constant routine *(Kerkhof & Van Dongen, 1996)*. In contrast Evening types tend to have a larger amplitude of body temperature. This means their rhythm of body temperature shows larger fluctuations during day *(Beahr et al., 2000)*. Concerning the relation of circadian variation and skin temperature, Sarabia et al (2008) has already stated that the skin temperature, in the case of this study the wrist temperature compared to the oral temperature, can be seen as a reliable marker for the circadian rhythm. With a heritability of 45% up to 70% of the wrist, temperature parameters, a relevant genetic influence can be suggested *(Lopez-Minguez et al., 2015)*. Numerous other studies are now taking advantage of the fact that the skin temperature can be seen as a reliably temperature marker for circadian rhythmic. For example, Shift-work studies *(Ferreira et al., 2013)* as well as studies that assess the optimal time for physical activity *(Rubio-Sastre et al., 2014)* use the skin temperature. However, what has not happened so far is the exact investigation of differences between Morning and Evening types with regard to skin temperature. It is yet an open question, whether measures of skin temperature reveal the same relations to circadian preference, given that they may be less sensitive than measures of core body temperature.

2.5.3 Morningness-Eveningness and cortisol

Cortisol is well known as the “stress hormone” and belongs to the group of Glucocorticoids. It is produced via the hypothalamus-pituitary-adrenal axis ("HPA") and released into the bloodstream whenever the body needs energy. In more detail, filtered information from the environment for example light, heat or cold, arrives collected in the control center hypothalamus. The hypothalamus signals via a hormonal messenger (adrenocorti-cotropic hormone (ACTH)) to the adrenal cortex that cortisol is to be produced and should be released into the bloodstream. ACTH is produced and launched on average 7 to 15 times a day. About 15 minutes later cortisol can be released into the bloodstream. Cortisol is on the one hand released pulsatile in the bloodstream during the day but also shows on the other hand a circadian rhythm in segregation. The circadian segregation is very sensitive to individual and environmental influences, like light exposure, anxiety or stress *(Molina, 2006; Czeisler et al., 1976; Jung et al., 2010)*. Under normal conditions, the cortisol fluctuation follows a distinct rhythm with small (short duration) but strong (large amplitudes) episodes *(Fries, Dettenborn & Kirschbaum, 2009)*. The cortisol level starts to increase in the second half of the night and peaks in the early hours of the morning. After that, it decreases slowly throughout the rest of the day and shows its nadir in the first half of the night *(Tsigos & Chrousos, 2002; Molina 2006)*. This sharp increase of cortisol segregation in the early morning occurs immediately after awakening and reaches its highest level at least 30 to 45 minutes after awakening. This effect is called: Cortisol-Awakening-Response (CAR) and was first investigated by Pruessner et al. in 1997 *(Fries et al., 2009; Pruessner et al., 1997)*. The cortisol level increase here up to 50 to 75 percent *(Pruessner et al., 1997)*. CAR occurs with a 75 percent probability in all adults after awakening *(Wüst et al., 2000)*. It is comfimed, that the CAR is a stable phenomenon and is less influenced by other factors. Studies prove that neither age, weight, smoking, drinking alcohol, sleep duration, time of wakening nor using an alarm clock got an impact on the CAR *(Wüst et al., 2000, Pruessner et al., 1997)*. What seem to have an influence on CAR, however, are gender and the individual chronotype. Women tend to have a stronger/steeper increase of cortisol with a delayed peak and decrease compared to men *(Wüst et al., 2000, Pruessner et al., 1997)*. Concerning circadian typology, Morning types tend to show higher cortisol levels after awakening than Evening types *(Bailey & Heitkemper, 1991; Oginska et al., 2010; Randler & Schaal, 2010)*. This effect can be seen on the one hand directly after awakening, with Morning types having higher cortisol levels than Evening types *(Randler & Schaal, 2010)* and on the other hand up to a timespan of 30 to 45 minutes after awakening *(Kudielka et al., 2006)*. In addition, it could be noted that Evening types feel less aroused than Morning types at the same time in the morning *(Bailey & Heitkemper, 1991)*. This circumstance suggests that the higher cortisol levels in the morning give a clear advantage over the Evening types for Morning types. It is probably easier for them to get out of bed in the morning and be more active than Evening types. Therefore, it is not surprising that the peak of cortisol level occurs earlier in Moring types in the morning *(Bailey & Heitkemper, 2001)*. Although the difference between the chronotypes seems very stable with regard to their cortisol levels in the morning, no significant difference in cortisol levels over the rest of the day could be detected *(Griefahn & Robens, 2008)*. Another important factor regarding the cortisol level in the morning seems to be the day of the week. There is evidence pointing towards a difference in CAR between weekdays and weekend. Kunz-Ebrecht and her colleagues showed that CAR is greater on working days compared to weekend days (the increase of the cortisol levels between awakening and 30 minutes later). The participants in this study rated themselves as more stressed during week as compared to the weekend *(Kunz-Ebrecht et al., 2004)*. This confirms the assumption, that CAR can be influenced by stress as well as cortisol segregation in general. Further, the rise of the cortisol level after awakening is also steeper on weekdays compared to days on the weekend *(Thorn et al., 2006)*.

2.5.4 Morningness-Eveningness and activity

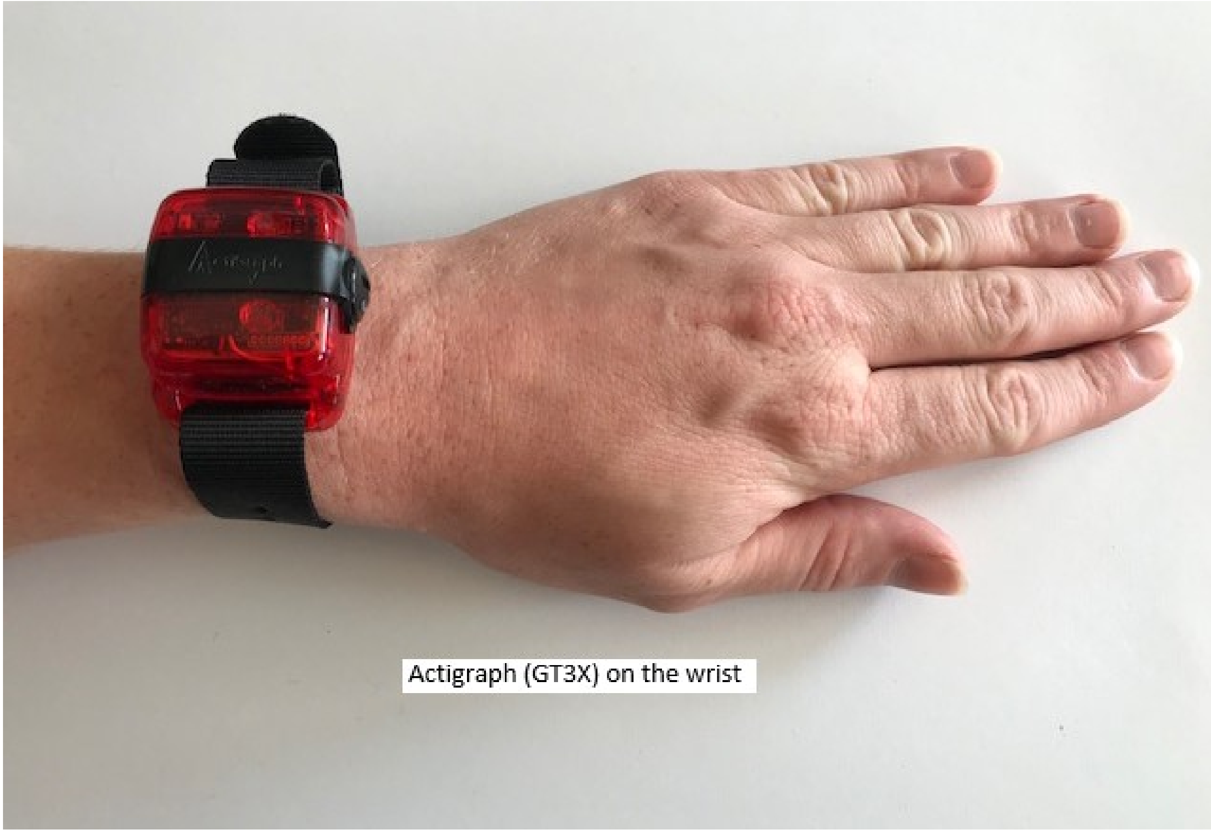
The following section refers to activity in connection with daytime preferences. Activity here refers to physical activity. This includes everything, such as running, swimming, sports, household or simply playing ball. Everything, except of standing, sitting and lying.

For a long time now, research, especially health-related research, has been focusing on finding out how physical activity affects our body, what is the appropriate level or when the best time of day would be. First, however, we need to clarify exactly what is meant by physical activity. The three epidemiologists Caspersen, Powell and Christenson from Atlanta deal with this terminology and differentiate between physical activity, exercise and physical fitness. According to them, physical activity is meant to be: “any bodily movement produced by skeletal muscles that results in energy expenditure. The energy expenditure can be measured in kilocalories” *(Caspersen, Powell & Christenson, 1985, pp. 126)*. Exercise has these prerequisites in common, but in contrast to physical activity it is planned and structured. Exercise is carried out because one pursues a goal with it, e.g. to achieve physical fitness. According to Caspersen et al., physical fitness is described as "a set of attributes" that a person can have. These attributes are then either health or skill related *(Caspersen, Powell & Christenson, 1985, pp. 126)*. It is well known that physical fitness or physical activity can be seen as a preventive measure against a variety of illnesses. For example, regular exercise can reduce the risk of colon cancer by 30 to 40 percent. In addition, other diseases like diabetes, hypertension or depression seem to be reduced with regular physical activity *(Warburton, Nicole & Berdin, 2006)*. Physical activity is therefore essential for a healthy life.

This fact is, of course, followed by two questions: question one deals with determining an optimal level of physical activity and question two refers to the perfect time of day for physical activity. The question of "how" can on the one hand be answered by self-assessments. Questionnaires such as the International Physical Activity Questionnaire, IPAQ *(Booth, 2000; Booth, 1996)* make it possible to compare appropriate physical activity behavior of people on an international level. On the other hand, physical activity can be assessed objectively by activity monitoring. Activity monitoring is in most of the cases done by actigraphy. Actigraphy is a non-invasive, objective and, above all, cost-effective method of determining and monitoring daytime fluctuations in activity. For this purpose, a so-called Aktiometer or actigraph record the body movements of the carrier over a certain period of time. The measurement period can vary from a few days to weeks. Usually the monitoring should last at least five days or more to obtain reliable results. An actigraph looks like a watch or, to put it more contemporary, like a fitness tracker. Depending on the test persons' circumstances, it is often worn on the wrist of the non-dominant hand. For infants and animals, it is possible to attach the actigraph to the ankle. If additional physiological parameters are to be determined, such as body temperature, it is also worn around the chest or hip together with other measuring instruments. An internal tri-axial (vertical, horizontal and lateral) accelerometer (acceleration sensor) records the body movements at a sampling frequency of 100 Hz. The collected data were then stored in the device and following transferred to a computer via USB or Bluetooth. With the help of the dedicated software ("ActiLife") the data can be visualized as rest-activity plots, where body movements are represented in dimensionless units, called "activity counts" over epochs of 1 minute *(Morgenthalter et al., 2007; Sadeh, 2011; Cellini et al., 2013; Littner et al., 2003)*. The actigraphs used in this dissertation were of the model series GT3X of the company "Actigraph" from Pensacola, Florida. The device is quite small and of lightweight (dimensions: 4.6cm x 3.3cm x 1.5cm, weight: 19 grams) with a red colored case, as it can be seen on **Picture 2**. In the studies of this dissertation, the test persons always wore the actigraphs on the wrist of their non-dominant hand with unisex, black bands, please see **Picture 3**. Actigraphy is used today in many ways, e.g. to determine activity rates in animals *(Calogiuri, Weydahl & Roveda, 2011)* or to study behavior during flights to other time zones *(Montaruli et al., 2009)*. Most frequently, however, it is used in sleep research to investigate sleep disorders and faulty sleep behavior in patients *(Littner et al., 2003; Morgenthaler et al., 2007)*.

Picture 2: Front of an Actigraph of the model series GT3X.

Picture 3: Actigraph on the wrist of the non-dominant hand.



Concerning question two: when is the perfect time of day for physical activity? ; Research has found different results. On the one hand, it could be shown that physical activity is most effective in the morning compared to the evening *(e.g. Rubio-Sastre et al., 2014)*. On the other hand, it could be proved; movements can be done fastest in the afternoon *(Gueugneau & Papaxanthis, 2010)*. The key factor seems to be above all the type of physical activity and the objective pursued. A generally valid time for physical activity cannot therefore be globalized, because the individual circadian preference is also very important for this. Vitale et al. (2015) suggested that Moring types tend to have an earlier acrophase in physical activity (02:32 p.m.) than Evening types (04:53 p.m.). Natale et al (2006) showed similar results with Evening types tending to have the acrophase of physical activity at 05:26 p.m. and Morning types at 04:39 p.m. Additionally, they can demonstrate a significant synchronicity effect for physical activity. In detail, Morning types were more active between 08:00 and 11:00 a.m. compared to Evening types. Evening types in contrast were more active at night (between 12:00 p.m. and 02:00 a.m.). In a Korean Study, a significant effect of chronotype on the acrophase of physical activity could also be found.

However, the acrophase was at 08:47 a.m. in Moring types and at 10:29 a.m. in Evening types *(Lee et al., 2014)*. A potential cultural influence with regard to daily routines and time schedules cannot therefore be excluded. Regarding adolescents and given time schedules in school, it could be shown that chronotype influences physical activity only on the weekend, when the students are allowed to behave according to their inner rhythm *(e.g. Tonetti, 2007)*. Schaal, Peter and Randler (2010) stated that morning-oriented students are more active in general than evening-oriented ones and they gave more positive attributes to the effects of physical activity. Evening-oriented students in contrast spend more time with electronic media (like smart phone and computer) than morning-oriented students *(Randler et al., 2016b; Randler, Horzum & Vollmer, 2014; Vollmer et al., 2014)*.

2.5.5 Morningness-Eveningness and personality

According to Eysenck *(2012, pp.1, part Introduction)* “personality is a fundamental concept in psychology”. For me, personality can be understood as the whole amount of traits that characterize an individual. However, today there are a vast number of models and theories that try to get to the bottom of an exact explanation and, above all, to explore personality. In this dissertation, however, the focus is on the individual differences with regard to Morningness-Eveningness. In the following I will therefore only deal with the relationship between Morningness-Eveningness and personality. Because it is known that, some individual differences between chronotypes can be related to individual differences in personality *(Adan et. al. 2012)*. Some previous studies are based on a correlation between Morningness-Eveningness and personality with respect to Eysenck's personality theory. This theory postulates a multidimensional view of personality with the manifestations: extraversion, psychoticism and neuroticism. Eysenck’s theory tries to explain, why some people manifest certain behavior *(Eysenck & Himmelweit, 1947; Eysenck & Eysenck 1976; Gray, 1981)*. Both, the review by Adan et al. (2012) and the review by Tankova, Adan and Buela-Casal (1994) report a correlation of Extraversion and Eveningness with Evening types reporting higher scores in Extraversion. Further studies support these findings *(e.g. Mitchell & Redman 1993; Langford & Glendon 2002)* and thus confirm that the association between Eveningness and Neuroticism is the most stable one. According to Adan et al.

(2012), contradictory results can be found with regard to the neuroticism scale. Some studies report higher scores in Evening types *(Tankova et al., 1994; Mecacci & Rochetti, 1998)* and some report higher scores in Morning types *(Tankova et al., 1994; Langford & Glendon, 2002)*.

A large number of further studies focus on the connection between Morningness-Eveningness and personality with regard to five dimensions. The five-factor model will be attributed to Costa and McCrae (1992). They postulate, to measure personality, the NEO- Five Factor Inventory (NEO-FFI). Here, the personality traits are determined within five dimensions, the so-called ocean dimensions: Openness to experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism. Test persons that score high in Openness are inquisitive, prefer variety in their lives and have multifaceted interests (e.g. “I am inspired by the motives that could be found in art and nature.”) Conscientious test persons are described as tidy, reliable and disciplined (e.g. “I keep my things neat and clean.”) while extroverted test persons are characterized as sociable, talkative and do like encouragements (e. g. “I really like to talk to other people.”). High values in the agreeableness scale suggest that the test person is caring, compliant and has a strong need for harmony (e.g. “I try to be kind to everyone I meet.”). Test persons classified as neurotic tend to be nervous, anxious and insecure (e.g. “I often feel stressed and nervous. “).

If we look now at the relationship between chronotype and personality in five dimensions, the following picture emerges: Conscientiousness is the personality trait that is mostly correlated to Morningness followed by Agreeableness *(Tsaousis 2010, Adan et al. 2012, DeYoung et al., 2007)*. This effect occurs even when being controlled for age and gender *(Randler 2008c)*. Eveningness, for example, could be related to Neuroticism, but only in female adolescents *(Randler 2008c)*. Interestingly, it was found that Agreeableness and Conscientiousness were positively correlated with sleep length *(Randler 2008c)*.

Chronotypes also differ in certain personality values: Morning types have a higher acceptance of social values (conservation and self-transcendence) and Evening types have a higher correlation with the preference for individual values, like openness to change and self-enhancement. Vollmer and Randler (2012) focused the reason for that in the cost-benefit consideration of the Evening types for the early social schedules. Furthermore, it could be determined that the chronotypes differ in temperament and character dimensions. Morning types have a higher persistency and show higher values in cooperation while Evening types scored higher in novelty seeking *(Randler & Saliger 2011)*. Díaz-Morales published in 2007 that chronotypes differ in their personality styles because they are acting individually with their social and environmental demands. Morning types preferred realistic and thought-guided thinking styles as well as the conservation-seeking style. However, Evening types preferred intuitive, feeling-guided and innovation-seeking thinking styles. They also preferred an unconventional behavior style, while Morning types were related to a conforming behavior style.

2.6 school-relevant achievement

In the present dissertation, aspects were determined that are necessary in everyday school life in order to master the requirements of the school system. These aspects were summarized under the term “school-relevant achievement”. This includes above all attention and concentration. Therefore, school-relevant achievement was assessed with the help of the Frankfurt Attention Inventory (second edition). The FAIR-2 makes it possible to determine three performance-based values, which can be used to describe the attention or concentration performance. The following section therefore deals with attention in general. Then the constellation of the FAIR-2 is explained in more detail and a short differentiation from the construct concentration is given. In addition, daytime variations in attention are discussed. Finally, the relation between school-relevant achievement and Morningness-Eveningness is referred to.

2.6.1 Attention

Cognitive functions include all brain psychological aspects related to recognition. This contains perception, memory, planning, problem solving and imagination as well as thoughts and expectations *(Häcker & Stapf, 2009, pp. 520)*. Attention can therefore also be counted as a cognitive function. Attention can be understood as a construct in which the performance of attention is reflected in various aspects and can be operationalized. The general attention performance can therefore be seen as the basis for coping with a multitude of cognitive demands in daily life *(Schweizer, 2005)*.

Research on the construct attention goes back well over 100 years. The clarification of what attention exactly is and what processes are needed for it has brought a variety of models and theories that make it difficult to give a unified definition of attention *(Moosbrugger & Oehlschlägel, 1996)*. In 1890, William James was the first trying to give a definition of attention. He describes attention as “the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought” *(pp. 404)*. Already decisive for this model are two important aspects, which are still valid today in modern attention research: the selection process and the limited capacity to maintain attention. Modern attention research can be seen from 1950 onwards. It draws attention mainly to the information processing process *(Goldhammer & Moosbrugger, 2006)*. The influential filter model of Broadbent (1958) belongs to the early attention models and postulates a model of perception with different stages. According to Broadbent, a certain basic or first processing happens with all incoming stimuli. Physical properties of the incoming stimulus, such as size, color, or shape, are stored in the short-term memory. Non-physical properties of a stimulus such as semantic properties, on the other hand, are subject to strong capacity restrictions. A selection process or a selective filter is therefore required to filter out the relevant stimuli and to ignore the irrelevant stimuli. The relevant stimuli can thus be better processed and transferred from the short-term memory to the long-term memory *(Broadbent, 1958, Lachter, Forster & Ruthruff, 2004)*. Based on the filter model, the attention process can be understood as a kind of selection process. Rützel (1977) believes that both external perception (perception of the nature of a stimulus with the sensory modalities) and internal perception are aligned with the incoming stimulus. The simultaneously incoming stimuli are then filtered according to certain criteria *(Rützel, 1977)*. The definition by Brickenkamp and Karl (1986), who claimed that attention is the ability of an individual to turn to task-relevant stimuli by ignoring task-irrelevant stimuli, was also highly appreciated. The capacity model of Kahneman (1973) takes care of the second important point of attention: a limited capacity. The capacity to process incoming stimuli is considered an important resource, but limited. Kahneman (1973) proposed that attention can be seen as a resource pool of capacity, and that all processing tasks consume resources from this limited pool. The resources must therefore be distributed wisely, which is made possible by the selection process *(Schneider & Fisk, 1983; Goldhammer &*

Moosbrugger, 2006; Kahneman, 1973). In contrast to the attention model of Kahneman (1973), which follows the approach of an unspecific capacity, there is the "Multiple Resource" model of Navon and Gopher (1979). This model also stems from the information processing approach and can therefore be counted among the models of modern attention research. In Kahneman's capacity model, it is assumed that there is a limited unspecific capacity that is used in the processing of incoming information and centrally controlled. Navon and Gopher, on the other hand, focus on a more specific approach in which the capacity can be embodied in multiple resources. According to Navon and Gopher, information processing depends on specific cognitive resources. Different resources are responsible for processing different areas or modules. For example, there is one resource for processing visual stimuli and another resource for processing auditory stimuli. However, if a resource is busy processing two very similar incoming stimuli, the limited resource of this module will be overloaded. Here a specific resource of another module can be used to support the information processing. According to Navon and Gopher, however, this is associated with a lower processing efficiency, since the supporting resource is actually specified for another processing module. However, the elegant model of Navon and Gopher, like so many models of information processing, has some shortcomings. For example, it remains unclear how the individual specific resources or modules are controlled and how many there are. To cope with an attention process, several information channels are usually used simultaneously *(Navon & Gopher, 1979; Goldhammer & Moosbrugger, 2006; Schweizer, 2006)*. Therefore, a general distinction of different attention processes or aspects of attention is advantageous. Based on the attention research of Posner and Boies (1971) as well as Posner and Rafal (1987) there are different components of attention that could be divided into two areas: one area describes the intensity aspects of attention and the other focusses on the selection process. The intensity aspect includes the so-called alertness and the vigilance. Alertness is a kind of wakefulness. In this case, there is a balance between physical and psychological willingness to react in order to guarantee optimal wakefulness or even alertness towards the environment *(Goldhammer, Moosbrugger & Schweizer, 2007)*. The state of general wakefulness is referred to as tonic alertness and the ability to increase the willingness to react to external stimuli for a short period of time as phasic alertness *(Sturm et al., 1999)*.

Vigilance is a kind of permanent/sustained attention of the organism. Permanent responsiveness is maintained in order to keep attention for a certain period of time and to continuously evaluate the incoming stimuli *(Goldhammer, Moosbrugger & Schweizer, 2007)*. In summary, Vigilance describes the ability to maintain and control a certain level of alertness *(Sturm & Willmes, 2001)*. To measure alertness, a classic reaction time task is used, where the test person is expected to react as quickly as possible to external stimuli (sensory, visual or auditory). When measuring vigilance, on the other hand, the focus is not only on reaction time but also rather on made mistakes or missed reactions to an external stimulus and their temporal course *(Sturm & Willmes, 2001)*. In the second area (selection process), there are the divided and the selective attention. The divided attention describes the ability to split resources in the information processing process between simultaneously incoming stimuli *(Goldhammer, Moosbrugger & Schweizer, 2007)*. The aforementioned "Multiple Resource" model by Navon and Gopher (1979) refers above all to this. But the "Attention Module" model by Allport (1980), for example, also deals with the simultaneous processing of incoming external stimuli. Accordingly, incoming stimuli could be processed simultaneously taking into account limited capacity, but possible declines in processing efficiency are to be expected *(Goldhammer & Moosbrugger, 2006; Schweizer, 2006)*. The last component is selective attention. It describes the ability to focus on specific incoming stimuli by ignoring other irrelevant stimuli *(Goldhammer, Moosbrugger & Schweizer, 2007)*. Selective attention is therefore often referred to as focused attention. Thus, from a large amount of simultaneously incoming external stimuli or information, those on which the focus is directed can be filtered out and processed under priority. A very impressive experiment conducted by Moray in 1959 vividly describes this circumstance, which is also known as Cocktail Party Phenomenon *(Cherry, 1953)*. Moray showed that we humans are able to communicate in a full room with many distracting stimuli by directing attention only to the conversation and suppressing disturbing stimuli. However, it has also been found that when a kind of cue stimulus (such as calling our name) appears in this amount of information received, attention is most likely directed away from the current conversation to the source of the stimulus. Selective attention has become indispensable in the perception of environment. In a crowded room we cannot perceive all conversations around us in detail, but only those to which our attention is either consciously directed or to which

we pay attention to. For the investigation of selective attention in a scientific design, a classic visual search task is usually constructed. The test persons are instructed to search for a particular target stimulus in a series of distracting stimuli *(Häcker & Stapf, 2009)*. The level of divided attention can be determined if, for example, the test persons are asked to search for a particular target stimuli while performing another ongoing task (e.g. Mourant, 2001).
Another important aspect, which will be briefly discussed here, especially with regard to the measurement used (FAIR-2), is the distinction from the construct concentration to the construct attention. In psychological research, but above all in German-speaking countries, it is the case that the constructs of attention and concentration are often differentiated. This assumption is also supported, for example, by Schmidt-Atzert, Büttner and Bühner (2004). Concentration is therefore to be understood as work and mentally challenging, whereas attention is purely to be associated with the process of perception *(Amelang & Schmidt-Atzert, 2006)*. On the other hand, there is a large structural analysis study by Moosbrugger, Goldhammer and Schweizer (2006), which contradicts a separation of the constructs. The aspect of effort in concentration can therefore be seen from the point of view of sustained attention and vigilance, which Posner and Rafal (1987) described as a kind of mental effort. Concentration is therefore understood in this dissertation and in the conceptualization of the FAIR-2 as a part of the multidimensional construct concept of attention.

2.6.2 The Frankfurt Attention Inventory

In the present dissertation, the Frankfurt Attention Inventory (second edition) was used to operationalize school-relevant achievement. FAIR first appeared in 1996 with its first edition *(Moosbrugger & Oehlschlägel, 1996)*. Meanwhile it enjoys a great popularity and is one of the leading concentration and attention tests. The aim of attention diagnostics is to assess and operationalize individual differences in concentration and attention performance. The reason for the development of the FAIR was the upcoming problem in attentional diagnostics that until then a large number of predominately used performance tests only pretend a potential attentional performance. Priority was given to the so-called "Durschstreich-Tests", in which the test persons had to discriminate between certain target items of irrelevant ones and cross them out. Here, however, it was possible that a test person could detect many target items without much concentration or attention. Misdiagnoses and an overestimation of the performance were the result *(Oehlschlägel & Moosbrugger, 1991; Moosbrugger & Reiß, 2004)*. In 1989 this problem was first discovered by Oehlschlägel and Moosbrugger and one year later it was discussed by Oehlschlägel at the Goethe University in Mainz *(Moosbrugger, Oehlschlägel & Steinwascher, 2011)*. The FAIR, published in 1996, was intended to set an example and stand for more fairness in evaluation and testing. In 2011, the revised second edition of the FAIR was presented, which impresses with an extensive standardization extension and update. The FAIR measures differences in the attention behavior of the test person and their ability to concentrate, in contrast to conventional performance tests. It thus addresses all the aforementioned aspects of attention: alertness, vigilance, divided and selective attention. A certain level of alertness is necessary to ensure an optimal willingness to react for the processing of the FAIR. Vigilance of the test person must be present in order to maintain the constant level of alertness over the entire processing duration and to be able to judge the material continuously. The selective attention is given in the processing of only the target items under ignoring irrelevant items. Divided attention is given on the one hand by the simultaneous processing of two target items and on the other hand by the task of working as quickly and thoroughly as possible. The FAIR can be used in adults (19-85 years) as well as in adolescents (14-18 years) and in children from 9 years onward.

The test includes 640 items, which consist of different circular symbols. These symbols differ in their inner shape, which is either another circle or a square, and concerning the number and the arrangement of dots, which are depicted inside the inner shape (see **Table 1**).

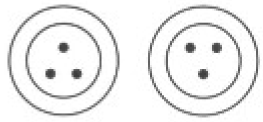
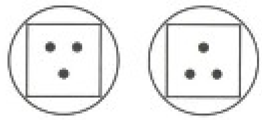
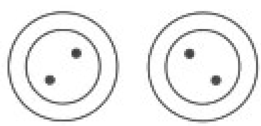
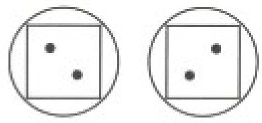
		Inner shape	
		Circular	Square
Number of dots	3		
	2		

Table 1: Different symbols of the FAIR-2 *(Moosbrugger & Oehlschlägel, 1996)*

The test person’s task is to identify all of the symbols, which are either of circular inner shape with three dots inside, or which consist of a square inner shape with two dots inside. To mark these symbols, test persons are asked to draw a continuous line underneath every row of items and mark identified symbols by drawing an upwards peak into the symbol itself. The 640 items are distributed into two halves with 320 items each. For every half, the test persons are given three minutes time to work on as many rows as possible, while being as accurate as possible. After the first three minutes have passed, the test persons are supposed to turn to the next page and continue to work on these items, no matter if they have been done with the previous page or not. Based on these data, three values describing the test person´s attention and concentration can be calculated. First, the speed value (L). L informs about the quantity of processed items during the entire processing time of 6 minutes. L thus represents an indicator of the speed. Secondly, the accuracy value (Q). Q informs about the percentage of concentrated and error-free processed items out of all processed items. Q takes into account the errors made during processing and relativizes the correctly processed items to the total number of processed items. Finally, the performance value (K), which informs about the continuously generated attention and concentration. K results out of the individual speed and accuracy value and combines these two test values into one. Higher scores in the values L, Q and K represent more processed items in general, less incorrectly processed items and a higher concentration performance. L can reach a maximum of 640, Q can reach a quotient of one and K can therefore also reach a maximum of 640. The individual test values can then be related to a normalization sample.

2.6.3 Attention and circadian variations

As previously mentioned, attention belongs to the wide range of cognitive functions. Research of daytime dependent variations in performance or more precisely in cognitive performance is nothing new and dates back to the beginning of the 18th century *(e.g. Gates, 1917)*. Kleitman was one of the first researchers to build a bridge between performance and chronotype or time-of-day fluctuations as well as physiological parameters like body temperature *(Kleitman, Titelbaum & Feiveson, 1938)*. It is now known that various aspects of cognitive performance are subject to daily fluctuations. It turned out that depending on the type of cognitive performance, different rhythms and thus different peaks can be seen in performance. For example Folkard, Wever and Wildgruber (1983) found out that the demands of a task, in particular the working memory load, play an important role in determining the peak performance. For example, the processing speed in simple search tasks shows its peak in the late afternoon *(Monk, 1982)*, whereas the processing speed in more complex tasks has its peak in performance in the forenoon (Folkard, 1975). These findings suggest that optimal cognitive performance depends on the one hand on the time of day but is also influenced on the other hand by other variables such as the different types of tasks. The same can be seen in the various components of attention. The different components or aspects of attention follow demonstrably a circadian rhythm, which means their expression in performance show significant fluctuations during the day. But not all components show significant daytime variations under all circumstances. In terms of selective attention, De Gennaro et al. (2001) proved fluctuations in different selective attention parts using a visual search task. The efficiency and the accuracy the test persons were editing the task showed a peak in performance in the afternoon (around 4 p.m.) while the processing speed peaks in the morning (around 10 a.m.). Valdez et al., 2005 proved that alertness (phasic and tonic) as well as selective attention varies significantly during the day. In contrast, vigilance showed no significant variations. Valdez et al. (2005) argues that the separation of daytime variations in vigilance between the other attention components gives a hint that vigilance might be strongly associated with fatigue. A few years later Valdez et al. (2010) could show that vigilance decreases when the need for sleep increases. A strong connection between attention and the need of sleep or the sleep/wake rhythm can therefore be assumed. This finding can also be proved by Kraemer et al. (2000). He found out that alertness presents a peak in performance immediately after awakening and again at forenoon (around 9 a.m.) *(Kraemer et al., 2000)*. In a constant routine with a “habitual” sleep/wake behavior alertness seems to be stable during the day. If the sleep/wake rhythm comes out of balance and a longer phase of wakefulness arises, the alertness decreases significantly *(Dijk, Duffy & Czeisler, 1992)*. Van Ekelen and Kerkhof (2003) investigated the influence of time of day on divided attention with a dual task procedure. The test persons had to move the cursor with a joystick to keep it on a simulated target and simultaneously memorizing different digits. The performance of the tasks showed a significantly increase in the morning and peaks around 8 a.m. According to Schmidt et al. (2007), who in their review are dedicated to the circadian variations of human cognition, the more complex the examined cognitive performance, the less significant the results are to be expected. This means above all that, depending on the attention components, the different aspects are examined with different tasks. Thus, the results are influenced by the demands of the task as well as its complexity. Furthermore, other variables seem to have an influence, such as fatigue, which is especially evident in their interaction with alertness and vigilance. Attention represented in cognitive performance is therefore to be understood as a multidimensional construct with numerous intervincing factors of different dimensions.

2.6.4 Morningness-Eveningness and school achievement

School achievement means the entirety of all relevant aspects that are necessary for mastering the demands of everyday school life. These aspects are reflected in the individual performance of a student and can be represented, for example, by the grades, motivation, emotion, well-being, attention and concentration. In the following, some relevant study results will be discussed which illustrate the association of school achievement (represented by various aspects) with daytime preferences (Morningness-Eveningness).

As previously described in Section 2.3 (Chronotype), the individual chronotype changes over the life span and simultaneously some daytime preferences. Above all, with regard to sleep behavior, striking changes during puberty can be seen. Adolescents tend here very strongly towards an evening orientation and therefore prefer to go to bed later and to get up later *(Randler, Faßl & Kalb, 2017)*. If one puts this now in connection with the currently existing school system and the school start times, it will be noticeable that a discrepancy could arise here. Whereas the primary school children (up to an age of approx. 10 years) easily get out of bed in the morning and are also most active in the morning, adolescents have great difficulties during puberty to keep an adequate sleep/wake behavior *(Bearpark & Michie, 1987)*. Older adolescents tend to go to bed later and would like to rise later. Consequently, they show shorter sleep times, especially during week *(Randler, Bilger & Díaz-Morales, 2009)*. During puberty, the adolescents are forced to get up early and go to bed early against their biological rhythm. This circumstance can be observed not only within a German west-east gradient, but also in various countries *(Randler, 2008d; Randler, 2008b)*. Adolescents need a sufficient number of hours of sleep. However, they are denied this by the early school start times. On the other hand, the adolescents try to compensate the sleep loss during the week with longer sleep times on weekends *(e.g. Caskardon et al., 1998; Wolfson & Caskardon, 1998)*. It is known, that a discrepancy in weekday-weekend sleep timing is associated with poorer academic performance and depressive symptoms in students *(Sun et al., 2019)*.

One of the main problems for the adolescents seems to be the early school start times. The adolescents are forced to be at given times in school and are forced to perform too early in the morning, especially with regard to their individual chronotype. This of course has negative effects on their school functioning *(Den Wittenboer, 2000)*. Years of research have shown that evening-oriented students have a significant disadvantage in school achievement compared to morning-oriented students. Results of several studies confirmed this concern in different cultures and showed that the higher the morning orientation of a student, the better the academic performance in school measured in grades *(e.g. Randler & Frech, 2009; Scherrer, Roberts & Preckel, 2016, Preckel et al., 2011, 2013)*. This effect does not only show in early puberty years, but can already be found in primary school children, who achieve better grades when having an earlier midpoint of sleep *(Arbabi et al., 2015)* and also when looking at students' leaving exam grades *(Randler & Frech, 2006)*. Even when controlling for total sleep length *(Escribano et al., 2012)*, gender and inductive reasoning *(Díaz-Morales & Escribano,* *2013)*, the individual chronotype predicted school achievement. By taking a closer look to student's morning or evening orientation, Preckel et al., (2019) differentiate between Morning types (high Morningness, low Eveningness), Evening types (low Morningness, high Eveningness), low Morning-Evening types (low Morningness and low Eveningness), and high Morning-Evening types (high Morningness and Eveningness). Also here, the results showed as expected that the higher the evening orientation the lower the academic performance. However, problems of students with evening orientation do not stop at disadvantages concerning their academic performance. Moreover, students with higher evening orientation report more school-related and even parent-related problems that students with higher morning orientation *(Vollmer et al., 2011)*, which stresses the need of finding a solution for students with higher evening orientation to better cope with school and social life even further. But there are also indications that Morningness-Eveningness does not influence all areas of the school achievements. Randler, Bechtold and Vogel (2016) could not prove any significant influence of chronotype on mathematical achievement in a standardized test. Preckel et al., (2011) even found a positive correlation between eveningness and cognitive abilities in adolescents. It would be important to go into the evening oriented students more in detail and to comply with them regarding certain time schedules. So Itzek-Greulich, Randler and Vollmer (2016) could show that evening-oriented students are more motivated and do also learn more in the evening. Even small changes in school schedule could make a difference. As Van der Vinne et al. (2015) showed, minor changes, like different scheduling of exams, could already help Evening types improve their academic performance, as there were no differences in grades between Morning types and Evening types, when exams were taken in the early afternoon. On the other hand, when exams were taken in the morning, morning-oriented students achieved better grades in comparison to evening-oriented students. Carrell, Maghakian and West, (2011) proved that only a 50 minute later school start can improve academic achievement. It would also be possible, however, that there are other factors that promote the advantage of Morning types in school achievement, for example motivational or emotional factors. This fact will be discussed in more detail in the next two sections.

2.7 Motivation and Emotion

Motivational aspects, emotions and feelings dominate our thoughts and behavior in daily life. They can be an incentive or an inhibitor for our actions. Therefore, they influence many aspects of our daily life. In the following, after an overview of concepts and theories, the relation with Morningness-Eveningness will be discussed. The respective section concludes with an outline of the interpretation of the meaning of Morningness-Eveningness in everyday school life.

2.7.1 Motivation

Motivation helps us to explain why we do something. It asks for the "why" of an action. Therefore, motivation describes a kind of process that is responsible for setting and evaluating specific individual goals. Central to this is why we behave in a certain way under certain circumstances *(Achtziger et al., 2019[4])*. In general, motivation can be seen as a theoretical, unitary construct that focusses on the quality and intensity of one´s behavior *(Ryan & Deci, 2000a; Deci & Ryan, 2008)*. From a psychological point of view, motivation is equated with the concept of need. It is the need that gives our behavior energy and guides it *(Myers, Wahl & Hoppe-Graff, 2008)*. As you can see, motivation can have many definitions. There are therefore countless approaches and theories to explain them. Depending on the point of view of the researcher at that time, new definitions for motivation were constantly resulting. First attempts to explain motivation made the Instinct Theory predominant until the late 20s. The theory describes motivation as an innate, genetically determined behavior that can be traced back to basic drives and instincts. Complex behaviors were therefore identified as instincts to be complied with. Despite famous representatives such as Konrad Lorenz (1937) or William McDougall (1928), who listed 18 different basic instincts, this view could not last long. One of the greatest weaknesses was that the theory merely named certain behaviors under certain circumstances, but did not explain them *(Wirtz, 2019[5]; Myers et al., 2008; Achtziger et al., 2019[4])*. In 1943, Abraham Maslow postulated, from a psychological point of view, a fairly advanced theory that explained what motivates behavior. In his Hierarchy of Needs, he describes that our behavior is motivated to meet certain needs. Some needs are at the forefront and need to be met before you can address other needs *(Myers et al., 2008)*. His original model from the 40s had five levels. Starting with the absolute basic needs such as air, food, drink, sex and sleep. This is followed by another basic need, the need for safety. This includes above all order, security, stability and freedom from fear. Need number three include all social needs, such as belongingness and love. The fourth and last basic need is the need for esteem. It contains achievement, status and respect. The fifth and last need is a growth need. It should cover personal growth and peak experiences *(McLeod, 2007)*. Maslow's hierarchy has been renewed over the years and expanded up to eight levels *(Maslow, 1964, 1970a and 1970b)*. Some of the aspects later added to Maslow's hierarchy are mainly about cognitive processes and self-realization. In 1977, Bandura followed these two aspects with his Self-Efficiency-Theory. Bandura is of the opinion that from cognitive processes, which are influenced by perceptual aspects, options for human behavior can be derived. It is hypothesized that expectations of personal efficacy in a situation determine whether coping behavior will be initiated and how much effort will be expended. To sum up, psychological procedures alter the strength of self-efficacy and so changes in human behavior are regulated by cognitive mechanisms. These cognitive mechanisms are influenced by successful performances. Motivational psychologist and personality theorist David McClelland went one-step further, claiming that there are two types of motivational systems that trigger and direct different behaviors *(McClelland, 1999; McClelland, Koestner & Weinberger, 1989)*. According to McClelland, there is an implicit motivational system and an explicit one. The implicit motivational system is based on unconscious motives that are primarily associated with emotional and affective stages. They are based on early childhood affective experiences. The explicit motivation system in contrast is based on conscious motives that control our performance motivation and to which a person has access at any time. They are based on later social learning experiences and are represented in the consciousness. Both motives appear simultaneously but are independent of each other. They do not function in the same way and correlate with different aspects of behavior. Conscious motives are present in a large variety, other than unconscious motives. They are universal and numerically less present. The implicit motivational system is therefore rather determined by affective disposition, whereas the explicit motivational system is guided by cognitive processes *(Achtziger et al., 2019[4]; McClelland, 1987)*.

The last theory, to which reference is to be made, is the Self-Determination-Theory of Deci and Ryan in 1985. One important aspect of the theory: it is focused of different types of motivation that cause behavior. It is assumed that the type of motivation is important for the outcome of the behavior for example well-being or successful performance. The two predominant types of motivation are autonomous motivation and controlled motivation. These mark the two endpoints of a continuum on which motivation is represented in general *(Deci & Ryan, 2008)*. The autonomous motivation consists out of intrinsic and identified motivation, whereas controlled motivation consists out of external and introjected motivation. Intrinsic motivation aims the personal development of a person. It is perceived as self-determined and pleasant. The action of a person is described as intrinsic motivated when it is the person´s decision to do something *(Ryan & Deci, 2000b)*. Identify motivation has a future personal benefit as its goal. It is perceived as highly self-determined and personally important. A person's action is described as intrinsic motivated if its benefit is consistent with own values. External motivation aims at achieving or avoiding certain consequences. It is perceived as necessary, rather compulsive and externally determined. The action of a person is described as externally motivated if externally determined goals are to be achieved. Last but not least, introjected motivation aims to adapt to social norms or to increase self-esteem. It is perceived as little self-determined and predetermined. The action of a person is described as introjected motivated, if the avoidance of guilt or shame is to be achieved, as well as striving for recognition *(Ryan & Deci, 2000b; Deci & Ryan, 2008)*.

2.7.2 Scales for Measuring Motivational Regulation for Learning (SMR-L)

The scales for measuring motivational regulation for learning (SMR-L), especially in a school setting, were designed by the German researchers Almut Thomas and Florian Müller. They determine the individual motivational aspects of the regulation in school learning in students. The motivational concept of the SMR-L is based on the Self-Determination-Theory of Deci and Ryan (1985) and deals therefore with the aforementioned dimensions: intrinsic motivation, identified, introjected and external regulation. In English-speaking countries, the Academic Self-Regulation Questionnaire *(Ryan & Connell, 1989)* is used to determine motivation based on the concept of the Self-Determination-Theory. For the German-speaking area, Thomas and Müller took up this issue. Already in 2007, Müller and colleagues dealt with the acquisition of motivational aspects in learning and validated a German form of the Academic Self-Regulation Questionnaire. However, problems repeatedly arose with the independent answering of the questionnaire, especially among younger students. They needed help in filling in the questionnaire, which they had problems understanding, especially with one dimension (integrated regulation). In 2015, they developed and validated a linguistically simplified and shortened form of the SMR-L on the basis of a sample of 2854 students from the 4th to 8th school level in the subjects of German and Mathematics. Students aged 8 to 16 years (51% female) from 27 different schools in Austria participated. The resulting 13-item SMR-L determines the intrinsic motivation, identified regulation and external regulation with three, introjected regulation with four items each. All items start with the root "Most of the time I'm learning in [subject] because,”. The subject can be replaced as required. To answer the items, students are given a four-point Likert format from completely correct (4) to not correct (1). Sum-scores from three to 12 can be reached in the scales intrinsic motivation, external and identified regulation and sum-scores from four to 16 in the scale introjected regulation. Higher scores represent a higher expression in the representative scale. The intrinsic motivation scale assesses, if the students have fun in learning in the representative subject or in school in general (e.g. “Most of the time I'm learning in [subject] because, I enjoy it.”). The identified regulation scale asks, if the students tend to learn, because they want to drive their personal development (e.g. “Most of the time I'm learning in [subject] because, I want to learn something new.”). The introjected regulation scale determines, if the students tend to learn because they want to be in a good position in front of their classmates and teachers (e.g. “Most of the time I'm learning in [subject] because, I want to make the other students think I'm good”.). Last but not least, the external regulation scale constitutes if the students tend to learn because they want to avoid negative consequences (e.g. “Most of the time I'm learning in [subject] because, I'm going to get in trouble at home”.). In the study by Thomas and Müller 2015, the SMR-L showed sufficient to good internal consistencies and scalar invariance between boys and girls, subjects and school levels could be confirmed. The results thus suggest that the SMR-L are a suitable and reliable instrument for measuring the different forms of motivation in learning at school in the sense of the Self-Determination-Theory. Last year, Thomas, Müller and Bieg developed the Scales for the Measurement of Motivational Regulation for Learning in University Students (SMR-LS). Here too, the SMR-LS showed acceptable internal consistencies, and the assumption of measuring invariance of the regulatory styles for the factors subject, gender and country were substantiated. So far, no further empirical data are available for the SMR-L and SMR-LS, but are very desirable.

2.7.3 Motivation and Morningness-Eveningness in school achievement

As mentioned in the beginning, motivation plays a decisive role in the sense of directing our behavior and determining its intensity. This circumstance becomes particularly clear in the school context. According to Thomas and Müller (2015), motivational aspects are important for continuous and successful learning in school and a healthy development of the students. Although students are rather self-determined motivated *(Thomas & Müller, 2015)*, some studies have found that within two years the general motivation of students drops significantly. The largest decrease could be observed in intrinsic motivation *(Scherrer & Preckel, 2019)*. This could also be proved by Thomas and Müller (2015) and additionally, they showed that also identified regulation decreases with increasing age of the students. This fact is not to be neglected, as research on this topic has clearly shown that intrinsic motivation plays a crucial role in school achievement. Self-determined forms of motivation (intrinsic motivation) are associated with higher academic achievement *(Deci et al., 1991)*. Intrinsic motivated students achieve better grades than students with a high extrinsic motivation *(Lin et al., 2003, Thomas & Müller, 2015)*. Observable correlates of motivation like willingness and endurance *(Lee & Reeve, 2012)* show moderate positive correlations with self-determined forms of motivation (intrinsic motivation and identified regulation) *(Thomas &Müller, 2015)*.

Very important for the motivation to learn in school seems to be above all factors such as the individual adjustment of the speed of learning, the amount of content as well as the level of difficulty and the individual support of the teacher *(Müller & Andreitz,* *2018)*. Positive feedback also increases self-reported interest *(Deci, Koestner & Ryan, 1999)*. In addition, other factors also play a role with regard to motivation and school achievement. The individual daytime preferences of the students seem to interact with motivation in school context. Arbabi et al. (2015) investigated the influence of Morningness-Eveningness on academic achievement with motivation playing a mediating role in primary school children (aged 10 years). They found out that morning-oriented students were more motivated in terms of "learning objectives". This means, their motivation in learning is more intrinsic motivated. They learn, because they want to expand their abilities. Eveningness in contrast was associated with higher "work avoidance". This means, the students do not learn motivated, they learn with investigating the little effort as possible. Furthermore, it could be seen that Morningness was positively correlated with the personality trait conscientiousness. Conscientiousness and motivation were further related to good grades. These findings could also be proved in a university student sample. Morning-oriented university students showed higher academic motivation. Personality traits like conscientiousness and openness to experience were significant predictors for academic motivation. Also other factors, like differed sleep patterns (e.g. sleep quality and daytime sleepiness) mediate academic achievement *(Önder et al., 2014)*. Roeser, Schlarb and Kübler (2013) confirm this. Here, Morning orientation was negatively associated with daytime sleepiness and positively with learning motivation, which, in turn, affected performance. Itzek-Greulich, Randler and Vollmer (2016) went one-step further and were able to demonstrate that the influence of Morningness-Eveningness on motivation in school is subject of a synchronicity effect. Evening types are more motivated and learn more in the afternoon. While in the morning, they showed lower interest and felt lower joy.

To sum up, self-determined forms of motivation (like intrinsic motivation) in school context result in better academic achievement (e.g. better grades). Moring orientation in this context is related to higher self-determined forms of motivation, conscientiousness and beneficial sleep behavior. The last two variables in turn influence school achievement individually. For this reason, it is important to see high school achievement from several perspectives. Factors such as individual chronotype, time of day, sleep behavior and personality must be considered.

2.7.4 Emotion, feeling and affect

Nowadays the terms emotion, feeling and affect are used synonymously to a large extent. Above all, emotions and feelings are difficult to distinguish from each other. However, one should separate these three terms from each other. Emotions are a complex phenomenon that involves a change in various components *(Puca, 2019[6])*. To be exact, with the change of three components: (1) physiological arousal, (2) resulting behavior and (3) conscious cognitive evaluation *(Myers et al., 2008)*. Demonstrated by the emotion of fear, the physiological arousal would be represented for example in tachycardia, sweating and dilated pupils. The resulting behavior would be represented in running away to escape the unpleasant situation. A possible cognitive evaluation would be, for example, the question: why is this dog following me, does he want to bite me? According to the well-known behavioral scientist Ekman, are the expressions of emotions innate and cross-cultural. He postulates 6 basic emotions, which mimics are cross-cultural represented: Happiness, surprise, fear, anger, disgust and sadness *(Ekman, 1994; Ekman et al., 1987; Ekman & Friesen, 1971)*. Many researchers are of the opinion that emotion has a fourth component: the subjective experience of an emotion. However, this fourth component could also be called feeling. A feeling thus describes the subjective experiential component of the emotion. Although feelings can be observed, they cannot be measured directly, since they are only available to the experiencing person himself. Feelings can therefore only be operationalized by asking the person directly. However, a person can also hide or pretend their predominant feelings, which make it difficult to precisely identify them with the emotion *(Puca, 2019[6])*. Finally yet importantly, there is the affect. Affects are much easier to distinguish from emotions or feelings. An affect can be understood as a kind of feeling, but it is experienced particularly intensively. It is very quickly perceived as the answer to an emotional reaction or situation and is often only slightly conscious of the person experienced. From this circumstance, the winged term "action in affect" has arisen. The person experiences a situation as particularly intense and reacts with a strong action tendency, which is difficult to control. After a short time, the whole spectacle is over and the person does not really know exactly what happened *(Müller, 2013)*.

Similar to motivation, emotions also have different theories about how they arise and how they interact with our thoughts and behavior. In the 17th century, two researchers postulated one of the first theories on the origin of emotions. William James (1884) and Carl Lange (1885; 2013), later also known as the James-Lange-Theory, believed that in an emotion-stimulating situation, we first become aware of our physiological responses to the situation, and only then, we can experience the emotion. In other words, physiology comes before experience. A few years later, however, this view was replaced by the theory of the researchers Walter Cannon *(Cannon 1927; 1931)* and Philip Bard *(Bard, 1928; 1934)*. The Cannon-Bard-Theory implied that in an emotional situation the physiological reaction as well as the subjective experience started at the same time. The Two-Factor-Theory by Stanley Schachter and Jerome Singer from 1962 represents a kind of fusion of the two theories. They postulated that in an emotion-triggering situation, physiological arousal must be present as well as cognitive interpretation of the situation in order to experience the emotion. All three theories contain the three components of an emotion (physiological arousal, subjective experience and cognitive interpretation) only the arrangement of these is different depending on the theory *(Myers, 2008)*. It is also crucial in these perspectives that emotions play a decisive role in behavior. Just like motivation, they can control our behavior and regulate intensity. Motivation and emotion are therefore closely linked and have a decisive influence on our behavior, as Izrad (2013) expresses it in his book Human Emotions: "My few is that the emotions constitute the primary motivational system for human being" (pp. 3).

2.7.5 Positive and Negative Affect Schedule

In 1988, Watson, Clark and Tellegen developed a questionnaire to determine the current state of mood. The Positive and Negative Affect Schedule (PANAS) determines the current state of mood of a person based on two separate dimensions (positive affect vs. negative affect). Positive affect (PA) describes whether a person feels awake, active and enthusiastic. When a person achieves high scores on this scale, they are fully focused, motivated, and full of energy. If a person achieves low scores on this scale, they can be considered as sad and lethargic. The dimension negative affect (NA) in turn indicates whether a person is under great stress and pressure, i.e. under maximum load. This is associated with an unpleasant state of mood, which includes influences such as anxiety, nervousness and anger. If a person reaches low values on this scale, they can be considered calm and relaxed. Each dimension is represented by 10 Items. The items are adjectives that describe different feelings and moods (e.g. “anxious” and “active”). The items should be answered on a five-point Likert scale. The test persons ranging their current state of mood by judging the adjectives from “very slightly/not at all” to “extremely”. Sum-scores for each dimension can reach from a minimum of 10 to a maximum of 50, whereas higher scores represent a higher expression of the current state of mood. Watson, Clark and Tellegen have found clear evidence in the previous literature to prove that PA and NA correlate with different variables. PA, for example, is associated with satisfaction and pleasant events *(e.g. Clark & Watson, 1986; 1988; Watson 1988a)*. NA, in contrast, can be associated with stress or poor coping behavior *(Wills, 1986; Clark & Watson, 1986)*. In their validation study, they also found that PA (but not NA) is associated with social activity and NA (but not PA) is associated with perceived stress. However, inconsistent findings repeatedly pointed out that the two scales PA and NA correlate only slightly with each other and that general reliability problems exist with the scales used so far, e.g. Bradburn´s NA and PA scales *(Watson, 1988b)*. Therefore, Watson, Clark and Tellegen decided to develop a brief, economic and reliable measurement for PA and NA. What they have also achieved with PANAS. It shows good discriminant and convergent validity, which still has a good stability after two months. Another interesting finding in the study by Watson, Clark and Tellegen (1988) was that PA (but not NA) showed a significant daytime variation. The PA scores of the test persons increased significantly during morning and then remained relatively stable over the rest of the day. Towards evening, they dropped again. This finding can also be confirmed by other study e.g. Porto, Duarte and Menna-Barreto (2006). In German-speaking countries, the translation of Krohne, Egloff, Kohlmann, & Tausch (1996) is used above all, as also in this dissertation.

2.7.6 Positive/negative affect and Morningness-Eveningness in school

As already mentioned in the section 2.7.3 ("Motivation and Morningness-Eveningness in school achievement"), motivation plays a key role in academic achievement. As with the connection between motivation and emotion described above, it can therefore be assumed that emotions also have an influence in this context. Some studies could already show that positive affects (like well-being and interest) are associated with a higher outcome in achievement and negative affects (like anxiety and anger) are related to worse achievement *(Gläser-Zikuda et al., 2005, Pekrun 1992, Pekrun et al., 2002)*. To this circumstance is added the fact that PA in particular fluctuates during the day and rises significantly in the morning *(Porto et al., 2006; Randler & Weber, 2015)*. Clark, Watson and Leeka (1989) made the same discoveries. PA (but not NA) showed significant circadian variation. In addition, they were able to show that Morningness-Eveningness is significantly related to PA. Morning types had a higher PA during the whole day than Evening types. Further studies confirm these findings and showed for example that Moring types had a higher positive mood and energetic arousal in the morning compared to Evening types *(Caminada & De Bruijn, 1992; Mathews, 1988; Jankowski & Ciarkowska, 2008)*. Especially Jankowski and Ciarkowska showed that energetic arousal was higher in Moring types in a time span between 8.00 a.m. and 5.00.p.m. This is the time were most of the people have to be at work, at university or at school. During the rest of the day, no significant difference between Moring and Evening types concerning energetic arousal could be found. If now, these findings should be transferred into the school context, it is noticeable that not many studies already dealt with this topic. Randler and his colleagues (2014) were one of the first researchers to investigate the influence of Morningness-Eveningness on PA in school. The aim of their study was to assess the affective state of students in the first lesson of class and to carry out a possible effect of chronotype. 97 students from class grades between 5 and 10 participated in the study. The affective state was measured at about 8.00.a.m. The results demonstrated that Morningness was associated with relaxation, good mood and activation in the morning. Above all, good mood showed the strongest association with Morningness. Morning-oriented students are therefore especially in a good mood in the morning compared to evening-oriented students. One year later, Randler and Weber (2015) investigated the influence of Morningness-Eveningness on affective state during the first and last lesion in class. As Watson et al (1988) have already shown PA rose significantly over the school day. In the sixth lesson, the scores for PA were higher than in the first lesson in class. NA showed no daily fluctuation. Morning-oriented students had significant higher scores in PA in the first and sixth lesson in class. So they can be seen generally in a good mood in school compared to evening-oriented students. Although the correlation coefficient between Morningness and PA in the first lesson in class was higher than in the sixth lesson, there was no synchronicity effect. Evening-oriented students are not in a better mood in the afternoon than morning-oriented students. As early in 2014 and here in 2015, Randler and colleagues suspected that the generally better mood among morning-oriented students could have an impact on their better school achievement as compared to evening-oriented students. Again, one year later, Randler, Bechtold and Vogel (2016) wanted to know if the interaction Morningness-Eveningness, time of day and PA has an impact on school achievement. A standardized mathematical test was used to assess academic performance at two different test points (first and 6th lesson in class). A total of 90 students of the ninth class participated in the study. The results revealed very interesting findings. On the one hand, there was no significant difference in the mathematical test results in terms of testing time and on the other hand, chronotype showed no significant influence on these. A synchronicity effect can therefore be excluded. PA again showed a clear increase from the first to the sixth lesson. NA seemed to remain stable throughout the day. Morning-oriented students had significant higher PA scores in the morning than evening-oriented students. Now to the interesting part of the results: NA correlated positively with the mathematical test scores in the first lesson in class. In detail, students with a higher NA in the first lesson in class do have higher scores in the mathematical test. This find is very surprising, since the literature so far mainly confirms that positive emotions are associated with higher school achievement *(Gläser-Zikuda et al., 2005, Pekrun 1992, Pekrun et al., 2002)*. Randler and his colleagues were not quite sure what exactly this result is based on. Some intervincing arguments that Randler and colleagues cite are for example a small sample size, a field setting, the age group or even the mathematical test, which might not be sensitive enough to make exact differentiations. It is clear that more studies are needed to find the underlying cause of the interaction between Morningness-Eveningness and PA/NA in school.

3. Aim of the dissertation

The aim of the present dissertation was to validate the measurement MESSi with the help of certain physiological parameters (body temperature and cortisol) as well as other intervincing variables. On the other hand, the MESSi should be usable in a student population to investigate the influence of Morningness-Eveningness on school-relevant achievement under consideration of certain variables (sleep/wake behavior, body temperature, motivational aspects and PA/NA). The general validation of the MESSi should be carried out in a university student sample. Two separate studies then emerged from this data collection ("Preliminary findings for the validity of the Morningness-Eveningness-Stability Scale improved (MESSi): Correlations with activity levels and personality" and "Weak Associations of Morningness-Eveningness and Stability with Skin Temperature and Cortisol Levels"). The main purpose of this survey was to test the measurements and the experimental devices used and to make relevant conclusions for further studies. It can thus be regarded as a kind of pilot study. Actigraphy was used because, in addition to the subjective information from the sleep diaries of the test persons, it enables an objective view of the sleep/wake behavior. Using actigraphy as a validation tool for questionnaires has already proven its worth *(e.g. Tonetti, 2007)* and provides additionally information on the activity profile of the test persons. The body temperature, more precisely the wrist temperature, was used as one of the most important biological markers for circadian rhythms *(e.g. Wever, 2013)*. Clear differences with regard to Morningness-Eveningness have already been proven *(e.g. Baehr, Revelle & Eastman, 2000)* and thanks to the study by Sarabia et al. (2008) which showed that wrist temperature can also be used as a valid measure; this biological marker was used in the present dissertation. In addition, the cortisol levels in the morning of the test persons were assessed to get an overview of the relation between Morningness-Eveningness and those. In addition, here the literature showed clear differences in the cortisol levels in the morning between the chronotypes *(e.g. Bailey & Heitkemper, 2001)*. A confirmation of the previous literature by using the MESSi was therefore assumed.

Aim number two of this dissertation, to make the MESSi usable in an adolescent population, thus gave rise to a third study ("Measuring circadian preference in

adolescence with the Morningness-Eveningness Stability Scale improved (MESSi)"). This study resulted from three separate surveys with a total sample of *N*=215 adolescents. The aim was to analyze the convergent validity of the MESSi with well-established measurements of circadian preference (survey one: Pediatric daytime sleepiness scale [PDSS], survey two: Composite Scale of Morningness [CSM] and survey three: Children's ChronoType Questionnaire [CCTQ]). Additionally, Confirmatory Factor Analysis (CFA) should be done to prove the three-structure model of the MESSi in the adolescent sample.
After the first three studies had been completed and promising results were obtained, the MESSi (adolescent version) should be used to investigate the impact of Morningness-Eveningness on school-relevant achievement in a field setting with an adolescent sample. Relevant intervincing variables such as motivational aspects in learning and the emotional state (PA/NA) should also be taken into account. It is already known from the questionnaire (SMR-L) and the study by Thomas and Müller (2015) that self-determined forms of motivation (e.g. intrinsic motivation) lead to better school performance than certain external forms (e.g. external motivation). It is also known that positive affects leads to better school performance than negative affects *(e.g. Gläser-Zikuda et al., 2005)*. However, these two topics have not yet been examined against the background of Morningness-Eveningness in the school context and the present dissertation is intended to address them. Study number four ("Circadian Preference and School-relevant Achievement: Implications for Skin Temperature, Emotional State and Motivation in Learning") unites this project and additionally physiological and behavioral markers (skin temperature and sleep/wake timing) were again determined.

Determining the individual chronotype of a person has not become so easy these days. It has to be taken into account that it is no longer possible to categorize people strictly according to groups with regard to certain cut-offs. Morningness-Eveningness is now understood as a multidimensional construct where a certain type of circadian preference may be more or less pronounced within an individual. This fact makes the MESSi irreplaceable in chronobiological research and should therefore be extended to several areas. One of these areas is the behavior of adolescents in school context. Adolescents with the onset of puberty find it particularly difficult to gain a proper foothold in school in the first few hours and to perform at the level expected of them. Especially adolescents aged between 15 and 18 years have to fight against their inner rhythm during the week and are forced to perform in school too early in the morning. Poorer performances especially at evening-oriented students, so building up a sleep deficit during the week, what is then tried to compensate on weekends, are the consequences. What long-term health consequences this can have for the adolescents, especially with regard to incorrect sleep behavior and the development of sleep disorders, cannot yet be known. In the short term, however, a clear decrease in motivation can be observed, as well as a worse mood at school and worse academic achievement, especially for evening-oriented students. It is not possible to completely change the German school system from one day to the next. What is possible, however, is to create understanding in society and in the direct environment of adolescents. The school system, represented by teachers, as well as parents, should understand what is going on in adolescents and how this influences their behavior, especially during puberty. A later school start time of just a few minutes, (approx. 50 minutes) could clearly benefit the adolescents. Not writing exams in the first two lessons in class would help both morning and evening-oriented students.

4. Study 1:
Preliminary findings for the validity of the Morningness-Eveningness-Stability Scale improved (MESSi): Correlations with activity levels and personality

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Contributions

Title of the paper: Preliminary findings for the validity of the Morningness-Eveningness-Stability Scale improved (MESSi): Correlations with activity levels and personality

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Corina Weidenauer (geb. Faßl)	1	40	100	50	60
Mirja Quante	2	0	0	10	20
Sara Mariani	3	0	0	20	10
Christoph Randler	4	60	0	20	10

Publication status: accepted for publication in Chronobiology International, 36(1), 135-142.

Preliminary findings for the validity of the Morningness-Eveningness-Stability Scale improved (MESSi): Correlations with activity levels and personality

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Abstract. Aim of the present study is an additional validation of the Morningness-Eveningness-Stability Scale improved (MESSi). We screened a total of 97 German students using the reduced Morningness-Eveningness Questionnaire (rMEQ) to identify a subsample (N = 42) of definite morning and evening types (31% males, mean age: 24.8 ± 5.8 years) The participants provided information about their sleep-wake rhythm (diary), personality traits (questionnaire) and experienced actigraphic monitoring. Correlations of the MESSi components "Morning affect sub-scale" (MA) ($r = 0.91$, $p < 0.01$) and "Eveningness sub-scale" (EV) ($r = -0.87$, $p < 0.01$) with the rMEQ showed good convergent validity. MA was also significantly negatively correlated with the acrophase and the midpoint of sleep as measured by actigraphy.

Keywords: chronotype, MESSi, sleep patterns, activity level, personality

Introduction

Our inner rhythm follows a nearly 24 h period (Häcker & Stapf 2009). During those 24 hours, there is a continuous alternation of active and resting phases of sleep and wakefulness. These alternations vary individually (Adan et al. 2012). Research has identified three different chronotypes: morning types, neither types and evening types. Morning types ("larks") prefer to wake up and go to bed early and tend to have their mental and physical peak performance in the first half of the day, whereas evening types ("owls") wake up and go to bed late and have their peak performance in the second half of the day (Adan et al. 2012).

Circadian typology is often measured by self-assessment questionnaires (Di Milia et al. 2013). While most of these scales use a one-dimensional construct, recently a multi-dimensional approach was advocated (Dosseville et al. 2013; Oginska 2011; Preckel et al. 2013; Randler et al., 2016). Therefore, the Morningness-Eveningness-Stability Scale (improved) was developed as an instrument to measure the three dimensions Morningness, Eveningness and Amplitude/Distinctness (Randler et al. 2016). The MESSi is available in German, Spanish, Farsi and Portuguese (Rahafar et al. 2017, Diaz-Morales and Randler 2017, Diaz-Morales et al. 2017; Rodrigues et al. 2018). While the MESSi is a good psychometric instrument, objective validations with behavior and physiological parameters are still missing.

Actigraphy is a non-invasive and objective method to determine circadian rhythmicity of sleep and activity in field settings (Sadeh 2011; Cellini et al. 2013, Quante et al. 2015), but lying awake in bed without moving may lead to misclassification on sleep versus wake (e.g. Paquet et al., 2007). To complete the findings, we asked the subjects to simultaneously fill in a sleep diary. In addition, we used a personality measure because individual differences between chronotypes can be related to individual differences in personality. For example, conscientiousness is strongly correlated to Morningness followed by agreeableness (Adan et. al. 2012).

The aim of the present study was to provide further evidence for the validity of the MESSi. More specifically, we wanted to test the convergent validity with the reduced Morningness-Eveningness Questionnaire (rMEQ) and investigate correlations with the individual sleep-wake rhythm using actigraphy and sleep diaries. Secondly, we wanted to explore correlations of circadian typology with personality and activity.

Materials and methods

Participants

97 students (24 men and 73 women) participated in the study (age: 18 - 54 years, M = 24.5, SD = 6.00). The rMEQ was used to select a subsample of morning and evening types (N = 42; age 8 - 54; M = 24.8, SD = 5.83; 22 morning types (5 men and 17 women) and 20 evening types (8 men and 12 women)). Most of them studied mathematical – nature science (45.2 %), economics – social science (21.4 %) and medical science (16.7 %). Nearly half of the students were single (47.6 %) or in a relationship (45.2 %), only 3 of them were married and 12 had a job. All of them did no night or shift work.

Variables and instruments

Morningness-Eveningness assessment

The Morningness-Eveningness-Stability Scale, improved (MESSi; Randler et al. 2016) was used to determine circadian typology and amplitude. The MESSi consists of three scales: Morning affect sub-scale (MA), Eveningness sub-scale (EV) and Distinctness/Stability sub-scale (DI). Each sub-scale is represented by 5 items with options ranging from 1 to 5. Higher scores represent higher expressions in the respective sub-scale. The MA sub-scale measures the affective facet of the Morningness Eveningness trait by asking how easy it is for the subjects to get out of bed in the morning, how awake they feel and how much time does it take them to have a clear mind. Finally, subjects are asked for their energy in the morning. The EV sub-scale determines the affective facet of the evening orientation and evaluates the energetic feeling, activity and mood in the evening (e.g. “In general, how is your energy level in the evening?”). The Distinctness sub-scale operationalizes how much the expression of the facets fluctuates throughout the day. Here, the mood and feelings are also included as well as concentration and motivation (e.g. “I can focus at any time of the day.”)

Circadian typology was also determined by the reduced Morningness-Eveningness Questionnaire (rMEQ; Adan and Almirall 1991, German version by Randler, 2013). It consists of 5 items, which ask the subjects for their preferred bed times, feeling of tiredness and well-being as well as a self-assessment of their chronotype. Two of the 5 items are realized in a Likert format (item 2 and 5) and the rest are done as a visual analog scale (item 1, 3 and 4). The subjects have to mark their preferred answer on a timeline or an amount of hours. They can reach scores from 4 (minimum) to 25 (maximum). The subjects can be classified into one of the three chronotype categories: morning types (cut-off sore: 18 – 25), neither types (12 – 17) or evening types (4 – 11).

Sleep quality

The Pittsburgh-Sleep-Quality Index (PSQI; Buysse et al.1989, German version by Riemann and Backhaus 1996) was used to determine the subjective sleep quality. Through 19 items, the subjects give a self-assessment of their sleep behavior within the previous four weeks. The 5 items related to peer/mate assessment were not included in the data collection. The subjects have to answer questions about their sleep habits (e.g. “How long has it usually taken to fall asleep during the last four weeks?”), different reasons for their insomnia (e.g. “How many times have you had a bad night sleep during the last four weeks because you had to get up to go to the bathroom?”), subjective sleep quality, taking sleeping pills and the impairments of their daily life (e.g.” During the last four weeks, did you have trouble getting your daily work done?”). Most of the items are in a 4-point Likert format (item 5 to 19) with the option for an individual answer (item 14). To answer item 1 to 4 the subjects have to give information about certain times (times of day, minutes and hours). Scores range from 0 to 21, allowing a classification of the subjects in “good” or “bad sleepers”. Higher scores represent a reduced sleep quality. The cut-off score can be located at 5. Subjects with a score higher than 10 were excluded from analyses.

Sleep diary

The subjects were asked to complete a standardized sleep-diary. It consisted of 9 items that the subjects had to answer on a daily basis (from Monday to Sunday). We asked the subjects to give information about their bed times and how long it took them to fall asleep. We also asked about naps and awakenings during the night. The sleep quality was rated on a scale (from 1 to 6, where higher values represent a worse sleep quality). We used information from the sleep diary to score the actigraphy data.

Actigraphy

Actigraphy was used for objective monitoring of activity levels and derivation of rest-activity rhythms. The actigraph sensors were of the model series GT3X (“Actigraph”, Pensacola, Florida). The device (dimensions: 4.6cm x 3.3cm x 1.5cm, weight: 19 grams) was attached to the wrist of the non-dominant hand of the subjects. An internal tri-axial (vertical, horizontal and lateral) accelerometer (acceleration sensor) records the body movements at a sampling frequency of 100 Hz. The data were stored in the device and were transferred to a computer via USB or Bluetooth. With the help of the dedicated software (“ActiLife”) the data can be visualized as rest-activity plots, where body movements are represented in dimensionless units, called “activity counts” over epochs of 1 minute. For each subject actigraphy was recorded over 10,080 epochs (1,440 one-minute epoch per day). Off-wrist detection was performed using the Choi algorithm (Choi et al, 2011). Sleep-wake detection on an epoch-by-epoch basis was performed using the Cole-Kripke algorithm (Cole et. al, 1992). The major sleep periods were set by marking the “in bed” and “out of bed” times of the subjects with the help of the sleep diary. We discarded recording days (from 00:00 AM to 11:59 PM) if there were less than 10 hours of valid signal during wakefulness. Recordings with less than 4 valid days were also excluded.

The descriptors for the rest-activity rhythms were derived using cosinor / parametric analysis and non-parametric analysis. The acrophase (time of peak activity) was calculated using the cosinor method (Cornelissen 2014). Two non-parametric parameters were calculated: the “M10 midpoint” (time of mean activity of the most active 10 h period) and the “L5 midpoint” (time of mean activity of the least active 5 h period; Van Someren et. al, 1997). In addition, another sleep parameter was calculated, the midpoint of sleep (midpoint between sleep onset and sleep offset; minutes from midnight).

Personality

To measure personality, the NEO- Five Factor Inventory (NEO-FFI, Costa and McCrae 1992) was used in its German version by Borkenau and Ostendorf (1993). The personality traits are determined within five dimensions: openness to experience, conscientiousness, extraversion, agreeableness and neuroticism. People who score high in openness are inquisitive, prefer variety in their lives and have multifaceted interests (e.g. “I am inspired by the motives that could be found in art and nature.”) Conscientious persons are described as tidy, reliable and disciplined (e.g. “I keep my things neat and clean.”), while extroverted subjects are characterized as sociable, talkative and do like encouragements (e. g. “I really like to talk to other people.”). High values in the agreeableness scale suggest that the subject is caring, compliant and has a strong need for harmony (e. g. “I try to be kind to everyone I meet.”). People classified as neurotic tend to be nervous, anxious and insecure (e.g. “I often feel stressed and nervous. “). Every dimension is assed with 12 items, so there is a total of 60 items. These are administrated in a 5-ranking format and 4 items of each dimension are recoded. People can reach scores from 0 to 48, whereas higher scores represent a higher expression of the respective trait.

Procedure

Data collection took place from January 1st to March 31st 2017. Recruitment information was disseminated via posters at the campus and circulars. We arranged screening visits with interested subjects. At the first meeting, the “pre-testing phase” started. The subjects gave their agreement for the conditions of participation and complete the MESSi, the rMEQ and the PSQI. If the subjects met the inclusion criteria (no shift work and no sleep disorder) a second appointment was arranged. The "main-testing phase" started with the second meeting for the subjects. They had to complete the NEO-FFI, wear the actigraph for one week (except when bathing or swimming) and record their sleep habits in the diary.

Statistical analysis

We calculated Pearson correlations (zero-order) between the components of the MESSi and rMEQ, sleep patterns, rest-activity rhythms descriptors and personality. We used multiple variance analyses (MANOVA) to assess the influence of circadian typology on the sleep patterns, activity and personality traits. Chronotype acts as the factor and the sleep patterns (going to bed and getting up times, values of the PSQI and subjective sleep quality rated with the sleep diary), as well as the activity rhythm descriptors and the personality traits (openness, concienceness, extraversion, agreeableness and neuroticism) as dependent variables. Although there is no significant difference between the groups (morning- and evening types) concerning age, all analyses were done controlled for age and it was taken into account as a covariate for the analyses because previous literature confirmed an important role of age in connection with circadian typology (e.g. Adan et al. 2012). The partial eta-squared was used as a measure for the effect size of the results. All statistical analyses were completed using SPSS version 25 (IBM Corp., Armonk, New York; released 2017).

Results

MESSi and rMEQ

Correlations between the MESSi subscales (MA, EV and DI) and the rMEQ showed a positive correlation of the MA with the rMEQ ($r = 0.91$, $p < 0.01$) and negative correlation with the EV ($r = -0.87$, $p < 0.01$). We did not find any significant correlations for the DI with the rMEQ.

MESSi and sleep quality

PSQI scores were negatively correlated with MA ($r = -0.42$, $p < 0.01$) and positively with DI ($r = 0.34$, $p < 0.05$). No further significant correlations between the PSQI and MESSi could be detected. The subjective sleep quality (rating from sleep diary) during the week ($r = -0.34$, $p < 0.05$) and on the weekend ($r = -0.32$, $p < 0.05$) showed negative correlations with MA. The subjective sleep quality on the weekend was positively correlated with EV ($r = 0.32$, $p < 0.05$). DI showed no significant correlations. Interestingly, the sleep quality during the week was positively correlated with the sleep quality on the weekend ($r = 0.45$, $p < 0.01$).

MESSi and rest-activity rhythms

MA showed a negative correlation with the acrophase ($r = - 0.71$, $p < 0.01$). This effect can be seen during the week ($r = - 0.67$, $p < 0.01$) and on weekends ($r = - 0.69$, $p < 0.01$). EV showed a positive correlation with the acrophase ($r = 0.69$, $p < 0.01$). This effect was also present during the week ($r = 0.66$, $p < 0.01$) and on weekends ($r = 0.61$, $p < 0.01$). There was no significant correlation with DI. MA correlated negatively with the midpoint of sleep ($r = - 0.68$, $p < 0.01$), both during the week ($r = - 0.66$, $p < 0.01$) and on weekends ($r = - 0.69$, $p < 0.01$). EV correlated positively with the midpoint of sleep ($r = 0.69$, $p < 0.01$), both during the week ($r = 0.73$, $p < 0.01$) and on weekends ($r = 0.72$, $p < 0.01$). DI showed no significant correlations. However, acrophase and midpoint of sleep during the week showed a positive correlation with the acrophase ($r = 0.71$, $p < 0.01$) and midpoint of sleep during the weekend ($r = 0.81$, $p < 0.01$).

The components of the MESSi showed no significant correlations with the non-parametric parameters M10 midpoint and L5 midpoint.

MESSi and Personality

MA showed a positive correlation with conscientiousness ($r = 0.49$, $p<0.01$) and extraversion ($r = 0.44$, $p<0.01$). EV showed a negative correlation with conscientiousness ($r = -0.34$, $p<0.05$). DI was positively correlated with neuroticism ($r = 0.32$, $p<0.05$) and negatively with conscientiousness ($r = -0.44$, $p<0.01$) and extraversion ($r = -0.34$, $p<0.05$).

Circadian typology and sleep patterns

The MANOVA showed a significant effect of circadian typology on all “getting up” and “going to bed” variables during the week and on the weekend. In order to simplify the reporting of the results, the “getting up” times from Monday to Friday were summarized in the variable “getting up during week” and from Saturday to Sunday in the variable “getting up weekend”. The “going to bed” times from Monday to Friday were summarized in the variable “going to bed during week” and from Saturday to Sunday in the variable “going to bed weekend”.

Morning types always reported earlier rising and going to bed times compared to evening types (Tables 1 and 2).

Table 1. Descriptive statistics (Mean and Standard deviation) for the sleep variables “getting up” and “going to bed” during the week and on the weekend, separated by chronotype.

	Morning types (N=22)	Evening types (N=20)
	M (SD)	M (SD)
“getting up during week”	07:09 am (55)	09:30 am (86)
“getting up weekend”	08:34 am (100)	10:39 am (66)
“going to bed during week”	11:06 pm (61)	01:15 am (77)
“going to bed weekend”	11:13 pm (79)	01:36 am (79)

Note: means are given in clock times and standard deviation in minutes.

Table 2. Chronotype effects on the “getting up” and “going to bed” variables during week and on the weekend from the MANOVA analysis (F-tests, p-values and partial η^2).

	F	*p*	ηp^2
“getting up during week”	40.65	<.001	0.51
“getting up weekend”	21.56	<.001	0.36
“going to bed during week”	34.76	<.001	0.47
“going to bed weekend”	33.40	<.001	0.46

Note: $p < 0.05$

Circadian typology showed a significant effect on the values of the PSQI, with ($F_{1, 40} = 5.47$, $p = 0.025$, $\eta_p^2 = 0.123$) and on the subjective sleep quality during the week ($F_{1, 40} = 5.02$, $p = 0.031$, $\eta_p^2 = 0.114$). No significant effect could be seen for chronotype on the subjective sleep quality on the weekend, but a tendency is shown ($F_{1, 40} = 3.12$, $p = 0.083$, $\eta_p^2 = 0.075$). Morning types always (PSQI: M = 3.9, SD = 2.7; subjective sleep quality during week: M = 1.9, SD = 0.6; subjective sleep quality on the weekend: M = 1.9, SD = 0.9) experienced a better sleep quality than evening types (PSQI: M = 5.5, SD = 1.5; subjective sleep quality during week: M = 2.3, SD = 0.7; subjective sleep quality on the weekend: M = 2.5, SD = 0.9).

Circadian typology and rest-activity rhythms

The results of the MANOVA showed a significant effect of chronotype on the acrophase ($F_{1, 40} = 39.55$, $p < 0.00$, $\eta_p^2 = 0.504$) both during the week ($F_{1, 40} = 35.43$, $p < 0.00$, $\eta_p^2 = 0.476$) and on the weekend ($F_{1, 40} = 43.27$, $p < 0.00$, $\eta_p^2 = 0.526$). Morning types (M = 02:55 pm, SD = 48 min) displayed an earlier peak in activity than evening types (M = 05:08 pm, SD = 1h 24 min), both during the week (morning types: M = 02:50 pm, SD = 56 min.; evening types: M = 05:04 pm, SD = 1h 26 min) and on weekends (morning types: M = 03:17 pm, SD = 1h 03 min.; evening types: M = 05:42 pm, SD = 1h 17 min). There was a significant difference between the acrophase during the week compared to the weekend ($t(41) = -2.72$, $p = .010$, $d = 0.70$). Acrophase during the week was significant earlier (M = 03.54 pm, SD = 1h 38 min.) compared to the weekend (M = 04.26 pm, SD = 1h 41 min.). In separate analysis by chronotype, no significant difference could be found for morning types, only for evening types, with $t(19) = -2.40$, $p = .027$, $d = 0.63$. Evening types showed a significant earlier acrophase during the week (M = 05.04 pm, SD = 1h 26 min.) than on the weekend (M = 05.42 pm, SD = 1h 17 min.).

Circadian typology showed a significant effect on the midpoint of sleep ($F_{1, 40} = 34.33$, $p < 0.00$, $\eta_p^2 = 0.468$) both during week ($F_{1, 40} = 42.65$, $p < 0.00$, $\eta_p^2 = 0.522$) and on weekends ($F_{1, 40} = 33.02$, $p < 0.00$, $\eta_p^2 = 0.458$). Morning types (M = 03:25 pm, SD = 1h 07 min.) had an earlier midpoint of sleep than evening types (M = 05:41 am, SD = 1h 24 min.). This effect was seen during the week (morning types: M = 03:15 am, SD = 50 min.; evening types: M = 05:21 am, SD = 1h 11 min.) and on the weekend (morning types: M = 03:41 am, SD = 1h 30 min.; evening types: M =

05:50 am, SD = 1h 18 min.). The difference between the midpoint of sleep during week and weekend was significant, with t(41) = -2.47, p = .018, d = 0.74. The midpoint of sleep during the week was significant earlier (M = 04.15 am, SD = 1h 27 min.) compared to the weekend (M = 04.42 pm, SD = 1h 46 min.). In separate analysis by chronotype, no significant difference could be found for morning types, only for evening types, with t(19) = -2.40, p = .027, d = 0.75. Evening types sowed a significant earlier midpoint of sleep during the week (M = 05.21 am, SD = 1h 11 min.) than on the weekend (M = 05.50 am, SD = 1h 18 min.). Circadian typology showed no significant effect on the non-parametric parameters M10 midpoint and L5 midpoint.

Circadian typology and personality

The circadian typology showed a significant effect on the personality of the subjects (extraversion with F1, 40 = 5.70, p = 0.022, ηp2 = 0.128 and conscientiousness with F1, 40 = 9.45, p = 0.004, ηp2 = 0.195). Morning types (M = 30.4, SD = 6.8) reported higher extraversion than evening types (M = 25.9, SD = 4.8). Similarly, morning types (M = 36.2, SD = 7.1) reported higher conscientiousness than evening types (M = 29.7, SD = 7.1).

Discussion

MESSi

Regarding the convergent validity of the MESSi with the rMEQ, we found high correlations between Morning Affect and Eveningness with the scores of the rMEQ. These findings underline the overall validity of the MESSi. The Distinctness/Stability (DI) component of the MESSi showed no correlation with the rMEQ scores, suggesting that this dimension acts independently of the two other dimensions (Randler et. al, 2016).

MA showed a negative correlation with the PSQI scores, meaning that morning types reported better sleep quality. This partly agrees with previous work. For example, Vitale and colleagues found out that evening types had a reduced sleep quality compared to morning and neither types (Vitale et al. 2015). However, most research found that eveningness orientation is a predictor of poor sleep quality (Roeser at al. 2012). In our study, this point of view is reversed: morning orientation emerged as a predictor for good sleep quality. Stability was positively correlated with the PSQI score. On other words, a higher Stability was connected to a worse sleep quality. This finding was contrary to our expectations. A high Stability usually represents a more consolidated inner rhythm leading to a more stable behavior regarding the sleep-wake cycle and thus to a better sleep quality. Further studies are necessary to understand these results. Possible interactions of the DI component of the MESSi with non-parametric variables from actigraphy could be considered. The correlation results of MA with the self-reported sleep quality of the subjects were in line with previous findings for the PSQI score (Vitale et al. 2015). The negative correlation of EV with the subjective sleep quality on the weekend suggests that the sleep behavior of evening types on the weekend is more affected by factors like social life, as it is for morning types. The subjective sleep quality during the week showed a positive correlation with the subjective sleep quality on the weekend. This may indicate that a poor sleep quality during the week cannot be compensated by a changed in sleeping behavior on the weekend.

The negative correlations of the MA with the acrophase and the midpoint of sleep underline the validity of the MESSi, because those subjects, who were identified as morning orientated persons, showed earlier peaks in activity and an earlier midpoint of sleep than evening persons. Our results confirm that the classification of the MESSi is congruent to activity and sleep behavior. In addition, these results support previous findings, that morning types show earlier peaks in performances and rising/bedtimes than evening types and thus have an earlier midpoint of sleep. (Adan et. al, 2012).

The correlations between MESSi and personality variables (NEO- Five Factor Inventory) showed a positive correlation of MA with conscientiousness and extraversion and EV was negatively correlated with conscientiousness. These results are in line with previous research (Tsaousis 2010, Adan et. al, 2012).Furthermore, we also show an interesting finding for stability, which was positively correlated with neuroticism and negatively with conscientiousness. This finding supports our expectation that a high stability is related to certain characteristics and habits, like being neurotic and having a bad sleep quality. In order to be able to exclude or support this assumption further studies are necessary.

Circadian typology

Morning types always showed earlier rising and going to bed times compared to evening types, which confirms previous findings (Duffy et al. 2001, Thun et. al, 2012). The comparison of the sleep patterns during the week and on the weekend is important to explore the influence of social effects (e.g. social jetlag) on the sleep-wake time (Roenneberg et al. 2012). The results of our study show that morning types experienced a better sleep quality during week than evening types. On the weekend, no significant difference, concerning sleep quality, could be found anymore. This suggests that morning types, due to their individual circadian typology, have an advantage over evening types in terms of dealing with daily requirements, for example the adaption of their inner rhythm to the “social” rhythm (Vollmer et al. 2011).

During the week and on the weekend circadian typology had a significant influence on the acrophase and the midpoint of sleep. In general, morning-oriented subjects showed earlier peaks in activity and earlier midpoints of sleep. The significant difference in acrophase and midpoint of sleep between week and weekend is expected: on the weekend, there is less pressure to get up and go to bed early. The daily routines can be fitted to the inner rhythm of the persons and “weekend activity” is more affected by factors like social life or environmental issues. Interestingly, no significant difference for acrophase and midpoint of sleep between week and weekend could be found for morning types. Only evening types showed significant later peaks in activity and later midpoints of sleep during the weekend. This suggests that the circadian rhythm of morning types has a better fit to the requirements during the week than evening types. Morning types have to adjust their inner rhythm minimally, so that only a small difference to the weekend is visible. The circadian rhythm of the evening types had to be more adjusted for the daily routine during the week than during the weekend. These findings support the preceding literature but do also show that circadian typology affects the activity level of evening types more than for morning types, compared to weekdays.

Morning types reported higher values for the extraversion and conscientiousness scale compared to evening types, which confirms previous studies (Adan et al. 2012). Conscientiousness is the trait, which is most strongly associated with morning orientation. In our study, morning types were more extraverted than evening types, which is a new finding and yet not well established. Tsaousis et al. found that correlations between chronotype and personality traits change when comparing different samples (students vs. workers, Tsaousis et al. 2010)). This suggests that there might be some intervening moderators considering the interaction of circadian typology and personality. These findings should be investigated in further studies with different chronotype and personality measures.

Limitations

Regarding the procedure, the subjects had to complete several questionnaires (rMEQ, MESSi and PSQI) face-to-face with the experimenter, which can cause observer-expectancy bias. Additionally, subjects completed asleep diary at home. Thus, assessment methods differed and we cannot rule out that participants completed diaries at the end of the study period and not on a daily basis.. Next, it should be noted that only students participated in the present study. It is well known that not every student can maintain a regular daily routine with fixed getting up and going to bed times. Therefore, it would be useful to choose a more diverse oriented sample in a further study, possibly also with different jobs and age groups. Finally, it should be mentioned that a different number of females and males participated and that this may interact with some results. A sex-balanced sample is recommendable for further studies.

Acknowledgements

We are grateful to the students that participated in this study. We want to thank Dr. Jan Kühnhausen for his statistical support as well as the LEAD Graduate School & Research Network.

Declaration of interest

The authors declare no conflict of interests.

Funding

This research was supported by a grant of the Gips-Schüle-Stiftung. The foundation had no influence on the study, the results and the decision to publish.

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5. Study 2:
Weak associations of Morningness-Eveningness and Stability with skin temperature and cortisol levels

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Contributions

Title of the paper: Weak associations of Morningness-Eveningness and Stability with skin temperature and cortisol levels

List of Authors	Author position	Scientific ideas (%)	Data generation (%)	Analysis and interpretation (%)	Paper writing (%)
Corina Weidenauer	1	40	100	75	50
Christian Vollmer	2	0	0	15	5
Katharina Scheiter	3	0	0	10	20
Christoph Randler	4	60	0	0	25

Publication status: accepted for publication in the Journal of Circadian Rhythms, 17(8).

Weak Associations of Morningness-Eveningness and Stability with Skin Temperature and Cortisol Levels

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Running Head: MESSi and physiological Markers

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Abstract. Differences in daytime preferences can be described on the dimension of morningness-eveningness (continuous) or circadian typology (categorical). Circadian typology is associated with our biological functioning, which is reflected in body temperature rhythm and the cortisol levels in the morning. The purpose of the present study was to explore the relationship between morningness-eveningness, stability and physiological markers (body temperature, cortisol) based on a three-dimensional conceptualization of morningness-eveningness, using the Morningness-Eveningness-Stability Scale improved (MESSi). In contrast to previously used unidimensional measures, the MESSi determines circadian typology and its amplitude in three dimensions: Morning affect (MA), Eveningness (EV) and Stability/Distinctness (DI). Furthermore, the differences of the cortisol levels between weekday and weekend were examined. The sample (*N* = 42) consists out of extreme chronotypes (age 18-54 years; *M* = 24.8 years, *SD* = 5.83; 22 morning types [5 men and 17 women] and 20 evening types [8 men and 12 women]). The participants were asked to measure their skin temperature for one week and sample four saliva probes for cortisol determination. Morning types showed a better fit in the actual temperature data to the approximating data as compared to Evening types. The Morning Affect (MA) component of the MESSi correlated positively with the acrophase of the skin temperature and the Stability/Distinctness (DI) component negatively with the nadir, but only for Evening types. Morning types also showed higher cortisol levels than Evening types immediately after awakening. The cortisol levels were higher on a weekday compared to the weekend. To conclude, the present findings demonstrate that the skin temperature is weakly associated with morningness-eveningness and the stability of the circadian phase.

Keywords: Morningness-eveningness, MESSi, body temperature, cortisol awakening response

1. Introduction

The human biological rhythm shows continuous fluctuations in a nearly 24-hour range (circadian rhythm) [1]. The distribution of active and rest phases or sleep and wakefulness differs between individuals [2]. These individual daytime preferences can be summarized as morningness-eveningness (M/E). Research has identified three different groups of so-called “chronotypes”: morning types (M-types), neither types, and evening types (E-types). M-types (“larks”) prefer to wake up and go to bed early and tend to have their mental and physical peak in performance during the first half of the day. In contrast, E-types (“owls”) prefer to get up late and go to bed late. Their peak in performance can be found during the second half of the day [3]. It is well known that circadian typology affects many areas of daily life, like cognition [4], eating habits [5], and mental disorders [6]. Therefore, it is important to correctly assess and estimate the individual circadian phase. This can be done on the one hand by using certain physiological and biological markers such as: melatonin secretion [7], cortisol measurement [8], body temperature recording [9] or gene-expression analysis by blood and epidermis samples [10, 11]. On the other hand, self-assessments can be used as a convenient way, especially when conducting research in large samples.

1.1 The MESSi

M/E can be measured by using different self-assessments. Depending on the purpose and context of the planed study, one can choose for example between the most commonly used Morningness-Eveningness Questionnaire (MEQ) by Horne and Östberg [12], the Diurnal Type Scale (DTS) by Torsvall and Åkerstedt [13] or the Munich ChronoType Questionnaire (MCTQ) by Roenneberg and his colleagues [14, 15, 3]. However, all of these measures refer to M/E as a unidimensional construct, with morningness and eveningness marking the two endpoints of one scale. For example, the MEQ only determines circadian preference on a specific phase of the day and categorizes the participants into groups by certain cut-offs [12]. However, M/E should be thought of and measured as a multidimensional construct, where morningness, eveningness and stability refer to different dimensions. The dimension morningness describes the affective facet of the morning orientation and takes for example into account how easy it is to get out of bed in the morning or how awake someone feels. The dimension eveningness determines the affective facet of the evening orientation and also evaluates activity aspects and mood in the evening. The third dimension distinctness/stability operationalizes the fact that circadian preferences fluctuate throughout the day. Subjective feelings, concentration and motivation plays also an important role [16]. Although M/E has been seen as a one-dimensional trait [15] some researches indicate that M/E should be determined by two separated dimensions [17]. Further it has been suggested, that the amplitude of the circadian preference should also been taken into account and should be an additional measure [18, 19]. Thereby, the amplitude of the circadian preference describes the range of the fluctuations in circadian preference.

The Morningness-Eveningness-Stability Scale (improved) tries to do justice to all those requirements. It is a self-assessment instrument that determines the individual circadian preference and its amplitude on three continuous dimensions: Morning affect (MA), Eveningness (EV) and Stability/Distinctness (DI). The two dimensions MA and EV determine circadian preference, whereas the third dimension DI deals with the fluctuations during the day. Measuring M/E this way allows to account for the fact that M/E is a two-dimensional trait with an additional measure, the amplitude of the circadian preference through the day. The MESSi does not categorize participants into distinct groups; rather, it allows to consider the fact that a certain type of circadian preference may be more or less pronounced within an individual. In addition, it reflects that individuals may show fluctuations in their circadian preference depending on other, contextual factors. Therefore, the MESSi represents an innovative and potentially more valid way to determine circadian preference. For more and detailed information, see [16, 20]. Despite its potential advantages, the MESSi requires further validation. One common way to validate self-assessments on circadian preference is to establish their relations with more objective measures of circadian typology, namely, physiological markers. The physiological markers that show strong daytime fluctuations and are hence sensitive to circadian rhythms are body temperature and the two hormones cortisol and melatonin. In the present paper, the relation between the MESSi and body temperature and cortisol level were established to further validate the instrument.

1.2 Circadian typology and body temperature

Body temperature has a very stable daytime rhythm, which has a nearly 25 h cycle even when controlling for environmental influences such as light and darkness [21]. Therefore, we decided to use the body temperature as one of the physiological markers in this study.

In general, the body temperature is controlled by a complex feedback system [22]. The thermoregulation system keeps the body temperature in balance between heat gain and heat loss [23]. The circadian regulation of the sleep-wake cycle is clearly associated with thermoregulatory mechanisms, but the circadian rhythm of the body temperature seems to be independent of the sleep-wake system [24].

To measure the rhythm of the body temperature, core body temperature, oral and skin temperature can be used. Usually, core body temperature is used, because its fluctuations are robust and less influenced by environmental issues. To measure the core body temperature, rectal measurements are often used. The participants have to wear small sensors [25, 26] over a long period or even to swallow small data-logger pills [27]. These methods are unpleasant for the participants and beyond that quite expensive. Furthermore, frequent controls and surveillance of the participants are necessary, so they normally have to stay in a sleep lab. Alternatively, to have a more unobtrusive way of measuring and to determine the circadian rhythm of the body temperature under natural everyday condition, the skin temperature can also be assessed using small sensors. iButtons are often used for this purpose [28]. These are temperature data loggers that can be attached to a random location on the skin of the participants. iButtons measure the skin temperature within a range of – 40 to +85 degrees Celsius with a possible deviation of 0.5 degrees Celsius. The rhythm of the skin temperature can be influenced by environmental characteristics such as physical activity or environmental temperature. Above all, the amplitude is strongly influenced and the acrophase seems to be quite robust [29]. The skin temperature fluctuations during a 24-h period normally show a wide range (between 31 °C and 36 °C) with the highest values appearing during sleep and the lowest during wake time. This can depend on the technique deployed by different sensors [29, 30]. The skin temperature drops rapidly after awakening and decreases over the remainder of the day until reaching its minimum in the evening. During the night the skin temperature increases again and peaks in the early morning hours [29, 30]. The aforementioned development of the body temperature across the day/night cycle describes the pattern that can be observed when averaging across people. However, there are individual differences in these phase shifts of the body temperature, some of which can be related to circadian preference. In particular, research has shown that M-types have earlier acrophase times (6 to 7 pm) in body temperature and their temperature minimum occurs also earlier (3 to 5 am) compared to E-types (acrophase: 8 to 10 pm, nadir: 5 to 6 am) [30-34]. It is yet an open question, whether measures of skin temperature reveal the same relations to circadian preference, given that they may be less sensitive than measures of core body temperature.

1.3 Circadian typology and cortisol

Another physiological marker that is known as a good indicator and whose relation to circadian preference is well established is the stress hormone cortisol. Cortisol is produced via the hypothalamus-pituitary-adrenal axis ("HPA") and released into the bloodstream when the body needs energy [35, 36]. Factors like anxiety [37] and light exposure [38] can strongly influence the secretion. Under normal conditions, the cortisol fluctuation follows a distinct rhythm with small (short duration) but strong (large amplitudes) episodes [39]. The cortisol level starts to increase in the second half of the night and peaks in the early hours of the morning. After that, it decreases slowly throughout the rest of the day and shows its nadir in the first half of the night [40]. This sharp increase in cortisol in the morning occurs immediately after awakening and reaches its highest level at least 30 minutes after awakening. This effect is called cortisol-awakening-response (CAR) [41]. Research is ambiguous about a potential influence of age and gender on CAR. It is assumed that the characteristics of the sample as well as the assessment methods influence the findings [39]. However, an influence of circadian typology on the cortisol level in the morning has been well established. In particular, M-types have a higher cortisol level after awakening than E-types [42-44]. This can be seen especially 30 and 45 minutes after awakening [45]. In addition, E-types feel less aroused than M-types at the same time in the morning [42]. Therefore, it is not surprising that the peak of cortisol level occurs earlier in M-types [8]. In addition, there is first evidence pointing towards a difference in CAR between weekdays and weekend. Kunz-Ebrecht and her colleagues [46] showed that CAR is larger on working days compared to weekend days. They assume that the anticipation of a working day increases the CAR. In addition, the rise of the cortisol level after awakening is steeper on weekdays compared to days on the weekend [47].

1.4 Aims of the present study

The first and main aim of the present study was to further validate the measurement MESSi with the help of the physiological markers body temperature (in this case, skin temperature) and cortisol (here: cortisol levels in the morning and CAR). Randler and colleagues [16] proposed that it is important to validate the MESSi with more objective variables, such as actigraphy [48], body temperature and cortisol. Against this backdrop, we expect significant correlations between the sum-scores of the three dimensions of the MESSi with the nadir and acrophase of the skin temperature, as well as with the cortisol levels in the morning and the CAR.

Second, we aimed at determining the relation among circadian typology and the rhythm of the skin temperature, the cortisol levels in the morning and the CAR. We hypothesize a significant effect of circadian typology on the acrophase and nadir on the skin temperature, as well as on the cortisol levels in the morning and the CAR. M-types should show earlier peak and nadir phases than E-types and present higher cortisol levels in the morning. The CAR should show a significant difference between the chronotypes, with Morning types having a greater CAR [8, 30-34, 42-44]. To investigate relations to chronotype, the reduced Morningness-Eveningness Questionnaire (rMEQ) [49] was used in addition to the MESSi, because, as mentioned before in the section 1.1, the MESSi's conceptualization does not rely on a categorization of people according to a fixed typology. The convergent validity of the MESSi and the rMEQ could already be shown in an earlier study [48].

Third, we wanted to examine a potential effect of circadian typology and preference on the cortisol levels in the morning and the CAR between weekday and weekend. To this end, we assumed that there would be significant differences in the CAR between weekday and weekend moderated by participant's chronotype. Fourth, we aimed at extending previous findings regarding differences in the CAR between weekday and weekend [46]. The cortisol levels in the morning and the CAR should show higher values on weekdays compared to weekend days.

The study is new and original in a way that it for the first time measures the relationship between these physiological variables and a three-dimensional measure of circadian preference. Usually, all studies in this respect are based on uni-dimensional measures that consider morningness-eveningness as one-dimensional. Here, we extend the findings based on three dimensions.

2. Material and Methods

2.1 Participants

A total of 97 university students (24 male and 73 female), aged 18 to 54 years, participated in the study. The mean age of the participants was 24.5 ± 6.0 years. We screened the whole sample by using the reduced Morningness-Eveningness Questionnaire (rMEQ) and the Morningness-Eveningness-Stability Scale improved (MESSi) to select a subsample of definite M and E-types (*N* = 42; mean age: 24.8 ± 5.8 years). Twenty-two M-types (5 male and 17 female) and Twenty E-types (8 male and 12 female) could be identified. The majority of the males (84.6%) did not take any medication but 8 females indicated that they took hormonal contraception. The participants did not do any night or shiftwork and were excluded when they reached scores higher than 10 in the Pittsburgh-Sleep-Quality Index (PSQI). 12 participants indicated to have a side job. One participant was excluded from the body temperature analysis because he lost his device.

2.3 Questionnaires

2.2.1 Morningness-Eveningness-Stability Scale, improved (MESSi) [16]

To determine circadian typology and its amplitude, the German version of the MESSi [16] was used. The MESSi contains three scales: Morning affect sub-scale (MA), Eveningness sub-scale (EV) and Distinctness/Stability sub-scale (DI). Each of those sub-scales is represented by 5 items with options ranging from 1 to 5. Higher scores represent higher expressions in the respective sub-scale. The MA sub-scale measures the affective facet of morningness-eveningness ("How easy is it for you to get up in the morning?") and the EV sub-scale determines the affective facet of the evening orientation ("After waking up, I feel sleepy for some time "). The DI sub-scale gives information about the stability of the orientation of the participants. It shows how much the expression of the facets fluctuates throughout the day ("I can be concentrated at any time of the day"). High scores represent a greater fluctuation. Analysis showed a Cronbach´s alpha of 0.95 for the MA component of the MESSi, 0.90 for EV and 0.72 for the DI component. The MESSi has been used in some countries already, and the three-factorial structure has been established by psychometric analysis [20].

2.2.2 Reduced Morningness-Eveningness Questionnaire (rMEQ) [49]

To determine circadian typology the shortened German version of the Morningness-Eveningness Questionnaire was used [50]. The questionnaire has 5 items. For the first question the participants has to mark a timespan, when they would like to get up ("If it was only for your own well-being and you could organize your day completely free, when would you get up?). The second question refers to the fatigue of the participants after getting up ("How tired do you feel in the morning in the first 30 minutes after awaking?"). Here they have to choose one of the four options ranging from "very tired" to "very awake". For the third and the fourth question, the participants have to mark again a timespan concerning their need to sleep ("At what time do you get tired at night and feel the need to go to sleep?) and their feeling through the day ("At what time do you feel best?). With the last question, they give a self-assessment regarding their own chronotype. Options range from "clearly a Morning type" to "clearly an Evening type". The participants can reach credit scores, ranging from 4 to 25. Classifications into one of the three chronotype categories are possible: morning types (18 – 25), neither types (12 – 17) or evening types (4 – 11). Analysis showed a Cronbach's α of 0.84 for the sum-score of the rMEQ. In a further done study, the rMEQ was set in relation to the Composite Scale of Morningness to show convergent validity (r = 0.885) [51]. In the present study, the rMEQ was used to classify the participants into the different chronotypes groups.

2.2.3 Pittsburgh-Sleep-Quality Index (PSQI) [52]

To determine the individual sleep quality of the participants, this 4-week-retrospective questionnaire was used. The 19 items require a subjective rating of seven sleep-related categories: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction (e.g. "How many times did you sleep badly because you woke up in the middle of the night or early in the morning?”). The 5 items related to peer/mate assessment were not included. The total scores can range from 0 to 21. Higher scores represent a worse sleep quality. The cut-off score for a bad sleep quality can be located at 5. A score higher than 10 suggests an impaired sleep disorder. Analysis of the study from Buysee et al.,(test-retest reliability) showed high correlations of the global PSQI scores (r = 0.85). The PSQI represents a sensitivity of 89.6 % and a specificity of 86.5% [52]. In the present study, the PSQI was only used to control for sleep disorders. No further calculations were done.

2.3 Physiological measures

2.3.1 Skin temperature

The skin temperature of the participants was measured by iButtons (Thermochron Temperature Data Loggers, type DS1922L, Maxim Integrated Products, Munich; Germany) [53] to determine natural fluctuations because the devices can be used in the participants’ home environment. The iButtons were attached to the inside of the non-dominant wrist of the participants using one-size sweatbands (HEAD, Kennelbach, Austria) to reduce most of the environmental influences. The skin temperature was recorded for seven days (00.00 am to 23:59 pm) every 2 minutes. Using the corresponding software (1-Wire, version 03.19.47) the data were extracted from the device. For every participant there were 720 temperature logs per day (5,040 in total). For each 24-h section temperature data were averaged into 20-min sections and missing data were interpolated. Temperature logs showing less than 28 degrees Celsius and higher than 40.8 degrees Celsius were excluded. The participants received the instruction to wear the device constantly (except for showering or taking a bath) and to note the timespan when they had to remove it. The temperature logs were visually screened for those timespans and the corresponding data were excluded.

2.3.2 Saliva cortisol

The cortisol levels of the participants were assessed in their saliva by using salivettes (Sarstedt, Nümbrecht, Germany). To this end, participants were asked to sample four saliva probes; two during the week and two on the weekend. The first probe on each day was to be taken immediately after awakening and the second one half an hour later. The participants were told not to eat, drink (other than water) or brush their teeth in these 30 minutes and not to exercise. They had to mark the label on the polypropylene container of the salivettes with the date and the number of the probe (first or second). The saliva probes were sent by post to a laboratory (Dresden Lab Service GmbH, Dresden, Germany) for analysis. They calculated the cortisol level in nanomol per liter for each participant of each probe and sent the results via mail.

2.4 Procedure

The study took place at the University of Tuebingen, Germany in the survey period from January 1st to March 31st, 2017. The recruitment information was given to all students of the university via mail and posters at the campus. Interested students were invited for a first screening. The sessions began for the participants with their agreement for the conditions of participation and the assessment of their demographic variables (age, gender, relationship status, handedness, occupation and medication). After that, they completed the rMEQ, the MESSi and the PSQI to identify the individual chronotype (and its amplitude) and exclude participants with sleep disorders. If the participants met all our criteria (especially definite M or E-type, no shift work and no sleep disorder), a second appointment was arranged. At this appointment the iButton was attached and the salivettes were handed out (4 for each participant). Participants got detailed information how to handle the devices and not to forget to note when they remove the iButton. After one week of sampling, a third appointment was arranged at which the participants returned the devices.

2.5 Data analysis

Mean differences for the participants` characteristics (age, gender, relationship status, PSQI and MESSi components) as a function of chronotype were determined by calculating t-statistics and chi-square statistics. To estimate circadian temperature rhythm parameters (acrophase and nadir) a curve-fitting cosinor procedure was applied and summary measures of R^2 (the variance statistic or goodness of fit of the actual data to the approximating 24h cosine curve) were calculated. The acrophase/nadir of the skin temperature represents the average acrophase/nadir of the skin temperature for each participant in the whole sampling time. Additionally, the amplitude (difference between acrophase and nadir) of the skin temperature was determine for each participant. Furthermore, Pearson correlations (zero-order) were calculated to account for the relationship of the dimensions of the MESSi with the skin temperature rhythm parameters and the cortisol parameters: CAR on a weekday, CAR on the weekend, first cortisol probe directly after awakening on a weekday (t1_weekday), second cortisol probe 30 minutes later on a weekday (t2_weekday), first cortisol probe directly after awakening on the weekend (t1_weekend) and second cortisol probe 30 minutes later on the weekend (t2_weekend).

Multivariate variance analyses (MANOVA) were run to assess the effect of chronotype on the body temperature rhythm and the cortisol parameters. Chronotype (M-types vs. E-types) represents the independent variable and the skin temperature rhythm parameters (acrophase, acrophase_time, nadir, nadir_time) as well as the cortisol parameters the dependent variables. Partial eta-squared was used as a measure of effect size. All statistical analyses were conducted using SPSS version 25 (IBM Corp., Armonk, New York; released 2017).

3. Results

3.1 Participant characteristics

To give further information, the participants´ characteristics are listed in **Table 1.** It shows the characteristics of the participants split by chronotype (The classification of the participants into their chronotypes is based on the values of the rMEQ). M-types scored significantly higher for the MA component of the MESSi. E-types showed significant higher values for the EV component of the MESSi. No significant group differences were found for age, gender, relationship status and the DI component of the MESSi.

Table 1. Descriptive statistics (*M*, *SD*, *n* and %) and test statistics for participant characteristics as a function of chronotype.

	M-types	E-types	Test statistic
Age (in years)	*M* = 24.86 (7.07)	*M* = 24.65 (4.25)	$t_{(40)} = .12$, $p = .905$
Gender			
Male	n = 5 (22.7%)	n = 8 (40.0%)	$X^2 = 1.46$, $p = .227$
Female	n = 17 (77.3%)	n = 12 (60.0%)	
Relationship status			
Single	n = 11 (50.0%)	n = 9 (45.0%)	$X^2 = 0.49$, $p = .782$
Relationship	n = 10 (45.5%)	n = 9 (45.0%)	
Married	n = 1 (4.5%)	n = 2 (10.0%)	
Dimensions of the MESSi			
MA	*M* = 21.64 (2.12)	*M* = 10.70 (2.45)	$t_{(40)} = 15.44$, $p < .001$
EV	*M* = 10.86 (3.37)	*M* = 19.85 (2.54)	$t_{(40)} = -9.81$, $p < .001$
DI	*M* = 18.27 (3.82)	*M* = 20.30 (3.08)	$t_{(40)} = -1.90$, $p = .065$

3.2 Validation of the MESSi

To investigate the validation of the MESSi correlation analysis showed no significant correlations between the rMEQ sum-score and the skin temperature parameters (acrophase: $r = .03$; nadir: $r = .05$ and amplitude: $r = -.02$). The MA and EV component of the MESSi showed also no significant correlations with the skin temperature parameters. The DI component, on the other hand, showed a weak negative correlation with the nadir of the skin temperature ($r = -.39$, $p = .05$), indicating that higher fluctuations in circadian preference are associated with a lower average skin temperature during nadir. DI showed no further significant correlations with the skin temperature parameters (acrophase: $r = -.12$ and amplitude: $r = .24$). Separated by chronotype, DI was negatively correlated with the nadir of the skin temperature ($r = -.50$, $p = .05$) for E-types. No further significant correlations for the components of the MESSi and the skin temperature parameters were found, even when split by chronotype.

Correlations analysis showed no significant correlations between neither the sum-scores of the rMEQ with the cortisol levels in the morning (first cortisol probe directly after awakening and second cortisol probe 30 minutes after awakening) and CAR nor the components of the MESSi with those variables.

3.3 Relation of Chronotype and physiological parameters

In **Table 2** the descriptive statistics of the skin temperature and its nadir/ acrophase, as well as the amplitude is shown split by chronotype. There is a significant difference in the average skin temperature. M-types showed a higher overall skin temperature than E-types.

Table 2. Descriptive and test statistic (*M* and *SD*) of the temperature (mean value in Celsius), nadir and acrophase values of the temperature (in Celsius) and the amplitude of the temperature.

	M-types	E-types	Test statistic
overall temperature	*M* = 33.41 (1.96)	*M* = 33.29 (1.71)	$t_{(19624)} = 4.53$, $p < .001$
Temperature during nadir	*M* = 32.22 (1.08)	*M* = 32.13 (0.99)	$t_{(39)} = 0.27$, $p = .787$
Temperature during acrophase	*M* = 34.57 (0.90)	*M* = 34.40 (0.83)	$t_{(39)} = 0.64$, $p = .527$
amplitude	2.36 (1.40)	2.27 (1.02)	$t_{(39)} = 0.23$, $p = .828$

The cosinor analyses of the skin temperature values showed a good fit ($R^2 = .24$) of the actual temperature data to the approximating 24 h cosine curve. In separate analyses by chronotype, M-types showed a better fit ($R^2 = .31$) than E-types ($R^2 = .19$), see **Figures 1 and 2**.

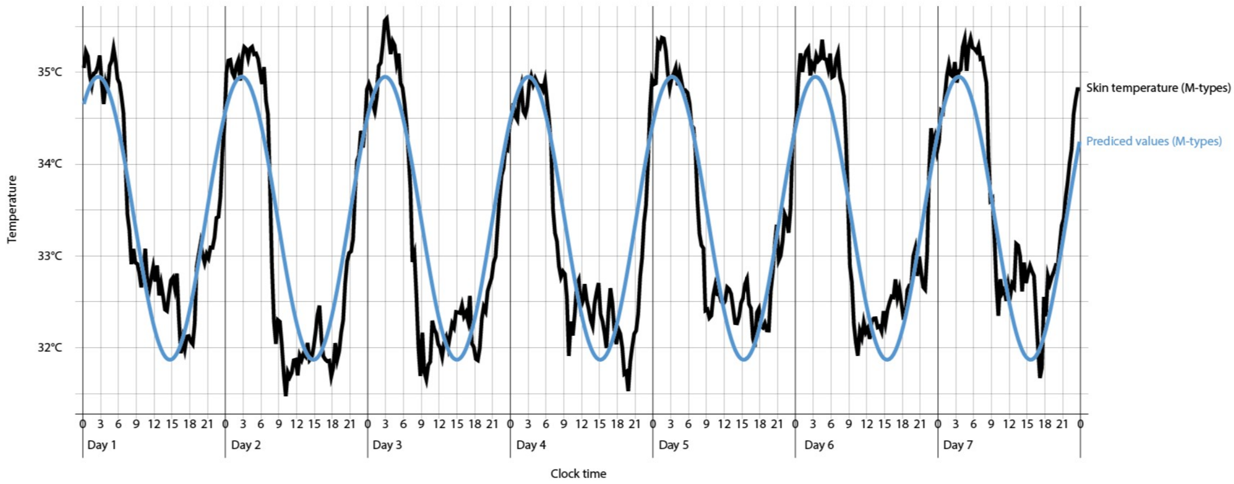

Figure 1: Actual and predicted skin temperature values for M-types.

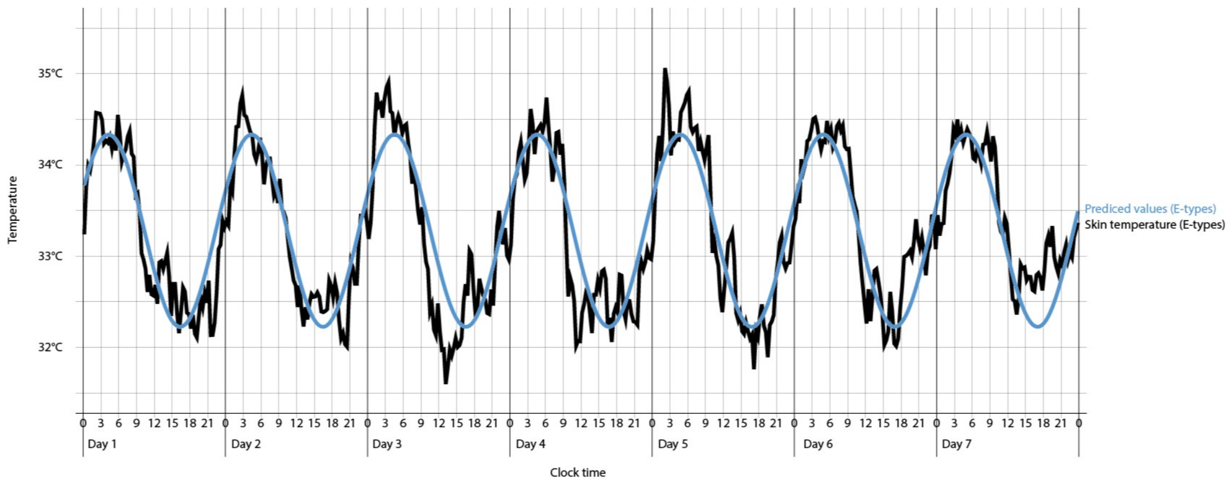

Figure 2: Actual and predicted skin temperature values for E-types.

The MANOVA showed no significant effect of Chronotype on the cortisol levels in the morning (first cortisol probe directly after awakening and second cortisol probe 30 minutes after awakening) and the cortisol-awakening-response. For detailed information, see the following **Table 3**.

Table 3: test statistic of the MANOVA (df, F and p-values and effect size) for the effect of Chronotype on the cortisol levels in the morning and the CAR.

variables	df	*F*	*p*	η_p^2
t1	1, 38	2.99	.092	.073
t2	1, 38	0.05	.833	.001
CAR	1, 38	0.94	.340	.024

T1 = first cortisol probe directly after awakening; t2 = second cortisol probe 30 minutes after awakening; CAR = Cortisol-Awakening-Response

3.4 Relation of Chronotype and circadian preference among cortisol levels in the morning and CAR depending on weekday

None of the components of the MESSi (MA, EV and DI) showed significant correlations with the cortisol levels in the morning (first cortisol probe directly after awakening and second cortisol probe 30 minutes after awakening), neither on the weekday nor on the weekend. The CAR on a weekday and on the weekend showed also no significant correlations with the components of the MESSi (MA.EV and DI).

In separate analyses by Chronotype, M-types showed a positive correlation of EV (r = .48, p = .05) with the first cortisol probe directly after awakening on a weekday. E-types showed a positive correlation of EV (r = .62, p .01) with the first cortisol probe directly after awakening on the weekend. The CAR on the weekend showed a negative correlation with EV (r = -.54, p = .05) only for E-types.

Chronotype showed a significant effect on the first cortisol probe directly after awakening on a weekday ($F_{1, 35}$ = 6.38, *p* = .016, η_p^2 = 0.14). M-types (*M* = 17.44, *SD* = 7.28) presented significant higher cortisol values after awakening than E-types (*M* = 12.18, *SD* = 5.53). Further analysis showed no significant effect of chronotype on the other cortisol levels in the morning (second cortisol probe 30 minutes after awakening on a weekday: $F_{1, 38}$ = 0.004, *p* = .952, η_p^2 = 0.00; first cortisol probe directly after awakening on the weekend: $F_{1, 38}$ = 0.52, *p* = .475, η_p^2 = 0.014; second cortisol probe 30 minutes after awakening on the weekend: $F_{1, 38}$ = 0.21, *p* = .646, η_p^2 = 0.006). Chronotype showed also no significant effect on the CAR, neither on a weekday ($F_{1, 38}$ = 1.87, *p* = .197, η_p^2 = 0.05) nor on the weekend ($F_{1, 38}$ = 0.04, *p* = .847, η_p^2 = 0.001).

3.5 Cortisol and weekday

Analysis showed a significant difference between the second cortisol probe 30 minutes after awakening on a weekday and the second cortisol probe 30 minutes later on the weekend (t_{39} = 4.45, *p* < .001, *d* = .384). The cortisol level 30 minutes after awakening on a day during week was significantly higher (*M* = 28.11, *SD* = 12.22) than the cortisol level 30 minutes after awakening on the weekend (*M* = 19.26, *SD* = 10.22). There were no significant differences between the first cortisol probes directly after awakening concerning weekday (t_{39} = -0.19, *p* = .847, *d* = .365).

The CAR showed a significant difference between the cortisol levels on a day during week and the weekend (t_{39} = 3.91, *p* < .001, *d* = .312). The CAR on a weekday (*M* = 13.04, *SD* = 12.80) reached higher cortisol levels than the CAR on the weekend (*M* = 3.89, *SD* = 12.39).

4. Discussion

4.1 Validation of the MESSi

Regarding the main aim of the present study (to further validate the MESSi), previous results [48, 54] could be significantly extended. In an earlier study, high correlations between the MA and the EV component of the MESSi with the scores of the rMEQ were found (for more detailed information, see [48]). In this study, morning-oriented participants showed significant higher scores for the MA component of the MESSi and evening-oriented participants for EV component, which confirms the validity of the MESSi. The DI component showed no significant difference between morning and evening-oriented participants. Nevertheless, with a p-value of *p = 0.065* a trend can be seen. This trend suggests that evening-oriented participants show higher fluctuations in their daily circadian preferences. So far, there is no exact explanation for this finding and therefore requires further research. However, it is suspected that morning-oriented people can better integrate their behavior into our "social clock driven society" [55, pp. 11]. Our daily life is determined by time schedules (in school, at university or at work) and evening-oriented persons are forced to adapt their behavior to those. For this reason, larger fluctuations in the behavior of circadian preference could be seen. To further validate the MESSi correlations between the sum-score of the rMEQ / the components of the MESSi and the skin temperature parameters were calculated. The rMEQ sum-score as well as the MA and EV component of the MESSi showed no significant correlations. At this point, it should be mentioned that only extreme chronotypes (M and E-Types) were considered for analysis. There might be stronger correlations if considered all chronotypes (Moring types, Evening types and Neither types). Further research could take this into account.

The DI component of the MESSi, on the other hand, showed a weak negative correlation with the nadir of the skin temperature. This suggest that higher fluctuations in circadian preference might lead to a lower skin temperature during nadir. This result suggests that the stability of circadian preference thorough the day may have an effect on physiological parameters of the body. A further interesting finding was the negative correlation of the DI component with the nadir of the skin temperature in E-types. Evening-oriented participants showed a lower temperature in the nadir phase, when their fluctuations in their circadian preferences are larger. The stability of the circadian phase during the day for evening-oriented participants could be associated with a biological marker. This is a new finding so far and needs further consideration. In addition, it gives an interesting insight into the skin temperature regulation, probably moderating by circadian preference. Evening-oriented people tend to show greater fluctuation in their circadian behavior throughout the day. These larger fluctuations could affect the rhythm of the skin temperature. Thus, the greater efforts that evening-oriented people have to make in order to keep up in everyday life may affect their skin temperature rhythm. This greater effort can lead to stress and sleep deprivation in evening-oriented people and these factors can affect the rhythm of the skin temperature [58-60].

4.2 Relation of Chronotype and physiological parameters

M-types showed a better fit in their actual temperature to the approximating data than E-types. This suggests that M-types have a more “regular rhythm” of skin temperature with smaller fluctuations. This could be due to a lower amplitude. It could be shown, that E-types tend to have a lager amplitude compared to M-types (Baehr et al., 1998). In this study, no significant difference between Chronotype and amplitude could be seen. In general, M-types showed a significant higher temperature than E-types. Even Horne and Östberg in 1976 [12] could show that M-types tend to have a higher daytime temperature than E-types. One might argue that

this result is caused by the female-based sample with more women in the morning type group and more men in the evening type group. It could be shown, that women tend to have a higher average body temperature in a 24-h rhythm compared to men and the circadian rhythm of the body temperature is influenced by the menstrual phase of females [56]. However, it should be considered that the skin temperature is less influenced by the female menstrual cycle compared to the core body temperature [57]. Important for further analysis would be a balanced sample controlling for the use of contraceptives and the menstrual cycle. Such a study might be carried out in women only.
The results of the calculated MANOVA showed no effect of circadian typology on the cortisol levels in the morning and the CAR at all. One possible explanation for these findings might due to the fact that only university students participated in the present study. In a study of Randler and Schaal [44] it could be found out, that bed times are one of the most relevant variables, that effect cortisol levels. Adolescents had to get up earlier and therefore sample the probes for cortisol determination at earlier times in the morning. Generally higher cortisol levels for adolescents are the result. Another important factor is the circumstance that in the present study the cortisol sampling was not controlled for a special weekday. As it can be read in the review of Clow and colleagues [62], a stressful weekday can influence the cortisol levels in the morning. Further studies should consider this fact and let the participants sample their probes on given days.

4.3 Relation of Chronotype and circadian preference among cortisol levels in the morning and CAR depending on weekday

None of the components of the MESSi, neither on the weekday nor on the weekend, showed significant correlations with the cortisol levels in the morning and the CAR. In the present study, cortisol was measured twice on two single days: on one day during week and on one day on the weekend. Further research should consider to measure cortisol on seven constant days.
In order to be able to view the results in more detail, the scoring on the components of the MESSi (MA, EV and DI) was presented separately by chronotype. These findings were then connected with the values of the cortisol levels in the morning. M-types that scored high on the EV component also have higher values in cortisol

directly after awakening during a weekday compared to M-types that scored low on EV. This suggests that a higher "evening" orientation (represented by higher scorings on the EV component of the MESSi) must be compensated with higher cortisol values after awakening to be better activated.

Interestingly, E-types that scored high on EV showed a positive correlation with the first cortisol sample directly after awakening on the weekend. Consequently, a negative correlation of EV with the CAR on the weekend for E-types was found. The cortisol values directly after awakening on the weekend might be high enough for an optimal activation. One possible explanation could be that on the weekend E-types can get up at a time that better corresponds to their inner rhythm and therefore a "good" activation by cortisol can be observed [44]. On the other hand, the circadian rhythm of the M-types is better adapted to the demands of everyday life [63]; hence, they do not have such a vast conversion of their circadian biological rhythm from weekday to weekend compared to E-types.

In line with Randler and Schaal [44], a significant influence of chronotype was present for the first cortisol values directly after awakening on a weekday. M-types showed significant higher cortisol values than E-types. This could be one possible explanation, why M-types get up easier in the morning [3]. From the beginning, their first cortisol values are higher as compared to E-types, so their body can be better activated. In contrast, E-types are forced to get up to earlier for their inner rhythm and thus their natural activation by an increased cortisol level might fail (Randler und Schaal [44]).

4.4 Cortisol and weekday

The analysis of the difference between the cortisol values on a weekday and on the weekend independent of chronotype and circadian preference showed a significant difference between the cortisol values 30 minutes after awakening. The values on a weekday were significantly higher than the corresponding values on the weekend. This effect can also be observed with the CAR. In line with other studies [47, 64,] the CAR on a weekday reached significantly higher cortisol levels than the CAR on the weekend. This means that during the week a higher activation of the body is necessary to start into the day. Some researchers attribute this difference to factors such as stress or anxiety at work [62, 65]. Another possible explanation could be due to the fact that the participants wake up at later times at weekends, as they usually do during the week. However, their body gets used to the wake-up times during the week and activates the body at the usual time with an increase of the cortisol level. If then the cortisol level is measured at a later time, in the usual increase may have fallen again.

4.5 Limitations

In the present study, chronotype was assessed by self-reported data with two questionnaires (rMEQ and MESSi). Future work can focus on using actual sleep data form objective devices, like e.g. actigraphy [33]. Further, we analyzed the skin temperature rhythm for the present study. One could consider determining the core body temperature because it is less affected by disturbing variables [22-24]. It could also be considered to collect information about the state of the participants and therefore control for stress or actual health [46]. The saliva cortisol probes were collected on one day during week and on one day on the weekend. It would be more prudent and recommendable to sample the cortisol levels every day for one week to be able to determine more external influences. Finally, it should be noted that further studies should pay attention to a gender-balanced sample.

4.6 Conclusion

The present findings demonstrate that the skin temperature is associated with morningness-eveningness and the stability of the circadian phase might have a potential effect on the skin temperature rhythm. It could be shown that physiological markers, such as cortisol levels, are intertwined in our circadian phase and that other factors (weekday vs. weekend) might play an important role for the activation in the morning. However, it should also be noted that the primary aim of the present study, namely to further validate of the MESSi with physiological parameters like skin temperature and cortisol levels, was not sufficiently satisfactory in this sample. Further analyses and investigations are planned to do justice to this project.

Conflicts of interest

The authors declare no conflict of interests.

Financial support

This research was supported by a grant of the Gips-Schüle-Stiftung. The foundation had no role in the study design, collection, analysis or interpretation of the data, writing the manuscript, or the decision to publish. We acknowledge support by Deutsche Forschungsgemeinschaft and Open Access Publishing Fund of University of Tübingen.

Ethics and consent

The research has been conducted in an ethical and responsible manner and is in full compliance with all relevant codes of experimentation and legislation. The study follows the principles of the Declaration of Helsinki and was approved by the Ethics Committee for Psychological Research of the Faculty of Mathematics and Natural Sciences (University of Tuebingen, Az.: 2016/0901/19). The study received a positive vote by the Committee. All participants gave their formal written consent after receiving instructions. The study was voluntary, unpaid and anonymous.

Acknowledgements

CW, KS and CR are members of the LEAD Graduate School [GSC1028] funded by the Excellence Initiative of the German federal and state governments.

Author Contributions

C.R. and C.W. designed the study. C.W. and C.V. made the analysis, C.W and C.R. wrote the manuscript. All authors reviewed the manuscript.

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6. Study 3:
Measuring circadian preference in adolescence with the Morningness-Eveningness Stability Scale improved (MESSi)

Contributions

Title of the paper: Measuring circadian preference in adolescence with the Morningness-Eveningness Stability Scale improved (MESSi)

List of Authors	Author position	Scientific ideas (%)	Data generation (%)	Analysis and interpretation (%)	Paper writing (%)
Corina Weidenauer	1	40	10	60	60
Lara Täuber	2	0	30	10	5
Sophia Huber	3	0	30	10	5
Kim Rimkus	4	0	30	10	5
Christoph Randler	5	60	0	10	25

Publication status: accepted for publication in Biological Rhythm Research, 1-13.

Measuring circadian preference in adolescence with the Morningness-Eveningness Stability Scale improved (MESSi)

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Abstract. Individual differences concerning daytime preferences and chronotype are mainly manifested in the variability of the rhythm of sleep and wakefulness. Circadian preference shows a great influence on health, performance and daily routine, not only in adults but also in adolescents. Further, circadian preference and chronotype changes throughout the life span and this affects especially adolescents. A wide-ranging determination of circadian preference in adolescents is therefore important to better interpret the effects of it on daily life. This study presents an extensive validation of the MESSi in adolescents. The MESSi determines the individual circadian phase and amplitude based on three sub-scales: Morningness (MA), Eveningness (EV) and Stability/Distinctness (DI). Based on three studies, the convergent validity of the MESSi with well-established measurements of circadian preference was analyzed with a total sample of N = 215. In study 1 the Pediatric daytime sleepiness scale (PDSS) was applied, in study 2 the Composite Scale of Morningness (CSM) and in study 3 the Children's ChronoType Questionnaire (CCTQ). The MESSi showed a good convergent validity with all sum-scores of the three measurements with the highest correlation coefficient between MA and the sum-scores. A Confirmatory Factor Analysis (CFA) was calculated to prove the three-structure model of the MESSi. The fit indices were good (TLI = 0.966, and CFI o= 0.972). The RMSEA was also good with 0.045 and PCLOSE was not significant (p = 0.651). This suggests a good fit for the measurement model. The results of the present study support the assumption that the MESSi is a valid instrument with a three-factor structure to measure circadian phase and amplitude in adolescents.

Key words: adolescents; circadian preference; daytime sleepiness, Morningness-Eveningness-Stability Scale improved (MESSi); questionnaire

Introduction

Individual variations in circadian preferences, especially in the sleep/wake rhythm, are reflected in circadian typology. According to the preferred behavior, certain chronotypes can be determined. Individuals that tend to be active in the first half of the day are considered morning types and evening types tend to be active later in the day (Adan et al. 2012). However, circadian preference is not a stable trait. Morningness-eveningness preference changes from early morning preference in childhood to late eveningness preference during puberty and in early adulthood (Randler et al. 2017; 2019). In infancy, most of the children are morning-oriented (e.g. Randler and Truc 2013), while adolescents show a significant tendency to evening-orientation. Remarkable gender differences during this change can be seen. Girls show an earlier breaking point towards Morningness (15.7 years) than boys do (17.2 years). Many other studies that dealt with the change of circadian preference in adolescents and adults confirmed these results. For example, by collecting an immense sample size of 25,000 subjects in 2004, Roenneberg et al (2004) found out that the midpoint of sleep on free days becomes increasingly later in 10 to 20 year old adolescents. Russo et al. (2007) could show significant age-related changes in sleep habits and Morningness-eveningness preference. Adolescents between 8 and 14 years showed a significant increase of Eveningness with increasing age. Also, the difference in sleep duration between schooldays and weekends increased with the age of the adolescents (Randler et al. 2019).

Circadian preference is often determined by self-assessment questionnaires that manly focus on a one-dimensional presentation of the trait, like for example the Morningness-Eveningness Questionnaire (MEQ) by Horne and Östberg (1976), leading from on endpoint “evening orientation” to the endpoint “morning orientation”. However, the question arises if there is really only one dimension to be focused on. Putilov et al. (2015) discovered that there might be four types to be classified concerning circadian preference, for example people that like to sleep long and go to bed early. Chronotype, as trait, should therefore be perceived as more complex and a multidimensional structure should be adopted (see also Putilov et al. 2017; Putilov 2016). That was only one reason why Randler et al. (2016) created the Morningness-Eveningness-Stability Scale (improved; MESSi). It is a self-assessment instrument to measure Morningness-Eveningness and amplitude. The scale consists out of three

dimensions: one for Morningness, one for Eveningness and another one for amplitude. Therefore, its structure does justice to the complexity of the construct. Preckel et al. (2013) postulated that Eveningness needs its own dimension and should be measured separately of Morningness. The introduction of a further dimension (amplitude) was inspired by the work and criticism of Oginska (2011) and Dosseville et al. (2013). It could be found, that the amplitude represents how strong the certain preference of a person for Morningness-Eveningness varies over the day. This can be equated with an indication of the stability of the expression. So far, there is one cross-cultural study (Germany, Spain and Iran), a Spanish adaption of the MESSi and its validation among workers and students (Rahafar et al. 2017; Diaz-Morales and Randler 2017; Diaz-Morales et al. 2017). The MESSi has also been validated by actigraphy in a university student population (Faßl et al. 2018).
As shown by Vagos et al. (2019) the adult version of the MESSi shows a consistent three-factor structure across age and gender. As mentioned earlier, the changes in circadian preference in adolescents must be followed and its meaning included in a multidimensional measurement. Therefore, in the present study tests whether the MESSi is adaptable to adolescents from a psychometric viewpoint. We assessed internal consistency, confirmatory factor analysis and convergent validity with other well-used questionnaires.

Methods

The study was divided into three different studies to avoid a high load of questionnaires for the pupils. All participants reported their demographics, filled in the MESSi (adolescent version) and habitual sleep and wake variables. While study I focused on daytime sleepiness, study II and III focused on convergent validity with two other questionnaires commonly used in adolescents.

Participants & data collection

The total sample (*N*=215) consisted of 113 girls, 99 boys and 3 without indication of gender. Data were obtained from three different gymnasia (highest stratification level of school teaching) in SW Germany, Baden-Wuerttemberg. In Baden-Wuerttemberg, 44% of all pupils choose the gymnasium at the 5th grade (see website: badenwürttemberg.de, 2017). Mean age was 13.43 ± 1.56 years (range 11-17 years). Girls were slightly older than boys (*p*=0.049).

Participants from study I: All pupils (*N* = 118) from study I visited the "Remstalgymnasium" located in Weinstadt. Mean age of this sample was 13.74 ± 1.98 years (range 11-17 years) and 50% were girls. Six classes (6^{th}, 7^{th}, two 9^{th} and two 11^{th} grade) participated from this gymnasium. Data collection took place from October 24 until November 9, 2018 between 7:40 am and 03:00 pm. Based on the information given in the Morningness-Eveningness-Stability Scale; improved (MESSi, for detailed information see "Measurement instruments").

Participants from study II: All pupils (*N* = 46) from study II visited the "Mörike-Gymnasium" located in Esslingen. Mean age of this sample was 12.78 ± 0.66 years (range 12-15 years) and 63% were girls. Three classes of the 7^{th} grade participated from this school. Data collection took place between 5^{th} of July until 13^{th} of July 2018 between the first and second lesson in class (8:00 and 9:30 am) and the 8^{th} and 9^{th} lesson (2:00 and 3:30 pm). Based on the classification by the CSM, 2 were Morning types, 11 were Evening types and 33 were Neither types.

Participants from study III: All pupils (*N* = 51) from study III visited the "Paul-Klee-Gymnasium" located in Rottenburg am Neckar. Mean age of this sample was 13.29 ± 0.50 years (range 13-15 years) and 49% were girls. Two classes of the 8^{th} grade participated from this school. Data collection took place between November 19 and November 20, 2018 between the first lesson in class (7:45 and 8:30 am) and the 4th lesson (10:20 and 11:05 am). Based on the classification by the Children's ChronoType Questionnaire (CCTQ, for detailed information see "Measurement instruments") 4 Morning types, 27 Evening types and 20 Neither types could be determined.

Ethical comments

All principals and the respective teachers gave their formal consent, all parents gave their formal written consent after receiving instructions, and all pupils gave their oral consent after being instructed about the study. The study was voluntary, unpaid and anonymous.

Measurement instruments

Morningness-Eveningness-Stability Scale improved (MESSi) for adolescents

The MESSi (Randler et al. 2016) was used to determine circadian preference and amplitude. The scale is represented by three sub-scales: morning affect sub-scale (MA), eveningness sub-scale (EV) and distinctness/stability sub-scale (DI). Each sub-scale consists of 5 items. These should be answered on a 5-point Likert format. Sum-scores for each sub-scale reach from 5 to 25. Higher scores represent higher expressions in the representative traits (sub-scale). MA provides information on the Morningness trait by asking for example how easy it is for the subjects to rise. EV assesses evening-oriented preference concerning energetic feeling, activity and mood (e.g. “In general, how is your energy level in the evening?”). DI refers to the determination of the amplitude; of the different facets of MA and EV fluctuating throughout the day (e.g. “I can focus at any time of the day.”) In the present study, the MESSi was subtlety changed to mirror an adolescent version. For example, we have changed all personal pronouns for the polite address in dealing with adults into a more colloquial version. The adolescent version is depicted in Appendix 1.

Pediatric daytime sleepiness scale (PDSS)

The pediatric daytime sleepiness scale was developed by Drake et al. (2003). The German version has been established by Schneider and Randler (2009). The PDSS is an 8-item questionnaire to measure excessive sleepiness in younger school age populations. The participants rate the frequency of different behaviors on a 5-point Likert scale: from never, 0; seldom, 1; sometimes, 2; frequently, 3; to always, 4. Examples are: drowsiness during homework, falling asleep during class or falling asleep after being awakened. One item is reverse coded. The ratings on all the items were added to a total score, ranging from 0 to 32. Higher scores indicate greater daytime sleepiness. For this study, a correlational analysis was applied, and we calculated the means. Cronbach´s α of the scale was 0.741.

Composite Scale of Morningness (CSM); adolescent version

The Composite scale of Morningness (Smith et al. 1989) in its German version for children and adolescents was adapted by Randler (2008; 2009) and used to determine circadian preference on the dimension Morningness-eveningness. The scale has a 13-item structure, 10 items are Likert-type scaled from 1-4 and 3 are scaled from 1-5. A total score between 13 (extreme eveningness) and 55 (extreme morningness) can be reached. The items ask for preferred bed times and rise times, times for peak performance as well as for morning affect items (feeling awake, feeling tired). The Cronbach's α of the scale was 0.871.

Children's ChronoType Questionnaire (CCTQ); adolescent version

The Children's ChronoType Questionnaire (Werner et al. 2009) was used in its German version to determine habitual bed and rise times on school and free days and circadian preference. The questionnaire consists of 27 items with a mixed-format. A first part concerns the demographics of the adolescents and was not taken into account for the present study. The second part (item 1 to 16) refers to the preferred bed times and rise times of the adolescents on school and free days, separately. In the third part (item 17 to 26), a Morningness-eveningness scale is integrated. Sum-scores from 10 to 48 indicate the individual chronotype while higher sum-scores represent Eveningness. This has to be kept in mind when considering the correlations. All 9 items of this part are Likert-type scaled from 1-5 and one from 1-3. The fourth and last part of the questionnaire (item 27) consist of only one item with a five-point Likert-format and determines a self-assessed chronotype score. Generally, the CCTQ is a parent-report but for the present study, it was changed into a self-report of the adolescents. Therefore, the questions were slightly converted for example from "on scheduled days, my child wakes up at?" into "on scheduled days, you normally wake up at?".

Habitual bed and rise times

Habitual bed and rise times were asked (directly after the items of the MESSi) for weekdays and weekends separately. The measure was given in an hour and minute (hh:min) format.

Statistical analyses

We used a confirmatory factor analysis (CFA) with AMOS 25 (IBM, Chicago; Arbuckle 2018) to fit the model structure. For the fit indices, we used the Tucker-Lewis Index (TLI), the Comparative Fit Index (CFI) and the Root Mean Squared Error of Approximation (RMSEA) and its PCLOSE (as it was recommended by Bentler (1992) and used in another study by Díaz-Morales et al. 2017). Other calculations (e.g. Pearson correlations zero order) were carried out with SPSS 25 (IBM, Armonk, NY). Internal consistency was assessed by calculating Cronbach's alpha for every scale of the MESSi separately. The data are available upon reasonable request.

Results

Internal Consistency

All three scales of the MESSi showed a good to acceptable Cronbach's alpha. MA showed an alpha of 0.889, EV an alpha of 0.818 and DI an alpha of 0.709. MA and EV were negatively correlated ($r = -0.406$, $p < 0.01$), as well as MA and DI ($r = -0.567$, $p < 0.01$). EV and DI were positively correlated with $r = 0.205$, $p < 0.01$.

Habitual bed and rise times

In the following **Table 1,** the descriptive statistics of the habitual bed and rise times during week and on the weekend are listed.

Table 1: Descriptive Statistics of the rise and bed times during week and on the weekend given in an hh:mm format.

	N	Mean	SD
Rise time week	215	6:22	0:20
Rise time weekend	215	9:31	1:27
Bedtime week	215	21:39	1:39
Bedtime weekend	215	23:19	1:41

All participants show significant later rise times on the weekend (T = -31.585, df = 214, $p < 0.001$) and significant later bed times on the weekend (T = -16.346, df = 214, $p < 0.001$). The correlations of the MESSi scales with the rise and bed times during week and on the weekend present some convergent validity of the MESSi (see **Table 2**).

Table 2: Pearson correlations between the MESSi scales and the rise and bed times during week and on the weekend

	N	MA	EV	DI
Rise time week	215	-0.76	0.062	0.003
Rise time weekend	215	-0.483**	0.344**	0.238**
Bedtime week	215	-0.121	0.192**	0.025
Bedtime weekend	215	-0.310**	0.241**	0.147

MA = Morningness, EV = Eveningness, DI = Distinctness/Stability ** (p < 0.01)

The negative correlation of MA with the rise and bed times on the weekend were significant. This indicates that more morning-oriented participants rise and go to bed earlier on weekends than more evening-oriented participants. EV showed positive correlations with rise and bed times on the weekend, as well as, with the bed times during week. Therefore, EV is related to later rise and bed times on weekends as well as to later bed times during the week. DI showed also a positive correlation with the rise times on the weekend. A higher fluctuation in daytime preference (lower Stability) is related to later rise times on the weekend.

Confirmatory Factor Analysis

As it can be seen in **Figure 1**, we set-up a three-factor structure similar to the adult version of the MESSi.

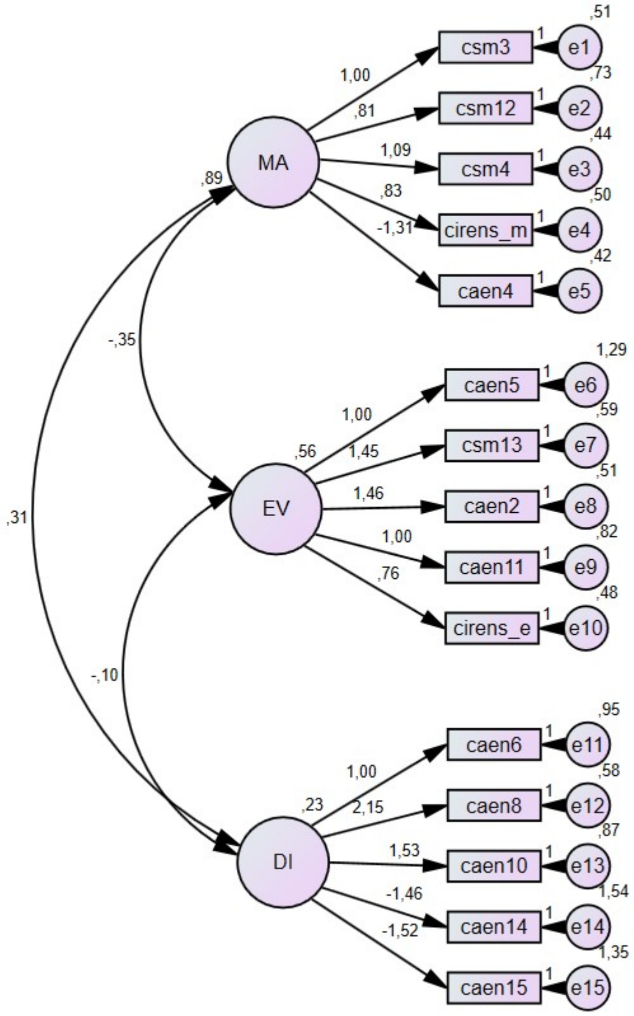

Figure 1: CFA model of the three-factor structure of the MESSi with the latent variables Morningness (MA), Eveningness (EV) and Stability/Distinctness (DI).

Without allowing any covariances between the error terms, the fit indices showed an almost good fit of the three-factor structure with TLI of 0.928 and a CFI of 0.941. The RMSEA was 0.066 (CI: 0.050 to 0.081) and PCLOSE was significant (p = 0.047). After allowing covariances between the error terms e6 (“My favorite time to study is in the evening.”) and e8 (“In the evening, I am the most efficient.”), as well as between e14 (“There are timespans during the day when I feel like I cannot do anything.”) and e15 (There are times of the day when I find it hard to think.”) as it can be seen in **Figure 2** (loading onto the same factor) the model fit was good.

The fit indices were good with a TLI of 0.966, and a CFI of 0.972. The RMSEA was good with 0.045 (CI: 0.025 to 0.063), and PCLOSE was not significant (p=0.651). This suggest a good fit for the measurement model.

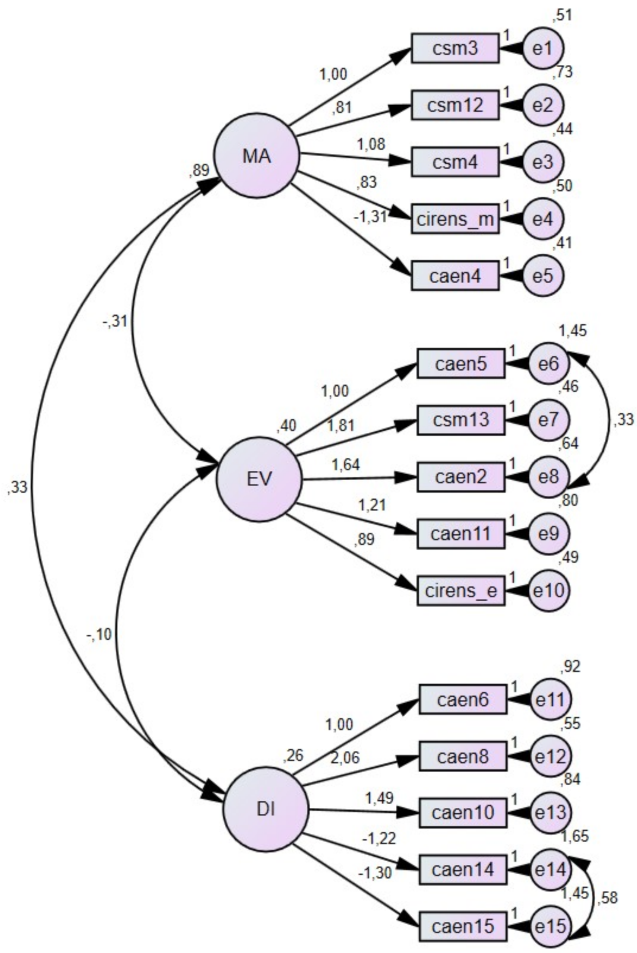

Figure 2: CFA model of the three-factor structure of the MESSi with the latent variables Morningness (MA), Eveningness (EV) and Stability/Distinctness (DI) and covariances between the error terms e6 and e8; e14 and e15.

Correlation analysis

Table 3 shows the results of the correlation analysis between the MESSi scales and age as well as the sum-scores of the CSM, CCTQ and PDSS.

Table 3: Relationship between MESSi subscales (MA, EV and DI) and Age, CSM, CCTQ and PDSS

	N	MA	EV	DI
Age	215	-0.213**	0.144*	0.124
PDSS	118	-0.723**	0.371**	0.493**
CSM	46	0.877**	-0.567**	-0.552**
CCTQ	51	-0.743**	0.434**	0.533**

*indicates p<0.05, **p<0.01. Please note sample sizes differ between N=215 (full sample), *N*=118 (PDSS; study I) *N*=51 (CSM; study II) and *N*=46 (CCTQ; study III).

Age was negatively correlated with MA and positively with EV. Therefore, Age showed a significant decline in MA and a significant increase in EV. This suggest that older adolescents become more evening-oriented and morning-orientation declines. The sum-score of the PDSS was negatively correlated with MA and positively with EV and DI. Morning orientation is therefore related to less daytime sleepiness and evening orientation to more daytime sleepiness. The Stability is lower in participants that show high sum-scores in the PDSS. The sum-score of the CSM showed a positive correlation with MA and a negative correlation with EV and DI. This proves the validity of the MESSi because participants with a high morning orientation in the MESSi do show a high sum-score in the CSM (higher sum-score indicates Morningness). On the other side is evening orientation related to a low sum-score in the CSM. Stability increases with higher sum-scores in CSM. The sum-score of the CCTQ was negatively correlated with MA and positively with EV and DI. Participants scoring lower on MA show higher scores on CCTQ (high sum-score in the CCTQ indicates Evening orientation) and participants scoring higher on EV do also show higher scores on CCTQ. Stability declines with higher scores in the CCTQ.

Discussion

This study applies the MESSi for the first time in an adolescent population and shows good psychometric characteristics. Regarding internal consistency, Cronbach's α was between acceptable and very good, proving the high reliability of this measurement also in the adolescent version. The Cronbach's α level were in the range of the adult versions, with the lowest level in the DI scale of the MESSi (see, e.g., Tomažič and Randler 2019). The negative correlation of MA and DI on the one hand, and the positive correlation of EV and DI on the other hand, suggests that morning orientation is related to a higher Stability of the respective circadian behavior during the day. This confirms previous assumption that morning orientation is related to a higher Stability because Morning types are more conscientious than Evening types (Adan et al. 2012; Randler 2008). This fact can be seen in a constant circadian preference behavior. Some studies showed similar results (e.g. Tomažič and Randler 2019), further studies are desired.

The habitual bed and rise times of the pupils showed later bed and rise times on the weekend. This suggests that pupils aren´t able to sleep as long as they want during week because they had to get up and be at school at given times (e.g. Tomažič and Randler 2019; Randler and Schaal 2010), and weekend oversleep is considered as some kind of catch-up sleep. The correlations of the MESSi scales with the rise and bed times prove the validity of the MESSi. All rise and bed times on the weekend correlated in the expected direction with MA and EV. Morning-oriented pupils got up and went to bed earlier than evening-oriented pupils (Giannotti et al. 2002; Russo et al. 2007). The correlation between DI and only the rise times on the weekend is remarkable, other correlations were insignificant. A lower stability in circadian behavior seems related to later rise times on the weekend. This could be due to the fact that there is a general association between EV and DI, which manifests itself in the rise times on the weekend. EV showed also a significant correlation with bed times during week.

Evening orientation in pupils increases strongly with rising age that it is also shown up in later bed times during week compared to morning-oriented pupils. This could lead to a lack of attention and concentration in evening-oriented pupils, thus putting them at a disadvantage in school (see also Tonetti et al. 2015; Randler and Frech 2009). Further studies should investigate this relationship based in a three-dimensional measure of circadian preference.

The three-factor structure of the MESSi can be confirmed with the present study. CFA analysis showed acceptable to good fit indices already in the basic model. By allowing covariances between some error terms, the model fit improved to a good fit. These results also confirm previous finds in other countries and highlight the multiple applications of the MESSi (Randler et al. 2016; Rahafar et al. 2017; Rodrigues et al. 2018).

Concerning the convergent validity between the MESSi scales and age as well as the sum-scores of the PDSS, CSM and CCTQ, all results were as expected. This confirms that the MESSi measures some similar constructs and is comparable to existing sales, but with the advantage of three dimensions, a balanced scoring (from 1-5), the same number of items per construct and an updated language. As mentioned before, age showed a significant increase in EV, indicating that older adolescents become more evening-oriented and morning orientation declines. This confirms the assumptions from previous studies that a break point in circadian preference occurs in puberty (Randler et al. 2017; Roenneberg et al. 2004). The correlations of MA and EV with the sum-scores of the PDSS showed a greater daytime sleepiness in evening-oriented pupils. These results were as expected but there does not seem much literature confirming our results because usually, researchers examining the PDSS used other sleepiness scales for assessment.

All components of the MESSi showed significant correlations with the sum-scores of the CSM and the CCTQ. While a high scoring on MA is always related to Morningness and high scoring on EV to Eveningness, a high scoring on DI also indicates Eveningness. On the one hand, this proves the convergent validity of the MESSi (Faßl et al. 2018; Díaz-Morales et al. 2017) and on the other hand, it strengthens the previously shown connection between EV and DI.

This was the first validation of the MESSi in an adolescent sample. The results of this study prove the validity of the MESSi in this sample and, as a conclusion; the MESSi can also be used in adolescents by a psychometric viewpoint. However, there should be also an assessment of the MESSi scores with actigraphy in adolescents, but it is expected that the results might mirror the actigraphy results in university students (Faßl et al. 2019).

Conflicts of interest

The authors declare no conflict of interests.

Complying with ethics of experimentation

The research has been conducted in an ethical and responsible manner and is in full compliance with all relevant codes of experimentation and legislation. The study follows the principles of the Declaration of Helsinki. The principles of the respective schools gave their formal consent, which is required following § 4.1. of the regulation “Werbung, Wettbewerbe und Erhebungen in Schulen“ made on 21. September 2002 (Az.: 6499.10/417) and updated on 28.10.2005. All parents gave their formal written consent for their children, and all participants gave their informed oral consent.

Financial support

This research was supported by a grant of the *Gips-Schüle-Stiftung*. The foundation had no role in the study design, collection, analysis or interpretation of the data, writing the manuscript, or the decision to publish.

Acknowledgements

We want to thank the Gymnasia and the pupils that participated in the study. CW and CR are members of the LEAD Graduate School [GSC1028] funded by the Excellence Initiative of the German federal and state governments. We also thank the principals, teachers, pupils and their parents for supporting these studies.

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7. Study 4:
Circadian Preference and School-relevant Achievement: Implications for Skin Temperature, Emotional State and Motivation in Learning

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Contributions

Title of the manuscript: Circadian Preference and School-relevant Achievement: Implications for Skin Temperature, Emotional State and Motivation in Learning

List of Authors	Author position	Scientific ideas (%)	Data generation (%)	Analysis and interpretation (%)	Paper writing (%)
Corina Weidenauer	1	50	100	80	70
Alena Rögele	2	0	0	0	10
Christoph Randler	3	50	0	20	20

Publication status: manuscript.

Circadian Preference and School-relevant Achievement: Implications for Skin Temperature, Emotional State and Motivation in Learning

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Abstract. Morningness-Eveningness can be described as individual differences in circadian preference for different physiological, cognitive and behavioral parameters. In school environment, this can have a special effect. Morning oriented students have an advantage over evening oriented students in terms of sleep habits and school achievement. The present study aims to investigate the effect of Morningness-Eveningness on school-relevant performance issues, like concentration and attention. Further, relations between circadian preference and state of emotional feeling as well as motivational aspects for school learning were assessed. Physiological and behavioral markers (skin temperature and sleep/wake timing) were additionally determined. Students (*N* = 30) of two different secondary schools from SW Germany participated in the study. The students were aged between 12 and 13 (*M* = 12.53, *SD* = 0.09), 23 were girls. The design of the study provides for two test points. At test point one, the students filled in the Positive and Negative Affect Schedule (PANAS), the adolescent version of the Morningness-Eveningness-Stability Scale improved (MESSi), the Composite Scale of Morningness (CSM) and the Scales of Motivational Regulation in Learning (SMR-L) and edited the concentration and attention test FAIR-2 (Frankfurt attention inventory, second edition). At test point two the students filled in again the PANAS and edited again the FAIR-2. Over a period of one week, the skin temperature (using iButtons) as well as the sleep habits (using actigraphy) of the students were monitored. Additionally, they filled in a sleep diary. All three performance values of the FAIR-2 (speed, accuracy and performance value) showed significant higher sum-scores at test point two. Only at test point one, morning oriented students showed higher speed and performance values compared to evening oriented students. Morning oriented students reported significant higher values for positive affect, independent of the test point. Morning orientation was also related with a higher intrinsic and identified motivation in school learning. Evening types showed up to 2 hour later rise times on Saturday and Morning types presented a higher average skin temperature during week. The results suggest that in this age group, Morningness-Eveningness has less effect on school-relevant performance than time of day. It seems that motivational aspects and emotions still play an important role in school achievement.

Key words: Morningness-Eveningness, school-relevant achievement, emotional feeling, motivational regulation

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1. Introduction

1.1 Morningness-Eveningness

All organisms on this planet: humans, plants and animals; live under a certain rhythmic order. Inside our bodies, a biological rhythm sets the clock for many events in daily life. Especially the time of active and rest phases through the day or sleep and wakefulness is determined by this conductor (Randler, 2008a). Biological rhythms are essential for our life! There are three common domains of biological rhythms: ultradian, circadian and infradian rhythms. Biological rhythms are described as ultradian when their period is shorter than 20 hours. Biological cycles with periods repeated in intervals longer than 28 hours are called infradian. In between those two biological rhythms, there is the so-called circadian rhythm, which has a leading part in biology. A circadian rhythm has a period of about 24 hours due to earth's rotation and its resulting alternation of light and darkness (Koukkari & Sothern, 2007). Within those 24 hours, individual differences occur in organizing one´s day. The individual daytime preferences can be summarized as Morningness-Eveningness. Already in 1906, researcher started to deal with the recurring variations in various skills throughout the day. For the first time a categorization of people in different groups dependent of their circadian preferences was done (Marsh, 1906). Nowadays, research has identified three different groups of so-called "chronotypes": Morning types, Evening types and Neither types. Morning types ("larks") tend to wake up early but prefer to go to bed early. They tend to have their mental and physical peak in performance during the first half of the day. In contrast, E-types ("owls") tend to get up late but prefer to go to bed late. Their peak in performance occurs during the second half of the day (Adan et al., 2012). Based on this categorization, circadian typology explores the individual differences in daytime preferences and can be seen as a very interdisciplinary research field (Randler, 2008a). Circadian typology affects many areas in our daily life, like human physiology (e.g. Bailey & Heitkemper, 2001), attention (e.g. Vollmer et al., 2013) or affective state (e.g. Randler & Weber, 2015). Therefore, it is important to correctly assess the individual circadian phase. On the one hand, this can be done by gene-expression analysis in a lab with blood and epidermis samples (Wittenbrink et al., 2018; Wu et al., 2018). On the other hand certain physiological markers can be used, like cortisol measurement (e.g. Bailey & Heitkemper, 2001), melatonin secretion (e.g. Lack et al., 2009) or body temperature recording (e.g. Baehr et al., 2000).

1.2 The Morningness-Eveningness-Stability Scale (improved)

Alternatively, self-assessments can be used to determine circadian typology especially when conducting research in large samples. The determination of circadian typology with self-assessments dates back to the 70s. Horne and Östberg developed the still commonly used Morningness-Eveningness-Questionnaire (Horne & Östberg, 1976). Today, there is a wide range of measurements of circadian typology: for example the Composite Scale of Morningness; CSM (Smith et al. 1989), the Diurnal Type Scale; DTS (Torsvall & Åkerstedt, 1980) or the Munich ChronoType Questionnaire ;MCTQ (Roenneberg et al., 2003, Adan et al., 2012, Di Milia et al., 2013). All these measurements have in common that they assess circadian typology as a one-dimensional trait, with Morningness and Eveningness marking the two endpoints of one continuum. Due to the work of other researchers (e.g. Preckel et al., 2013; Oginska, 2011; Dosseville et al., 2013; Putilov ,2016), circadian typology should no longer be seen as a one-dimensional construct, but rather as a multi-dimensional circadian preference. Randler and colleagues (2016a) then considered the complex structure of the construct and created (from already three existing scales: Composite Scale of Morningness, Caen Chronotype Questionnaire; CCQ, Dosseville et al., 2013 and Circadian energy scale ;CIRENS, Ottoni et al., 2011) the three-dimensional measurement: MESSi. The Morningness-Eveningness-Stability Scale (improved) is a self-assessment instrument to measure Morningness-Eveningness and its amplitude. The MESSi has three dimensions: one for Morningness (MA component), one for Eveningness (EV component) and one for amplitude (DI component). The amplitude represents how strong the circadian preference of an individual fluctuates throughout the day. This can be equated with an indication of the stability of the expression. The MESSi does not categorize individuals into chronotypes. The scale rather allows considering the fact that a certain type of circadian preference may be more or less pronounced within an individual. In addition, it reflects that individuals may show fluctuations in their circadian preference depending on other, contextual factors. So far, there is a cross-cultural study (Germany, Spain and Iran), a Spanish and a Slovenian adaption of the MESSi, its validation among workers and students and a psychometric analysis study (Rahafar et al., 2017; Diaz-Morales & Randler, 2017; Tomažič & Randler, 2018; Díaz-Morales et al., 2017; Vagos et al., 2019). In order to be able to use the MESSi also in a school context, the MESSi (adolescents) was validated in a sample size of 215 students this year (Weidenauer et al., 2019). The MESSi (adolescents) was therefore used in this study as well.

1.3 Sleep

Sleep plays an important role in our body. It helps our body to recharge its energy during sleep in order to be active when we are awake. As mentioned earlier, circadian rhythm has a great impact on the sleep/wake cycle. Just as with circadian rhythm, an inheritance can be detected for sleep (Adan et al., 2012). For example, Andretic et al., (2008) named sleep as a “complex phenotype” (pp. 362). Within this phenotype inter-individual differences concerning sleep behavior can be shown. The differences in sleep characteristics can be generally traced back to individual differences in daytime preferences (Roenneberg et al., 2007). Therefore, Morning- and Evening types show significant differences in their sleep timing. Morning types do have earlier wake and bed times than Evening types (Horne & Östberg, 1976; Duffy et al., 2001; Adan et al., 2012). In contrast, Eveningness for example is associated with a greater need for sleep and shorter times in bed (Tillard et al., 1999). If we compare individual differences in sleep behavior from weekday to weekend, clear differences in terms of circadian typology are also evident here. Evening types show later bed and rise times on the weekend compared to Morning types and longer times in bed on the weekend compared to weekdays (Tillard et al., 1999; Roepke & Duffy, 2010). These and further results demonstrate that Evening types accumulate a sleep debt during week and try to compensate this on the weekend. This so-called “social jetlag” is common in our society because we are ruled by given time schedules at work, university or in school (Roenneberg et al., 2012; Roenneberg, 2012). Adolescents meets this circumstance, however, particularly hard because the individual circadian preference changes throughout the life span “from lark to owl”. The breaking point towards Eveningness can be located at about 15 years in girls and 17 years in boys (Randler et al., 2017). Previous research shows that evening oriented students have a disadvantage in school relevant achievement compared to morning-oriented students (Preckel et al., 2013; Randler & Frech, 2006).

To determine the effect of sleep behavior in context with circadian preference on school relevant achievement, the habitual sleep/wake times, the total sleep time and the sleep efficiency was measured in two ways: a standardized sleep diary was filled in by the students and additionally actigraphy was used. Actigraphy is a non-invasive and objective method to determine circadian rhythmicity of sleep and activity in flied settings (Sadeh 2011; Cellini et al., 2013; Quante et al., 2015). An accelerometer (acceleration sensor) in the device records the body movements of the person and can be stored in the device until download. Actigraphy is mainly used in sleep research and a clinical environment to investigate sleep disorders in patients. However, use of actigraphy increased also in other research fields. Chronobiology likes to take advantage of actigraphy for example, to investigate the behavior of flights to other time zones (Montaruli et al., 2009) or to test validity of questionnaires. (e.g. Thun et al., 2012; Faßl et al., 2019). Previous studies could show that actigraphy tends to underestimate the beginning of sleep - it is registered too early. The fact of lying awake in bed without moving is not taken into account by the device (Hedner et al., 2004, Lichstein et al., 2006; Paquet et al., 2007). That’s the reason why the students filled in a sleep diary in this study.

1.4 Skin temperature

Our Body shows a constant and robust rhythm of body temperature with a nearly 25 h cycle (Wever, 2013). Even when controlled for environmental influences like light and darkness, environmental temperature or weather conditions, the rhythm of the body temperature stays constant and is therefore also ruled by our inner circadian rhythm (Aschoff, 1960; Aschoff, 1965 and Aschoff, 1967). Same with previous findings on circadian typology, individual differences in the body temperature rhythm can also be seen here. Already Horne and Östberg (1976) could show that Morning types have a higher daytime temperature than Evening types. Further, Morning types tend to have their acrophase and peak times in body temperature up to 2 hours earlier than Evening types (Baehr et al., 2000; Waterhouse et al., 2001; Kerkhof & Van Dongen, 1996; Bailey & Heitkemper, 2001). Beyond that, Evening types show larger fluctuations in the body temperature rhythm compared to Morning types, which can be seen on a higher amplitude (Baehr et al., 2000). These differences do also occur when measuring body temperature with different methods: rectal or oral (Duffy et al., 1999; Gupta & Pati, 1994; Adan et al., 2012). In general, research tends to determine the rhythm of the core body temperature rectally because the fluctuations are less influenced by environmental issues. To determine core body temperature small sensors had to be wear over a long period of time or data-logger pills had to be swallowed (Kolka et al., 1997; Byrne & Lim 2007; O`Brien et al., 1998). These methods are unpleasant and expensive; furthermore, the subjects had normally to stay in a lab. Therefore, we decided to measure the skin temperature of the students with iButtons. The skin temperature is usually determined by small, wireless temperature data loggers, called iButtons (Smith et al., 2009). iButtons can measure the skin temperature in humans and animals within a range of – 40 to +85 degrees Celsius with a possible deviation of 0.5 degrees Celsius. Originally they came from logistics and were designed to control the temperature of goods on long routes. The now "misused" iButtons consist of a temperature sensor, a computer chip with real-time measurement, storage for the obtained data and a lithium battery. All this is wrapped in a stainless steel cap. The iButton can be attached on a random place of the skin and fixed with the appropriate accessory. The possible measurement time intervals can range from a few seconds to hours and must be programmed on the computer before the first application (Lichtenbelt et al., 2006; Smith et al., 2009). Their advantage is that they are wireless and that it is not necessary to stay within the range of a power source or router. Thus, skin temperature can be measured under everyday conditions. They also perform well in a direct comparison with conventional temperature measuring instruments used in research, such as thermistors (Smith et al., 2009). Their disadvantage is that they are not waterproof. It is therefore necessary that the device is removed when can get in contact with water. The device has then to be stored carefully and to be re-attach correctly on the skin. This can lead to device and data lost as well as to biased data. Further, it should be mentioned that the skin temperature can be influenced by environmental characteristics such as physical activity or environmental temperature. Above all, the amplitude is strongly influenced but the acrophase seems to be quite robust (Martinez-Nicolas et al., 2013). Under normal conditions, the skin temperature drops rapidly after awakening and decreases over the rest of the day until reaching its minimum in the evening. During the night, the skin temperature increases again and peaks in the early morning hours. Their 24h fluctuations can show a wide range (between 31 °C and 36 °C) with the highest values appearing during sleep and the lowest during wake time. This can depend on the technique deployed by different sensors (Martinez-Nicolas et al., 2013, Sarabia et al., 2008). So far, there is not enough research on how the fluctuations of the skin temperature behave with regard to circadian preference.

1.5 School-relevant achievement

Attention has been studied by psychologists and philosophers for over a hundred years. It has first been defined by William James in 1890, who describes attention as “the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought” (p. 404). This definition already points to the core aspects of attention, which include selection, concentration and focusing only on parts of the stimuli surrounding a person (Rützel, 1977). Thus, attention consists of several dimensions (Sturm & Zimmermann, 2000), which also integrate concentration, even though some authors argue, that concentration and attention should be seen as distinct concepts (e.g. Schmidt-Atzert et al., 2004). Instead, concentration can be understood as sustained attention, meaning keeping up attention during a longer period of time (Sturm & Zimmermann, 2000).

Attention, and therefore concentration as well, being a part of attention, vary over the course of a day (Schmidt et al., 2007). Like other cognitive functions, attention is being influenced by the homeostatic sleep pressure and the circadian pacemaker (Rogers et al., 2003). Concerning vigilance, or sustained attention, performance seems not to be stable during the day, probably due to the interaction of the homeostatic sleep pressure and the circadian pacemaker. When participants are sleep deprived while working on sustained attention tasks, performance deteriorates during night-time, but improves again during daytime, even though participants have spent a longer time awake than during the night-time measure (e.g. Cajochen et al., 1999; Wright et al., 2002). The same pattern was found concerning selective attention under sleep deprivation (De Gennaro et al., 2001) and divided attention (Van Eekelen & Kerkhof, 2003). Therefore, different aspects of attention all seem to be influence by the circadian rhythm in the same way and seem to change in dependence of it.

Not only the circadian rhythm, but also the individual chronotype influence cognitive and attentional performance, as different chronotypes show their best performance at different times of the day. Lara, Madrid and Correa (2014) for example found, that continuous performance on a vigilance task decrease over time, when the task was administered to evening types in the morning, whereas vigilance decrement was found in morning types when working on the task in the evening. In accordance to this finding, evening types also showed vigilance decrement on a driving simulation task, when taking it in the morning, but not in the evening (Correa, Molina ,& Sanabria, 2014). Moreover, eveningness was associated with the inattention component of ADHD in adults presumed to have ADHD (Caci, Bouchez, & Baylé, 2009). At last, students with higher evening orientation also report more attention problems at school than morning types (Giannotti et al., 2002).

Knowing that attention is being influenced by circadian rhythm, and furthermore by individual chronotype, it is important to take a closer look at chronotypes and their effects in the school context as well. As the individual chronotype of students often changes towards an evening orientation during puberty (Bearpark & Michie, 1987; Randler, Faßl & Kalb, 2017), school lessons starting in the early morning could be problematic for many students. Results of several studies confirmed this concern in different cultures and showed that the higher the morning orientation of a student, the better the academic performance in school measured in grades (Randler & Frech, 2009). This effect does not only show in early puberty years, but can already be found in primary school children, who achieve better grades when having an earlier midpoint of sleep (Arbabi et al., 2015) and also when looking at students' leaving exam grades (Randler & Frech, 2006). Even when controlling for total sleep length (Escribano et al., 2012), gender and inductive reasoning (Díaz-Morales & Escribano, 2013), the individual chronotype predicted school achievement. Concerning gender, chronotype seems to play a moderating role, which hints at a relationship of gender and academic performance for evening types (Rahafar et al., 2016).

However, problems of students with evening orientation do not stop at disadvantages concerning their academic performance. Moreover, students with higher evening orientation report more school-related and even parent-related problems that students with higher morning orientation (Vollmer et al., 2011), which stresses the need of finding a solution for students with higher evening orientation to better coping with school and social life even further. As Van der Vinne et al. (2015) showed, minor changes, like different scheduling of exams, could already help evening types improve their academic performance, as there were no differences in grades between morning types and evening types, when exams were taken in the early afternoon. On the other hand, when exams were taken in the morning, morning oriented students achieved better grades in comparison to evening oriented students.

1.6 State of emotional feeling

Emotions and feelings are essential for our daily live. Already a long time ago, they offered an evolutionary advantage and have therefore remained until today. To give a clear definition of what emotions are, is difficult and needs to take different aspects into account. According to Izard, emotions consist of the experience or conscious feeling, the process that occurs in the brain and the observable expressions in the face. Further, he postulates that “emotions constitute the primary motivational system for human being” (Izard, 2013, pp. 3). This statement, as well as previous research, suggests that emotions and feelings are integrated in many areas of our daily lives and can have a significant influence on them. Positive and negative affects influence for example our food intake (Randler & Weber, 2015), our overall sleep (Ong et al., 2017) or motivational aspects (e.g. Bye et al., 2007). A very important aspect that also seems to be related to positive/negative affects is learning and therefore school achievement. Some studies could already show that positive affects (like, well-being and interest) are associated with a higher outcome in achievement and negative affects (like anxiety and anger) are related to worse achievement (Gläser-Zikuda et al., 2005; Pekrun, 1992; Pekrun et al., 2002; Randler et al., 2016b). It is also important to note that positive and negative affect is influenced by circadian variation. Porto et al., (2006) could find out that 86% of subjects displayed significant circadian variation in the positive affect. Only 25% displayed significant circadian variation in the negative affect. Positive affect seems to be more influenced by circadian preference. Previous research has now connected these topics. In 2014, Randler and colleagues determined mood and circadian typology of students in the early morning hours in class. Results showed that Morningness was positively related to good mood and activation. One year later in the follow-up study, Randler and Weber (2015) assessed positive and negative affect in the first and last lesson in class and explored the difference concerning circadian typology. Positive affect showed a clear daytime influence with being higher in the last lesson in class. Negative affect showed no significant difference between the first and last lesson. Morning types do also showed a higher positive affect compared to Evening types independent of time of day. Interestingly, negative affect was related to the actual sleep duration. Students with a shorter actual sleep duration reported higher negative affect values. These results are thought-provoking and give rise to the assumption, that a possible sleep deficit in evening-oriented students is associated with higher negative affect and can possibly lead to disadvantages in school achievement compared to morning-oriented students. Therefore, Randler, Bechthold and Vogel (2016) decided to investigate a possible influence of circadian typology and time of day on school achievement. They found out, that circadian typology and time of day did not influence the mathematical achievement. But an effect of circadian typology on positive affect could be observed: Morning oriented students reported higher positive affect values than evening oriented students. In contrast, negative affect remained stable concerning circadian typology. However a relation between negative affect and mathematical achievement could be seen. Negative affect was positively correlated with the mathematical test scores, indicating that a higher negative affect leads to higher scores in the mathematical test, but only in the first lesson. An exact explanation for this relation is yet not clear. There might be other intervenient variables. Further research on this topic is therefore needed.

1.7 Motivational regulation in school learning

In general, motivation can be described as a theoretical, unitary construct that focusses on the quality and intensity of one´s behavior (Ryan & Deci, 2000a; Deci & Ryan, 2008). Motivation helps to explain the regulation of certain reasons why to do something. In research, there are many theories that try to explain the meaning of motivation for human behavior and performance. Most of them take the view that from cognitive processes, which are influenced by perceptual aspects, options for human behavior can be derived. For example, the Self-Efficiency-Theory (Bandura, 1977) states that psychological procedures alter the strength of self-efficacy. It is hypothesized that expectations of personal efficacy determine whether coping behavior will be initiated and how much effort will be expended. So, changes in human behavior are regulated by cognitive mechanisms. These cognitive mechanisms are influenced by successful performances. One of the most popular theories concerning motivation in behavior is the Self-Determination-Theory of Deci and Ryan in 1985, which is focused most in the present study. One important aspect of the theory: it is focused of different types of motivation that cause behavior. The theory accounts also social circumstances, self-regulation and universal psychological needs, which are important for the origin of motivation. It is assumed that the type of motivation is important for the outcome of the behavior for example well-being or successful performance. Motivation is seen on a continuum where autonomous motivation marks one endpoint and controlled motivation the other (Deci & Ryan, 2008). The autonomous motivation consists of intrinsic and identified motivation. During autonomous motivation, a feeling of self-endorsement of the action is present. Intrinsic motivation aims at the personal development of a person. It is perceived as self-determined and pleasant. The action of a person is described as intrinsic motivated when it is the person´s decision to do something (Ryan & Deci, 2000b). Identify motivation has a future personal benefit as its goal. It is perceived as highly self-determined and personally important. A person's action is described as intrinsic motivated if its benefit is consistent with own values. As mentioned before, controlled motivation marks the other endpoint of the continuum of motivation. Controlled motivation consists of external and introjected motivation. External motivation aims at achieving or avoiding certain consequences. It is perceived as necessary, rather compulsive and externally determined. The action of a person is described as externally motivated if externally determined goals are to be achieved. Last but not least, introjected motivation aims to adapt to social norms or to increase self-esteem. It is perceived as little self-determined and predetermined. The action of a person is described as introjected motivated, if the avoidance of guilt or shame is to be achieved, as well as striving for recognition (Ryan & Deci, 2000b; Deci & Ryan, 2008).

The scales for motivational regulation in school learning focus exactly on these four motivational aspects. The SMR-L is based on the Academic Self-Regulation Questionnaire (Ryan & Connell, 1989), which is mainly used in English-speaking countries. According to Thomas and Müller (2015), motivational aspects are important for continuous and successful learning in school and a healthy development of the students. Therefore, it is important to promote and exactly determine the student's motivation in school learning. It could be shown that intrinsic motivation decreased in adolescents within a school year. Although intrinsic motivation fulfills an important part in school achievement. A higher intrinsic motivation predicts a better performance (Corpus et al., 2009). As mentioned earlier, positive and negative emotions are related to motivational aspects (Gläser-Zikuda et al., 2005; Pekrun, 1992; Pekrun et al., 2002; Randler et al., 2016b). An appropriate school setting should therefore take into account several aspects (motivational regulation, emotional state, circadian typology) in order to promote an optimal performance of the adolescents.

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2. Methods and Measurements

Data were obtained from two different secondary schools (highest stratification level of school teaching) in SW Germany, Baden-Wuerttemberg. Data collection was spread into two test points (test point 1 and test point 2). Test point 1: the students reported their demographics, filled in the PANAS, the MESSi (adolescent version), the CSM, and the SMR-L and edited the FAIR-2. Test point 2: the students filled in the PANAS and edited the FAIR-2. Over a period of one week, the skin temperature (using iButtons) as well as the sleep habits (using actigraphy) of the students were monitored. Additionally, they filled in a sleep diary.

<u>2.1 Participants & data collection</u>

A total of *N* = 30 students participated in the study. The sample consists of 23 girls and 7 boys. Mean age was 12.53 ± 0.09 years (range 12 to 13 years).

Friedrich-List grammar school: A sub-sample (*N* = 16) of the students visited the "Friedrich-List-Gymnasium" which is located in Reutlingen. Mean age of this sample was 12.63 ± 0.13 years (range 12-13 years) with 11 girls and 5 boys. Data collection took place between March 13 and 14, 2019. Test point 1: March 13 in the first and second lesson in class (7.35 to 9.10 am); test point 2: March 14 in the 7th lesson (12.50 am to 01.35 pm) in class. Based on the classification of the CSM, 3 were Morning types (girls), 3 were Evening types (girls) and 10 were Neither types (5 girls and 5 boys).

Johann-Vanotti grammar school: A sub-sample (*N* = 14) of the students visited the "Johann-Vanotti-Gymnasium" which is located in Ehingen (Donau). Mean age of this sample was 12.43 ± 0.14 years (range 12-13 years) with 12 girls and 2 boys. Data collection took place between May 5 and 10, 2019. Test point 1: May 5 in the first and second lesson in class (7.45 to 9.20 am); test point 2: May 10 in the 6th lesson (12.15 am to 01.00 pm) in class. Based on the classification of the CSM, 2 students were Morning types (girls), 1 was an Evening type (girl) and 11 were Neither types (9 girls and 2 boys).

2.2 Measurements

2.2.1 Questionnaires

Morningness-Eveningness-Stability Scale improved (MESSi) for adolescents

The MESSi (Randler et al. 2016a) is a three-dimensional measurement to determine circadian preference and amplitude. In this study, the adolescent version (Weidenauer et al., 2019) was used. The MESSi consist of three sub-scales. Each of these measures an independent dimension of Morningness-Eveningness and its amplitude. The Morningness (MA) sub-scale determines the affective facet of the Morningness trait by taking for example into account how easy it is to get up in the morning or how awake the subjects feel (e.g. "How easy do you get up normally in the morning?"). The Eveningness (EV) sub-scale in contrast, measures the affective facet of the Eveningness trait and concerns energetic feeling, activity and mood (e.g. "In general, how is your energy level in the evening?"). The Distinctness/Stability (DI) sub-scale assesses the range of the fluctuations in circadian preference through the day. The subjective feeling, concentration and motivation were taken into account (e.g. “I can focus at any time of the day.”). Each sub-scale is represented by five items with a 5-point Likert format. The sum-scores for each sub-scale reach from five to twenty-five. In terms of the MA and EV sub-scale, higher scores represent higher expressions in the representative trait. Concerning the DI sub-scale, a higher score represent greater fluctuations and therefore a lower stability. So far, the MESSi has been used in a cross-cultural study (Germany, Spain and Iran) and a Spanish adaption was done with their validation among workers and students (Rahafar et al., 2017; Diaz-Morales & Randler 2017; Diaz-Morales et al., 2017). The three-factorial structure has been established by psychometric analysis (Vagos et al., 2019) and a validation was done by actigraphy in a university student population (Faßl et al., 2019). Cronbach’s alpha in the present study for the MA sub-scale was 0.885, for the EV sub-scale 0.876 and for the DI sub-scale 0.807.

Composite Scale of Morningness (CSM); adolescent version

To determine circadian typology, the one-dimensional Composite Scale of Morningness (Smith et al., 1989) in its German version for children and adolescents was used (Randler, 2008b; 2009). The scale consists of 13 items. 10 items are Likert-type scaled from 1-4 and 3 are scaled from 1-5. An overall sum-score with values between 13 (extreme eveningness) and 55 (extreme morningness) can be calculated. The students can be categorized on the dimension Morningness-Eveningness in Evening types (13-26), Neither types (27-43) or Morning types (44-55). The scale asks for information about preferred bed and rise times (e.g. “When do you get tired and would like to go to bed?”), for morning affect items (feeling awake [e.g. “How awake do you feel in the 30 minutes after getting out of bed in the morning?], feeling tired), how easy it is for the students to get out of bed (e.g. “How easy is it for you to get up in the morning?”), times for peak performance (physical and mental [e.g. “Are you more active in the morning or in the evening?”]), as well as a self-rating on chronotype (“Some people are Morning types, some people are Evening types. To which of those types do you belong to?”). In the present study, Cronbach´s alpha for the scale was 0.864.

Positive and Negative Affect Schedule (PANAS)

To determine the current state of emotional feeling of the students, the Positive and Negative Affect Schedule (PANAS) was used (Watson, Clark, & Tellegen, 1988) in its German version by Krohne et al., 1996. The current state of emotional feeling is assessed by two dimensions: positive affect and negative affect. The schedule is represented by 20 items. 10 of those are measuring the positive affect and 10 are measuring the negative affect. The items are adjectives that describe different feelings and moods (e.g. “anxious” and “active”). The items should be answered on a five-point Likert scale. The students are ranging their current state of emotional feeling by judging the adjectives from “very slightly/not at all” to “extremely”. Sum-scores for each dimension can reach from a minimum of 10 to a maximum of 50, whereas higher scores represent a higher expression of the current state of emotional feeling. Re-test reliability was r = 0.78, p = .01 for positive affect and r = 0.89, p= .01 for negative affect.

Scales for motivational regulation in learning (SMR-L)

To determine the motivational aspects for the regulation in learning, the German SMR-L (Thomas & Müller, 2015) was used. The scales consist out of 13 items that measure intrinsic motivation (e.g. “I mostly study at school because I enjoy it.”), identified, external and introjected regulation on a four-point Likert format. Intrinsic motivation, external and identified regulation are represented by three items and introjected regulation is represented by four items. Sum-scores from 3 to 12 can be reached in the scales intrinsic motivation, external and identified regulation and sum-scores from 4 to 16 in the scale introjected regulation. Higher scores represent a higher expression in the representative scale. In the original version, the scales should determine the motivational aspects for the regulation in learning in a certain school subject. In the present study, the aim was to determine in general, the motivational aspects for the regulation in learning at school, not in a certain subject. Therefore, each item starts with the prefix: “Mostly, I work and study **at school** because…” Cronbach´s alpha for the intrinsic motivation was 0.848, for external regulation 0.687, for identified regulation 0.621 and for introjected regulation 0.712.

2.2.2 Attention and concentration test

FAIR-2

The FAIR-2 by Moosbrugger and Oehlschlägel (2011) was used to measure student's individual differences in behavioral attention and concentration. The test includes 640 items, which consist of different circular symbols. These symbols differ in their inner shape, which is either another circle or a square, and concerning the number and the arrangement of dots, which are depicted inside the inner shape (see Table 1). Student's task was to identify all of the symbols, which are either of circular inner shape with three dots inside, or which consist of a square inner shape with two dots inside. To mark these symbols, students are asked to draw a continuous line underneath every row of items and mark identified symbols by drawing an upwards peak into the symbol itself. The 640 items are distributed into two halves with 320 items each. For every half, students are given three minutes time to work on as many rows as possible, while being as accurate as possible. After the first three minutes have passed, students are supposed to turn to the next page and continue to work on these items, no matter if they have been done with the previous page or not. Based on these data, three values describing student's attention and concentration can be calculated. First, the speed value (L). L informs about the quantity of processed items during the entire processing time of 6 minutes. L thus represents an indicator of the speed. Secondly, the accuracy value (Q). Q informs about the percentage of concentrated and error-free processed items of all processed items. Q takes into account the errors made during processing and relativizes the correctly processed items to the total number of processed items. Finally, the performance value (K), which informs about the continuously generated attention and concentration. K results out of the individual speed and accuracy value and combines these two test values into one. Higher scores in the values L, Q and K represent more processed items in general, less incorrectly processed items and a higher concentration performance. L can reach a maximum of 640, Q can reach a quotient of 1 and K can therefore also reach a maximum of 640. The individual test values can then be related to a normalization sample. Moosbrugger and Oehlschlägel (1992) report re-test reliability after two weeks being .81 for each speed and performance value and .73 for accuracy value. Re-test reliability in the present study between test point 1 and 2 were .86 for the speed value, .75 for the accuracy value and .83 for the performance value.

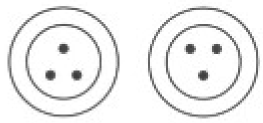
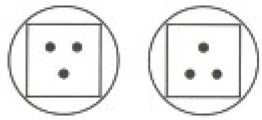
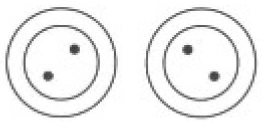
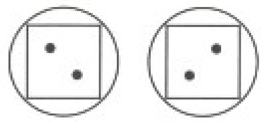
		Inner shape	
		Circular	Square
Number of dots	3		
	2		

Table 1. Different symbols of the FAIR-2 (Moosbrugger & Oehlschlägel, 1996).

2.2.3 Sleep parameters

Actigraphy

Actigraphy was used for the objective monitoring of the sleep/wake rhythm of the students. The actigraph sensors were of the models series GT3X and are produced by the company “Actigraph” (Pensacola, Florida). The red device (dimensions: 4.6cm x 3.3cm x 1.5cm, weight: 19 grams) was attached to the wrist of the non-dominant hand of the students with the help of a black uni-sex wrist band. An internal tri-axial (vertical, horizontal and lateral) accelerometer (acceleration sensor) records the body movements of the students every 60 seconds and with a sampling frequency of 100 Hz during data-collection period. The collected data were stored in the device and could be transferred to a computer via USB or Bluetooth. With the dedicated software (“ActiLife”) the data can be visualized as rest-activity plots, where body movements are represented in dimensionless units, called “activity counts” over an epoch of 60 seconds. Off-wrist detection was performed using the Choi algorithm (Choi et al, 2011) and the Cole-Kripke algorithm (Cole et. al., 1992) was used for the sleep/wake detection on an epoch-by-epoch basis. The “major sleep period” was set by marking the “in bed” and “out of bed” times of the students. The information from the habitual sleep/wake times, given in the sleep diary, were used for this purpose. A recording day was categorized from 12:00 am to 12:00 am on the following day. The variables "In Bed" (given in clock times in a hh:mm format), "Out Bed" (given in clock times in a hh:mm format), sleep "Latency" (minutes), sleep "Efficiency" (indications in %), "Total Sleep Time" (TST, minutes), "Wake After Sleep Onset" (WASO, minutes) and "Awakenings" were given and calculated by the software ActiLife.

Sleep diary

During the data-collection period of one week, the students had to fill in a standardized sleep diary. In the present study, the sleep diary is represented by nine items, which the students hat to answer every day. They were asked to give information about their habitual sleep/wake times, what they did in bed until sleep onset and getting out of bed, having naps as well as the nap duration and a rating of their subjective sleep quality in general school marks (from 1 to 6, whereas a higher value represents a worse quality).

2.2.4 Skin temperature

iButtons

To measure the 24-h skin temperature fluctuations small, coin-like devices, named iButtons, were used. The iButton (Thermochron Temperature Data Loggers, type DS1922L, Maxim Integrated Products, Munich; Germany) was attached to the inside of the non-dominant wrist of the students using one-size, uni-sex sweatbands (HEAD, Kennelbach, Austria) to keep the environmental temperature on a constant level. The skin temperature was recorded for seven days (00.00 am to 23:59 pm) every 2 minutes. The temperature logs were stored in the device and extracted with the dedicated software (1-Wire, version 03.19.47). Every student got 720 temperature logs per day, 5,040 in total. For each 24-h section temperature data were averaged into 20-min sections and missing data were interpolated. Temperature logs showing less than 28 degrees Celsius and higher than 41 degrees Celsius were excluded. The students received the instruction to wear the device constantly (except for showering or taking a bath) and to note the timespan when they had to remove it. The temperature logs were visually screened for those timespans and the corresponding data were excluded.

2.3 Data analysis

To give detailed information, descriptive statistics were done for the sleep parameters ("In Bed" and "Out Bed" times, "Total Sleep Time" and sleep "Efficiency") as well as for the average skin temperature of the students during week and the average values of the motivational regulation in school learning (intrinsic, identified, introjected and external motivation) separate for Morning, Evening and Neither types. Mean differences for the student's school relevant achievement values (speed, accuracy and performance value) between test point 1 and test point 2 were determined by calculating t-statistics, also split by Chronotype. Mean differences for the student´s emotional state of feeling (positive and negative affect) between test point 1 and test point 2 were also determined by calculating t-statistics. To investigate the relation between the components of the MESSi; adolescent (MA, EV and DI) and the CSM sum-score, the sleep parameters, the skin temperature parameters (acrophase, nadir and amplitude), the school relevant achievement values, the emotional state of feeling and the motivational regulation in school learning pearson correlations (zero order) were done. The same correlation analysis was calculated for the relation of the CSM sum-score and those variables. Further Pearson correlations (zero order) were done between the emotional state of feeling and the school relevant achievement as well as the motivational regulation in school learning. To investigate the effect of Morningness-Eveningness on the sleep parameters, the skin temperature parameters, the state of emotional feeling and the motivational regulation in school learning, multiple variance analyses (MANOVA) were run. The factor Chronotype was represented as a three-ranging (Morning vs. Evening vs. Neither types) independent variable. The partial eta-squared was used as a measure for the effect size of the results.

To estimate the skin temperature parameters (acrophase and nadir) a curve-fitting cosinor procedure was applied and summary measures of R^2 (the variance statistic or goodness of fit of the actual data to the approximating 24h cosine curve) were calculated. The acrophase/nadir of the skin temperature represents the average acrophase/nadir of the skin temperature for each student per week. Additionally, the amplitude (difference between acrophase and nadir) of the skin temperature was determine for each student. All statistical analyses were completed using SPSS version 25 (IBM Corp., Armonk, New York; released 2017).

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3. Results

3.1 MESSi (adolescents) and CSM

To test for convergent validity in this sample, correlations between the components (MA, EV and DI) of the MESSi (adolescents) and the CSM sum-score were calculated. The MA component of the MESSi (adolescents) showed a positive correlation with the CSM sum-score (r = .764, p = .01), whereas the EV component showed a negative correlation (r = -.528, p = .01). The DI component correlated negatively with the CSM sum-score (r = -.506, p = .01), indicating that morning oriented students have a higher stability in circadian preference. In **Figure 1,** the relation of circadian typology (determined by the sum-score of the CSM) and the stability of circadian preference (assessed by the dimension DI of the MESSi; adolescents) is illustrated.

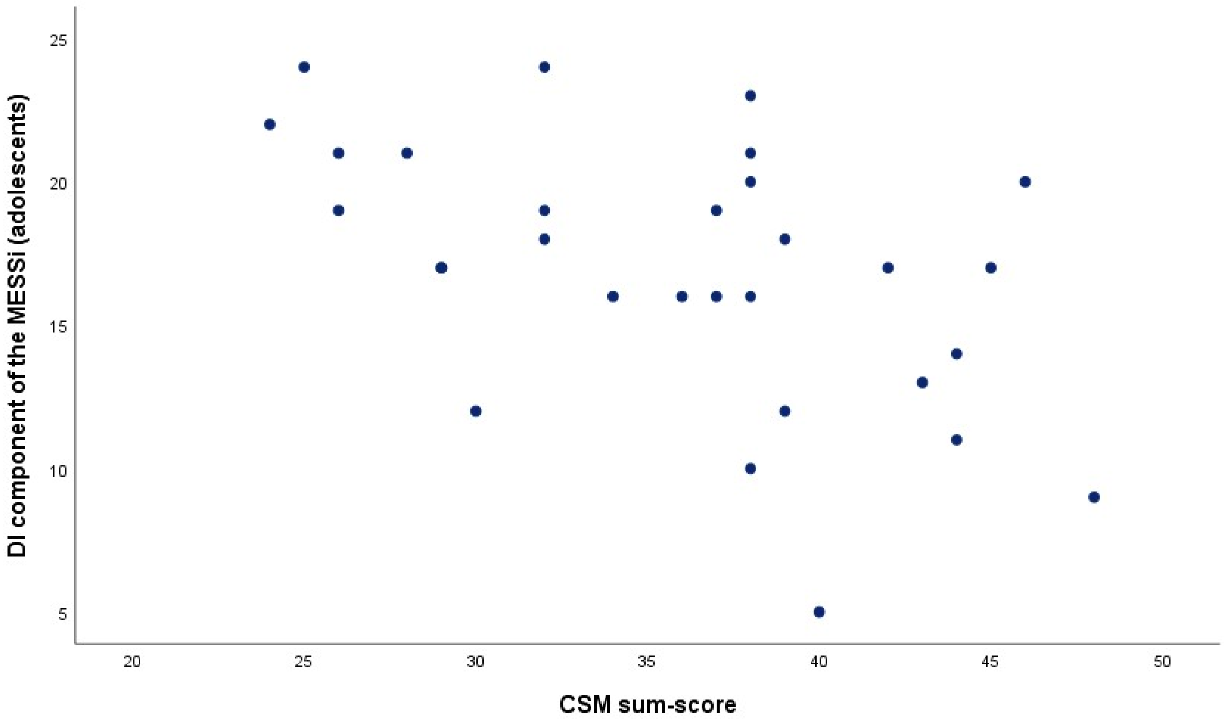

Figure 1: Correlation of the Composite Scale of Morningness sum-score with the Stability/Distinctness (DI) component of the Morningness-Eveningness-Stability Scale, improved (adolescents), r = -.506, p = .01.

3.2 Sleep

To give detailed information on the sleep of the students, descriptive statistics of the sleep parameters ("In Bed" and "Out Bed" times, "Total Sleep Time" and sleep "Efficiency") are shown in **Table 1**. On average, the students went to bed at 9.44 pm (*SD* = 32min) and got up at 7.03 am (*SD* = 27min). They were 469 minutes in bed (*SD* = 39min) and they reported a sleep efficiency of 84% (*SD* = 5%).

Table 1: *Descriptive statistics (M and SD) of the sleep parameters ("In Bed", "Out Bed", "Total Sleep Time" and sleep "Efficiency") during week.*

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
				M(SD)			
In Bed	9.59pm (1h16min)	9.19pm (37min)	9.22pm (28min)	9.25pm (33min)	9.57pm (50min)	10.10pm (1h18min)	9.56pm (1h9min)
Out Bed	7.25am (1h37min)	7.41am (1h22min)	6.19am (15min)	6.28am (21min)	6.21am (22min)	7.36am (1h40min)	7.33am (1h33min)
TST	491min (63min)	449min (67min)	462min (42min)	454min (53min)	491min (73min)	462min 81min)	472min (60min)
Efficiency	84% (5%)	83% (11%)	85% (7%)	85% (8%)	85% (6%)	82% (7%)	83% (7%)

TST = Total Sleep Time

The students went to bed earliest on Tuesday and got up earliest on Wednesday. On Monday and Friday, they slept longest and the greatest sleep efficiency was reported from Wednesday to Friday.

<u>3.2.1 Sleep and Morningness-Eveningness</u>

To investigate the effect of Morningness-Eveningness on the sleep parameters ("In Bed" and "Out Bed" times, "Total Sleep Time" and sleep "Efficiency"), the following analysis were done. In **Table 2,** the correlations of the components of the MESSi (adolescents) with the "In Bed" times are represented. The EV component correlated positively with the "In Bed" times on Monday, Tuesday, Wednesday, Thursday and Sunday, indicating that a higher preference in Eveningness is associated with later "In Bed" times on these days The MA and DI component showed no significant correlations with the "In Bed" times during week.

Table 2: *Pearson correlations (zero order) of the components (MA, EV and DI) of the* Morningness-Eveningness-Stability Scale, improved *(adolescents) with the average "In Bed" times of the students during week.*

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
MA	-.143	-.278	-.220	.063	-.252	-.331	-.105
EV	.386*	.631**	.681**	.402*	.195	-.090	.439*
DI	-.037	.286	.008	-.029	.010	.073	-.016

*significant correlation at a level of *p = 0.05*
**significant correlation at a level of *p = 0.01*

The "Out Bed" times showed only on Tuesday a positive correlation with the EV component of the MESSi (adolescents), with *r* = .364, *p* = .01. Almost the same results can be observed for the "Total Sleep Time" during week: EV showed a negative correlation with the "Total Sleep Time" on Tuesday (*r* = -.506, *p* = .01) and Wednesday (*r* = -.372, *p* = .05), indicating that a higher preference in Eveningness is associated with a lower "Total Sleep Time" on these days.
The CSM sum-score presented similar results. On Tuesday (*r* = -.437, *p* = .05) and Wednesday (*r* = -.470, *p* = .01) the sum-score correlated negatively with the "In Bed" times. No further significant correlations between the CSM sum-score and the "In Bed" times during week could be found. The "Out Bed" times during week showed no significant correlations with the sum-score of the CSM as well as the "Total Sleep Time". The sleep "Efficiency" showed no significant correlations at all.
Further, the analysis showed a significant effect of Morningness-Eveningness on the "Out Bed" time on Saturday ($F_{2, 27}$ = 3.72, *p* = 0.038, η_p^2 = 0.216). Evening types had the latest time to get up (*M* = 09.33 am, *SD* = 2h 32min) followed by Mornings types (*M* = 07.20 am, *SD* = 51min) and Neither types (*M* = 07.18 am, *SD* = 1h 26min). The "In Bed" time on Sunday also showed a significant effect of Morningness-Eveningness, ($F_{2, 27}$ = 3.56, *p* = 0.042, η_p^2 = 0.209). Neither types showed the latest time to go to bed (M = 10.19 pm, SD = 1h 15min) followed by Evening types (M = 10.17 pm, SD = 1h 51min) and Morning types (M = 09.30 pm SD = 1h 5min). No further significant effect of Morningness-Eveningness, neither on the "Out Bed" and "In Bed" times nor on the sleep "Efficiency" and "Total Sleep Time" could be found.

3.3 Skin temperature

The following section gives more information on the skin temperature rhythm of the students. The skin temperature range of the students (*N* = 16) was given between 29 and 37 degrees Celsius (*M* = 33.53, *SD* = 1.63). The average skin temperature varies significantly through the week ($F_{6,\ 77136}$ = 143.32, *p* < .001, η_p^2 = 0.011) with the highest skin temperature on Saturday and Sunday. Please see **Table 3** for detailed information.

Table 3: *Descriptive statistic (M and SD) of the skin temperature (mean value) given in degrees Celsius on the different weekdays.*

day	N	Mean	Standard Deviation
Monday	11094	33.39	1.74
Tuesday	11281	33.47	1.65
Wednesday	11282	33.48	1.66
Thursday	11267	33.36	1.66
Friday	11017	33.41	1.58
Saturday	10440	33.63	1.63
Sunday	10762	33.89	1.44

The cosinor analyses of the skin temperature values showed a good fit (R^2 = .34) of the actual skin temperature values to the approximating 24 h cosine curve. In separate analyses by Chronotype, Morning types showed the best fit (R^2 = .44) of their actual skin temperature values to the approximating 24 h cosine curve followed by Evening types (R^2 = .33) and Neither types (R^2 = .32), see **Figure 1-3**.

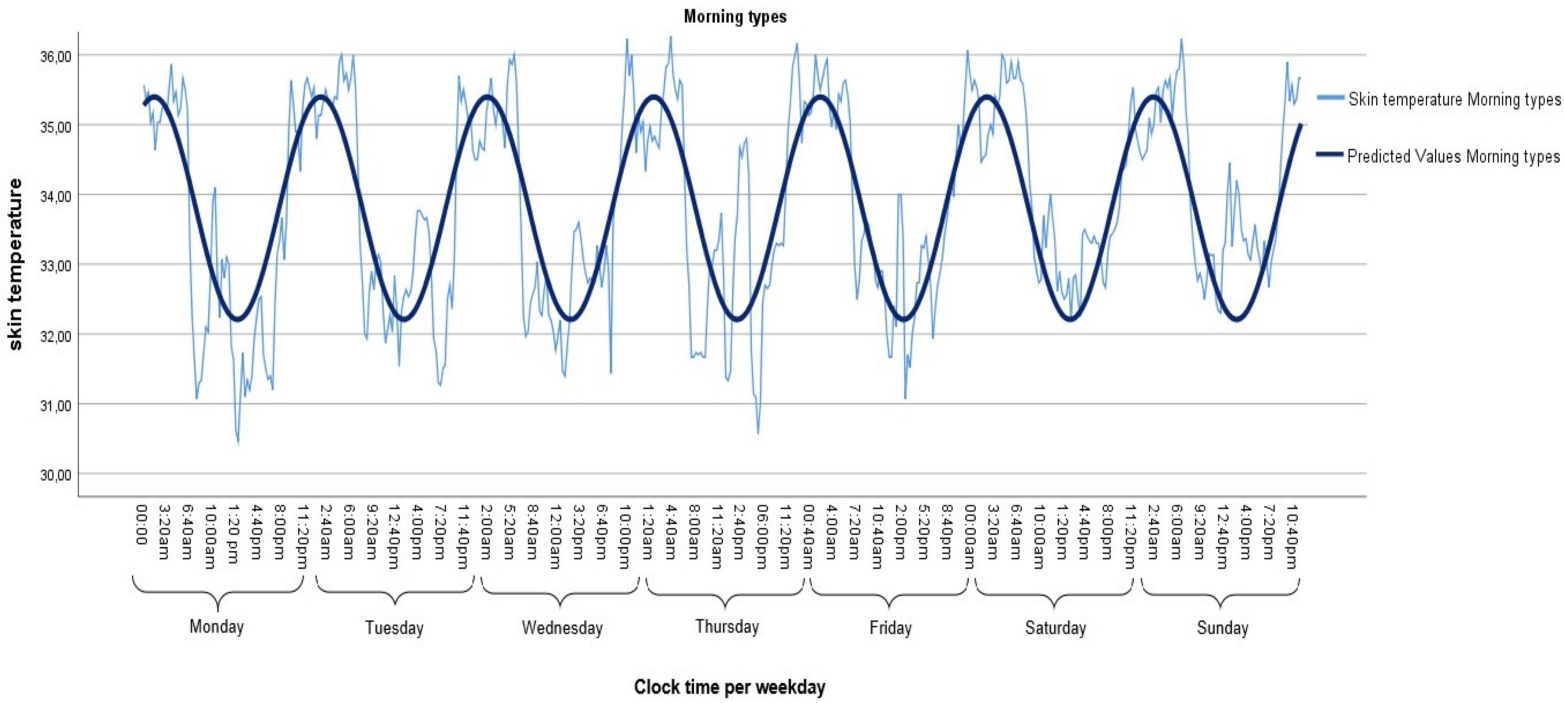

Figure 1: Actual and predicted skin temperature values for Morning types.

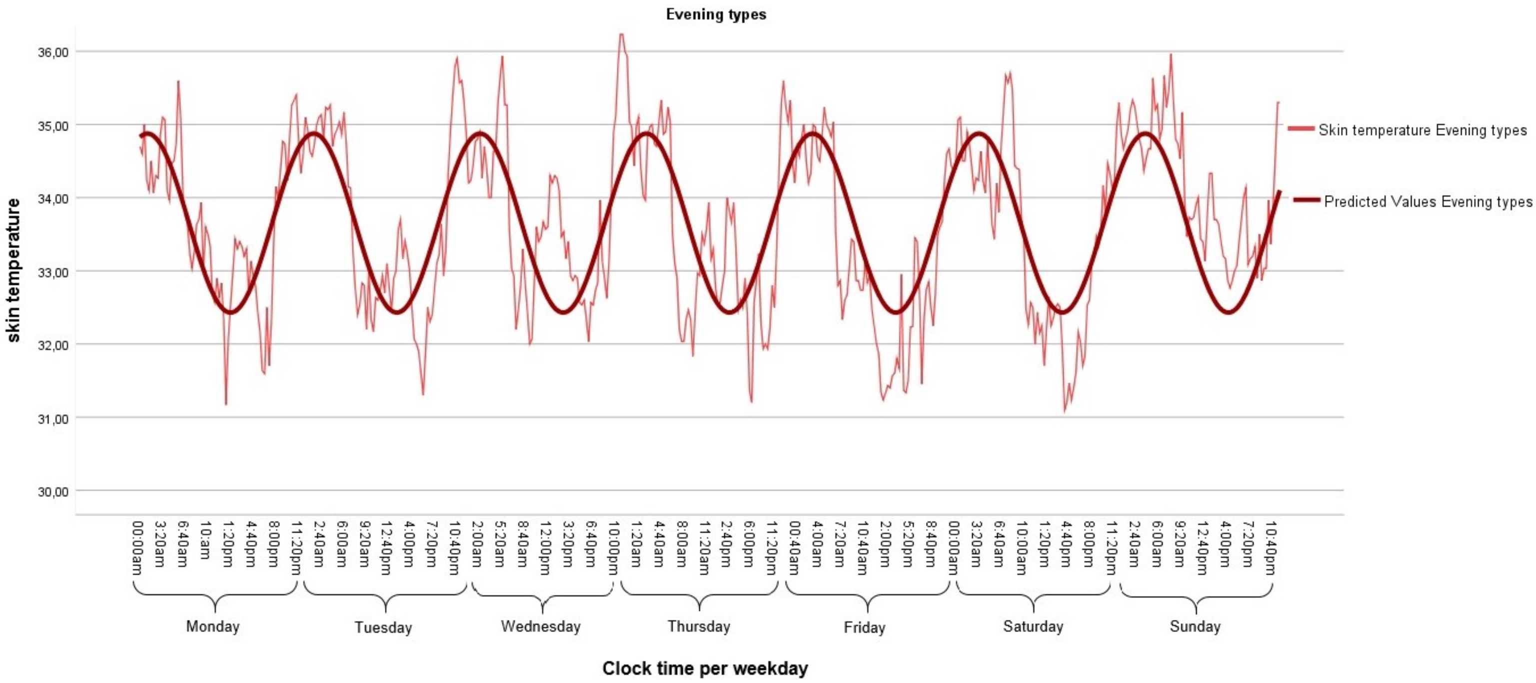

Figure 2: Actual and predicted skin temperature values for Evening types.

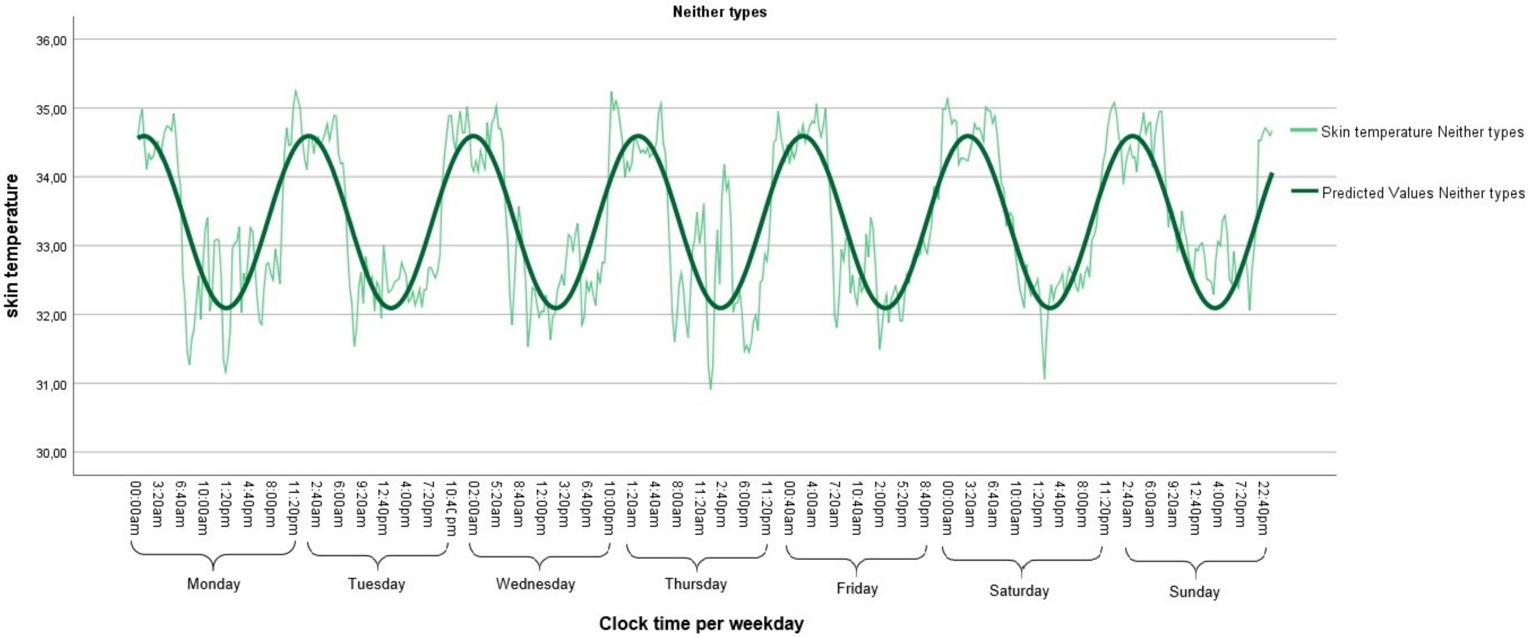

Figure 3: Actual and predicted skin temperature values for Neither types.

3.3.1 Skin temperature and Morningness-Eveningness

The following section refers to the effect of Morningness-Eveningness on the skin temperature parameters (peak, nadir and amplitude). Correlation analysis showed no significant correlations neither between the components of the MESSi (MA, EV and DI) and the skin temperature parameters, nor between the CSM sum-score and these.

Further analysis showed a significant effect of Chronotype on the average skin temperature ($F_{2,\ 77140}$ = 569.06, p < .001, $\eta_p{}^2$ = 0.015). Morning types had the highest skin temperature (M = 33.85, SD = 1.72) compared to Evening types (M = 33.67, SD = 1.56) and Neither types (M = 33.37, SD = 1.61). Chronotype showed no further significant effects on the skin temperature parameters (peak, nadir and amplitude).

3.4 School relevant achievement

School relevant achievement was represented in the speed, accuracy and performance values of the test FAIR-2. The students reached significant higher scores in all three values at the second test point. Please see **Table 4** for detailed information.

Table 4: *Descriptive and test statistic (M and SD) of the average speed, accuracy and performance values split by test point 1 and test point 2.*

	Test point 1	Test point 2	Test statistic
speed value	M = 311.90 (70.63)	M = 436.67 (103.17)	$t_{(29)}$ = -12.24, p < .001
accuracy value	M = 0.90 (0.09)	M = 0.93 (0.05)	$t_{(29)}$ = -3.58, p = .001
performance value	M = 282.95 (77.42)	M = 410.74 (108.20)	$t_{(29)}$ = -11.28, p < .001

3.4.1 School relevant achievement and Morningness-Eveningness

The sum-score of the CSM correlated positively with the speed (r = .373, p = .05) and performance (r = .366, p = .05) values at test point 1. Indicating that morning oriented students showed higher speed and performance in editing the FAIR-2 at test point 1. No significant correlation could be found between the CSM sum-score and the accuracy value at test point 1. On test point 2, no significant correlations could be found between the sum-score of the CSM and the school relevant achievement. The components of the MESSi; adolescents (MA, EV and DI) showed no significant correlations with the school relevant achievement, neither at test point 1 nor at test point 2.

Both at test point 1 and test point 2, Chronotype had no significant effect on the school relevant achievement. But concerning the difference between the school relevant performance on test point 1 and test point 2, Chronotype showed an effect on this difference. Please see **Table 5** for explanation.

Table 5: *Descriptive and test statistic (M and SD) of the average speed, accuracy and performance values of Morning, Evening and Neither types, split by test point 1 and test point 2.*

		test point 1	test point 2	
		M (SD)		test statistic
Morning types	speed value	363.60(47.01)	487.00(83.36)	$t_{(4)}$ = -4.32, p = .012
	accuracy value	0.95(0.05)	0.97(0.04)	$t_{(4)}$ = -0.81, p = .464
	performance value	346.77(55.49)	472.03(92.49)	$t_{(4)}$ = -3.63, p = .022
Evening types	speed value	305.25(66.05)	432.25(93.97)	$t_{(3)}$ = -6.05, p = .009
	accuracy value	0.91(0.05)	0.92(0.05)	$t_{(3)}$ = -0.41, p = .712
	performance value	280.97(74.13)	401.50(103.39	$t_{(3)}$ = -5.04, p = .015
Neither types	speed value	330.86(73.02)	425.52(109.32)	$t_{(20)}$ = -9.74, p < .001
	accuracy value	0.88(0.09)	0.93(0.05)	$t_{(20)}$ = -3.67, p = .002
	performance value	268.13(77.47)	397.90(111.95)	$t_{(20)}$ = -9.37, p < .001

Neither types showed in all three school relevant achievement values a significant difference between test point 1 and test point2. Morning and Evening types showed only in the speed and performance value a significant difference between test poin1 and test point 2.

3.4.2 School relevant achievement and state of emotional feeling

Correlation analysis showed significant correlations between the school relevant achievement values and the negative affect scale of the PANAS. At test point 1 the speed value (r = -.435, p = .05) and the performance value (r = -.410, p = .05) showed a negative correlation with the negative affect scale, indicating that students with a lower negative affect reached higher scores in the speed and performance values. The accuracy value showed no significant correlation with the negative affect scale. All three school relevant achievement values showed no significant correlations with the positive affect scale of the PANAS at test point 1. At test point 2, the three school relevant achievement values (speed: *r* = -.444, *p* = .05; accuracy: *r* = -.523, *p* = .01; performance: *r* = -.942, *p* = .01) showed a negative correlation with the negative affect scale of the PANAS. The positive affect scale showed also no significant correlations with the school relevant achievement values here.

3.5 State of emotional feeling

To investigate the difference between the positive and the negative affect of the students, t-test statistics were calculated. The analyses showed that at test point 1 and at test point 2 the students had significant higher values in the positive affect scale than in the negative affect scale. Therefore, there was also a significant difference ($t_{(29)} = 10.30$, $p < .001$) between the positive (*M* = 62.13, *SD* = 14.91) and negative (*M* = 27.80, *SD* = 9.54) affect scale regardless of the test point. The students reached significant higher values in the positive affect scale compared to the negative affect scale. Please see the following **Table 6** for detailed information.

Table 6: *Descriptive and test statistic (M and SD) of the average positive and negative affect values of the Positive and Negative Affect Schedule (PANAS) separate for test point 1 and test point 2.*

	Positive affect	Negative affect	Test statistic
test point 1	31.63(7.52)	13.87(4.08)	$t_{(29)} = 10.72$, $p < .001$
test point 2	30.50(8.30)	13.93(5.71)	$t_{(29)} = 9.23$, $p < .001$

3.5.1 State of emotional feeling and Morningness-Eveningness

The sum-score of the CSM correlated positively with the positive affect scale of the PANAS at test point 1 (*r* = .367, *p* = .05) and at test point 2 (*r* = .381, *p* = .05). Independent of test point, the CSM sum-score showed also a positive correlation with the positive affect scale (*r* = .397, *p* = .05), indicating that morning oriented students had higher values in the positive affect scale of the PANAS compared to the negative

affect scale. With the negative affect scale, the CSM sum-score showed no significant correlations.
The MA component of the MESSi (adolescents) showed positive correlations with the positive affect scale of the PANAS at test point 1 (r = .564, p = .01) and at test point 2 (r = .487, p = .01). Independent of the test point, MA showed also a positive correlation with the positive affect scale (r = .555, p = .01). With the negative affect scale, the MA component of the MESSi (adolescents) showed no significant correlations. The EV component of the MESSi (adolescents) showed no significant correlations with the scales of the PANAS at all. The DI component of the MESSi (adolescents) correlated negatively (r = -.534, p = .01) with the positive affect scale of the PANAS at test point 1, indicating that higher fluctuations of circadian preference lead to lower values in the positive affect. Independent of the test point, DI showed a negative correlation with the positive affect scale (r = -.446, p = .05).
The ANOVA showed a significant effect of Chronotype on the state of emotional feeling ($F_{2, 27}$ = 3.19, p = .057, η_p^2 = 0.191). At test point 2, Moring types (M = 37.60, SD = 7.60) had significant higher values in the positive affect scale than Evening types (M = 25.00, SD = 12.27) and Neither types (M = 29.86, SD = 6.82). No significant effect of Chronotype could be found for the negative affect scale at test point 2 and for positive and negative affect at test point 1 at all. Independent of the test point, a trend could be seen in the effect of Chronotype on the positive affect scale, ($F_{2, 27}$ = 2.96, p = .069, η_p^2 = 0.180). Morning types (M = 74.20, SD = 14.92) showed higher values in the positive affect scale compared to Evening types (M = 52.00, SD = 18.65) and Neither types (M = 61.19, SD = 12.95). No significant effect of Chronotype could be seen for the negative affect scale of the PANAS.

3.6 Motivational regulation in learning

The motivational regulation in learning is represented by the identified, intrinsic, introjected and external motivation scales of the SMR-L. The students reached the highest values in the identified motivation scale (M = 9.47, SD = 0.31) compared to the intrinsic (M = 8.33, SD = 0.41), introjected (M = 7.77, SD = 0.50) and external motivation scale (M = 5.90, SD = 0.40).

Further analysis showed a positive correlation of the intrinsic motivation scale with the positive affect scale of the PANAS (r = .578, p = .01) indicating that a higher intrinsic motivation in school learning is associated with a higher positive affect. The intrinsic motivation scale showed no significant correlation with the negative affect scale. The identified motivation scale presented a positive correlation with the positive affect scale (r = .437, p = .05), indicating that a higher identified motivation in school learning is associated with a higher positive affect. The identified motivation scale showed no significant correlation with the negative affect scale. The introjected motivation scale exposed a positive correlation with the negative affect scale of the PANAS (r = .505, p = .01), indicating that a higher introjected motivation in school learning leads to a higher negative affect. The introjected motivation scale showed no significant correlation with the positive affect scale. The external motivation scale demonstrated a negative correlation with the positive affect scale (r = -.389, p = .05), indicating that a higher external motivation in school learning is associated with a lower positive affect. The external motivation scale showed no significant correlation with the negative affect scale.

3.6.1 Motivational regulation in learning and Morningness-Eveningness

The sum-score of the CSM showed positive correlations with the intrinsic (r = .610, p = .01) and identified (r = .602, p = .01) motivation, indicating that morning orientation is associated with a higher intrinsic and identified motivation in school learning. Further the sum-score of the CSM showed a negative correlation with the external motivation (r = -.381, p = .05), indicating that evening orientation is associated with a higher external motivation. For introjected motivation, no significant correlation with the CSM sum-score can be observed. The MA component of the MESSi (adolescents) presented positive correlations with the intrinsic (r = .562, p = .01) and identified (r = .528, p = .01) motivation of the SMR-L. For introjected motivation, no significant correlation with the MA can be observed. Concerning the EV component, no significant correlations could be found with the motivational regulation in learning. Thus, the DI component correlated negatively with the intrinsic (r = -.723, p = .01) and identified (r = -.554, p = .01) motivation, indicating that high fluctuations in circadian preference are associated with a lower intrinsic and identified motivation in school learning. DI also presented a positive correlation with the external motivation

(r = .366, p = .05), indicating that higher fluctuations in circadian preference are associated with a higher external motivation in school learning. For introjected motivation, no significant correlation with the DI can be observed.

Chronotype demonstrated a significant effect on intrinsic ($F_{2, 27}$ = 8.37, p = .001, η_p^2 = 0.383), identified ($F_{2, 27}$ = 5.14, p = .013, η_p^2 = 0.276) and introjected ($F_{2, 27}$ = 4.10, p = .028, η_p^2 = 0.233) motivation in school learning. Morning types had significant higher values in the intrinsic and identified motivational scale compared to Evening and Neither types. Neither types reached the highest values for the introjected motivational scale. See **Table 7** for detailed information. Chronotype showed no significant effect on the external motivation.

Table 7: *Descriptive statistic (M, SD and N) of the average values of the motivational regulation scales (intrinsic, identified, introjected and external motivation) for school learning of the Scales for Motivational Regulation in Learning (SMR-L) separated for Chronotype.*

	Morning types	Evening types	Neither types
		M (SD)	
intrinsic motivation	9.80(1.79)	5.00(1.41)	8.62(1.90)
N	5	4	21
identified motivation	11.00(0.71)	7.75(2.63)	9.43(1.40)
N	5	4	21
introjected Motivation	5.20(1.79)	6.75(3.20)	8.57(2.48)
N	5	4	21
external motivation	5.00(1.22)	6.50(2.32)	6.00(2.32)
N	5	4	21

4. Discussion

4.1 MESSi (adolescents) and CSM

To test convergent validity of the MESSi (adolescents) in this sample, correlations between the MESSi´s components (MA, EV and DI) and the CSM sum-score were done. The analysis present similar results to previous done studies (Faßl et al., 2019; Weidenauer et al., 2019). The MA component correlated positively and the EV component negatively with the CSM sum-score. This indicates that higher values in the MA component are associated with a greater morning orientation and vice versa for the EV component and evening orientation. Interesting was also the finding that the stability component of the MESSi (DI) was negatively correlated with the CSM sum-score. As reported in Weidenauer et al. (2019), this indicates that morning oriented students have a higher stability in their circadian preference (higher values in the DI component suggest a higher fluctuation in daytime preferences). This finding manifests that morning orientation is associated with a more constant circadian preference through the day. Previous research could show that morning types are on the one hand more conscientious (e.g. Faßl et al., 2019; Adan et al., 2012) and on the other hand more satisfied with their life (e.g. Randler, 2008c) compared to Evening types. Perhaps this will make it easier for morning-oriented people to structure their daily lives better and incorporate stronger routines. It should be noted that circadian preference plays a role in the daily fluctuations of organizing one´s day and that this requires further investigation.

4.2 Sleep

In the present study, there were no “unusual” fluctuations in the sleep/wake timing of the students, meaning, on average, they showed earliest rise time during week and latest bed times on the weekend. Regarding Morningness-Eveningness, only on some days (Tuesday, Wednesday, Thursday, and Sunday) evening orientation was associated with later bed times and shorter sleep times. Only on Saturday and Sunday, clear differences between the chronotypes (Morning, Evening and Neither types) could be found. Evening types tend to rise up to two hours later on Saturday and Neither types as well as Evening types tend to go almost an hour later to bed on Sunday. Later rise and bed times for Evenings types especially on the weekends are already known (e.g. Tillard et al., 1999; Horne & Östberg, 1976). One possible explanation why there were no significant differences in sleep timing between the chronotypes during week in the present study might be, that students have normally strict and constant routines for their sleep timing because they have to be at school at given times. It appears that in this age group, circadian preference has little influence on sleep timing. It is known, that the breaking point towards Eveningness is a few years later (Randler et al., 2017). A greater evening orientation in students might show clearer differences between the chronotypes in the sleep timing also during week.

4.3 Skin temperature

As mentioned earlier, the skin temperature of the students was objectively measured with the help of iButtons during one week in their home setting. While the correlations analysis of the skin temperature parameters (peak, nadir and amplitude) showed no significant influence of Morningness-Eveningness, Morning types tend to show a higher average skin temperature during week. Even Horne and Östberg (1976) could show that Moring types had a higher overall temperature compared to Evening types. However, the oral temperature was determined here and not the skin temperature. The present results represent an extension of previous research. Further, the cosinor analysis showed the best fit of the actual skin temperature values to the approximating 24 h cosine curve for Moring types. One might expect that Morning types do also show a significant lower amplitude. It has been shown for example in the study of Baehr et al. (2000) that Evening types have a larger amplitude. However, this could not be confirmed in this study. Baehr and colleagues (2000) reported that a lower amplitude was associated with older people. In the present study, the students were very young (aged between 12 and 13). A possible highly fluctuating skin temperature rhythm and hormonal influences might cause the findings. In addition, it could be found out that in the present study, the average overall skin temperature varies during week. On Saturday and Sunday the students had the highest average overall skin temperature. Skin temperature differences during week in students have been little explored so far. A study of Sarabia et al. (2008) measured the wrist temperature in university students with iButtons for one week during holidays and during one week with normal conditions. They could show that there are a few masking factors for the rhythm of the wrist temperature. A shifted sleep timing, later food intakes and naps, especially after food intake, can increase the wrist temperature during the day. This could be a possible explanation for the increased skin temperature of the students on the weekend. Additionally, an increase in physical activity, resulting from more weekend leisure activity, could also be an intervincing factor.

4.4 School-relevant achievement

In the present study, school-relevant achievement was measured with the FAIR-2. Three attention and concentration based values (speed, accuracy and performance) give information about the students' performance. The results demonstrated that the students performed best at the second test point. All three performance values showed significant higher scores at test point two than at test point one. This suggests that the attention and concentration based performance of the students increases during school day. The results confirm previous research and support the findings that later school start times improve students` achievement and health (e.g. Wahistrom, 2002; Carrell, Maghakian & West, 2011; Boergers, Gable & Owens, 2014).

Concerning the effect of Morningness-Eveningness on school-relevant achievement has to be reported that no significant influence could be found. Chronotypes (Morning, Evening and Neither types) did not differ in their school-relevant achievement. Also no synchronicity effect could be found: Moring types did not show better performance at test point one compared to test point two and vice versa for Evening types. This effect, however, was assumed on the basis of existing literature (e.g. Hahn et al., 2012; Itzek-Greulich, Randler & Vollmer, 2016). In a study by Randler, Bechtold and Vogel (2016), no evidence could be provided that Chronotype has an effect on mathematical achievement. The researchers assumed that the reason for this was a too small sample size to see significant results in a field study. This could also be true for the present study as well. A further intervincing aspect could be the age of the students. The students were aged between 12 and 13 years. It is known that the breaking point towards Eveningness is located at an older age: between 15 and 16 years in girls and 17 years in boys (Randler, Faßl & Kalb, 2017). An older age group of students could allow a clearer differentiation of the individual

Chronotypes and thus show clearer differences in achievement. In contrast to the study by Randler, Bechtold and Vogel (2016), significant correlations between the CSM sum-score and the school-relevant achievement values could be found in the present study. The sum-score of the CSM showed a positive correlation with the speed and performance value at test point one. This indicates that morning oriented students showed higher speed and performance. The results partly confirm the previous literature that Morningness is associated with better performance and achievement (e.g. Preckel et al., 2013; Preckel, et al., 2019; Díaz-Morales & Escribano, 2013; Randler & Frech, 2009).

It is already known that emotions and feelings are related to educational outcome. Positive emotions lead to a higher outcome and negative emotions to a lower educational outcome (Gläser-Zikuda et al., 2005; Rahafar et al., 2016). Also in the study by Randler, Bechtold and Vogel (2016), affective well-being was associated with school achievement. Negative affect was positively related to the mathematical scores. In the present study, negative affect was negatively correlated with the achievement values, indicating, that lower negative affect was associated with higher school-relevant achievement values. Since negative affect seems to remain stable throughout the day (e. g. Randler & Weber, 2015; Randler et al., 2016b) this would be an important incentive to find out how negative affect can be reduced in general to enable students to improve their school achievement.

4.5 State of emotional feeling

In the present study, the students represented higher values in the positive affect scale compared to the negative effect scale regardless of the test point and Morningness-Eveningness. These results confirm previous research (e .g Randler & Weber, 2015; Randler et al., 2016b). The students represent a constant higher affective well-being. This might be an indication of a generally good attitude towards school and learning of the students in this sample. A few studies could investigate that for example gender, contextual background, age and students 'perception of their competence are potential factors that interfere with students 'attitude towards learning and school (Candeias et al., 2010). It might be possible that affective well-being also belongs to this factors.

Regarding the emotional state of feeling in terms of Morningness-Eveningness, the sum-score of the CSM showed a positive correlation with the positive affect scale of the PANAS at test point one and test point two. This indicates, that morning oriented students reported a higher positive affect. The negative affect scale showed no significant correlation with the CSM sum-score at all and also none with the components of the MESSi. A part of these findings has already been shown for example in the study of Randler and Weber (2015) or Randler et al. (2016b). However, the MESSi has not yet been set in relation to affective well-being. The correlations of the components (MA and EV) of the MESSi (adolescents) confirm the findings and thus continue to confirm the validity of the MESSi (adolescents). Interesting is the negative correlation of the DI component of the MESSi (adolescents) with the positive affect scale. Higher fluctuations of circadian preference lead therefore to lower values in the positive affect. This is a new finding so far and demonstrates that the stability of circadian preference during day can effect the emotional state of feeling. Higher fluctuations require more adaption of the individual circadian preference to the daily challenges. The increased effort, the students had to perform, could affect the emotional state of feeling. The variance analytical calculations confirm the correlation analysis and proof that Moring types tend to have a higher positive affect than Evening and Neither types. Same as in the study of Randler et al. (2016b), there were no significant difference between the Chronotypes concerning the negative affect. Therefore, it might be useful for further studies to set only the positive affect in relation with Morningness-Eveningness.

4.6 Motivational regulation in learning

In the present study, the scales for motivational regulation in learning from Thomas and Müller (2015) were used to determine the motivational background of the students. The scales respond to the emerging question: for what reason do the students want to learn? The scales of Thomas and Müller are still a quite new measurement, which is why there are not many studies available yet, especially in view of a potential association with Morningness-Eveningness. The students in the present study reached the highest values in the identified motivation scale. These results are consistent with the findings of Thomas and Müller (2015). According to Thomas and Müller, younger students in particular indicate that they want to learn in order to drive their personal development. However, this observation must also be compared with the findings of Scherrer and Preckel (2019). They found, that in general, the motivation of students' decreases during their school carrier, especially the intrinsic motivation. The high values of the students in the present study in self-regulated motivation styles are therefore to be expected at an average age of 12-13 years.

Further analysis showed positive correlations between identified/intrinsic motivation and the positive affect scale of the PANAS. The introjected motivation scale represents a positive correlation with the negative affect scale and the external motivation scale showed a negative correlation with the positive affect scale. In summary this indicates, that a regulation style perceived as self-determined leads to higher affective well-being, whereas a regulation style perceived as externally-determined is more associated with negative affect. These findings so far confirm previous assumption (e.g. Gillet et al., 2013) and could also been proved in the studies of Thomas and Müller (2015) as well as Thomas, Müller & Bieg (2018).

Concerning the effect of Chronotype on the motivational regulation in learning it can be reported that Morning types are mostly intrinsic and identified motivated compared to Evening and Neither types. So, Morning types tend to learn because they have fun in school and during learning and want to drive their personal development. Interesting is the finding that Neither types reached the highest values in the introjected motivational regulation. So, most of the students in the present study tend to learn because they want to be in a good position in front of their classmates and teachers. Why these results are reflected here like this, is unclear. However, it must be said that the classification of the different chronotypes was based on the sum-score of the CSM. A more detailed differentiation or fragmentation of circadian preference, as it was done in study of Preckel et al. (2019), could lead to a clearer insight. The correlation analysis demonstrated similar results and therefore confirms the findings. The sum-score of the CSM and the MA component of the MESSi (adolescents) represented a positive correlation with intrinsic and identified motivation, indicating that morning orientation is associated with self-determined regulation styles. Another aspect worth mentioning is the relation of the Stability of circadian preference with the motivational regulation. The DI component of the MESSi showed negative correlations with the intrinsic and identified motivational scale and a positive correlation with the external motivational scale. Higher fluctuations in circadian preference are associated with lower self-determined and higher externally-determined regulation in school learning. As mentioned earlier, higher fluctuations of circadian preference also lead to a lower affective well-being. The stability of circadian preference throughout the day seems to effect the emotional state as well as motivational aspects. The stability of circadian preference could possibly be seen as an important intervincing factor in school environment. However, there is an urgent need for further studies to examine a potential influence on school achievement.

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5. Conclusion

In the present study, it seems that in the age group 12 to 13 years, time of day has a greater impact on school-relevant achievement than the individual Chronotype. Later school starts or at least the writing of exams at later school times could help to improve students' school-relevant achievement. It is also shown that emotions and feelings as well as motivation continue to play an important role in school achievement. Here, the stability of the circadian preference could be identified as an intervincing factor. It might be possible that the higher affective well-being, a more self-determined motivational regulation in school learning and a higher stability in circadian preference foster the advantages of morning-oriented students in school achievement.

Acknowledgements

We are grateful to the students of the Friedrich-List- and Johann-Vanotti-Gymnasia that participated in this study. We want to thank the teachers, the school management and the principals for their support as well as the parents of the students. C.W., A.R., and C.R. are members of the LEAD Graduate School [GSC1028], funded by the Excellence Initiative of the German federal and state governments.

Complying with ethics of experimentation

The research has been conducted in an ethical and responsible manner and is in full compliance with all relevant codes of experimentation and legislation. The study follows the principles of the Declaration of Helsinki and was approved on the one hand by the Ethics Committee for Psychological Research of the Faculty of Mathematics and Natural Sciences (University of Tuebingen, AZ: Faßl_2018_0726_129) and on the other hand by the regional council (department for school and education) of Tuebingen (Az.: 71-31/71-33/6499.21). The study received a positive vote by the Committee and the regional council. The principles of the respective schools gave their formal consent, all parents gave their formal written consent for their children, and all students gave their formal written consent.

Declaration of interest

The authors declare no conflict of interests.

Funding

This research was supported by a grant of the *Gips-Schüle-Stiftung*. The foundation had no role in the study design, collection, analysis or interpretation of the data, writing the manuscript, or the decision to publish.

Author Contributions

C.R. and C.W. designed the study. C.W. and C.R. made the analysis, C.W, A.R. and C.R. wrote the manuscript. All authors (C.W., A.R. and C.R.) reviewed the manuscript.

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8. General discussion

The individual chronotype is now highly regarded and in many respects explored. The field of chronobiology, in particular, has become generally known after the Nobel Prize was awarded in 2017. To see the individual chronotype as an important part of human biology and to know and accept one's individual time of day preferences is becoming more and more important in today's society. In a society determined by socially accepted schedules, it is important to understand the limitations and functioning of your body and, in case of doubt, to listen to them.

Even today, the individual chronotype is most commonly determined by self-assessment questionnaires *(Adan et al., 2012)*. Chronotype is understood here as Morningness-Eveningness preference and seen as uni-dimensional construct, with Morningness and Eveningness marking the two endpoints of one scale. The test persons are then categorized into certain groups based on specific cut-off values (e.g. Morningness-Eveningness Questionnaire [MEQ] by Horner & Östberg, 1976). As already mentioned in the "*Theoretical background*", however, one would like to avoid dividing humans into chronotype categories. Morningness-Eveningness, on the other hand, should be understood more as individual time of day preferences with variations in time of day and be represented as a multi-dimensional construct. Above all, the daily fluctuations of Morningness-Eveningness should be given more importance and regarded as an independent dimension *(Preckel et al., 2013; Ogińska, 2011; Dosseville et al., 2013)*. For this reason, the measurement MESSi entered the scene in 2016 *(Randler et al., 2016a)*. It is now important to use the advantages of this multi-dimensional measurement and to use it as effectively as possible in research. Selected here is a field that already enjoys a good acquaintance with chronotype and underlines its importance in our society all the more: school achievement. Outstanding research shows again and again a clear influence of chronotype on school achievement *(e.g. Escribano et al., 2012; Díaz-Morales & Escribano, 2013; Preckel et al., 2019; Rahafar et al., 2016)*. Furthermore, it seems that evening-oriented students have a clear disadvantage compared to morning-oriented students (*e.g. Randler & Frech, 2009; Scherrer et al., 2016, Preckel et al., 2011, 2013)*. This circumstance needs to be explored with all possible resources and to clarify what causes it.

8.1 Validation of the MESSi

First, the validation of the MESSi is to be addressed. **Study 1** and **2** were dedicated to this project and resulted from one survey. The results of these studies confirmed on the one hand that the MESSi is a valid measurement for circadian preference and its amplitude, but also showed some insufficient co-variations.

Study 1 showed a good convergent validity of the MESSi. The components MA and EV of the MESSi were strongly correlated with the rMEQ sum-score, with MA having the strongest correlation (MA: r=0.91 and EV: r=0.87). Presented in **Study 2**, Morning types (categorized with the help of the rMEQ) demonstrated higher scores in the MA component of the MESSi compared to Evening types. Evening types, in contrast, showed higher scores in the EV component of the MESSi than Morning types. Similar results could be observed in the study by Díaz-Morales et al. (2017). They validated the MESSi among adult workers and young students of Spain also with the help of the rMEQ. Again, there was a positive correlation of MA with the rMEQ sum-score detected and a negative correlation of EV with the rMEQ sum-score. Both the results of this **Study 1** of the present dissertation and the results of Díaz-Morales et al. (2017) demonstrate that MA and EV correlate similarly strongly with the rMEQ sum-score. As with Díaz-Morales et al. (2017), this raises the question of whether Morningness and Eveningness are really two clearly separable dimensions. This question will be addressed later on.

Concerning the DI component of the MESSi, the results of **Study 1** showed no significant correlation with this component and the rMEQ sum-score. Even Díaz-Morales et al. (2017) could only prove a weak correlation. But a clear tendency, reported in the present **Study 2**, could be observed with Evening types showing higher scores in the DI component of the MESSi compared to Morning types. Although this tendency was only barely not significant (p=0.065), it indicates that Evening types have a lower stability in their circadian preference than Moring types. The results indicate, on the one hand, that the dimension DI can be clearly separated from the other two other dimensions (MA and EV) and, on the other hand, it confirms the initial assumption. The original assumption that Evening types may have greater fluctuations in their circadian preference claims that they must adapt their behavior and their actual preferences to those of our "social clock driven society" *(Koukkari &*

Sothern, 2007 [pp.11]). Evening types are often forced to be at school, university or at work at given times and to perform although this contradicts their inner rhythms *(e.g. Vollmer et al., 2011)*. In their free time after work/school or on weekends they can arrange their lives as they like. For example, they slept much longer on weekends to compensate their accumulated sleep deficit *(e.g. Taillard et al., 1999; Horne & Östberg, 1976)*. This results in an asynchronicity between their individual circadian preferences and the given ones of our society. Stronger fluctuations are probably only one of the long-term consequences of this lifestyle.

Sticking to the subject of sleep, the results of **Study 1** were as followed. To further validate the MESSi, their components were set in relation to the midpoint of sleep. The midpoint of sleep indicates the time of the midpoint of the average sleep duration. For example, if a person goes to bed at 12.00 p.m. and gets up at 6.00 a.m., the midpoint of sleep would be set at 3.00 a.m. in the early morning. Using the midpoint of sleep to determine chronotype is a traditional procedure and is often used *(Roenneberg et al., 2003; Roenneberg et al., 2007)*. The results of **Study 1** showed that Moring types have an approximately 2 hours earlier midpoint of sleep than Evening types. This is confirmed by the negative correlation of the MA component of the MESSi with the midpoint of sleep. Evening types in contrast have a later midpoint of sleep which is expressed by the positive correlation of the EV component with the midpoint of sleep. Morning types therefore also have about 2 hours earlier bed and rise times than Evening types. This circumstance was observed during the week as well as on weekends. A confirmation of the validity of the MESSi on the basis of rise and bed times is thus clearly given and also confirms the previous literature *(e.g. Horne & Östberg, 1976, Duffy et al., 2001; Thun et al., 2012; Adan et al., 2012)*.

With regard to sleep quality, it should be reported that the MA component of the MESSi correlated negatively with the sum-score of the PSQI (Pittsburgh Sleep Quality Index, by Buysse et al.1989) and with the subjectively assessed sleep quality by the test persons. Morning types reported consistently (during the week as well as at the weekend) a better sleep quality in comparison to Evening types. The EV component of the MESSi additionally showed a positive correlation with the subjective sleep quality at the weekend, which strengthened the assumption of a worse sleep quality in Evening types. This theory is partly supported by the positive correlation of the DI component of the MESSi with the sum-score of the PSQI. Greater fluctuations in circadian preference are therefore associated with poorer sleep quality. Previously it was reported that Evening types show greater fluctuations in their circadian preference. This could be a possible explanation for the poorer sleep quality in Evening types as well. It shows that the inconsistency in their circadian preference may have an impact on the quality of their sleep. Thus, a further consequence of the asynchronicity of their inner biological rhythm and the predetermined "social rhythm" would manifest itself in Evening types. Some studies have already shown that Evening types have a poorer sleep efficiency compared to Morning types and thus also a poorer sleep quality during the week. At weekends, these sleep parameters usually do not differ in terms of chronotype *(Vitale et al., 2015)*. Vitale and colleagues were also able to demonstrate that Evening types have a shorter sleep duration during the week compared to Morning types and move significantly more at night. On weekends they extend their sleep duration and sleep more calmly with less movement. One possible assumption here could be that the stress during week of having to fight against their inner rhythm puts more pressure on them during sleep. Merikanto et al. (2012) was able to show in a Finnish population that Evening types are more often troubled by nightmares and have more insomnia symptoms than Morning types. The stability of the individual circadian preference can therefore have an impact on sleep quality. This manifests itself mainly in Evening types, as they are more preloaded due to their asynchronicity.

As just mentioned in Vitale et al. (2015), physical activity also shows an impact of chronotype. In general, Morning types tend to have the highest level of physical activity earlier in the day compared to Evening types (*e.g. Vitale et al., 2015, Natale et al., 2006, Lee et al., 2014; Adan et al., 2012)*. In students, this behavior is particularly evident: morning-oriented students are generally more active than evening-oriented students and also have a more positive attitude towards the beneficial effects of physical activity *(Schaal et al., 2010)*. Evening-oriented students in contrast spend more time with electronic media *(Randler et al., 2016b; Randler, Horzum & Vollmer, 2014; Vollmer et al., 2014)*. From a biological point of view, Morning types also reach earlier peak values in other physiological parameters (such as body temperature *[Beahr et al., 2000]*, serum cortisol *[Bailey & Heitkemper, 2001]* and melatonin *[Mongrain, Carrier & Dumont, 2006]*) compared to

Evening types. It could be possible that the physiology of the Morning types adapt to these conditions and trigger the need for physical activity earlier in them as compared to Evening types. From a psychological point of view, however, the social factors should not be overlooked. Since Evening types generally tend to start their day later *(Adan et al., 2012)*, they have to reschedule all leisure activities, such as sports, to a later time in the afternoon or evening. They probably have no time for physical activity in the afternoon. For example, evening-oriented students demonstrate more daytime naps than morning-oriented students *(Gau et al., 2007)*.
The results of **Study 1** of the present dissertation also confirm previous findings and indicated that Morning types are more active in the afternoon (02.55 p.m.) and Evening types are more active in the late afternoon/early evening (05.08 p.m.). As a valid measurement of circadian preference, the MESSi is also confirmed in physical activity. The MA component showed a negative correlation with the acrophase of physical activity whereas the EV component correlated positively with it. This effect was observed both during the week and at the weekend.

As already mentioned, a well-documented influence of Morningness-Eveningness on other physiological parameters could be determined. Further physiological parameters were therefore identified for the validation of the MESSi in the present dissertation. Especially the circadian rhythm of the body temperature shows a relevant influence of chronotype. The body temperature rhythm is very stable *(Wever, 2013)* and has therefore been used for years for the biological manifestation of chronotype *(e.g. Aschoff, 1960, Aschoff, 1965, Aschoff, 1967)*. It could be shown that Morning types reach their maximum (acrophase) and minimum (nadir) temperature approximately 2 h earlier than Evening types. Evening types in contrast tend to have a larger amplitude in body temperature *(Kerkhof & Van Dongen, 1996, Baehr et al., 2000, Waterhouse et al., 2001, Bailey & Heitkemper, 2001)*. The core body temperature or the oral temperature is commonly used for such studies; since they are both resistant to environmental influences such as, for example, weather conditions or certain clothing. However, it has already been shown that the skin temperature, preferably the wrist temperature, can also be considered as a reliable marker for the circadian rhythm *(Sarabia et al., 2008)*. Therefore, for the **Study 1** and **2** surveys, the wrist temperature was determined using iButtons.

As mentioned earlier, not all validation attempts for the MESSi were completely satisfactory. Thus, in the results of **Study 2**, no significant correlations of the MESSi components MA and EV and the rMEQ sum-scores with different skin temperature parameters (acrophase, nadir and amplitude) were found. Also, an influence of chronotype (classified by the rMEQ) on these variables could not be empirically proved. Only the DI component of the MESSi displayed a weak correlation with the nadir. This indicates that higher fluctuations in circadian preference are associated with a lower average skin temperature during nadir. What exactly causes this relation is unclear. In the result of **Study 1**, larger fluctuations in circadian preference were associated with a poorer sleep quality. It is imaginable that the stability of the circadian preference also influences biological variables. It is clear that further research is needed to investigate the relationship between stability in circadian preference and skin temperature.
Regarding another physiological variable, the cortisol levels in the morning, similar results could be seen. None of the components of the MESSi (MA, EV and DI) showed significant correlations with the cortisol levels in the morning (t1 = first cortisol probe directly after awakening and t2 = second cortisol probe 30 minutes later) and the CAR (cortisol-awakening-response). Only an influence of chronotype on t1 was found during the week. Morning types had higher values here compared to Evening types. Cortisol has been chosen as a further physiological „validation-variable“, because the influence of chronotype on the cortisol levels in the morning is well established. Normally, it can be seen that Morning types tend to show higher cortisol levels after awakening than Evening types *(e.g. Bailey & Heitkemper, 1991; Ogińska et al., 2010)*. This effect can be seen on the one hand directly after awakening *(Randler & Schaal, 2010)* and on the other hand up to a timespan of 30 to 45 minutes after awakening *(Kudielka et al., 2006)*. These findings could be partly proved by the results of **Study 2**, with Morning types showing significant higher cortisol values directly after awakening. It is assumed that this stronger biological activation in the morning helps Morning types to start their day easier and gives them a biological advantage over Evening types *(Adan et al., 2012)*.
In summary, it must be stated that a validation of the MESSi by the physiological variables skin temperature and cortisol levels in the morning as well as CAR could not be sufficiently confirmed. However, it is assumed here that this is not due to the

psychometric properties of the MESSi, but to the characteristics of the sample. In both studies the variables age and sex were not considered. Although the cortisol levels in the morning provide relatively stable results and there is even less influence of age, there is a clear influence of gender *(Wüst et al., 2000, Pruessner et al., 1997)*. Above all, a gender-balanced sample could be advantageous with regard to body temperature, since it is known that the female menstrual cycle has an influence on it *(Kattapong et al., 1995; Shechter et al., 2011)*. In addition, including all chronotypes, also Neither types, could be advantageous because it could already be shown that Morning types have a higher overall temperature over the day than Evening types *(Kattapong et al., 1995)*. This was also confirmed by the results of **Study 2** of this dissertation. A chronotype and gender-balanced sample should therefore be considered for further research. With regard to the cortisol levels in the morning it is to be said in conclusion that the test persons only sampled saliva probes on two days in the survey week. Beyond that, these two days were not specified except that it should be one day during the week and one day at the weekend. It would be better to let the test persons collect saliva probes on all days of the week in the morning. Thus a weekly course can be carried out. Here definitely further investigations should take place, which bring the MESSi in connection with physiological parameters. A gender-balanced sample, in which women are checked for contraceptives or even a sample consisting only out of men, would be advantageous.

Last but not least, the validation of the MESSi was based on personality. Until the survey of **Study 1** and **2**, the MESSi was only associated with personality traits in the original study by Randler and colleagues (2016a). A Big Five measurement, the TIPT (Ten Item Personality Inventory, by Gosling, Rentfrow & Swann, 2003), was used for this purpose. It turned out that the MA component of the MESSi correlates positively with Agreeableness and Conscientiousness. One year later Díaz-Morales and Randler could show in a Spanish population that the MA component also correlated positively with Conscientiousness and the EV component negatively with it. The DI component had a negative correlation with Conscientiousness and Extraversion. The additional CSM sum-score also showed a strong positive correlation with Conscientiousness. The results of these two studies can be partially confirmed and supplemented by the findings represented in **Study 1** of the present dissertation. The

MA component correlated positively with Conscientiousness and Extraversion. EV correlated negatively with Conscientiousness as well as the DI component. In addition, DI showed a negative correlation with Extraversion and a positive correlation with Neuroticism. The validity of the MESSi is supported in this survey by the significant effect of chronotype on Conscientiousness and Extraversion. Morning types report higher Conscientiousness and Extraversion in comparison to Evening types. In the study by Díaz-Morales and Randler (2017) the validity of the MESSi is supported by the almost numerically identical correlation of MA (r=.32) and CSM sum-score (r=.33) with Conscientiousness. It is noticeable that depending on the characteristics of the sample (age, gender and ethnic origin) and the measurement used, there are different correlations with the different personality traits. However, one trait seems to be superior to the other and has a clear link between Morning-Eveningness and Conscientiousness. Morning types seem to be much more conscientious in comparison to Evening types *(Adan et al., 2012; Tsaousis, 2010)*. This expressive connection raises the question, where does it come from? Conscientiousness is regarded as one of the five so-called OCEAN dimensions (Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism) of the NEO Five Factor Inventory (NEO-FFI) of Costa and McCrea (1992). The dimension includes different dynamic (success and task orientation) and control (origination and respect of standards/procedures) elements *(Allik & Allik, 2002)*. It is defined as a personality trait with high levels of tidiness, sense of responsibility and discipline as well as prudence in behavior and thinking *(Wirtz, 2019[7])*. A conscientious person primarily follows the socially predetermined norms and rules, never acts thoughtlessly or even spontaneously, and always approaches his or her life and goals in an organized manner *(Roberts et al., 2009, Rahafar, 2018)*. In other words. „Conscientious individuals are clean and tidy, work hard, follow the rules of society and social decorum, think before acting, and are organized“ *(Jackson et al., 2010)*.

Morning types, on the other hand, have many characteristics that fit into the profile of a conscientious person *(Rahafar, 2018)*. They like to get up early and organize their daily routine as our society likes to see it *(Adan et al., 2012)*. Moring-oriented students, for example, act under time pressure considerate *(Vollmer, Pötsch & Randler, 2013)*, they do more physical activity and are more open to the positive characteristics of physical activity *(Schaal et al., 2010)*. Additionally, Morning-oriented adolescents are more likely to accept social values (like conservation and self-transcendence), while evening-oriented adolescents prefer more individual values (like openness to change and self-enhancement). Díaz-Morales (2007) stated in his work that Morning types have a realistic and thought-guided thinking style and seek for conservation. Further he postulates that the behavior of Morning types is “upstanding and self-controlled; they relate to authority in a respectful and cooperative manner and tend to behave in a formal and proper manner in social situations” *(Díaz-Morales, 2007; pp. 755)*. Morning types thus present a behavior that is considered desirable by our society and is associated with Conscientiousness. This and the fact that it is easier for Morning types to adapt their behavior to the social time schedules anyway because of their inner rhythm and that they interact with their environment in a more adapted way could be the reason that they are generally considered more conscientious and thus be more satisfied in life *(Randler, 2008e)*.

8.2 MESSi and adolescents

Another aim of this dissertation was to check whether the MESSi can be used in an adolescent sample. For this purpose, the original version by Randler and colleagues (2016a) was slightly changed in its wording to adapt the questions to the adolescent language use. **Study 3** was then carried out within three different surveys. The analysis for **Study 3** showed that the internal consistency of the MESSi was given with good to acceptable Cronbach’s alpha values (between 0.709 and 0.889) with MA showing the best values. This proves the high reliability of the MESSi also in the adolescent version. The results of the confirmatory factor analysis (CFA) indicate a good fit of the three factor structure of the MESSi similar to the adult version *(Randler et al., 2016a, Rahafar et al. 2017; Rodrigues et al. 2018)*. The convergent validity of the adolescent version of the MESSi was checked with the correlation analysis between the components of the MESSi and two commonly used chronotype questionnaires for adolescents: the Composite Scale of Morningness (CSM); adolescent version *(Smith et al. 1989; Randler, 2008f; 2009)* and the Children's ChronoType Questionnaire (CCTQ); adolescent version *(Werner et al. 2009)*. All three components of the MESSi (MA, EV and DI) showed significant correlations with the sum-scores of the CSM and CCTQ in the expected manner. While a high scoring on MA is always related to Morningness, a high scoring on EV is always related to Eveningness. At this point, reference should once again be made to the question initiated at the beginning by Díaz-Morales and colleagues if the two dimensions MA and EV can be considered separately. The question came up because in the study of Díaz-Morales et al. (2017) MA and EV showed similar strong correlations with the rMEQ sum-score. The results of **Study 3** clearly show that MA and EV have correlations with different strengths with the sum-scores of the other questionnaires. This confirms that the MESSi measures some similar constructs but within three clearly distinguishable dimensions.

On the basis of the results from **Study 3**, another assumption made at the beginning can also be confirmed. The results of **Study 2** indicated that Evening types have higher values in the DI component than Morning types. These results were not significant but the clearly presented tendency indicated that Evening types have a lower stability in their circadian preference compared to Morning types. Here in **Study 3**, the negative correlation of MA and DI on the one hand, and the positive correlation of EV and DI on the other hand, suggests that morning orientation is related to a higher stability of the respective circadian behavior during the day. Morning types are proven to find it easier to balance their inner rhythm with the social rhythms of our society, which is expressed in a more stable circadian preference over the day.

In addition to the analyses for **Study 3** presented so far, the MESSi has also been related to other variables that have been shown to be strongly influenced by circadian preference: habitual sleep/wake times during week and on the weekend (like it was already carried out with the MESSi in a student population in **Study 1**), daytime sleepiness and age.

Concerning the habitual sleep/wake times, it should be said that all of the rise and bed times on the weekend correlated in the expected direction with MA and EV. Morning-oriented adolescents got up and went to bed earlier than evening-oriented adolescents *(e.g. Giannotti et al. 2002; Russo et al. 2007)*. In the results of **Study 1**, this could be observed both during the week and at the weekend but in a university student population. In **Study 3**, this finding could not be observed during week, as the adolescents are probably too strongly tied to the given school times. However, the EV component of the MESSi showed a positive correlation with the bed times during week. Evening-oriented adolescents tend to go to bed later during week than morning-oriented adolescents. It could already be shown in adult populations that due to the later bed times, evening orientation is associated with less arousal *(Bailey & Heitkemper, 1991)* and greater sleepiness in the morning *(Taillard et al., 1999; Taillard et al., 2004)*. This circumstance also seems to manifest itself in the population of **Study 3**, since the sum-score of the PDSS correlated positively with EV and negative with MA. Evening-oriented adolescents experienced a greater daytime sleepiness than morning-oriented adolescents. Interestingly, the connection between Eveningness and Stability is also evident here. The DI component correlated negatively with the sum-score of the PDSS and thus indicates that a higher fluctuation in circadian preference is associated with a stronger daytime sleepiness, like it is also evident in evening-oriented adolescents. Regarding the age of the adolescents from **Study 3**, it can be noted that with increasing age, the evening orientation increases and vice versa the morning orientation decreases. This is expressed by the positive correlation of EV and the negative correlation of MA with age. This fact has already been confirmed in many studies with large sample sizes and various measurements for circadian typology *(e.g. Randler, Faßl & Kalb, 2017; Roenneberg et al., 2004)*.

The MESSi therefore joins the range of these measurements as a reliable and valid measurement of circadian typology and amplitude. The results of **Study 1** and **2**, as well as of **Study 3** demonstrate that the MESSi is comparable to existing scales and does justice to the multi-dimensional view of Morningness-Eveningness with the advantage of three distinguishable dimensions (Morningness, Eveningness and Stability). With the balanced scoring (from 1-5) and the same number of items per dimension, the MESSi still has a short processing time. It can therefore be regarded as an economic paper-pencil questionnaire that could easily be converted into a computer-based test. The MESSi does not ask for specific times of day and therefore makes adaptations in other languages particularly easy *(e.g. Tomažič & Randler, 2018; Díaz-Morales & Randler, 2017; Demirhan et al., 2019)*. With its updated language it can also be used in an adolescent sample without any problems. However, it is precisely at this point that the question arises as to what age in an adolescent sample the MESSi can be used without assistance. It would be possible that questions concerning mood and energetic arousal are not understood by younger students. Here it would be important to validate the MESSi in different age groups in order to check its age range in applicability. Especially on the basis of the results of this dissertation it becomes apparent that it was irrevocable to see Morningness-Eveningness as a multi-dimensional construct and to introduce a further dimension (Stability). However, the interactions of this dimension with other variables have not yet been sufficiently explored. From a chronobiological point of view, this dimension is not yet fully developed and will need further revision at a later stage.

8.3 Circadian preference and stability in school

By **Study 1-3** the preparatory work was done to be able to use a reliable measurement of circadian preference in school context finally in **Study 4**. The impact of Morningness-Eveningness on school-relevant achievement should be investigated under consideration of other intervincing variables such as motivational aspects in learning and the emotional state.

To test further convergent validity of the MESSi also in this adolescent population, correlations between its components and the CSM sum-score were done. The components of the MESSi correlated as expected: a high morning orientation in the MESSi was associated with a high CSM sum-score, which means a classification into Morning type. For evening orientation there were similar results: high scores in EV were associated with a low sum-core of the CSM, which indicated a classification into Evening type. The findings from **Study 3** can thus be proved also in this population. The DI component of the MESSi showed a negative correlation with the CSM sum-score, indicating that morning oriented adolescents in **Study 4** had a higher stability in circadian preference. This result thus confirms the findings from **Study 2** and **3**. Finally, it can be said that the convergent validity of the MESSi with the CSM can also be confirmed in this sample and that the MESSi is comparable to this scale. The initial assumption that morning orientation is associated with a more stable circadian preference can be finally manifested by the results of **Study 4**.

Concerning the habitual sleep/wake times of the adolescents in this sample an influence of Morningness-Eveningness can be observed only on a few days: evening orientation was associated with later bed times from Monday to Thursday and on Sunday. Later rise times were set in relation with Eveningness only on Tuesday. Only on the weekend clear differences between the different chronotypes (Morning, Evening and Neither types; classified by the CSM) could be seen. Evening types tend to rise up approximately two hours later on Saturday and Neither types as well as Evening types tend to go almost an hour later to bed on Sunday. Chronotype differences in habitual sleep/wake times are nothing new and already well researched. Especially later rise and bed times on weekends in Evening types to compensate the sleep deficit accumulated during the week ,are well documented *(e.g. Taillard et al., 1999; Horne & Östberg, 1976)*. In contrast to **Study 4**, the results of **Study 1** showed a clear effect of chronotype on all rise and bed times both during the week and at the weekend. However, **Study 1** was carried out in a population of university students and not as in **Study 4** in an adolescent sample who still go to school. Schoolchildren are very strongly bound to the school's given times and are therefore forced to adapt their inner sleep/wake rhythm. This could be one possible explanation for the irregular findings on the habitual sleep/wake times in **Study 4**. This explanation is supported by the findings from **Study 3**, which was also carried out in an adolescent sample. Here it was shown that the components of the MESSi correlate with the habitual bed and rise times only at the weekend. Morning-oriented adolescents got up and went to bed earlier than evening-oriented adolescents. EV showed also a positive correlation with bed times during week, indicating later bed times in evening-oriented adolescents similar to the findings of **Study 4**. It seems, therefore, that despite given school start times evening-oriented adolescents tend to go to bed during the week later than morning-oriented adolescents. The evening orientation therefore appears to manifest itself in adolescents especially in bed times.

Looking at the results of **Study 4** on temperature analysis, it can be noticed that the results are almost the same as in **Study 2**. Neither the components of the MESSi (MA, EV and DI) nor the CSM sum-score showed significant correlations with the skin temperature parameters (acrophase, nadir and amplitude). However, significant differences between the chronotypes were found (in **Study 2** classified by the rMEQ and in **Study 4** classified by the CSM): Morning types demonstrated a higher overall skin temperature than Evening or Neither types. Morning types also showed a more regular course in their skin temperature, represented in a better fit of their actual skin temperature values to the approximating 24 h cosine curve. These findings would appear to be reflected both in a sample of adolescents and in a sample of university students. What is really interesting from **Study 4** is the finding that adolescents had a higher overall skin temperature at the weekend than during the week. As already mentioned in the discussion on the results of **Study 4**, skin temperature differences among adolescents have so far only been researched to a limited extent. Sarabia et al. (2008) could already show in a university student population that there are a lot of masking factors for the skin temperature, like shifted sleep timing, later food intakes and naps. These factors can increase the skin temperature. Referring now to the adolescents and their sleep deficit accumulated during week, which is to be compensated at the weekend by shifted sleep timing, a significant interference in the biology of the adolescents may become apparent. Their inner, biological rhythm is suppressed during the week and they have to adapt it to predetermined time schedules and social influences (such as leisure activities only in the afternoon/evening). This is no longer the case on weekends or holidays. The increased overall skin temperature at the weekend among adolescents could be another indication that their circadian rhythm is struggling with the adaptation requirements. Sarabia et al. (2008) have already done very good preparatory work for this. It would now be very important to also include these masking factors in an adolescent population, taking into account their circadian preference.

In **Study 4** of the present dissertation, school-relevant achievement was measured with the Frankfurt Attention Inventory (second edition), short FAIR-2. Three attention and concentration based values (speed, accuracy and performance) could be calculated and give information of the adolescents achievement. These three values were then set in relation to different variables such as Morningness-Eveningness, time of day and positive/negative Affect.

The components of the MESSi showed no significant correlations with one of the three attention and concentration values. Only the CSM sum-score showed a positive correlation with two of them (speed and performance value) and only at the first test point (first to second lesson in class). This indicates that morning-oriented adolescents showed higher speed and performance in editing the FAIR-2 in this timespan. This partly confirms the previous literature that Morningness is associated with better performance *(e.g. Preckel et al., 2013, Preckel, et al., 2019; Díaz-Morales & Escribano, 2013; Randler & Frech, 2009)*. However, no synchronicity effect could be confirmed here that morning-oriented adolescents perform better in the morning and evening-oriented adolescents perform better in the afternoon. In fact, no influence of circadian typology on the attention- and concentration-based values was found at all in this study. As already stated in Randler, Bechtold and Vogel (2016), it is conceivable that the sample size was too small to obtain significant results in such a field study. In addition, it would also be possible that the FAIR-2 is not specific enough to differentiate school achievement between chronotypes. The FAIR-2 was chosen to obtain a general picture of the attention and concentration of adolescents, which are core prerequisites for cognitive performance *(Schweizer, 2005)*. Until now the FAIR-2 has not been used in any known study to investigate chronotype differences in adolescent's school achievement. Perhaps a more subject-oriented investigation would be necessary for further research to see clear chronotype differences. However, the gender difference would also have to be taken into account here, which clearly indicates that girls perform better in school than boys *(e.g. Steinmayr & Spinath, 2008)*.

Looking at all adolescents from **Study 4** together without chronotype differentiation, the following picture emerges: the test point has a significant influence on the attention and concentration performance. All three performance values showed significant higher scores at test point two compared to test point one. All adolescents performed best at the second test point. This shows that the attention and concentration of the adolescent's increases over the day, similar to the example of positive Affect *(e.g. Watson et al., 1988; Porto et al., 2006; Randler & Weber, 2015)*. Accordingly, adolescents would be more receptive to teaching later in the day and could perform better cognitively. Previous literature is confirmed as saying that later school start times could improve student's achievement and health *(e.g. Wahistrom, 2002; Carrell et al., 2011; Boergers, Gabel & Owens, 2014)*.

If we stick to the circumstance mentioned shortly before that positive affect increases over the day, this could not be replicated in the results of **Study 4**. No significant difference could be discovered between test point one and two with respect to the positive Affect. The negative Affect did not show any significant difference and seemed instead to be stable over the day, as already shown in other studies *(e.g. Watson et al., 1988; Randler & Weber, 2015)*. The reason why there is no increase in positive Affect could be that the adolescents in this sample generally have an absolute higher positive Affect than the negative Affect, regardless of the test point. This might be an indication of a generally good attitude towards school and learning of the adolescents in this sample. More interesting is the negative correlation of the negative Affect with the attention and concentration values both at test point one (speed and performance value) and test point two (speed, accuracy and performance value). This effect therefore seems to be stable over the day and indicates that adolescents with a lower negative affect reached higher scores in the representative attention and concentration scale. It is already known that emotions and feelings are related to educational outcome *(e.g. Gläser-Zikuda et al., 2005)*. Above all, the lack of negative emotions can lead to better academic achievement for example less test anxiety leads to better gradings. It is also known that especially girls are more susceptible to test anxiety than boys. That is why test anxiety also functions more as a mediator for academic achievement in girls *(e.g. Hembree, 1988; Rahafar et al., 2016)*. This circumstance could have played a decisive role in **Study 4** of the present dissertation. **Study 4** included a total of 30 adolescents, 23 of whom were girls. It would therefore be possible for gender to occur as an intervening factor or mediator for school-relevant achievement via negative Affect.

If the influence of Morningness-Eveningness on positive/negative Affect (PA/NA) is considered here, the following becomes apparent: the Morningness component of the MESSi (MA) and the CSM sum-score correlated positively with PA regardless of the test point. This indicates that morning-oriented adolescents had higher values in the PA compared to the NA. This of course confirms the validity of the MESSi as well as the previous findings. Randler and his colleagues (2016a) could already determine in the original study of the MESSi that the MA component correlates positively with PA. In contrast to the study by Randler et al. (2016a), no significant correlation between EV and PA could be discovered in **Study 4** at all. However, there is an interesting addition concerning the stability of circadian preference and PA. The DI component of the MESSi showed a negative correlation with PA independent of the test point, suggesting a stable correlation over the day. This relation indicates that higher fluctuation of circadian preference lead to lower values in positive Affect. Since we already know from **Study 2** and **3** that EV is associated with higher fluctuation in circadian preference, the lower PA by higher fluctuation could indicate indirectly to an evening preference.

Higher fluctuation in circadian preference over the day could indicate a worse adaptation of the inner circadian rhythm to the requirements of given school times. This, in turn, would mean more effort for the organism of the adolescent and could be reflected in a lower PA over the day. Based on the varainzanalytic results from **Study 4**, it can be seen that Moring types tend to have a higher positive affect than Evening and Neither types. This confirms previous done research *(e.g. Randler & Weber, 2015; Randler, Bechthold & Vogel, 2016)*. Finally, it should be mentioned that NA has no correlations, neither with the components of the MESSi nor with the CSM sum-score. The variance analysis also showed no influence of Morningness-Eveningness on NA. Circadian influences, such as Morningness-Eveningness or time of day, therefore seem to manifest themselves only in PA.

If motivational aspects, the last variable, are brought into play, the following is shown. Motivational regulation styles, which are perceived as self-determined (in this case identified and intrinsic motivation in learning), were linked to higher affective well-being. This was expressed in the positive correlation of PA with those motivational regulation styles. In contrast, motivational regulation styles, which are perceived as externally determined (in this case introjected and external motivation in learning), are associated with negative Affect. In detail, the introjected motivation scale demonstrated a positive correlation with the NA scale and the external motivation scale showed a negative correlation with the PA. The results from **Study 4** thus confirm previous findings *(e.g. Gillet et al., 2013; Thomas & Müller, 2015; Thomas, Müller & Bieg, 2018)* and again suggest that emotion and motivation are linked in human behavioral system *(e.g. Izrad, 2013)*. Furthermore, the results from **Study 4** show that there is a clear connection between Morningness-Eveningness and motivational aspects. The sum-score of the CSM as well as the MA component of the MESSi correlated positively with intrinsic and identified motivation. This indicates that morning-oriented adolescents have more self-determined regulation styles in learning compared to evening-oriented adolescents. The varainzanalytic analysis proved that findings and showed that Morning types reported mostly intrinsic and identified motivation compared to Evening and Neither types. In contrast, the sum-score of the CSM also showed a negative correlation with the external motivation indicating that evening-oriented adolescents reported higher external motivation in learning. Also in terms of motivation, a significant impact of the stability of the circadian preference can be observed. DI correlated negatively with intrinsic and identified motivational regulation and positively with the external motivation. Higher fluctuations in circadian preference are therefore associated with lower self-determined and higher externally determined regulation in learning. Since Morningness is associated with higher self-determined motivational regulations styles and Eveningness with higher external-determined motivational regulations styles, the question arises whether stability of circadian preference could be seen as a kind of mediator between Morningness-Eveningness and motivational regulations styles in learning? It is clear of the results of **Study 4** that the stability of circadian preference seems to play a decisive role in the emotional and motivational experience and behavior in the school context of adolescents. This should not be ignored and investigated in further studies. It also seems that positive affect and self-determined motivational regulation styles in learning in the long term give the morning-oriented adolescents an advantage over the evening-oriented adolescents.

The results of the present dissertation confirm that the Morningness-Eveningness-Stability Scale improved (MESSi) by Randler et al. (2016a) is a reliable and valid instrument to measure circadian preference and amplitude, even in adolescents. The circadian preference, given in the MESSi is congruent to intervincing variables, like sleep/wake timing, activity and personality. The validation of the MESSi with the help of physiological markers, like body temperature and cortisol levels, unfortunately did not provide fully satisfactory results and should therefore not be considered as closed. With regard to the stability of the circadian preference, very interesting results have been obtained which could be of particular importance in everyday school life. Especially with regard to sleep/wake timing, positive Affect and motivational regulation styles, a higher stability in circadian preference seems to give morning-oriented students an advantage over evening-oriented students. Further it could be seen again that later school times could help to improve the student’s school-relevant achievement in terms of attention and concentration.

Of course, there are some notable limitations in the present dissertation. First of all, the influence of sex on Morningness-Eveningness and some other variables considered in the studies of the dissertation (e.g. body temperature, cortisol, personality) is well-documented. A gender-balanced sample would be helpful for further research. Second, the skin temperature was assessed to set it in relation to Morningness-Eveningness. However, since skin temperature has proven to be sensitive to environmental influences and a positive validation of the MESSi with it was not satisfactory, the core body temperature could be considered for further investigations. Thirdly, in **Study 4**, the data were only collected in one class level and thus only in a small age range. Several class levels and also different school systems should be considered for further investigations, especially with regard to the increasing evening orientation with increasing age of the adolescents. Finally, it should be mentioned that for the determination of the school-relevant achievement a general attention and concentration test (FAIR-2) was used. However, this did not reflect any subject-specific differences. It would therefore be conceivable to use the MESSi in combination with the SMR-L subject-specific, in order to get a better overview of the students' school situation. This could also be done over a longer period of time with a longitudinal study with regular test intervals.

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Appendix

The appendix includes all scales and questionnaires that are not standardized and/or publicly available and/or in which changes have been made to the used research design.

Appendix 1: Morningness-Eveningness-Stability Scale; improved (MESSI) by Randler et al. (2016a)

(Incl. habitual bed and rise times)

Bitte beantworten Sie alle Fragen. Bitte kreuzen Sie jeweils nur eine Antwort an.
Bitte überlegen Sie nur kurz und antworten Sie spontan.

[CSM 3] Wie leicht fällt es Ihnen normalerweise morgens aufzustehen?
1 [ ] überhaupt nicht leicht
2 [ ] nicht so leicht
3 [ ] teils/teils
4 [ ] ziemlich leicht
5 [ ] sehr leicht

[CSM 4] Wie wach fühlen Sie sich morgens in der ersten halben Stunde nach dem Aufwachen?
1 [ ] überhaupt nicht wach
2 [ ] etwas wach
3 [ ] mittel
4 [ ] ziemlich wach
5 [ ] sehr wach

[CSM 12] Wie lange dauert es bei Ihnen morgens nach dem Aufstehen, bis Sie einen klaren Kopf haben und klar denken können?
5 [ ] 0 bis 10 Minuten
4 [ ] 11 bis 20 Minuten
3 [ ] 21 bis 40 Minuten
2 [ ] 41 bis 60 Minuten
1 [ ] mehr als 60 Minuten

Im Allgemeinen, wie hoch ist Ihre Energie
1) ***morgens***: 1 [ ] sehr niedrig 2 [ ] niedrig 3 [ ] mittel 4 [ ] hoch 5 [ ] sehr hoch
2) ***abends:*** 1 [ ] sehr niedrig 2 [ ] niedrig 3 [ ] mittel 4 [ ] hoch 5 [ ] sehr hoch

Bitte geben Sie an, inwieweit die folgenden Aussagen auf Sie zutreffen. *Bitte machen Sie in jeder Zeile ein Kreuz.*	**Trifft völlig zu**		**Teils/ teils**		**Trifft überhaupt nicht zu**
	5	4	3	2	1
Nach dem Aufwachen fühle ich mich noch längere Zeit schläfrig. CAEN4	[ ]	[ ]	[ ]	[ ]	[ ]
Mein bevorzugter Zeitpunkt zum Lernen ist abends. CAEN5	[ ]	[ ]	[ ]	[ ]	[ ]
Meine Stimmung ist den ganzen Tag über gleich. CAEN6	[ ]	[ ]	[ ]	[ ]	[ ]
Ich kann mich zu jeder Tageszeit konzentrieren. CAEN8	[ ]	[ ]	[ ]	[ ]	[ ]
Meine Motivation ist zu jeder Tageszeit gleich. CAEN10	[ ]	[ ]	[ ]	[ ]	[ ]

Es gibt Zeiten am Tag, an denen ich mich zu nichts in der Lage fühle. CAEN14	[ ]	[ ]	[ ]	[ ]	[ ]
Es gibt Tageszeiten, an denen es mir schwer fällt zu denken. CAEN15	[ ]	[ ]	[ ]	[ ]	[ ]
Ich bin eher abends als morgens aktiv. CSM 13	[ ]	[ ]	[ ]	[ ]	[ ]
Abends bin ich am leistungsfähigsten. CAEN 2	[ ]	[ ]	[ ]	[ ]	[ ]
Meistens bin ich abends bester Laune. CAEN 11	[ ]	[ ]	[ ]	[ ]	[ ]

Zu welcher Uhrzeit stehen Sie an Wochentagen auf?
[ ]:[ ] Uhr

Zu welcher Uhrzeit stehen Sie am Wochenende auf?
[ ]:[ ] Uhr

Wann gehen Sie vor Wochentagen ins Bett?
[ ]:[ ] Uhr

Wann gehen Sie am Wochenende ins Bett?
[ ]:[ ] Uhr

Appendix 2: MESSi (adolescent version)

Bitte beantworte alle Fragen. Bitte kreuze jeweils nur eine Antwort an.
Bitte überlege nur kurz und antworte spontan.

Wie leicht fällt es dir normalerweise morgens aufzustehen?
1 [ ] überhaupt nicht leicht
2 [ ] nicht so leicht
3 [ ] teils/teils
4 [ ] ziemlich leicht
5 [ ] sehr leicht

Wie wach fühlst du dich morgens in der ersten halben Stunde nach dem Aufwachen?
1 [ ] überhaupt nicht wach
2 [ ] etwas wach
3 [ ] mittel
4 [ ] ziemlich wach
5 [ ] sehr wach

Wie lange dauert es bei dir morgens nach dem Aufstehen, bis du einen klaren Kopf hast und klar denken kannst?
5 [ ] 0 bis 10 Minuten
4 [ ] 11 bis 20 Minuten
3 [ ] 21 bis 40 Minuten
2 [ ] 41 bis 60 Minuten
1 [ ] mehr als 60 Minuten

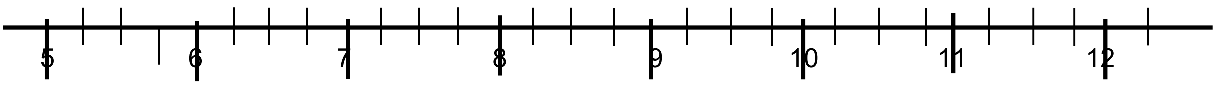
Im Allgemeinen, wie hoch ist deine Energie
1) ***morgens***: 1 [ ] sehr niedrig 2 [ ] niedrig 3 [ ] mittel 4 [ ] hoch 5 [ ] sehr hoch
2) ***abends:*** 1 [ ] sehr niedrig 2 [ ] niedrig 3 [ ] mittel 4 [ ] hoch 5 [ ] sehr hoch

Bitte gib an, inwieweit die folgenden Aussagen auf dich zutreffen. *Bitte mache in jeder Zeile ein Kreuz.*	**Trifft völlig zu**		**Teils/ teils**		**Trifft überhaupt nicht zu**
	5	4	3	2	1
Nach dem Aufwachen fühle ich mich noch längere Zeit schläfrig.	[ ]	[ ]	[ ]	[ ]	[ ]
Mein bevorzugter Zeitpunkt zum Lernen ist abends.	[ ]	[ ]	[ ]	[ ]	[ ]
Meine Stimmung ist den ganzen Tag über gleich.	[ ]	[ ]	[ ]	[ ]	[ ]
Ich kann mich zu jeder Tageszeit konzentrieren.	[ ]	[ ]	[ ]	[ ]	[ ]
Meine Motivation ist zu jeder Tageszeit gleich.	[ ]	[ ]	[ ]	[ ]	[ ]
Es gibt Zeiten am Tag, an denen ich mich zu nichts in der Lage fühle.	[ ]	[ ]	[ ]	[ ]	[ ]
Es gibt Tageszeiten, an denen es mir schwer fällt zu denken.	[ ]	[ ]	[ ]	[ ]	[ ]
Ich bin eher abends als morgens aktiv.	[ ]	[ ]	[ ]	[ ]	[ ]
Abends bin ich am leistungsfähigsten.	[ ]	[ ]	[ ]	[ ]	[ ]
Meistens bin ich abends bester Laune.	[ ]	[ ]	[ ]	[ ]	[ ]

Appendix 3: reduced Morningness-Eveningness Questionnaire (rMEQ) by Randler (2013)

Bitte beantworten Sie alle Fragen und kreuzen Sie bitte jeweils nur eine Antwort an.
Überlegen Sie nur kurz und antworten spontan.

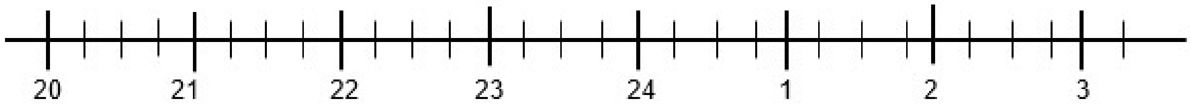
Wenn es nur nach Ihrem eigenen Wohlbefinden ginge und Sie Ihren Tag völlig frei einteilen könnten, wann würden Sie dann aufstehen? Bitte markieren Sie die Uhrzeit auf der Zeitleiste.



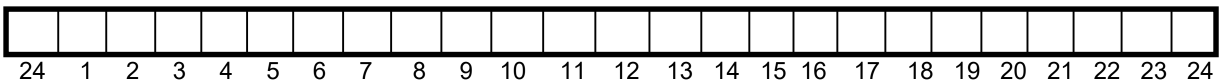
Wie müde fühlen Sie sich morgens in der ersten halben Stunde nach dem Aufwachen?

O sehr müde
O ziemlich müde
O ziemlich frisch
O sehr frisch

Um wieviel Uhr werden Sie abends müde und haben das Bedürfnis schlafen zu gehen? Bitte markieren Sie die Uhrzeit auf der Zeitleiste.



Zu welcher Tageszeit fühlen Sie sich Ihrer Meinung nach am besten?



Man spricht bei Menschen von „Morgen- und Abendtypen“. Zu welchem der folgenden Typen zählen Sie sich?

O eindeutiger „Morgentyp“
O eher „Morgen- als Abendtyp“
O eher „Abend- als Morgentyp“
O eindeutiger „Abendtyp“

Appendix 4: Children's ChronoType Questionnaire (CCTQ) by Werner et al. (2009)
(German and adolescent version)

An geregelten Tagen (Schultagen)…

1. …wachst Du normalerweise um ____ : ____ Uhr auf.
2. …wachst Du meistens
   - O selber
   - O durch ein Familienmitglied (Mutter/Vater)
   - O mittels Wecker auf.
3. …stehst Du normalerweise um ____ : ____ Uhr auf.
4. …bist Du normalerweise hell wach um ____ : ____ Uhr.
5. …machst Du normalerweise einen Mittagsschlaf:
   O Ja O Nein
   wenn ja, an wie vielen geregelten Tagen in der Woche? _____
6. Zu welcher Zeit machst Du normalerweise einen Mittagsschlaf? Wann stehst Du wieder auf?
   von ____ : ____ Uhr bis ____ : ____ Uhr.

An Abenden vor geregelten Tagen…

1. … gehst Du normalerweise um ____ : ____ Uhr ins Bett.
2. … bist Du normalerweise um ____ : ____ Uhr bereit einzuschlafen.
3. …brauchst Du normalerweise circa ____ Minuten, um einzuschlafen.

Wie ergeht es Dir an Tagen, an denen dein Schlaf-Wach-Rhythmus nicht durch die Schule oder familiäre Aktivitäten bestimmt wird?

An freien Tagen…

1. …wachst Du normalerweise um ____ : ____ Uhr auf.
2. …wachst Du meistens
   - O selber
   - O durch ein Familienmitglied (Mutter/Vater)
   - O mittels Wecker auf.

…wachst Du normalerweise zur selben Zeit wie an geregelten Tagen auf und schläfst dann nochmals ein?
O Ja O Nein
Wenn ja, für wie lange schläfst Du meistens nochmal ein? ____ Minuten

3. … stehst Du normalerweise um ____ : ____ Uhr auf.
4. …fühlst Du dich normalerweise hell wach um ____ : ____ Uhr.
5. …machst Du normalerweise einen Mittagsschlaf ?
   O Ja O Nein

zu welcher Zeit machst Du normalerweise einen Mittagsschlaf? Wann stehst Du wieder auf?
von ____ : ____ Uhr bis ____ : ____ Uhr

An Abenden vor freien Tagen…

1. … gehst Du normalerweise um ____ : ____ Uhr ins Bett.
2. … bist Du normalerweise um ____ : ____ Uhr bereit einzuschlafen.

3. …brauchst Du normalerweise ____ Minuten, um einzuschlafen.
Bitte versuche Dich in den nächsten Fragen spontan einzuschätzen. Überlege nicht zu lange, es gibt kein „richtig“ oder „falsch“.
1. Wenn Du am Morgen geweckt wirst: Wie leicht bzw. schwer fällt es Dir aufzustehen?

- O sehr schwer
- O eher schwer
- O mittelmäßig schwer
- O wenig schwer
- O nicht schwer/ich muss nie geweckt werden.

2. Wie wach fühlst Du dich während der ersten halben Stunde nach dem Aufwachen am Morgen?

- O überhaupt nicht wach
- O wenig wach
- O mittelmäßig wach
- O eher wach
- O sehr wach

3. Wann würdest du aufstehen, wenn Du dich frei entscheiden dürftest (z.B. in den Ferien)?

- O vor 6:30
- O 06:30 - 7:14
- O 7:15 - 9:29
- O 9:30 - 10:14
- O nach 10:15

4. Wann würdest Du ins Bett gehen, wenn Du selbst entscheiden könntest und am nächsten Tag frei hast?

- O vor 18:59
- O 19:00 - 19:59
- O 20:00 - 21:59
- O 22:00 - 22:59
- O nach 23:00

5. In welchem Zeitraum des Tages fühlst Du dich am aktivsten?

- O 07:00 – 11:00 Uhr
- O 11:00 – 15:00 Uhr
- O 15:00 – 20:00 Uhr

6. Nimm an, Du würdest zweimal in der Woche eine sportliche Aktivität machen, die aus Zeitgründen von 7 bis 8 Uhr morgens ist. In welcher Verfassung wärst Du?

- O wäre in sehr guter Verfassung
- O wäre in guter Verfassung
- O wäre in mittelmäßiger Verfassung
- O wäre in wenig guter Verfassung
- O wäre in nicht guter Verfassung

7. Zu welcher Zeit am Abend beginnt Deine Müdigkeit und Dein Bedürfnis nach Schlaf?

- O vor 18:30
- O 18:30 - 19:14
- O 19:15 - 21:29
- O 21:30 - 22:14
- O nach 22:15

8. Wenn Du täglich um 6:00 Uhr aufstehen müsste, wie wäre das für Dich?

- O sehr schwierig
- O eher schwierig
- O mittelmäßig schwierig
- O wenig schwierig
- O nicht schwierig

9. Wenn Du am Morgen aufwachst, wie lange brauchst Du um hell wach zu werden?

- O 0 Minuten, Sofort
- O 1 bis 4 Minuten
- O 5 bis 10 Minuten
- O 11 bis 20 Minuten
- O ≥ 21 Minuten

Nachdem Du diese Fragen jetzt alle beantwortet hast, hast Du bestimmt ein Gefühl dafür bekommen, wie Du deinen eigenen „Chronotyp“ einschätzen würdest:

- O definitiv ein Morgentyp
- O eher ein Morgentyp als ein Abendtyp
- O weder ein Morgentyp noch ein Abendtyp
- O eher ein Abendtyp als ein Morgentyp
- O definitiv ein Abendtyp
- O Ich weiß es nicht

Appendix 5: Composite Scale of Morningness (CSM), by Randler (2008f, 2009) (Adolescent version)

Bitte beantworte die Fragen zum Thema „Schlaf" ohne lange nachzudenken.
Bitte kreuze jeweils nur eine Antwort an.

Stell dir vor, die Schule fällt aus. Du darfst aufstehen, wann du möchtest. Wann stehst du morgens auf?
5[ ] vor 6:30 Uhr
4[ ] zwischen 6:30 Uhr und 7:45 Uhr
3[ ] zwischen 7:45 Uhr und 9:45 Uhr
2[ ] zwischen 9:45 Uhr und 11 Uhr
1[ ] nach11Uhr

Du hast morgen keine Schule und du darfst ins Bett gehen wann du möchtest. Wann gehst du abends ins Bett?
5[ ] vor21Uhr
4[ ] zwischen 21 Uhr und 22:15 Uhr
3[ ] zwischen 22:15 Uhr und 0:30 Uhr
2[ ] zwischen 0:30 Uhr und 1:45 Uhr
1[ ] nach 1:45 Uhr

Wie leicht fällt es dir morgens aufzustehen?
1[ ] überhaupt nicht leicht
2[ ] nicht so leicht
3[ ] ziemlich leicht
4[ ] sehr leicht

Wie wach fühlst du dich morgens in der ersten halben Stunde nach dem Aufwachen?
1[ ] überhaupt nicht wach
2[ ] etwas wach
3[ ] ziemlich wach
4[ ] sehr wach

Wie müde fühlst du dich morgens in der ersten halben Stunde nach dem Aufwachen?
1[ ] sehr müde
2[ ] ziemlich müde
3[ ] ziemlich fit
4[ ] sehr fit

Der Sportunterricht beginnt um 7 Uhr. Wie wäre das für dich?
4[ ] Ich wäre gut in Form.
3[ ] Ich wäre ziemlich in Form.
2[ ] Es wäre ziemlich schwierig für mich.
1[ ] Es wäre sehr schwierig für mich.

Für eine Klassenarbeit, die sehr anstrengend ist, möchtest du in Bestform sein. Du kannst dir deinen Tag völlig frei einteilen. Wann würdest du diese schreiben?
4[ ]von 8 bis 10 Uhr
3[ ]von 11 bis 13 Uhr
2[ ]von 15 bis 17 Uhr
1[ ]von 19 bis 21 Uhr

Manche Menschen sind Morgentypen, andere dagegen Abendtypen. Zu welchem Typ würdest du dich zählen?
4[ ] eindeutig „Morgentyp"
3[ ] eher „Morgentyp" als „Abendtyp"
2[ ] eher „Abendtyp" als „Morgentyp"
1[ ] eindeutig „Abendtyp"

Wann würdest du am liebsten morgens aufstehen, um zur Schule zu gehen?
4[ ] vor 6:30 Uhr
3[ ] zwischen 6:30 Uhr und 7:30 Uhr
2[ ] zwischen 7:30 Uhr und 8:30 Uhr
1[ ] nach 8:30 Uhr

Stell dir vor, du müsstest jeden Morgen um 6:00 Uhr aufstehen. Wie wäre das für dich?
1[ ] sehr schwierig und unangenehm
2[ ] ziemlich schwierig und unangenehm
3[ ] etwas unangenehm, aber kein größeres Problem
4[ ] einfach und nicht unangenehm

Wie lange dauert es bei dir morgens nach dem Aufstehen, bis du richtig wach bist und klar denken kannst?
4[ ] 0 bis 10Minuten
3[ ] 11 bis 20 Minuten
2[ ] 21 bis 40 Minuten
1[ ] mehr als 40 Minuten

Bist du eher morgens oder abends aktiv?
4[ ] ausgesprochen morgens aktiv (morgens wach, abends müde)
3[ ] eher morgens aktiv
2[ ] eher abends aktiv

Wann wirst du abends müde und möchtest deshalb schlafen gehen?

5[] vor 21 Uhr
4[ ] zwischen 21 Uhr und 22:15 Uhr
3[ ] zwischen 22:15 Uhr und 0:30 Uhr
2[ ] zwischen 0:30 Uhr und 1:45 Uhr
1[ ] nach 1:45 Uhr

1[ ] ausgesprochen abends aktiv (morgens müde, abends wach)

Appendix 6: Scales for the Measurement of Motivational Regulation for Learning (SMR-L), by Thomas & Müller (2015)

Liebe Schülerin! Lieber Schüler!

Bitte fülle den Fragebogen so ehrlich wie möglich aus. Alle Angaben werden streng vertraulich behandelt.

Meistens arbeite und lerne ich in der Schule…	stimmt völlig	stimmt eher	stimmt eher nicht	
… weil es mir Spaß macht.				
… weil ich die Sachen, die ich hier lerne, später gut gebrauchen kann.				
… weil ich besser als meine Mitschüler sein möchte.				
… weil ich sonst Ärger mit meiner Lehrerin bekomme.				
… weil ich es mag, Aufgaben aus diesem Fach zu lösen.				
… weil ich etwas dazulernen möchte.				
… weil ich mich sonst schämen würde.				
… damit die anderen Schüler denken, dass ich gut bin.				
… weil ich sonst zu Hause Ärger bekomme.				
… weil ich gerne über dieses Fach nachdenke.				
… weil ich den Stoff verstehen möchte.				
… weil es peinlich ist, nichts zu wissen.				
… weil meine Eltern es von mir verlangen.				
