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Conceptualizing and measuring psychological resilience: What can we learn from physics?

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ABSTRACT

The number of resilience conceptualizations in psychology has rapidly grown, which confuses what resilience actually means. This is problematic, because the conceptualization typically guides the measurements, analyses, and practical interventions employed. The most popular conceptualizations of psychological resilience equate it with the ability to (1) resist negative effects of stressors, (2) "bounce back" from stressors, and/or (3) grow from stressors. In this paper, we review these three conceptualizations and argue that they reflect different concepts. This is supported by important lessons from engineering physics, where such concepts are clearly differentiated with precise mathematical underpinnings. Against this background, we outline why psychological resilience should be conceptualized and measured in terms of the process of returning to the previous state following a stressor (i.e., bouncing back). By establishing a clearer language of resilience and related processes, measurements and interventions in psychological research and practice can be targeted more precisely.

1. Introduction

The term resilience derives from Latin ("re" – back, "salire" – to leap/jump), and literally means to "bounce back". The topic is of interest across a variety of scientific domains, but has mostly been studied in the field of psychology (Hosseini et al., 2016). Resilience is a major theme in different disciplines, such as clinical-, developmental-, sport-, social and organizational psychology. Perhaps because of its popularity, different conceptualizations of resilience have been proposed in the last decades (e.g., Bryan, et al., 2019; Fletcher & Sarkar, 2013; Smith et al., 2008; Southwick et al., 2014). In this paper, we point out that the variety of definitions has become confusing, which is problematic because the conceptualization also guides the way we measure and analyze resilience, and influences interventions in practice. Other scientific fields do not suffer from this confusion and have clear, well-accepted definitions of resilience and related concepts. For instance, the modern conceptualization of resilience in physics-engineering dates back to the 19th century and describes the capacity of materials to return to their previous form or shape after being perturbed (Gere & Goodman, 2009; Hassler & Kohler, 2014; Kakani & Kakani, 2004). Accordingly, the measurement and analysis of resilience is distinguished from other properties of materials (e.g., stiffness, plasticity) with precise mathematical underpinnings, which is not the case in psychology.

Given the conceptual confusion of resilience in psychology, we argue that important lessons can – and should – be learned from engineering physics, the materials science branch in particular. In Section 2, we outline different conceptualizations of resilience and their implied measurements in psychology. In Section 3, we describe the unambiguous definitions and measures of resilience and of related concepts in materials science. In Section 4, we discuss the consequences of conceptual confusion, and propose how a clear conceptualization of resilience in psychology can be accomplished. In Section 5, we propose specific guidelines for the measurement of resilience and related concepts in psychology. In Section 6, we conclude with a summary, and important theoretical and practical implications.

2. Resilience in psychology

A recent review shows that a myriad of inconsistent definitions has been used in resilience papers (Bryan et al., 2019). Most definitions include in some way the concept of resisting negative effects of stressors, bouncing back from stressors, and/or growing from stressors. Sometimes, these concepts are even combined into one definition. For instance, in their book chapter on a resilience framework for

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psychological research, policy, and practice, Masten and Powell (2003) define resilience as the ability to resist, cope with, recover from, and succeed in the face of adverse life experiences. Accordingly, examining the literature of the last decades, various definitions exist in different sub-disciplines (e.g., sport psychology, developmental psychology, clinical psychology), and conceptualizations have changed over the decades (e.g., Bryan et al., 2019; Galli & Gonzalez, 2015; Smith et al., 2008). Hence, no unified, agreed-upon approach and measure for psychological resilience currently exists.

Going back to the early works on resilience in psychology, it was originally conceptualized as a personality trait (Block & Block, 1980). This conceptualization assumes that individuals differ in how they adapt to adverse events or stressors across domains and time. For example, a person who is high in resilience would adapt well to stressors occurring in the work life, in the personal life, and so forth. The trait-conceptualization of resilience is still used today in clinical settings to distinguish individuals that are more or less prone to developing psychopathology (e.g., Hu et al., 2015; Smith et al., 2008). Trait-resilience is commonly measured using self-report questionnaires assessing general tendencies of people to respond to stressors. A well-known questionnaire in this regard is the Ego-Resiliency Scale (ER89; Block & Kremen, 1996). This questionnaire serves to measure an individual's general capacity to deal with stressors. Important to note here is that, although the trait approach considers resilience to be a stable characteristic, it does not specify whether this characteristic helps to resist stressors, bounce back after stressors, change or grow from stressors, or some combination of these.

Recent conceptualizations are often more explicit about what is meant by resilience, or being resilient, and can be sorted into three broad categories: An ability to resist stressors, to bounce back from stressors, or to grow from stressors (e.g., Bryan et al., 2019; Smith et al., 2008). The first category defines resilience as resisting change and maintaining a healthy state despite encountering stressors. In accordance with this definition, resilience is typically marked by the absence of psychopathology after traumatic experiences in clinical psychology (e.g., Bonanno, 2004; Bonanno et al., 2011; Luthar & Cicchetti, 2000; Luthar et al., 2000), or the maintenance of well-being or skill (e.g., career success) after stressors in sport-, social-, and organizational psychology (Bryan et al., 2019; Sarkar & Fletcher, 2014). Comparably, in the domain of developmental psychology, resilience has been defined as "good outcomes in spite of serious threats to adaptation or development" (Masten, 2001, p. 228). This may be assessed through self-reports at a single moment in time. For instance, persons may be asked whether they faced severe adversity or not, and what their level of psychological well-being is. If a person was exposed to a potentially traumatic event, but is functioning well and maintains a high level of well-being, one may infer that the person demonstrated resilience based on this resistance conceptualization (e.g., Luthar et al., 2000). Another common approach is to measure, at one particular moment, personality characteristics that "protect" individuals against stressors. For instance, the Resiliency Scales for Children and Adolescents (e.g., Prince-Embury, 2008, 2010) and the Resilience Scale for Adults (Friborg et al., 2005) have been used for this purpose. The latter is specifically tailored to measure protective factors related to, among others, perception of self and social resources.

According to the second category, resilience can be conceptualized as a return to a previous or original state following a stressor (e.g., Carver, 1998; Fletcher, 2019; Hill et al., 2018a, 2018b; Masten, 2001; Masten & Obradović, 2006; Pincus et al., 2018; Pincus & Metten, 2010; Smith et al., 2008; Vella & Pai, 2019). This conceptualization thereby fits with the original Latin meaning of resilience, which is to "bounce back". A Brief Resilience Scale has been constructed for this aim, which is a self-report measure on an individual's ability to bounce back following stressors (Smith et al., 2008). In the past decade, however, researchers have also pointed to the importance of measuring the actual resilience process, that is, the temporal evolution from the occurrence of the stressor to the return to the previous state. Accordingly, Hill et al., recently (2018b) defined resilience as "the dynamic process by which a biopsychosocial system returns to the previous level of functioning, following a perturbation caused by a stressor" (p. 367). Empirical studies have started collecting dense repeated measures, or time series, to capture this dynamic process. For instance, Van de Leemput et al. (2014) expressed resilience in terms of the recovery rate to one's normal (previous) emotional state following stressors in daily life. If this recovery rate decreases (i.e., critical slowing down), it would reflect a loss of resilience, which may lead to a sudden, negative change in the individual's level of functioning (see also Helmich et al., 2021; Hill et al., 2018a, 2021; Kuranova et al., 2020; Scheffer et al., 2018; Wichers et al., 2016, 2019).

According to the third category of conceptualizations, resilience denotes the ability to functionally adapt and grow, or thrive, in response to a stressor. For example, Richardson (2002) proposed a resiliency model according to which "resilient reintegration refers to the reintegrative or coping process that results in growth, knowledge, self-understanding, and increased strength or resilient qualities" (p. 310). In this case, improvements in the level of functioning following stressors is termed resilience. Some psychological questionnaires aim to capture this process of growth. For instance, the widely used CD-RISK aims to measure typical characteristics of resilient people, where resilience is operationalized as "the personal qualities that enable one to thrive in the face of adversity" (Connor & Davidson, 2003, p. 76). Finally, growth following stressors has also been equated with the concept of plasticity (e.g., Kiefer et al., 2018; Taleb, 2012). More specifically, Kiefer et al. (2018) used the term *phenotypic plasticity*, which reflects the structural or behavioral changes of an organism in response to a stressor in order to form a more adaptive state. This idea of plasticity is in line with the popular perspective that individuals become more "resilient" when they have a history of stressors or adversity compared to individuals who encountered little or no adversity (e.g., Collins & MacNamara, 2012; Savage et al., 2018; Seery, 2011; Seery et al., 2010). For instance, Fletcher and Sarkar (2012) illustrated resilience based on the example of an athlete who wins the Olympic gold medal despite adverse events on the road to the Olympic Games. The idea behind this phenomenon is that encounters with stressors prepare individuals to deal with larger amounts of (future) adversity, and enable them to develop more adequate responses to such events. In line with recent developments focusing on the temporal process, phenotypic plasticity is typically detected in time series, where the focus is on how individuals grow beyond their previous functioning following stressors (cf. Hill, Den Hartigh, et al., 2020; Hill, Kiefer et al., 2020).

Taken together, since the 1980s the study of resilience in psychology has rapidly gained in popularity among psychologists. It has been conceptualized as an ability to resist stressors, to bounce back from stressors, and to grow from stressors. Furthermore, from the proposed conceptualizations and measurements one may infer that the majority of research considered resilience as a constellation of psychological characteristics, which would cover the ability to resist, cope with, bounce back from, and succeed in the face stressors, and which can be measured through questionnaires (e.g., Bryan et al., 2019; Masten & Powell, 2003; Smith et al., 2008). More recently, time serial measures have been introduced to measure the process of resilience more directly. This is in line with the observation that researchers have started to approach resilience not as a latent construct, but as a property that can be assessed by measuring the process of recovery following stressors (e.g., Hill et al., 2018a, 2018b, 2021; Scheffer et al., 2018; Van de Leemput et al., 2014; Wichers et al., 2016).

Now, in order to advance theory and subsequently interventions on resilience, the first and foremost important prerequisite is that the conceptualization is clarified in psychology. With a clear conceptualization, one can better target the measures, analyses, and interventions focused on resilience. In this sense, the field of psychology could learn from the field of engineering physics, specifically materials science, where the definition and measure of resilience have been clear and unchanged for many years. In addition, although psychology and physics are different domains, some definitions in materials science bear interesting parallels with resilience conceptualizations in psychology. Moreover, scholars in the field of psychology have recently identified the need for "a definition of resilience that is scalable across levels of analysis and suitable for communication across disciplines" (Masten et al., 2021).

3. Resilience and related concepts in materials science

In materials science, the three conceptualizations of resilience that exists in psychology – resistance, bounce back, growth or plasticity – clearly differ from each other with precise mathematical underpinnings. Hence, there is no definitional ambiguity regarding what resilience in a material is and what it is not, which is likely due to the existence of a unified approach to define material properties. Specifically, concepts can be distinguished from each other by investigating the *stress-strain relationship* of a given material. Stress represents the force that is applied to a material and strain represents the deformation of the material. Here, stress can take different forms and may reflect, among others, pressure that is applied to a material or stretching and twisting it.

When a material shows no (or very little) change in its state when the stress is applied, it is considered to be stiff. In this sense, stiffness resembles the first resilience conceptualization in psychology, namely the resistance in face of stressors (e.g., Bonanno, 2004; Luthar et al., 2000; Masten, 2001; Sarkar & Fletcher, 2014). Indeed, the material property *stiffness* corresponds to the degree to which a material resists deformation when exposed to stress. This can be illustrated with the example of a steel beam, which provides structural stability for a building by resisting deformation despite being exposed to high levels of stress (i.e., carrying weight). Mathematically, stiffness is represented by

$$k = \frac{F}{\delta} \tag{1}$$

where k represents stiffness, F represents the applied force (i.e., stress), and δ represents displacement (i.e., strain). This formula indicates that the smaller the displacement of the material (i.e., the more deformation is resisted) relative to the applied stress, the stiffer a material is. The opposite of stiffness is *flexibility*. This is a material's ability to deform easily with little stress (e.g., a rubber band being stretched with minimal effort). Hence, flexibility is marked by a large displacement relative to the applied force.

The property of stiffness is distinct from *resilience*. In materials, resilience is defined as the property of storing the energy that stress applies to the material, which is released (i.e., reflected back) once the stressor is removed. In this case, releasing the stored energy has to cause the material to return to its previous shape and size (e.g., Gere & Goodman, 2009; Hassler & Kohler, 2014; Kakani & Kakani, 2004). This resilience conceptualization nicely fits with the resilience definition in psychology, according to which bouncing back following a stressor is the key process (e.g., Carver, 1998; Hill et al., 2018a; Pincus & Metten, 2010; Smith et al., 2008). To provide a simple example of resilience in materials, think of a spring. When deforming force is applied to a spring, it stores the applied energy and "springs" back to its previous shape and size, once the force is removed. Note that this component also distinguishes resilience from stiffness, because for the latter no deformation is required (and may even be undesirable). Resilience of materials can be calculated based on the elasticity of the material:

$$U_r = \frac{\sigma_y{}^* \varepsilon_y}{2} \tag{2}$$

where U_r represents the resilience of a material per unit volume, σ_y represents the elastic limit of a material, and ε_y represents the strain displayed up to the elastic limit. This formula thus determines resilience as the area under the curve (AUC) of the stress-strain profile up to the elastic limit (see Fig. 1).

There is an additional resilience property that is not reflected in the figure, but is relevant to mention here. When stress is repeatedly applied to a material, its resilience may change as the material becomes fatigued (Stephens et al., 2000). A sign of this fatigue is that the material requires more time to return to its previous shape and size following the exposure to stress (Suresh, 1998). Such a phenomenon has also been demonstrated in psychology, most notably the phenomenon of critical slowing down, which means that individuals require increasing amounts of time to return to their previous state following a sequence of stressors (e.g., Scheffer et al., 2018; Van de Leemput et al., 2014; Wichers et al., 2016).

The final property we aim to discuss is *plasticity*, which describes a permanent deformation as a result of stress, and which may be either dysfunctional or functional. When a metal is supposed to return to its previous shape and size following stress exposure, the deformation is undesirable. For example, if a spring does not return to its previous shape and size, it becomes dysfunctional for its purpose. This aligns with insights from psychology that negative long-term psychological consequences may occur when stressors are too large (e.g., Carver, 1998; Connor & Davidson, 2003). On the other hand, exposing materials to stress can also enhance desirable properties and therefore be functional. To give an example, in order to produce steel, iron is exposed to extreme temperatures to reduce the amount of carbon in its composition. Thereby, the exposure to stress (heat in this case) enables the material to become stronger and more durable compared to its previous state. A parallel may be drawn between the latter form of plasticity and the idea of (posttraumatic) growth and phenotypic plasticity in psychology (e.g., Carver, 1998; Ghalambor et al., 2007; Hill, Kiefer et al., 2020; Kiefer et al., 2018; Richardson, 2002; Seery et al., 2010; Tedeschi & Calhoun, 2004). Plasticity in materials does not have a mathematical denotation, but is instead a general term for different types of permanent changes that persist even when the stress has been removed. The type of plasticity can be derived from the shape of the stress-strain curve, beginning after the elastic limit until the fracture point (see Fig. 1).

4. Toward more conceptual clarity in psychology

Psychology and physics are different domains, and the same terminology does not necessarily reflect the same theoretical concept. Nevertheless, the concept of resilience has clear parallels across materials and psychological constructs. Yet, despite these parallels, the concept of resilience and its boundaries are much more clouded in psychology. First, while various conceptualizations have been introduced in psychology, there is one resilience conceptualization in materials science. As a consequence, the number of resilience measures in psychology (e.g., questionnaires, interviews, time series) is relatively large, whereas there is a unified framework to assess resilience in

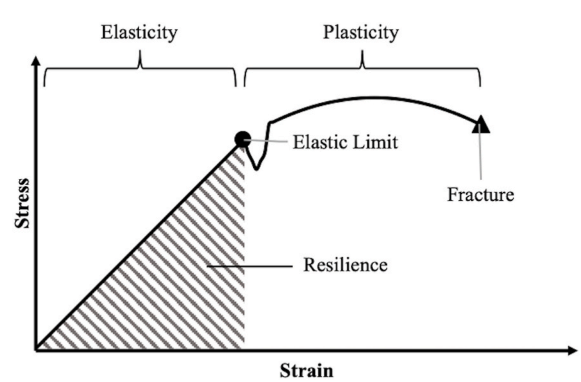

Fig. 1. Stress-strain relationship of a hypothetical material. The material shows elasticity, marked by the linear relationship between stress and strain, up to its elastic limit after which plasticity occurs until the point of fracture. The area under the elasticity of the material represents its resilience.

materials science. Second, while resilience in psychology is often attributed to particular personal characteristics, it is considered as a property that can be assessed based on the stress-strain relationship in materials science. In other words, in materials science, resilience is often defined in terms of *its response* when exposed to stress. Attempts to conceptualize and measure resilience in terms of a response to stress process have only recently been introduced in some psychological studies (e.g., Hill et al., 2021; Scheffer et al., 2018; Van de Leemput et al., 2014; Wichers et al., 2016). However, in order to improve conceptual clarity in psychology, we argue that this should be at the core of resilience research. Next, we can assess how psychological characteristics aid in the stress responses, for instance. That may allow us to determine the extent to which demonstrating resilience (or resistance, or growth) can be attributed to more stable capacities or characteristics.

Before explaining how resilience in psychology should be conceptualized in our view, let us illustrate why confusing different conceptualizations is problematic. To start with an example from materials science, it may seem that a stiff material that resists changes under stress is largely similar to a resilient material that returns to the previous shape following stress. Yet, think about a case in which one is constructing a machine such as an airplane. If an airplane speeds down the runway during take-off, the lift that is created on the wings causes them to bend upwards and allow the airplane to leave the ground. Thus, the material in the wings needs to allow some flexibility, deform with shocks and vibrations within the elastic limit, and obviously not break under high stress. When a stiff material is used for the wings instead of a resilient material, this may lead to a catastrophic failure of the take-off attempt. Indeed, the stiff material would resist the deformation and thereby not allow for the necessary flexibility in the wings that creates the lift. As another illustration, the difference between resilience and plasticity is also important to ensure the desired outcome. If the aim is to induce a functional change, it would be undesirable if a material just demonstrates resilience (Hassler & Kohler, 2014). For example, the process of creating steel would fail if a metal returns to its previous state after the heat (i.e., stress) exposure. In this case, resilience hinders the functional change of the metal toward a "stronger state" of steel.

A recent review in psychology revealed that many resilience interventions and training programs are poorly targeted, which is largely due to the various changing definitions and the outcome measures employed (Forbes & Fikretoglu, 2018). In other words, similar to materials science, a precise conceptualization of resilience is important here. For instance, when a resilience intervention is aimed at resisting the negative impact of stressors, people may become unequipped to successfully recover from a stressor that cannot be resisted. Relatedly, constantly trying to resist stressors can be emotionally exhaustive, which could lead to dysfunctional patterns such as burnouts (e.g., Te Brake et al., 2008). Hence, interventions aimed at improving resistance are not necessarily effective to improve resilience (i.e., bouncing back after a stressor). Furthermore, interventions aimed at growth or plasticity are targeted at yet another stress response. For instance, in the field of sports athletes are often exposed to training stress or load to improve their performance. In this case, the stressors foster adaptational processes that go beyond resilience (cf. Hill, Kiefer et al., 2020; Kiefer et al., 2018; Taleb, 2012). That is, the trainings are aimed at growing stronger rather than recovering to the previous state (e.g., Bellinger, 2020; Coutts et al., 2007; Zatsiorsky et al., 2020).

In order to provide more conceptual clarity, we argue that resilience in psychology should be defined as the process of returning to the previous state following a stressor (i.e., bouncing back, e.g., Carver, 1998; Hill et al., 2018a; Pincus & Metten, 2010). Resistance responses are not resilience and should therefore not be conceptualized as such. Moreover, growth or plasticity is a phenomenon that goes beyond resilience (Carver, 1998). Another important point is that resilience is not just a constellation of personal characteristics that needs to be determined. More specifically, resilience as the process of bouncing back following stressors *could be* related to particular characteristics such as a positive personality or confidence (e.g., Sarkar & Fletcher, 2014), just like resilience in materials science could be related to the constellation or geometrical shape of materials. Although these characteristics may provide the capacities to deal with stressors, it should be noted that they do not reflect the process of bouncing back following stressors. Consequently, measuring resilience requires an assessment of the process of returning to the previous state after a stressor (e.g., Hill et al., 2018b; Scheffer et al., 2018). In the next section, we will provide more detail and guidance on the measurement and analysis of resilience.

5. Guidelines for measuring resilience and related processes in psychology

5.1. Resilience

If resilience is defined as bouncing back after a stressor, then this has consequences for the way we measure resilience, and specifically the number of measurements we take. After all, if we would measure resilience at only one time point, it is impossible to know how a person's state responds to, and returns after, encountered stressors. To be more concrete, when measuring at one moment only, one may at best obtain a general, self-reported estimation of a person's tendency to demonstrate resilience (e.g., Smith et al., 2008). In order to measure resilience as a return to the previous state following a stressor, we can adapt the materials science approach to derive the deformation (i.e., strain) caused by a stressor, as well as the time it takes a person to return to their previous state following the stressor (see Fig. 2; Bruneau et al., 2003; Hill et al., 2021; Kuranova et al., 2020). In line with previous literature, different types of variables (e.g., positive and negative emotions, cognitions, behaviors) may reveal information about resilience, just like different elements of materials may be tested for their resilience.

In a sub-field of psychology (psychoendocrinology), interesting strides have already been made to quantify resilience. Researchers in this domain have determined different AUC measures to extract resilience scores based on cortisol and heart rate changes after stress exposure. This AUC informs about response duration and return to previous levels after the stress exposure, based on the trapezoid formula (for more information, see Altman, 1991; Pruessner et al., 2003; for other approximations of the AUC, see Bruneau et al., 2003; Hill, Kiefer et al., 2020; Hill et al., 2021):

$$AUC = \sum_{i}^{n-1} \frac{(x_{i+1} + x_i)^* \, t_i}{2} \quad (3)$$

Where x_i represents the individual measurement point, n represents the total number of observations, and t_i represents the time difference between the measurement points. Applying this method, researchers provided insights into individuals' resilience during a social stress task, for instance (e.g., Childs & de Wit, 2014; Garcia-Leon et al., 2019; Gerber et al., 2017; Kudielka et al., 2004; Liu et al., 2017; Mazurka et al., 2018). In these studies, researchers typically measured cortisol levels and/or heart rate at different measurement points during an experiment in which participants had to give a presentation and do an arithmetic test in front of judges. Resilience is then quantified by calculating the AUC on the measures from before to after the stress onset, thereby applying Equation (3).

The AUC may also be used for longer time series spanning days, weeks, or longer. For example, Kuranova et al. (2020) applied AUC calculations to quantify changes in recovery speed in psychopathological symptoms to predict changes in resilience. The findings suggest that recovery rates, as indicated by increased AUCs, may indeed indicate resilience losses leading to higher risk for adolescents to develop more symptoms in the following year. This is in accordance with the earlier mentioned study by Van de Leemput et al. (2014) showing that, following a series of minor stressors, increasing recovery time in daily emotions may be a warning signal for suddenly emerging

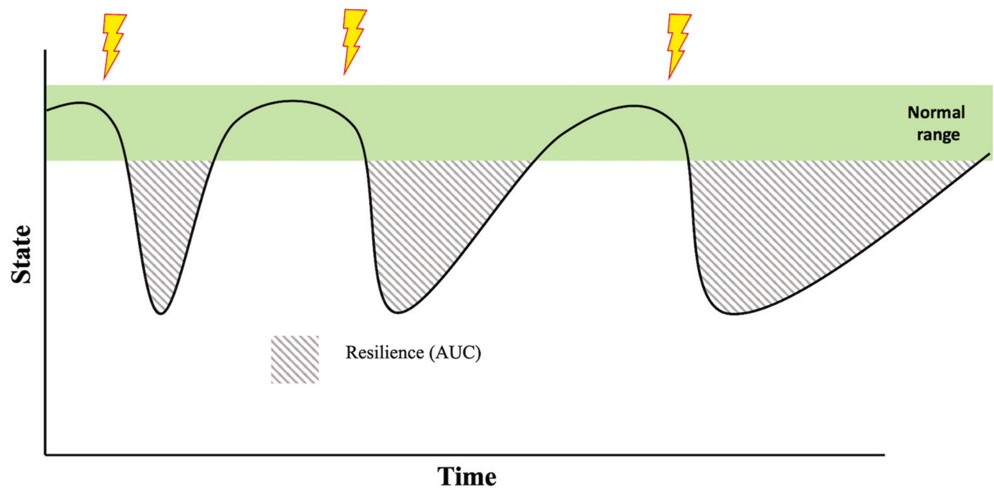

Fig. 2. Illustration of determining the AUC to indicate changes in a person's resilience. The black line represents a hypothetical state over time. As a result of the stressors (marked by the lightning bolts) the state becomes perturbed and the variable drops. The grey-striped area indicates the resilience. In this example, the area under the curve increases with repeated stressors due to the increasing time the variable requires to return to the previous state. This reflects a loss of resilience.

psychopathology (see also Helmich et al., 2021; Hill et al., 2018a, 2018b; Kuranova et al., 2020; Wichers et al., 2016, 2018).

Taken together, in order to measure resilience in psychology, a focus on the stressor-recovery process is necessary, just like the stress-strain relationship is central in materials science. Specifically, the AUC increases if either a stressor causes a larger perturbation or the individual requires more time to return to the previous state while the strength of the stressor remains stable (Hill et al., 2021). Because critical slowing down is marked by increasing sensitivity to stressors (i.e., increasing perturbation strength) and increasing recovery times (Helmich et al., 2021; Scheffer et al., 2009, 2012, 2018; Van de Leemput et al., 2014), it can reveal resilience losses in a comparable way as the AUC. An important point that follows from this, is that resilience is neither fixed nor static. It depends on the strength of the stressor, as well as on the history of stressors. Just like a material may become fatigued when repeatedly stressed, thereby returning more slowly to the previous state, the recovery time of the state of an individual may become longer following repeated stressors (e.g., Scheffer et al., 2012, 2018, 2009; Hill et al., 2021; Van de Leemput et al., 2014; Wichers et al., 2016).

5.2. Resistance and growth

Alternative conceptualizations of resilience in the psychology literature – reflecting resistance and growth or plasticity – may also be determined based on the stress-strain relationship parallel with materials science. To illustrate, the phenomenon where change in a psychological state is resisted after a stressor (stiffness), can be derived when examining the maximum deformation (or strain) that occurs immediately following the stressor. If the magnitude of the stressor can objectively be determined (e.g., average maximum deformation caused by the stressor), one may simply derive the stiffness formula used in engineering physics:

$$k = \frac{F}{\delta_{max}} \tag{4}$$

where k represents the resistance, F denotes the stressor's magnitude, and δ_{max} reflects the largest (undesired) change from the previous state. This equation implies that the smaller the maximum deviation from the previous state is, the larger the resistance value becomes and vice versa. Conversely, the larger the stressor, the larger the resistance score becomes. To give an example in the clinical psychology domain, if a particular traumatic event is associated with increasing DSM-5 symptoms of post-traumatic stress disorders or depressions, we could measure the diagnostic criteria on a daily basis to determine how many symptoms are expressed (see Fig. 3). Note that no bouncing back is required to determine how strongly the stressor is resisted. This means that while resilience requires a return to the previous state, the resistance can be determined independently of the process over time.

With regard to the other related concept, growth or plasticity may be reflected in the time-series when the level of functioning increases beyond its previous state following a stressor (Calabrese, 1999, 2001; Carver, 1998). In this case, the state needs to be measured both before and after the stressor, in order to determine whether growth has actually occurred. To compute this growth, a similar logic corresponding to the stiffness calculation may be applied. This means that growth or plasticity can be calculated based on the highest observed level of functioning following a stressor, compared to the state preceding the stressor:

$$P = \frac{X_{max}}{X_{t-s}} \tag{5}$$

where P represents plasticity, X_{max} represents the maximum score in the level of functioning (following the stressor), and $X_{t\text{-}s}$ denotes the state preceding the stressor. In this formula, a score larger than 1 would indicate potential growth and a score below 1 would indicate potential decline in the level of functioning.[1] As illustrated in Fig. 4, a positive change in well-being may occur after an initial (negative) response to stressors (Tedeschi & Calhoun, 2004). Comparable measures have been applied in sports science, in order to determine whether or not the body grows stronger following the exposure to particular doses of training stress or load (e.g., Bellinger, 2020; Coutts et al., 2007; Zatsiorsky, 1995). In these examples, positive adaptations cause the individuals to be better off than before encountering the stressors (cf. Carver, 1998).

6. Conclusion and directions for theory and practice

In this paper, we reviewed various definitions of resilience in psychology, and argued that these have clouded our understanding of the concept. We further argued that important lessons can be learned from other fields like materials science, where resilience is defined and measured in an unequivocal way with precise mathematical underpinnings. In line with the field of materials science, when speaking

[1] Note that this measure is not well-suited to determine resilience because a score equal to 1 cannot distinguish whether a stressor was resisted (i.e., stiffness) or whether a return to the previous state (i.e., resilience) occurred.

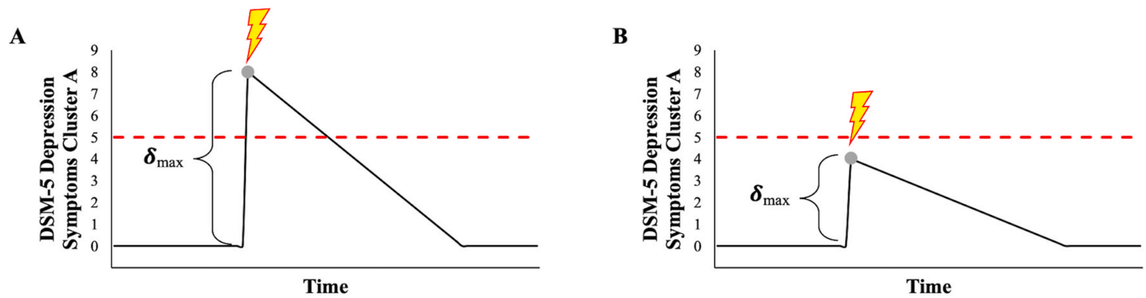

Fig. 3. Example of a resistance calculation in psychology. The state of an individual worsens (i.e., increase in number of symptoms) following an adverse event (marked by the lightning bolt). This adverse event may be associated with maladaptation, as reflected by the presence of 5 symptoms of the cluster A for depression (i.e., red dotted line). In example A, the individual develops 8 symptoms. Following Equation (4), the individual would be assigned a stiffness score of 5/8. Person B develops fewer symptoms in response to the same event, yielding a stiffness score of 5/4, which is greater than in example A. Thus, person B shows greater resistance to the stressor than person A (i.e., higher stiffness). Note that the resilience process would include the diagonal line following the lightning bolt, which is not accounted for in determining the resistance. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

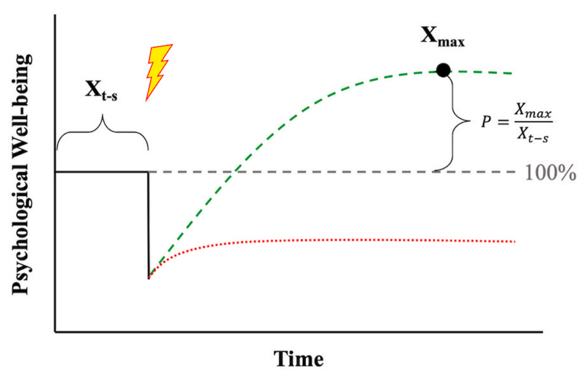

Fig. 4. Example of calculating growth or plasticity. The black solid line represents the state of a person (e.g., well-being) before a stressor (lightning bolt) is encountered. Following the stressor, the person may grow beyond the previous state (i.e., green striped line) yielding a plasticity score larger than 1 (i.e., maximum well-being exceeds the level before the stressor). If the person fails to return to the previous state (e.g., red dotted line), equation 5 would yield a negative score. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

about conceptual clarity we refer to a clarification of what resilience actually means. This clarity cannot be accomplished by trying to unify the conceptualizations as they already exist in psychology, because this could lead to a mixture of different concepts. Relatedly, we recommend to refrain from splitting the concept of resilience into different 'types' of resilience. For instance, in line with the fact that resilience has been defined in terms of resisting stressors and recovering from stressors, researchers have suggested to split the concept into "robust resilience" and "rebound resilience", respectively (Fletcher & Sarkar, 2016). Yet, the consequences for the way in which (robust and rebound) resilience should then be measured and analyzed remain unclear. If we would start this discussion, resisting stressors and bouncing back from stressors should be considered as different phenomena. We aimed to clarify this in the current article by pointing out how resistance, as well as growth and plasticity, need to be measured and analyzed differently than resilience.

Hence, we consider resilience as the process of returning to the previous state (i.e., bouncing back), following a stressor. This definition fits with the conceptualization in materials science and with the domain general definition of resilience as "the ability of an entity or system to return to normal condition after the occurrence of an event that disrupts its state" (Hosseini et al., 2016, p. 47; for related definitions in psychology, see; Hill et al., 2018b; Kuranova et al., 2020; Smith et al., 2008; Van de Leemput et al., 2014). Consequently, resilience should be measured in the process of returning to the previous state following a stressor, based on calculations like the AUC, critical slowing down, or comparable measures. In other words, resilience can only be inferred from psychological processes if returning to the previous state can be measured or implied. Any theory of resilience should therefore focus on the mechanisms that are at play while individuals recover from stressors. An in-depth discussion on possible mechanisms is beyond the scope of this paper, but interesting strides have already been made, for instance by modeling resilience using a dynamical systems approach (for reviews, see Hill et al., 2018a; Kiefer et al., 2018; Masten, 2014; Montpetit et al., 2010; Pincus & Metten, 2010; Pincus et al., 2018; Scheffer et al., 2018). Interestingly, this approach may also offer a coherent framework to understand the phenomena of resistance, and growth or plasticity (e.g., Den Hartigh et al., 2021; Hill, Den Hartigh et al., 2020; Kiefer et al., 2018; Pincus & Metten, 2010).

In addition to the implications on the level of measurement and theory, interventions and intervention evaluations in practice can also become better targeted with more conceptual clarity. Specifically, an intervention may aim to train an individual to resist the negative impact of a stressor (stiffness), return to the previous state (resilience), or grow from the stressor (plasticity). The different outcomes need to be evaluated with proper data collection procedures and according to mathematical underpinnings. For example, if the aim is to evaluate resilience, simply measuring the state of an individual at a single time point before the stressor and at some point following the stressor does not provide the necessary resolution of capturing the resilience process (cf. Helmich et al., 2021). Indeed, a higher temporal resolution is necessary to map how the state of the individual returns after the stressor (Forbes & Fikretoglu, 2018). On the other hand, a measurement point right before and after the stressor could provide sufficient information on the resistance to the stressor.

In conclusion, resilience is a major topic across different disciplines in psychology. In parallel with a branch of engineering physics – materials science –, we conceptualized resilience as a process in which an individual's state or functioning bounces back to the previous level following a stressor. This entails that any measurement of (psychological) resilience should reflect the return to a previous state or functioning following stressors. If we are interested in resisting stress or growth from stress, we are relating to different processes, parallels of which can be drawn with stiffness and plasticity in materials science, respectively. It is important to make this distinction, because people who are resilient are not necessarily "stiff", and vice versa, and the same argument can be made for plasticity. As a consequence, in theory and practice, the measurement and intervention of psychological resilience can only be well-targeted if the conceptualization is clear.

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Author note

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