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Abstract

The phenomenological philosopher Martin Heidegger's proposed transition from readiness-to-hand to presence-at-hand and the hypothesis of extended cognition were addressed empirically in an experiment on tool use. It involved a video game of steering erratically moving objects to a target while per- forming a secondary cognitive task. A strong perturbation of the hand-pointer linkage in the video game induced the transition from ready-to-hand to present-at-hand. In Experiment 1, this perturbation resulted in decreased motor performance and improved recall of task-irrelevant features. Experiment 2 replicated these results and addressed additional questions. Measures of movement variability based on the multifractal formalism confirmed the hypothesized decrease in functional integration of the tool during the perturbation. Dynamical interactions allow user and tool to act as a system. The tool is properly described as ready-to-hand during normal operation but as present-at-hand during perturbation. Physiological measures showed that the ready-to-hand to present-at-hand transition does not necessarily lead to a stress response.

Cognitive and movement measures reflect the transition to presence-at-hand

Heidegger's phenomenological philosophy has had a surprisingly significant influence on the cognitive sciences. This influence began when the critiques of AI by Hubert Dreyfus in the 1960s and 1970s (Dreyfus, 1972) were transformed into several positive research programs such as Heidegerrian AI (Agre & Chapman, 1987), enactive cognitive science (Varela, Thompson, & Rosch, 1991), and dynamical systems cognitive science (van Gelder, 1995) that have continued into the 21st century (Stewart, Gapenne, & DiPaolo, 2011; Thompson, 2007; Wheeler, 2005; Wilson, 2004). Heidegger has also been an inspiration to those who argue in favor of the thesis of extended cognition, the claim that cognitive systems sometimes encompass portions of the nonbodily environment (Chemero, 2009; Clark, 1997; McClamrock, 1995; Wilson, 1995, 2004). Yet despite the profound influence of Heidegger's philosophical ideas on cognitive science, there had been no attempt to verify his ideas empirically until recently (Dotov, Nie, & Chemero, 2010). That is, Heidegger's ideas have been very influential on research in the cognitive sciences, but no one had bothered to evaluate their worth empirically.

The phenomenology of tool use

The portions of Heidegger's views that have been most relevant to cognitive science are empirically testable. In Chapter III of Division 1 of *Being and Time*, Heidegger (1962) distinguishes three modes of experiencing the world. Most human activity, Heidegger argued, is absorbed, skillful engagement with entities in the world. When we are coping skillfully with the world, we experience entities around us as *ready-to-hand*. To use Heidegger's example, a hammer is encountered ready-to-hand, as a piece of equipment, when it is being simply used to drive in nails. Our engagement with entities ready-to-hand does not involve explicit awareness of their properties; instead, we “see through” them to the task we are engaged in. When we are smoothly driving in nails with a hammer, we are aware of the thing we are building, but not the size, shape or color of the hammer.

Heidegger argues that skilled coping, the way we engage with entities as ready-to-hand, is the primary way of engaging with the world. Sometimes, though, our skillful coping is severely disturbed. When this happens, we encounter entities as *present-at-hand*. The hammer is encountered as present-at-hand when we can no longer use it, when we must stop hammering and consider the hammer's shape or color or weight. When considered this way the hammer is no longer experienced as a useful tool, but merely an object with various properties that may or may not be relevant to the task. Indeed, when hammering is no longer possible, not just the hammer, but also the whole situation we are in-from the nails, the wood, and the whole network of entities that the hammer is connected to-are revealed to us and experienced as objects separated from the context of their functions.

Within cognitive science, this phenomenology has been one of the inspirations for the hypothesis of extended cognition, i.e., the claim that cognitive systems sometimes extend beyond the bio- logical body (Chemero, 2009; Clark, 1997; McClamrock, 1995; Wilson, 1995). A thinker, Heidegger argues, is a being-in-the-world. Hammers and other tools that are ready-to-hand are liter- ally part of the cognitive system, the being-in-the-world, in which the tool plays a role in completing a task. When you are smoothly coping with a hammer that is ready-to-hand, the ready-to-hand hammer recedes in your experience, and your focus is on the task you are completing. Your experience of the hammer is no different than the experience of the hand with which you are wielding it.[1] When a tool malfunctions, however, it hinders the task at hand and becomes an object of concern. Hence, rather than being part of an extended cognitive system, it is now an object that requires attention from the cognitive system. When the tool breaks entirely, it becomes present-at-hand, an object we experience as not serving a function. The hypothesis of extended cognition is controversial, but all parties to the debate, whether pro (Clark, 2008; Menary, 2007; Sutton, 2010) or con (Adams & Aizawa, 2008; Rupert, 2009), agree that whether cognitive systems extend beyond the biological body is an empirical matter (Wagman & Chemero, 2014).

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[1] Reports of neural correlates of such effects exist as well. In a study where macaque monkeys were trained to use a rake, bimodal neurons sensitive to objects within reach by hand expanded their visual receptive fields to match the enlarged space accessible by hand and rake (Iriki, Tanaka, & Iwamura, 1996).

Heidegger's phenomenology also suggests a non-representational account of dealing with the world (Dreyfus, 2002), an account that might seem to contradict most of cognitive science. Not all human activity, however, consists of skillfully dealing with the world. The approach allows for a form of cognition consistent with traditional cognitive science to occur (van Gelder, 1997, pp. 439e448). This is often overlooked by both proponents and opponents of the approach. Instead of posing cognitivist against embodied theories, here we provide empirical support for an interpretation according to which these correspond to separate modes of dealing with the environment. The importance of this hinges not only on the promotion of explanatory pluralism but also on delineating theoretically and empirically the actual fit between the approaches.

According to Heidegger's taxonomy, encountering the world can occur either in cognitive or non-cognitive modes (Dreyfus, 2007). On the one hand, Heidegger argued that most of our engagement with the world is situated, skillful, absorbed coping that does not involve representing the environment. It has been shown repeatedly that the theoretical tools of cognitivism fail to apply to the part of phenomenology dealing with absorbed coping (Dreyfus, 2002, 2007; Dreyfus & Kelly, 2007; Kelly, 2000, 2002). Not surprisingly, cognitivism has little to say about skillful action. In particular, the motor control aspects of skillful action are better accounted for using dynamical systems theory (Kelso, 1995; Thelen & Smith, 1994). On the other hand, when dealing with a workspace and faced with problematic or new situations we need to study the workspace, think about what has gone wrong, what to do next, and learn a new skill (Dreyfus, 2002). This seems to demand a repre- sentational, cognitivist approach. This form of skill learning can be accounted for using traditional approaches in cognitive psychology (e.g., Anderson, 1982). To summarize the stance,

> "… the Heideggerian claim is that action-oriented coping, as long as it is involved […] is not representational at all and does not involve any problem solving, and that all representational problem solving takes place offline and presupposes involved background coping. Showing in detail how the representational un-ready-to-hand in all its forms depends upon a background of

> holistic, nonrepresentational coping is exactly the Heideggerian project and would, indeed, be the most important contribution that Heideggerian AI could make to Cognitive Science." [Dreyfus, 2007, p. 1150]

How do the modes of encountering the world and the transition between them relate to measurable aspects of cognition and behavior? Our goal is to answer this question by applying the empirical methods of cognitive science and human movement science in the context of an experimental task that instantiates the transition from an absorbed coping mode dominated by skillful action to a cognitive mode dealing with a situation that resists skillful action. By providing evidence for Heidegger's modes of experiencing tools, particularly skillful coping with ready-to-hand tools, we can also provide evidence in favor of the hypothesis of extended cognition.

Empirical approach

The primary objective of the present study was to investigate behavioral aspects of the transition from ready-to-hand to present- at-hand. Participants played a computer game that allowed them to engage with it in absorbed coping mode. The game also allowed the breakdown of the tool to be induced experimentally. Its *task space*[2] (Saltzman & Kelso, 1987) was constructed in analogy with pole balancing. It constituted an unstable and fluctuating dynamical system that could be stabilized if the participant applied the appropriate mapping from patterns of movement on the screen to patterns of movement of the mouse (for details, Appendix A). A perturbation was incorporated by manipulating the linkage from mouse movements to patterns of movement on the screen, i.e. the tool could be perturbed temporarily while the participant was engaged in the task.

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[2] The notion of task space resembles the notion of subspace in linear algebra. It refers to the *minimal set* of internal and external forces and informational variables that make possible the satisfactory performance of a given task of moving in a real environment (Mottet, Guiard, Ferrand, & Bootsma, 2001; Park, Collins, & Turvey, 2001; Wilson & Golonka, 2013). The minimal description of the task space points to the minimal motor control required from the participant. It is useful to think of task space as a system of constraints instead of dividing it in external (physics) and internal (information processing) parts (Oyama, 1993; Oyama, Griffiths, & Gray, 2001). It is also useful to distinguish it from the notion of workspace which is a larger set and in the context of the current study would comprise things such as the type of computer screen used in the experiment.

Previously, Dotov et al. (2010) used motion tracking to record the movement of the hand-mouse, i.e., at the boundary between body and tool. The character of variability of the hand kinematics supported the hypothesis that during smooth coping the hand and tool are functionally integrated into a single system performing the task whereas with perturbation this integration was reduced. A simultaneous task of counting backwards was used to infer cognitive load. Counting rate decreased during the perturbation, consistent with Dreyfus' interpretation that participants engage in a cognitive activity of problem solving and start paying attention to the workspace when they are having trouble performing the task. These results demonstrated the thesis of extended cognition and of Heidegger's proposed phenomenology of tool use.

The empirical support of the theory can be extended by using the same basic task but changing the strength and type of the perturbation, applying more advanced analytical techniques, and measuring additional dimensions of cognitive performance. If participants are paying more attention to the tool when it is encountered in the present-at-hand mode they are also expected to notice more things about the workspace. Experiment 1 focused on this prediction. Additional dimensions of tool use were addressed in Experiment 2. First, the analysis of movement variability was extended in order to strengthen the characterization of tool integration. Second, physiological response to the perturbation- induced transition of modes was measured. Finally, severe break- down needs to be instantiated in order to fully match the phenomenological description of present-at-hand. The tool mal- function in the previous study was only strong enough to impair but not interrupt performance. In the second experiment reported here we used a stronger perturbation and completely decoupled the mouse.

Experiment 1

Overview

Heidegger claimed that when tools break down, and are experienced as present-at-hand, we become aware of their physical properties. Therefore, participants who experienced a severe perturbation were expected to notice and remember more of the non-functional, physical properties of the workspace. In order to test this, participants' memory for features such as the colors and shapes of the objects in workspace was probed after the experiment. The experimental paradigm comprised the same balancing task used previously (Dotov et al., 2010) and a concurrent cognitive task.

The main task was explained to the participants as a computer game of herding sheep.[3] Three objects (the sheep) were programmed to stay in a group but be pushed away by the mouse cursor (the tracking object) at a rate proportional to the distance between the cursor and the target objects, i.e. the farther the tar- gets from the tracking object the faster they escaped. This allowed the targets to be directed by the participant. The objective was to keep them inside a center area. This could be achieved by positioning the tracking cursor on the outer side of the targets relative to the center. The equilibrium configuration where the tracking object was on top of the targets was unstable. It was also impossible to maintain due to the random force added to the targets' velocities. Consequently, constant engagement was required from the participant. More technically, the task consisted of the continuous stabilization of an inherently unstable and erratic dynamical system whereby the group of target objects escaped exponentially fast from the cursor on a vector facing away from the cursor (for details see Appendix A). The targets' escape rate and noise were configured so that the task was challenging yet tractable for novice participants.

To instantiate a perturbation of the primary task, the gain of the mouse cursor was decreased for a portion of the middle of the trial. Performance in a concurrent cognitive task consisting of counting backwards by three was recorded using a microphone. The measure of object features recall was obtained post-trial. Note that in this context 'tool' is not just the mouse. The tool consists of the mouse, its projection as a cursor on the screen, and the repelling force between the cursor and targets. Throughout this article 'tool' refers to the hand pushing the mouse pushing the pointer pushing the targets.

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[3] A sample video recording from an earlier version of the experimental task containing only one target can be found at http://bioweb.me/herding-center-of- mass.

Method

Participants

Students (*n* = 31) taking an introductory class in psychology participated in exchange for course credit. The experimental procedure was approved by the Institutional Review Board. All participants reported using the mouse with the right hand habitually.

Apparatus and computer game

The participants were seated in front of an office table with a mouse and monitor on it, and a computer equipped with a microphone. A custom Matlab (Mathworks, Natick, MA) script employing the capabilities of the PsychoPhysics Toolbox (Brainard, 1997; Pelli & Zhang, 1991; Pelli, 1997) was used to implement the computer game. A group of three target figures moved inside an area which covered most of the screen. The targets consisted of a circle, triangle, and diamond colored in yellow, green, and red, respectively. All four were scaled in size to approximately fill the area of a 16 by 16-pixel square. The play area consisted of black background, a boundary (purple circle) for the target objects and a center (small gray circle). The tracking figure was a blue square replacing the mouse cursor on the screen. For perturbation, the gain of the mouse (the velocity of the cursor) was reduced by a factor of ten.

Target figures were driven additively by three forces: a small random force in the *x*- and *y*-dimensions, the scaled difference between target vector and cursor vector in the screen coordinates, and nonlinear attractive forces among each pair of targets which kept them grouped in a cloud. The target figures were constrained within the oval of the play field. The program recorded the tracking and target figures trajectories in the 2D coordinate system of the play area.

Design

Each trial consisted of three phases: Block 1 (pre-perturbation), Block 2 (perturbation), and Block 3 (post-perturbation). Participants were randomly assigned to the control (null perturbation) or experimental (perturbation) group. The between-subjects design was necessary because participants could not perform more than one trial. The implicit and uninstructed character of the item recall task meant that participants would be biased if they were to perform a second trial. The dependent variables comprised counting rate, post-trial item recall, and level of performance in the motor task.

Procedure

The participants sat in front of the desk and performed a single trial after having heard an explanation of the experimental procedure, the game, the repelling force linking the targets to the mouse, and having signed an informed consent form. It was stressed that the primary task was to keep the target objects in the center. A practice trial of the counting task was performed as well. Participants were instructed to continue counting rather than make corrections in the case of a mistake in counting. The instructions did not disclose the memory aspect of the task but mentioned that an additional survey would be administered. After completing one trial the participants filled the inventory of object features recall.

Performance measures

Counting rate was estimated from the audio recording. *Mean distance from the field center* was the average across time and tar- gets of the distances between each target and the center of the field, normalized to a percentage of the maximum distance to the border. The inventory of *workspace features recall* consisted of a pencil and paper questionnaire. It comprised ten questions pertaining to the shapes and colors of the target and tracking figures and the play field and had a score range of zero to ten. To reduce the chance of random correct guesses, color identifications were only counted as correct if they also matched the shapes of the respective objects, e.g. “the tracking object was square and was blue”.

Results

Performance

Four participants, two from each group, failed to perform the primary task. The inclusion criterion was satisfied if targets touched the boundary for less than half of the duration of the trial. The cognitive measures are summarized in Fig. 1. The scores for *work- space feature recall* were higher in the perturbation group ($M = 5.29$, $SD = 1.20$) than in the no-perturbation group ($M = 4.30$, $SD = 1.49$), $t(25) = 2.01$, $p < 0.05$, one-tailed. With respect to *counting rate*, Block did not have an effect, $F(2,50) = 1.50$, $p = 0.23$, nor did experimental group, $F(1,25) = 1.66$, $p = 0.21$. There was no interaction between the two factors, $F(2,50) = 1.30$, $p = 0.28$.

Block affected *mean distance from center*, $F(2,50) = 7.86$, $p < 0.01$. Multiple comparisons revealed that Block 3 was lower than Block 1 ($p < 0.05$) and Block 2 ($p < 0.05$) and there were no differences between Blocks 1 and 2 ($p = 0.51$). Experimental group did not affect mean distance from center, $F(1,25) = 1.70$, $p < 0.20$. An interaction between the two factors was observed, $F(2,50) = 8.34$, $p < 0.01$. In the experimental group, mean distance from the center was higher in Block 2 than in Block 1 ($p < 0.001$) and Block 3 ($p < 0.01$) which did not differ from one another ($p = 0.57$). In the control group, after adjustment for multiple comparisons, distance from the center was not significantly lower in Block 2 relative to Block 1 ($p = 0.04$). It was lower in Block 3 relative to Block 1 ($p < 0.01$), and not different between Blocks 2 and 3 ($p = 0.30$).

Discussion

Participants who experienced the perturbation of the primary motor task remembered more task-irrelevant features of the objects in their workspace. The features queried in the survey—colors and shapes of the objects on the screen—had no bearing on either of the motor or counting tasks. This result is in line with what would be expected if the workspace became present-at-hand. Workspace as present-at-hand implies a more cognitive mode of performance (Dreyfus, 2002, 2007) as shown here. Expectedly, the mean distance between the target objects and the center area increased due to the tool malfunction. This verifies that performance of the tool was also impacted by the perturbation. Additionally, performance tended to improve across the trial and in the last block it was superior in both conditions.

Interestingly, the effect of the perturbation on counting rate was not statistically significant, contrary to the apparent decrease (see Fig. 1) and the results reported previously (Dotov et al., 2010). This could be explained by the relative strength of the perturbation. In the previous experiment the cursor responsiveness (gain) was decreased and random jitter was added. Here only the gain was manipulated. This suggests that the severity of the cognitive shift is dependent on the type of perturbation.

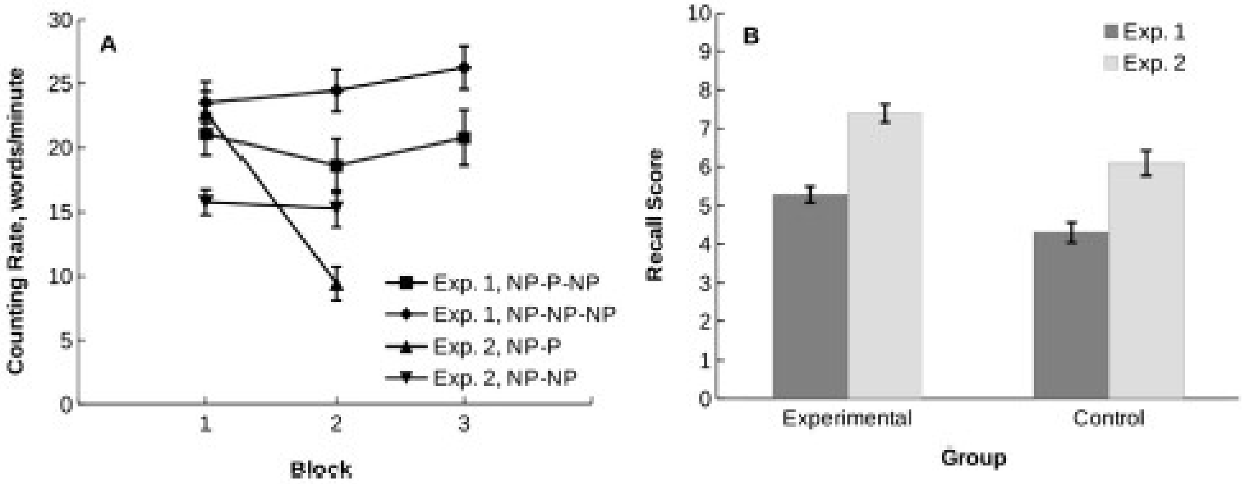

Fig. 1. Task performance measures across the two experiments: (a) counting rate in words per minute; (b) item recall in terms of correctly identified object features. Note that the two experiments differed in design. Experiment 1 involved three blocks per trial where the middle block comprised the perturbation in the experimental group (NP-P-NP) or not in the control group (NP-NP-NP). Trials in Experiment 2 involved two blocks where the second block comprised the perturbation in the experimental group (NP-P). Error bars show standard errors.

Experiment 2

The hypothesis of extended cognition together with the phenomenology of Heidegger implies that tool and user become integrated elements of a single system during skillful coping. Yet, phenomenology and extended cognition do not make any direct predictions about the motor aspects of this sensorimotor integration. What does it mean to say that a tool is functionally integrated, and how could this integration be quantified using modern methods? The character of the system has to be considered to answer this question. A hand-held tool is an element of the system performing the task. This system also comprises the participant's hand, neuromuscular apparatus, central nervous system, and sense-organs, as well as the environment through which the consequences of motor activity become sensory stimulations, thus closing the loop. The tool can be said to be coupled to a highly nonlinear system made of extremely large number of degrees of freedom. Furthermore, the integration of the tool in this body-brain-environment closed loop is soft and temporary (Kugler & Turvey, 1987). Evidently, a tool such as a hammer is not structurally integrated in the person's motor apparatus in the same way that, say, the fingers of the hand are; no afferent and efferent neural connections run between the spinal cord and the hammer. Therefore, the extended cognition hypothesis implies that it is the dynamical interaction between the user's motor apparatus and the tool that binds them into a unitary system.

Interaction-dominant dynamics

A system that acquires functional unity by virtue of the dynamical interactions among its loosely assembled components is said to obey interaction-dominant dynamics[4] (van Orden, Holden & Turvey, 2003). Interaction-dominant dynamics results in a statistical property of fluctuations in the given system known as $1/f^{\beta}$ scaling. Such scaling is a signature of cooperative coupling among multiscale processes recruited to support the same global dynamic. In practice, one speaks of $1/f^{\beta}$ scaling where $0<\beta \leq 1$ ($\beta = 0$ corresponds to white noise and $\beta = 1$ to pink noise).

The technicalities linking $1/f^{\beta}$ noise and interaction-dominant dynamics are beyond the scope of this article. There is one important analytical result, however, that requires mentioning. West and colleagues showed that $1/f$ is an optimal solution to the problem of maximizing the coupling[5] in and among complex networks (Aquino, Bologna, Grigolini, & West, 2010; West, Geneston, & Grigolini, 2008). This explains why, they argued, a range of physiological and nervous system processes exhibit $1/f^{\beta}$ scaling (some examples and reviews in, Buzsa'ki, 2006; Peng, Havlin, Stanley, & Goldberger, 1995; West & Shlesinger, 1990; Yu, Romero, & Lee, 2005).

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[4] In contrast, a system driven by component-dominant dynamics has parts that are separable both structurally and functionally.

[5] They actually use information exchange as a generalized form of coupling. Note, however, that ‘information’ may mean different things in mathematics, theoretical physics, and cognitive science. Multiscale coupling of complex systems, the term used here to avoid confusion, is consistent with the aforementioned work on information exchange maximization.

Cognitive systems have been shown to exhibit such scaling in a variety of tasks and domains (Kello et al., 2010). The component sub-processes of an interaction-dominant systems are also expected to exhibit this form of scaling (Kello, Anderson, Holden, & Van Orden, 2008). According to the interpretation of the extended cognition hypothesis advanced here, the tool and the hand skillfully manipulating the tool should exhibit $1/f^{\beta}$ scaling because they are components of a system softly assembled by way of interaction dominant dynamics.

The hand accelerations during normal performance of the herding task were found to exhibit $1/f^{\beta}$ scaling (Dotov et al., 2010). This is evidence that interaction-dominant dynamics underlie the integration of the tool within the sensorimotor loop, consistent with the hypothesis of extended cognition. Furthermore, this scaling was reduced due to the perturbation, i.e. hand accelerations became more random, implying that the functional coupling be- tween tool and user was reduced (Aquino et al., 2010; West et al., 2008).

For methodological reasons, this empirical support needs to be extended. A stronger form of evidence supporting the role of $1/f^{\beta}$ scaling as an indicator of interaction-dominant dynamics has become available (Thornton & Gilden, 2005). Non-linear mechanisms of control can add another layer of complexity whereby a recorded time-series exhibits changes in scaling (the β in $1/f^{\beta}$) across time and scale (Ivanov et al., 1999, 2001; Vicsek, 1993). This heterogeneity of scaling is known as multifractality. Ihlen and Vereijken (2010) demonstrate that multifractality, unlike monofractal scaling, helps distinguish interaction-dominant from component-dominant systems.

In the present study, the *local Holder exponents* (*h*) and the range of their spectrum *D*(*h*) were determined in lieu of the methodologically complicated b exponents of the power spectrum $1/f^{\beta}$ (for the details on mono- and multi-fractal signals and the corresponding methods, see Appendix B). Note, however, that in theory and with sufficient data the local Holder exponents and the spectral ($1/f^{\beta}$) and variability (generalized Hurst) scaling exponents are expected to converge. The data on which we performed this multifractal analysis was the time series of an accelerometer placed on the hand holding the mouse during trials of the experiment.

For technical reasons, the acceleration signal is appropriate because of its stationarity and spectral bandwidth. From a theoretical stand- point, the acceleration signal is closest to the forces that the hand impacts in order to interact with the mouse. Given the findings of Ihlen and Vereijken (2010), an extended fractal spectrum is expected during skillful coping. Furthermore, disrupting the linkage between mouse and pointer, i.e. breaking the tool, should result in a decrease of the multifractal spectrum, implying reduced and simplified dynamical coupling between participant and tool.

Physiological response

According to the *cognitive activation theory of stress* (Ursin & Eriksen, 2004), physiological stress is produced by unexpected perturbations to a general homeostatic equilibrium which has cognitive as well as physiological dimensions. Measures such as increase in heart rate and galvanic skin response (GSR) have been used to implicitly determine cognitive load in the context of human-computer interaction. This implies that the perturbation- induced transition to present-at-hand might have a detectable effect on stress variables in addition to cognitive and movement ones.

Method

Participants

The participants in Experiment 2 consisted of 20 students who were compensated with a payment of five dollars for their participation. Half of these students were randomly assigned to the experimental group. The procedure was approved by the Institutional Review Board. All participants reported using the mouse with the right hand habitually.

Design

In a two (group) by two (trial block) design, the trials finished at the end of Block 2. A post-perturbation block was not used because the length and strength of the perturbation caused the target objects to float out of control. The dependent variables comprised of counting rate, item recall, the multifractal measure extracted from hand accelerations, and physiological measures.

Materials and apparatus

To minimize chance recognitions in feature recall, the pointer and three targets consisted of less typical shapes: a green star, red diamond, blue inverted triangle, and yellow square, respectively while the center of the field was a gray octagon. The G-Link accelerometer (MicroStrain Inc., Williston, VT), fastened against the dorsal side of the right hand using a velcro band strapped in a loop around the hand, was used to sample hand acceleration data at 256 Hz. A selected acceleration series is shown in Fig. 2. A dedicated sensor was required due to the low sampling rate and spatial precision of the mouse.

Total breakdown in Block 2 (35e70 s into the trial) consisted of 20 s of intermittent freezing of the cursor (switching gain between zero and one with a random period ranging from two to five seconds) followed by 15 s where both targets and cursor froze in place for the remainder of the trial, i.e. the participants saw a static screen not responding in any way to their hand movements. Physiological sensors (BIOPAC Systems Inc., Goleta, CA) sampled cardiovascular activity via the pulse plethysmogram (PPG) and arousal via galvanic skin response (GSR) from the left index finger at a rate of 200 Hz.

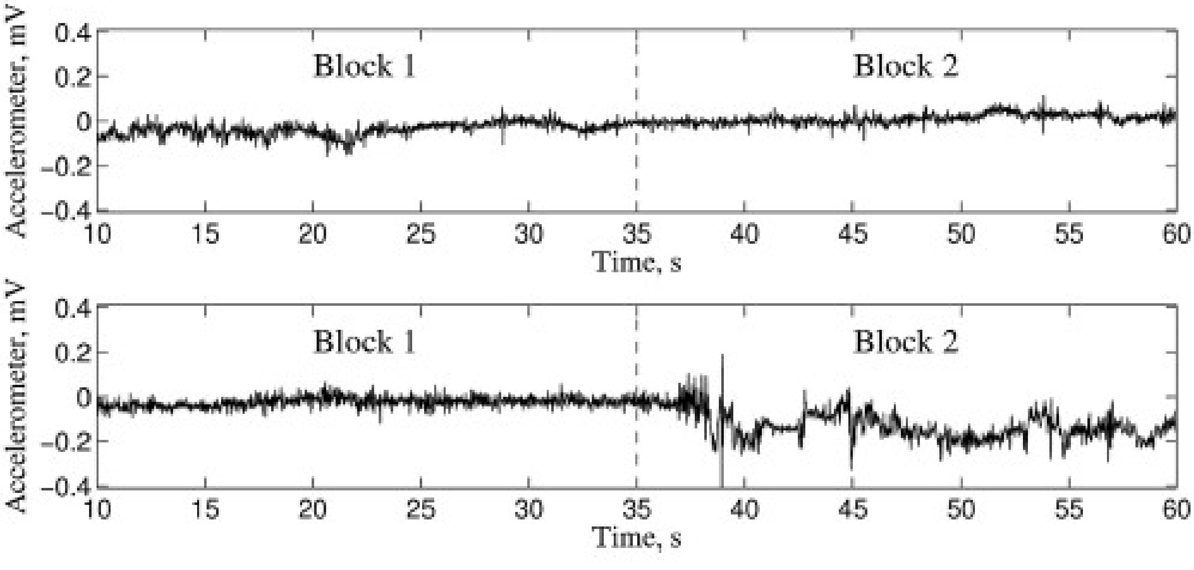

Fig. 2. Sample raw accelerometer data in the lateral dimension of hand movements. Trials are from the control (top) and experimental (bottom) groups in Experiment 2.

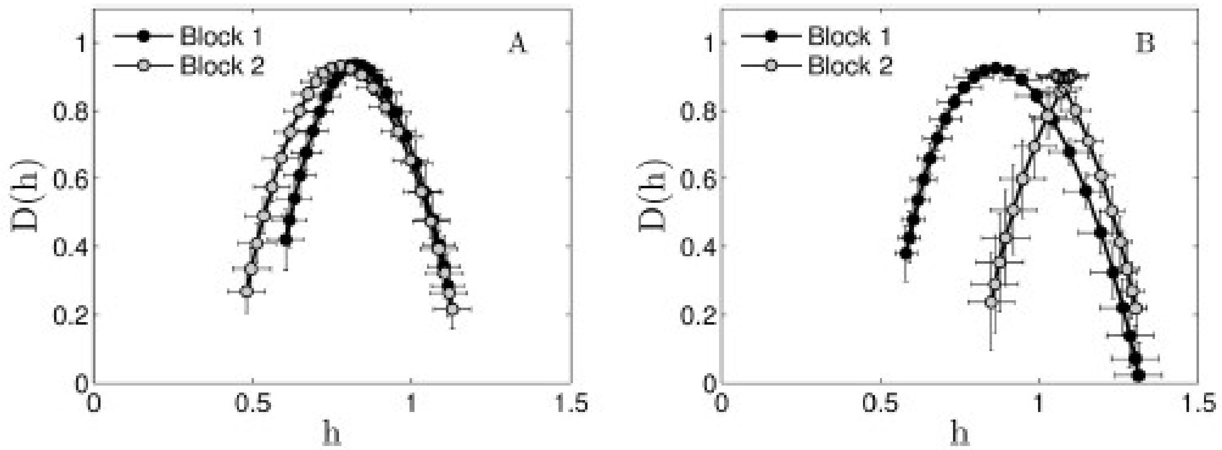

Fig. 3. Averaged singularity spectrum functions for Blocks 1 and 2 in the control (a) and experimental (b) groups. Each point corresponds to a different moment q value with the minimal q producing the highest exponents and the maximal q producing the lowest exponents (see Appendix B). The multifractal range in group and block is the largest width of the respective curves. The functions shown here are down-sampled by a factor of two for better visibility. Error bars show standard deviations.

Analysis of movement variability

The local Holder exponents provide an image of the multi- fractality in the hand accelerations. The range of local Holder exponents, or the singularity spectrum, was calculated using the Wavelet Transform Modulus-Maxima method (WTMM, see Appendix B) using software available from the PhysioNet online repository[6] for analysis of physiological signals (Goldberger et al., 2000). A particular point in this spectrum corresponds to the β exponent in $1/f^{\beta}$ noise. The range of the width of the spectrum is given by $h_{\text{range}} = h_{\text{max}} - h_{\text{min}}$ (the width of the parabolas in Fig. 3). The parameters of the analysis were determined based on typical recommendations so as to minimize the variability of the $h(q)$ estimates across blocks and participants: sufficient spread of the q-moment from -5 to 5, full scale range (window span from the minimum up to the maximum possible in the 25-s-long section), and the third derivative of the Gaussian kernel wavelet. Data were integrated as a preliminary step to the WTMM. The first ten and last ten seconds of the acceleration time series in the trial were removed in order to avoid transient effects such as due to sharp initial adjustment of the mouse.

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[6] http://www.physionet.org/physiotools/multifractal/.

Analysis of physiological response

The pulse plethysmogram (PPG) can provide a reliable approximation of heart rate (Seely & Macklem, 2004). Inter-beat-intervals (IBI, ms) between consecutive peaks in the recording were extracted using a custom peak-picking algorithm, visually inspected, and then averaged across trial. GSR was averaged across trial as well.

Results

Performance

The basic performance outcomes are summarized in Fig. 1B (light gray bars). The mean item recall score ($M = 6.10$, $SD = 1.45$) was lower in the control than in the experimental condition ($M = 7.40$, $SD = 1.07$), $t(18) = 2.28$, $p < 0.05$. Two participants in the experimental group were excluded from the counting rate analysis due to failure of reliable auditory recording. Block affected counting rate, $F(1,16) = 17.89$, $p < 0.001$. Group in itself did not affect counting rate, $F(1,16) < 1$. A significant interaction between Group and Block was found, $F(1,16) = 15.32$, $p < 0.01$. Comparisons revealed that counting rate in Block 1 ($M = 22.71$, $SD = 7.54$) in the experimental group was higher than Block 2 ($M = 9.43$, $SD = 5.87$), $p < 0.01$, and this was not the case in the control group where Block 1 ($M = 15.77$, $SD = 4.48$) did not differ from Block 2 ($M = 15.26$, $SD = 6.54$), $p = 0.56$.

Hand kinematics

The width of the singularity spectrum h_{range} was not affected by block, $F(1,18) = 0.43$, $p = 0.52$, nor condition, $F(1,18) = 1.22$, $p = 0.28$, but a significant interaction between the two factors was found, $F(1,18) = 10.25$, $p < 0.01$. As shown in Fig. 3, in the experimental condition h_{range} was lower in Block 2 ($M = 0.50$, $SD = 0.18$) than in Block 1 ($M = 0.73$, $SD = 0.17$), $p < 0.05$, whereas in the control condition Block 2 ($M = 0.65$, $SD = 0.14$) did not differ from Block 1 ($M = 0.51$, $SD = 0.15$), $p = 0.08$.

Physiological response

As shown in Fig. 3, mean IBI increased and GSR decreased over blocks without an effect of group. IBI tended to be higher both in the perturbation group Block 2 ($M =$

739, *SD* = 110) and the non-perturbation group Block 2 (*M* = 763, *SD* = 158) relative to the perturbation group Block 1 (*M* = 682, *SD* = 91) and non- perturbation group Block 1 (*M* = 729, *SD* = 173). The change over blocks was statistically significant, $F(1,18) = 12.53$, $p < 0.01$. Condition did not have an effect, $F < 1$, and no interaction was found, $F < 1$. GSR tended to be lower both in the perturbation group Block 2 (*M* = 4.70, *SD* = 2.06) and the non-perturbation group Block 2 (*M* = 5.00, *SD* = 2.17) relative to the perturbation group Block 1 (*M* = 4.89, *SD* = 2.14) and the non-perturbation group Block 1 (*M* = 5.51, *SD* = 2.11). The change over blocks was statistically significant, $F(1,18) = 15.28$, $p < 0.01$, but no effect of condition, $F < 1$ and no interaction, $F(1,18) = 2.96$, $p = 0.10$, were found.

Discussion

Complete tool breakdown instantiated by decreasing and then zeroing the mouse gain led to reduced counting rate and increased awareness of features of the workspace. These results are expected because the present-at-hand mode implies a cognitive mode of performance that encompasses all features of the workspace and not just the tool itself (Dreyfus, 2002, 2007).

Holder exponents were similar for all non-perturbation conditions, and were consistent with the mono-fractal $1/f^{\beta}$ exponents found in Dotov et al. (2010). Additionally, the observed extended scaling range h_{range} expands the findings in Dotov et al. (2010) that during skillful coping the participant and tool formed a unified, extended system driven by dynamical interactions. For reference, time-series characterized by a single scaling exponent (mono- fractal) would have resulted in zero-width spectrum where all h_q are equal, i.e. the curves in Fig. 3 would be compressed to single points. The Holder exponents range decreased due to the perturbation consistent with a reduction in multifractality. The drop in this range shows that task space malfunction reduced the functional integration of the tool within the sensorimotor loop. Pole balancing, which serves as a task space model for the sheep herding game, has been found to exhibit a very modest multifractal spectrum ($h_{\text{range}}<0.1$) (Harrison, Kelty-Stephen, Vaz, & Michaels, 2014). This could be explained with the relative difficulty of the task; anyone who has tried to balance a stick on his or her finger can attest that the task usually ends with prompt failure.

Physiological measures associated to stress response were collected in order to determine how startling or frustrating the perturbation was. GSR and heart rate did not respond to the experimental condition of tool perturbation (see Fig. 4) indicating that the perturbation instantiated in the current experiment did not act like a startle stimulus and did not frustrate participants. Both heart rate and GSR, however, decreased through the trial. This suggests that participants became relaxed while resting seated. These results imply either that the engaging character of the task along with the strength of the perturbation could be increased or that the presumed linkage between cognitive and physiological stress responses has been exaggerated.

General discussion

The goal of the experiments reported here was to investigate empirically Heidegger's phenomenology of tool use, and the transition from ready-to-hand to presence-at-hand in particular. In doing so we also expanded the mapping between the phenomenological description and observable dimensions of cognition and motor control. To verify the phenomenological description empirically, Experiment 1 instantiated a transition from ready-to-hand to present-at-hand. We investigated how participants playing a simple video game are affected by a disruption of the linkage between mouse movement and object movement on the screen. In the condition where this perturbation occurred, participants remembered more task-irrelevant features of the workspace. Experiment 2 replicated and expanded upon this result. Both an increase in recall and drop in counting rate were observed with the more severe perturbation of the mouse-cursor linkage. Note that one could have predicted the inverse if relying solely on considerations from cognitive psychology and the fact that the unperturbed task is likely to be easier than the perturbed.

At the level of motor performance, the findings of Dotov et al. (2010) were expanded. Scaling heterogeneity in the hand accelerations suggest that rich dynamic interactions during skillful action are what allowed the tool to be functionally integrated. This is in line with the stance that skillfully manipulated tools can be treated as parts of an extended cognitive system and that dynamic interactions temporarily bind this system together. Breakdown caused the scaling range to decrease, i.e. the interaction of the motor system with the tool decreased in complexity. Combined with the parallel changes in cognitive performance, these findings constitute a demonstration of the transition from ready-to-hand to present-at-hand and the extended cognition hypothesis.

Experimental phenomenology for the cognitive sciences

As noted above, Heidegger's phenomenology has had significant influence on cognitive science, but without much in the way of empirical confirmation of its tenets. We believe that the results reported here have consequences for the practice of the cognitive sciences. Traditionally, the cognitive sciences have focused on perception of and cognition about objects and their properties (e.g., Marr, 1982). Heidegger's phenomenology distinguishes between this kind and cognition of another variety, engaging with tools as ready-to-hand. This opens avenues of research for cognitive scientists, who can use the tools of nonlinear dynamics to explore interaction-dominant cognitive systems, in a way that has been difficult to explore using more traditional cognitivist methods. At the same time, perception of and cognition about objects and their properties (as present-at-hand) have been successfully studied with more traditional computational methods, but have been difficult to explore using nonlinear dynamics. We used traditional cognitive psychology measures and constructs (memory scores, counting rates, cognitive load) to demonstrate the present-at-hand mode. The experiments and methods described here are therefore intended as complementary to, and not as a replacement for, traditional, computational cognitive science.

Other categories of equipment exist and in the future experimental phenomenology (Dotov & Chemero, 2014) could construct different tasks in order to investigate them as well. The list of things that count as equipment according to the extended cognition hy- pothesis and that can break down in a given task comprises the physical properties of the apparatus but also the dynamical relations that make the task possible. It is important to avoid the misconception that only physical stuff such a computer mouse could play the role of equipment that gets perturbed and thus disclosed phenomenally. Note that the equipment in the current experiments is defined in Appendix A as a system of dynamical constraints that make a task space, not as the mouse.

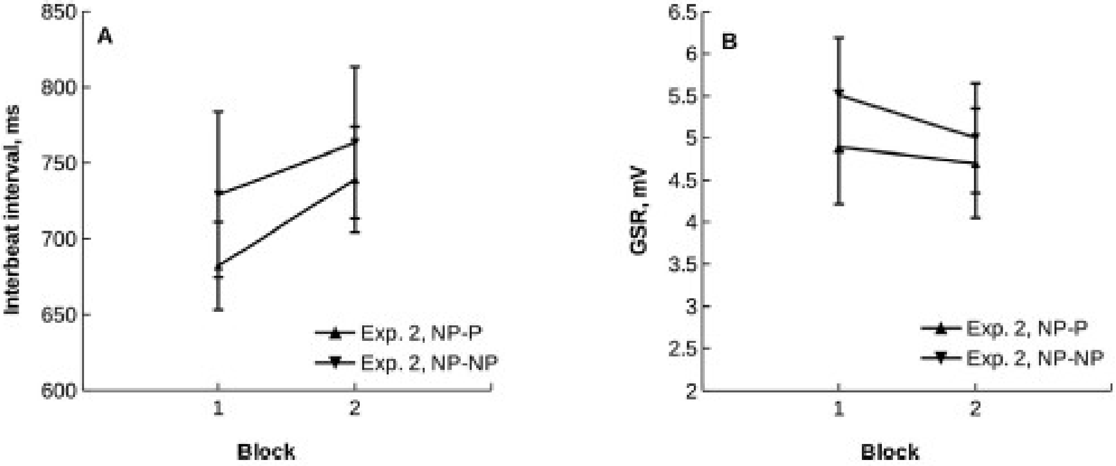

Fig. 4. Physiological response measured in the Experiment 2 summarized per group and trial block. (A) Heart rate as the average interbeat interval; (b) GSR. Error bars show standard errors.

Heidegger's phenomenology is not to be restricted to the realm of concrete physical entities such as hammers and computer mouse; being-in-the-world is much broader and is meant to illuminate various kinds of understanding, whether understanding a tool, language, or ourselves. Animal and human use of tools as material objects has been investigated within cognitive science (for review, Osiurak, Jarry, & Le Gall, 2010). Our decision to use a computer mouse and objects on the screen to instantiate a human- tool system was one of convenience, not theoretical necessity.

Finally, experimental phenomenology poses interesting new challenges to the experimentalists. Breakdown cases can disclose not only properties of the equipment but its *aboutness* too. In breakdown a user “now sees for the first time *what* the missing article was ready-to-hand *with,* and what it was ready-to-hand *for*” (Heidegger, 1962, p. 105). If phenomenology can also give us in- tuitions about how aboutness is disclosed, what sort of experimental paradigm could give empirical access to it? This is yet another reason why experimental phenomenology is an exciting new domain.

Appendix A. Task space and its dynamics

The task was described as a sheep-herding game to the participants. In fact, it consisted of trying to stabilize the following system. The whole system of targets $\mathbf{u}_k$, k = {1; …; 3}, and cursor **w**, expressed as vectors in the Cartesian coordinate system of the screen, was given by the dynamical mappings

$$
\begin{aligned}
u_{kj}[n+1] &= u_{kj}[n] + dt\left(a\left(u_{kj}[n] - w_j[n]\right) + bv_{kj}[n] + c\eta_{kj}[n]\right) \\
v_{kj}[n] &= \left(u_{kj}[n] - \frac{1}{3}\sum_{i=1}^{3} u_{ij}[n]\right)^3 \\
w_j[n+1] &= w_j[n] + dt\left(g\left(F_j[n] - w_j[n]\right)\right)
\end{aligned}
\tag{A1}
$$

here *j* = {1, 2} stands for the *x*- and *y*-dimension components, *dt* is the frame period, *a* is a gain that scales the repulsive force acting from the cursor to the targets, the term **v** with a negative parameter *b* keeps the targets in a pack, **η** is a random jitter, **F** is the mouse coordinates vector, and the gain of the cursor *g* controls the responsiveness of the cursor to the mouse.

In normal operation the gain is unity, *g* = 1. A perturbation in- volves setting *g* = 0.1 or *g* = 0 which leads the tracking object to respond sluggishly or stop moving altogether. The other parameters *a* = 0.05, *b* = -0.06, and *c* = 0.002 are held constant throughout the trial. In particular, the low value of *a* that was determined during pilot trials keeps the targets from diverging too quickly from the tracking cursor. In this way the difficulty of the basic task can be adjusted. In accord with the inverted pendulum balancing analogy the present configuration would correspond to a damped pendulum. The frames are updated at a rate of 50 fps giving *dt* = 0.02 *s*. The targets are constrained within the boundary of the designated play area.

The target escaping from the cursor was designed to resemble the fall of an inverted pole away from the unstable equilibrium at the vertical, shown in Figure A1. In particular, target location $\mathbf{u}_k$, k = {1; …; 3}, corresponds to the pole's center of mass projection on the horizontal x_G and cursor location **w** corresponds to the pivot location on the horizontal, *x*. The equation for the dynamics of the pole ca be re-written to better show the resemblance with the repulsive force linking cursor and targets. The second-order equation of motion of the inverted pole in one dimension is given for the angle relative to the vertical.

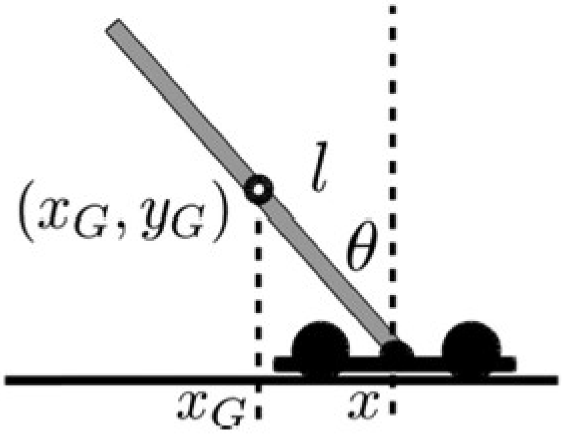

Fig. A1. An inverted pole on a cart described by its angle relative to the vertical (q), the distance from pivot to center of gravity (*l*), horizontal and vertical coordinates of the center of gravity (x_G, y_G), and horizontal coordinate of the pivot (x).

$$\dot{\theta} = \frac{g}{l}(\sin(\theta)) \tag{A2}$$

Because $\sin(\theta) = (x_G - x)/l$, where l is the length to the center of gravity, x_G is the projection of the center of gravity on the horizontal, and x is the position of the pivot relative to the horizontal, Eq. (A2) becomes

$$\dot{\theta} = \frac{g}{l^2}(x_G - x) \tag{A3}$$

The constants can be reduced to one parameter l = g/l^2.

$$\dot{\theta} = \lambda(x_G - x) \tag{A4}$$

This is written in a discrete form suitable for simulation as fol- lows. Compare the second line of this second-order dynamic to the first-order dynamic of the targets with respect to the cursor, Eq. (A1).

$$\begin{aligned} \theta_1[n+1] &= \theta_1[n] + dt\theta_2[n] \\ \theta_2[n+1] &= \theta_2[n] + dt\lambda(x_G[n] - x[n]) \end{aligned} \tag{A5}$$

Appendix B. The local singularity spectrum

The notion of singularity is essential to understanding what is meant of fractality in a time series. Singularities in a waveform are sharp turns, points of discontinuity where the derivative of the waveform is not defined. Qualitatively these can be described as broken or fractured (see Figure B1) and this is one of the reasons why Mandelbrot (1983) coined the term fractals. Individual singularities are said to have strength describing how sharp the discontinuity is. A singularity is quantified by powers of time. A Taylor series expansion would fit a smooth curve with integer powers and a singularity with non-integer, fractional, powers of time. Figure B1 shows a sample trajectory with four local singularities singled out from the rest of the waveform. The local trend at time *i* is $f(t) = s_h(- t_i)^h$; *h* is the strength and *s* scale of the local trend. For $h < 0.5$ the local trend has the shape of a cusp, the trajectory “bounces back” at point *i*. For $0.5 < h < 1$ the singularity is weak and the trajectory has the tendency to persist in the same direction. For $h = 0.5$ the trajectory has neither persistent nor anti- persistent tendencies. When $h > 1$ the curve is smoother but the same pattern is repeated but over its difference.

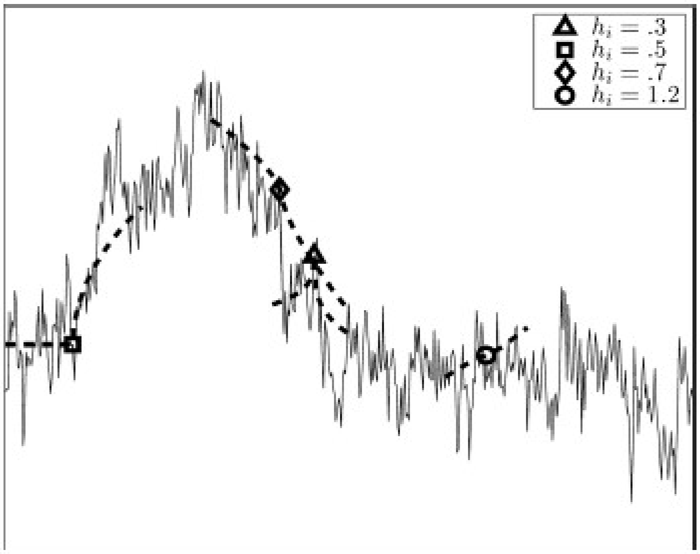

Fig. B1. A pink noise series ($h_i = 1$) was obtained numerically and four additional singularities of different strength have been superimposed additively along with their local trends traced out for illustrative purpose.

Fractal curves such as the one shown in Figure B1 are made of singularities at every point and every scale. This implies that low- amplitude singularities fit within (or are superimposed over) larger amplitude singularities. As an example, white Gaussian noise is a fractal series that is described by $h = 0.5$ at every point and every scale of observation; pink noise (1/*f*) signals are described everywhere by $h = 1$ (Muzy, Bacry, & Arneodo, 1993).

Usually fractal time series are introduced by way of the power- laws that relate a statistical property of the signal and scales over which the given property is estimated. For example, the so-called Hurst exponent is related to the exponent a in the fluctuation function of window size $F(L) \propto L^{\alpha}$. In theory and with infinite data the strength of the singularities given by the local Holder exponent h converge with the Hurst and generalized Hurst scaling exponents.

Here we used a structural approach that should make it easy to see how a time series can be *multifractal.* In particular, the characterization in terms of h can vary across time or across scale of the signal (Muzy et al., 1993). The singularity spectrum $D(h)$ then is simply a measure of the distribution of the local Holder exponents found throughout a given time series. For example, the short series in Figure B1 is $1/f$ noise (h = 1 at all times and scales) with four different local singularities of relatively large scale superimposed for demonstration purposes.

Fractal analyses based on variance and detrending are prone to reporting spurious long-range-correlations due to strong discontinuous trends such as outliers and steady level shifts (Barunik & Kristoufek, 2010). Accelerometers produce such nonstationarities (see the perturbation section of Fig. 3) consisting of sharp spikes due to a sudden push or level shifts due to change in inclination. For this reason, multifractal detrended fluctuation analysis (MFDFA) is not the ideal choice here and we should consider instead the *wavelet transform modulus maxima* (Muzy et al., 1993) method (WTMM) which has certain advantages (Dang & Molnar, 1999; Gao et al., 2006). WTMM finds the distribution of local Holder exponents of a signal by using wavelet transforms to locally isolate fluctuations by scale and remove unwanted trends that can result in spurious estimates. First, the convolution of the original series with a selected *wavelet* function is obtained in a sliding window over time-shifted (n) and amplitude-rescaled (s) copies of the kernel wavelet to obtain $W(n,s)$, the *time-scale decomposition* of the signal.

$$W(n,s) = \frac{1}{s}\sum_{k=1}^{N} x_k \psi\left[\frac{k-n}{s}\right]. \qquad \text{B1}$$

It is conventional to use a derivative (the third derivative in the present study) of the Gaussian function as a kernel wavelet (Kantelhardt et al., 2002). The modulus-maxima of these indicate the location and strength of the sought-after singularities in the series and from there a partition function *Z(s)* of the singularities for scale *s* is built.

$$Z(q,s) = \sum_{i=1}^{i_{max}} |W(n_i,s)|^q. \qquad \text{B2}$$

The whole procedure is repeated over moments *q* which “bias” the detection towards fluctuations of a smaller or larger scale. For fractal signals *Z(q,s)* is related to scale as:

$$Z(q,s) \sim s^{\hat{\tau}(q)}. \qquad \text{B3}$$

Finally, $h(q)$ is given by $\tau(q) = qh(q) - 1$ and $D(h) = minq\,[qh - \tau(q)]$ (for details consult, Kantelhardt et al., 2002; Muzy et al., 1993). Negative values of *q* stress the scaling of small fluctuations whereas positive *q* stress large fluctuations. A mono-fractal signal exhibits the same kinds of singularities at all scales and times, a single *h* is needed, hence *D*(*h*) reduces to a single point. The Hurst exponent *H* usually estimated using methods such as *detrended fluctuation analysis*, used in Dotov et al. (2010), is found inside this spectrum, $h\,(q = 2) \sim H$. All calculations described here were performed using parameters $-5 \leq q \leq 5$, $s_{min} = 2^2$, $s_{max} = 10^4$, and third-order Gaussian kernel wavelet.

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