Cockroaches, Performance, and an Audience:

Reexamining Social Facilitation 50 Years Later

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Abstract

What are the underlying mechanisms driving social facilitation? Some social psychologists have proposed that social facilitation may be driven by basic mechanisms such as the level of arousal produced by the presence of an audience, while others have ascribed it to more socially and cognitively complex drivers such as a self-aware quest for social approval. In a now seminal study, Zajonc, Heingartner, and Herman (ZHH) (1969) demonstrated that the audience effect of social facilitation was exhibited in the *Blatta orientalis* cockroach: cockroaches were faster to complete a simple task (traversing a runway) when among other cockroaches than when alone, yet slower when the task was complex (traversing a maze). This finding suggested that arousal was a likely driver of social facilitation in the cockroach (since self-aware mechanisms were unlikely to apply). It also invited consideration of the possibility that arousal may be a contributing factor to social facilitation in humans. Despite ZHH's influence, a faithful direct replication has never been attempted. Such a replication is crucial in illuminating the underlying drivers of social facilitation.

An important objective of social psychology is to understand how people's behavior is influenced by others. Indeed, this was the precise purpose of one of the earliest experiments within social psychology. Triplett (1898) found that bicyclists were faster when racing among other bicyclists than when riding alone. In a follow-up study, he supported this finding by showing that when children played a game involving a fishing reel, they reeled faster when playing with another child than when alone. This phenomenon, known as social facilitation, can be defined as improvement in individual performance when working with others rather than alone. Typically, when a person is a novice to a task (or the task is inherently complex) they will perform better when alone compared to among others. However, when a person is an expert at a task (or the task is inherently simple) just the opposite tends to be true. For example, a novice basketball player may shoot free-throws better when alone compared to when she is being watched by an audience. On the other hand, a star basketball player may improve her free throw accuracy in the presence of an audience compared to when she is practicing alone. This example has been shown empirically in both basketball (Kotzer, 2007) and pool (Michaels et al., 1982, as cited in Myers, 2012). Everyday experience suggests that it is apparent that audiences profoundly affect human performance. What is much less apparent is why this is the case. What are the underlying mechanisms that drive social facilitation?

Proposed Mechanisms for Social Facilitation

There currently exist two broad families of theories that propose underlying mechanisms for social facilitation: the arousal-based family and the self-awareness family (Steinmetz & Pfattheicher, 2017; Uziel, 2007). The arousal-based family consists of theories in which the underlying mechanisms are predicated upon arousal. This family was initiated via Zajonc's (1965) influential drive theory. Zajonc theorized that the presence of others elicits arousal, thus causing actors to revert to their dominant response. When a task is simple or performed by an expert, the dominant response is often the “correct” response. When the task is complex or performed by a novice, the dominant response is often the “incorrect” response. In subsequent years, other arousal-based theories have developed upon the key points of the drive theory (e.g. Cottrell, 1972).

The self-awareness family consists of theories in which the underlying mechanisms are predicated upon a more cognitively and socially complex driver than arousal. This consists of theories such as the theory of objective self-awareness (Duval & Wicklund, 1972) and control theory (Carver & Scheier, 1981), in which researchers posit that it is not arousal which drives social facilitation, but rather attention towards self-awareness. For example, in the control theory (Carver & Scheier, 1981), it is believed that the presence of others elicits attention to the self in order to gauge one’s performance against one’s own standards. In the presence of others, more attention is brought to conforming to this behavioral standard. When alone, less attention is brought to this behavioral standard thus causing a behavioral regression to the mean.

An Attempt to Adjudicate Mechanism: Zajonc, Heingartner, and Herman (1969)

While the control theory and other theories under the self-awareness family appear to apply when examining social facilitation in organisms such as humans or apes, they appear less applicable in the case of socially and cognitively simpler species such as cockroaches. If social facilitation could be demonstrated for such a species, then arousal-based theories are more likely to be playing a contributing role in social facilitation.

Perhaps guided by related intuitions, Zajonc, Heingartner, and Herman (1969) (hereafter, ZHH) demonstrated social facilitation in an animal as socially and cognitively basic as the cockroach. In ZHH, cockroaches traversed a simple-runway or a complex-maze, either alone or among an audience of other cockroaches. Upon commencement, they were motivated to avoid noxious floodlight with the only available respite being a darkened area at the end of the runway or the terminal end of the maze. Each cockroach ran 10 consecutive trials with the median time used to compare among conditions. We seek to replicate the key finding of ZHH: the cockroaches were inhibited by the presence of other cockroaches when in the maze (i.e. the complex task), yet facilitated when in the runway (i.e. the simple task).

Through this experiment, ZHH provided support for the drive theory of social facilitation since self-awareness was unlikely to act as an operating mechanism in cockroaches. More generally, ZHH suggested that it is at least possible that the arousal-based mechanisms may apply broadly to nearly any species exhibiting social facilitation (including humans). Importantly, however, arousal-based mechanisms need not necessarily be mutually exclusive with the self-awareness-based mechanisms. It is possible, for example, that arousal drives social facilitation effects in cockroaches, but it is only one of several mechanisms underlying social facilitation effects in humans.

The Importance of Replicating ZHH

As discussed above, ZHH purported to provide crucial evidence in support of the arousal-based drive theory of social facilitation. We propose that there are two important reasons to attempt a careful replication of ZHH: first, despite its theoretical importance, prior attempts at replications have not closely adhered to the original study’s methods and have yielded conflicting results. Second, ZHH has proven to be extraordinarily influential across multiple domains which has underscored the relevance of this study and the importance of having confidence about its truth value.

First, prior ZHH replication efforts have been conceptual and have yielded intriguing but mixed results. Two notable replications focused on centipedes and rats. Centipedes were found to be significantly faster in a simple task while in the presence of other centipedes than when alone (Hosey, Wood, Thompson, & Druck, 1985). This replication provided support for ZHH. However, results with rats and mice proved to be less clear-cut. At times these results aligned with the drive theory: rats learned a complex task faster when alone compared to within the presence of another rat (Levine & Zentall, 1974; Zentall & Levine, 1972). In other studies, however, the results diverged from the drive theory. In perhaps the closest experiment to a direct replication of ZHH, Hamrick, Coogan, and Woolam (1971) failed to find a significant interaction in mice that were in pursuit of a sucrose solution. When mice went through the complex-maze, their run time did not significantly differ when alone than among an audience of other mice. Contradictory to expectations, mice in the simple-runway were actually faster alone than when among other mice. Beyond a host of potential methodological differences between this study and that of ZHH[1], there is also recent evidence that rats and mice may exhibit a degree of metacognition greater than previously understood (Foote & Crystal, 2007; Mogil, 2019) – which suggests that social facilitation in these species may be attributable to self-awareness related mechanisms.

[1] Although similar to ZHH in some ways, Hamrick et al. (1971) featured key differences that could provide viable explanations for its failure to replicate. For one, a more complex Lashley III maze was used instead of the cross maze from ZHH, most likely due to using mice instead of cockroaches. More importantly, the researchers themselves posited that some interactions failed "due primarily to large inter-subject variability and low power due to small sample size rather than to any similarity in learning across groups" (Hamrick et al., 1971, p. 172). This issue of inter-subject variability is further magnified by the different method of subject time analysis. While ZHH used one time per subject, derived from the median of ten consecutive trials, Hamrick et al. (1971) had mice perform three consecutive trials over ten days while using the median time *from each day* for their analysis. A sample size of only six mice per group makes this issue even more apparent, affording the possibility for one mouse to have a large, unsystematic impact on the results.

Second, it is also urgently important to replicate ZHH due to the fact that it has proven to be extraordinarily influential across many domains. It is frequently included in several introductory psychology textbooks, including textbooks in: organizational psychology (Haslam, 2004), research methods (Dunn, 2009), safety management (Davies, Ross, Wallace, & Wright, 2003), learning, cognition, and motivation (Cormier, 1986), and sports psychology (Tod, Thatcher, & Rahman, 2010). Furthermore, it is also included in psychology textbooks that have been translated to multiple languages including Polish (Aronson, Wilson, & Akert, 1994/1997), French (Leyens & Yzerbyt, 1997), German (Lewin, 1986; Krämer, 2008), and Czech (Tod et al., 2010/2012). ZHH also continues to be cited in textbooks which have been published within the last five years (Stangor, 2016; Tozman & Peifer 2016) as well a forthcoming textbook (Garcia, Reese, & Tor, in press).

In addition to its nearly ubiquitous inclusion in psychology textbooks, the original ZHH paper has received several hundred citations including in realms well outside of psychology. This includes research in: biology (Clayton, 1978), biomedical informatics (Farzanfar, Frishkopf, Migneault, & Friedman, 2005), entomology (Punzo, 2007), sociology (Marshall, 2002), sports economics and science (Dewenter & Namini, 2013; Dohmen, 2008; Dohmen & Sauermann, 2016), marketing (Gaumer & LaFief, 2005), gambling issues (Rockloff, Greer, & Evans, 2012), computer science (Jørgensen, 2004), and computational mathematics (Conte, Edmonds, Moss, & Sawyer, 2001). It has even been featured in a *New York Times* bestseller (Berger, 2017).

The field of psychological research is in the midst of a replication crisis, with large scale attempts at replications often failing to replicate more often than not (Open Science Collaboration, 2015). While it is important for all research to be subject to replication attempts, it is especially imperative for studies like ZHH, which are frequently and widely discussed within scientific literature. This necessity is further compounded due to the fact that there has never been a faithful attempt at a direct replication over the 50-year longevity of this seminal work.

Proposed Method

Materials

The materials will be developed and used as similarly as possible to that of ZHH with the only necessary changes being due to a lack availability of certain construction materials from the 1960s, or due to a lack of clarity on a small number of procedural items from ZHH (all three authors are deceased which precludes opportunities for direct clarifications). A full list of procedural comparisons with the original ZHH is listed in Table 1. The original study used a 20-inch clear plexiglass cube that housed either a straight runway going across the length of the box (Fig 1a), or a maze consisting of two runways that intersected perpendicularly (Fig 1b).

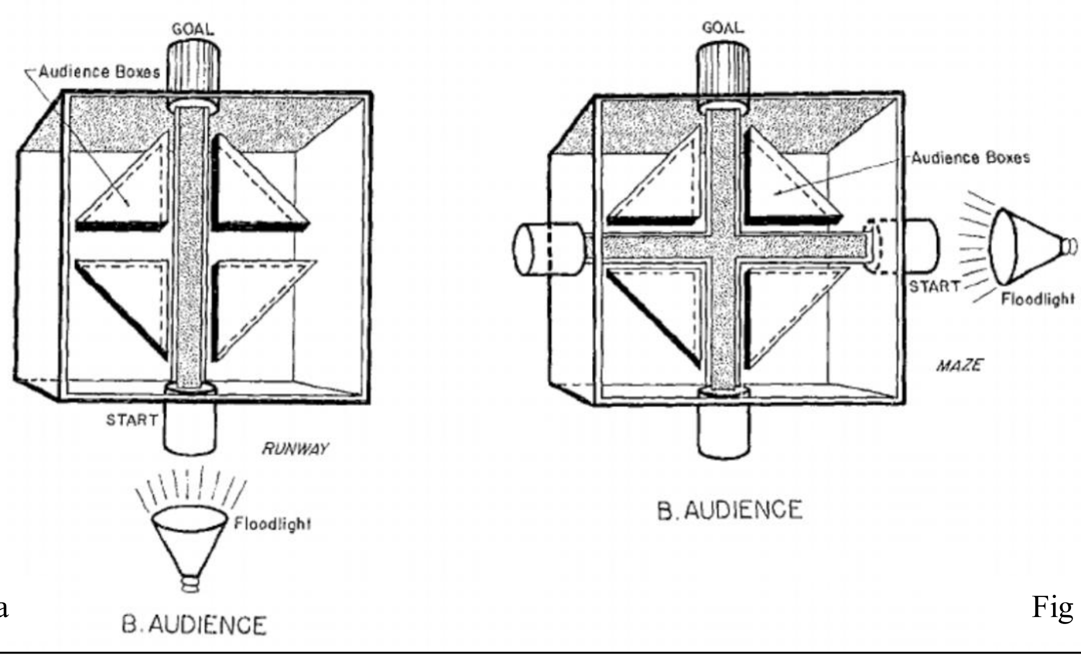

Fig 1a Fig 1b

Figure 1: Illustration of maze used as shown in Zajonc, Heingartner, and Herman (1969).

At 8.25 inches from the top of each vertical cube wall was an opening of 1.75 inches by 0.75 inches which was where the inner runway or maze connected exterior boxes for the cockroaches to either begin or end the experiment. Space between these allowed for a guillotine gate made of sheet metal in order to "open" or "close" the runway or maze from the boxes. Each goal or starting box was made of clear plexiglass, with the goal box being darkened in order to offer respite from the noxious light (described below). The runway and maze themselves were rectangular, created using black bakelite flooring 2 inches wide, clear plexiglass walls 1 inch high, and clear plexiglass covering 0.125 inches thick. The length of each runway mirrored the interior length of the box (20 inches) while the maze was two intersecting runways and thus each "leg" of the maze was 9 inches long with a 2 inches by 2 inches crossroads interior. In identical positions, both the runway and the maze contained four "audience boxes" which were rectangular boxes cut diagonally, thus being 9 inches wide by 9 inches long in order to go along the full length of each wall of the maze (or the majority of the runway wall) and 1 inch tall in order to fit perfectly with the height of the runway wall or maze wall. Clear plexiglass was used for all faces of these except for the flooring which was made of black bakelite. Each wall of the audience boxes fit directly along the runway or maze with corresponding air holes along both walls to allow for cockroaches to have olfactory awareness of one another. On the exterior of the boxes by the openings were square flanges and sets of tracks to allow for ease of replacing cockroaches and boxes. Finally, ZHH utilized a 150-watt floodlight set 10 inches directly behind the start box to facilitate the movement of the cockroaches.

The runway, maze, and its encompassing box will use the descriptions and schematics from the original paper described above, and we will attempt to create a nearly identical copy of the original materials with the following minor, but necessary, differences: while ZHH used clear plexiglass for the majority of the runway, maze, and audience boxes, they utilized black opaque bakelite plastic for the actual flooring for the cockroaches and alcohol to swab it between trial sets. Due to the present rarity and price of this type of plastic, black opaque acrylic will be used for the floorings instead with an acrylic-specific solution to swab them between trial sets.

The acrylic-specific solution (Brillianze) will be utilized instead due to the tendency of pure alcohol to crack plexiglass. This solution is a silicon-based product whose known ingredients have been shown to have no ill effects on the cockroach. Further, it is thought to be as effective as alcohol as a cleaning agent.

Though ZHH never clearly specified how the runway or maze were held above ground as to fit the center wall openings, we will utilize hinge-like pieces fastened along the interior to keep them suspended. Additionally, a simplified version of the tracks and flanges on the exteriors of the walls, as well the corresponding sheet metal guillotine, will be used in order to facilitate the replacement of cockroaches and boxes. Finally, while the dimensions of the runway and maze are well detailed, ZHH does not provide more detail about the noxious stimulus beyond it being a 150-watt floodlight. Due to the popularity of halogen-tungsten incandescent bulbs in floodlights in the 1960s, which tended to have an output of 20 – 26 lumens per watt, we estimate that the original floodlight had an output between 3,000 to 3,900 lumens (Gendre, 2003). However, in part due to the Energy Independence and Security Act of 2007, most of these types of bulbs have been phased out due to their inefficiency and price. Thus, we will use an LED-based floodlight set to have the same lumen output. A detailed visual schematic of our planned recreation of the box is available upon request.

Participants and procedure

The following proposed procedure exactly repeats the audience effect process of ZHH's Experiment 1: the cockroaches will traverse either a simple-runway (Fig 1a) or complex-maze (Fig 1b). Within both the runway and maze, half of the cockroaches will perform while in the presence of other cockroaches housed in "audience boxes", while the other half will perform while alone. Among all conditions, the cockroaches will begin their trial by being placed in the start box, the barrier that separates the start box from the runway or maze will be removed, and the noxious floodlight will be turned on. Running 10 consecutive trials with 1 minute between each, cockroaches will be timed from the opening of the barrier to the moment their last leg passes into the goal box. We will terminate each trial just as was done in ZHH, at the end of 5 minutes or 'immediately after the roach's last leg crossed the entrance of the goal box' (ZHH, p. 87). The median time across the 10 trials will be used as each cockroach's time.

Between each trial the runway or maze will be cleaned and given time to evaporate. The same will be done for the starting and goal boxes, except they will be cleaned between each trial set. ZHH may have swabbed the apparatus with alcohol between trial sets as a means to remove any "chemical traces" that could be picked up between participants. A similar explanation was provided by Gates & Allee (1933), a paper that influenced ZHH, and more recently by Rivault, Cloarec, & Streng (2002). Another potential factor, brought to our attention by an anonymous reviewer of this manuscript, concerns the tendency of cockroaches to "spit" as a stress response, which may also unduly influence the behavior of future participants.

Beyond chemical traces, electric fields at 1 kV (or a modeled field of 8-10 kVm^{-1}) have been shown to elicit an avoidant response in the cockroach (Newland et al., 2008). However, ZHH never mentioned recording the electric field during their experiment, so we are unable to be sure that we are exactly equal in electric field reading. We can, however, ensure that the presence of an intrusive electric field will not be present during our study by using an electrostatic field meter to show that no area exceeds the threshold of 1 kV. Additionally, our initial observations suggest that the actual electric fields in the experimental area will be negligible. Nonetheless, we will also use the silicon-based Brillianze to clean the apparatus which is often used to remove electric charges from acrylic in addition to being used to remove potential chemical traces left by participants.

For both the runway and maze conditions, the goal box will be darkened thus offering the best respite from the noxious stimulus. The entirety of the wall containing the goal box will be covered by a black poster board. For all audience condition trials 10 cockroaches will be placed in each of the four audience boxes. Following ZHH, we too will utilize the adult female Oriental Cockroach (*Blatta orientalis)* for both the audience and participant pools. Additionally, housing and familiarity of cockroaches will be done just as was done in ZHH. Though all cockroaches will be adult female Oriental Cockroaches, the ones used to fill the audience boxes will come from a different colony and housed differently than those participating in running the mazes. The audience cockroaches, which will remain consistent throughout all audience conditions, will be housed "in common quarters of the laboratory colony" (ZHH, p. 87). Cockroaches participating in the experimental conditions, however, will be "housed in individual mason jars supplied with screened lids. They [will be] maintained in dark quarters with a relatively constant temperature of about 75 degrees Fahrenheit. The insects [will be] fed an ad libitum diet of peeled and sliced apples" (ZHH, p. 86).

Table 1 summarizes the process of replicating every detail of ZHH. While most details match exactly, there was certain content that the original researchers were not specific about. We addressed these via accessing expertise opinions on insect behavior (including an entomologist who is a co-author on this paper).

Table 1

List of Procedural Comparisons between ZHH and the Present Work

Procedure	ZHH	Same?	Present Work
Species	Oriental Cockroach (*Blatta orientalis)*	Yes	
Housing (Audience)	Common quarters	Yes	
Housing (Participants)	Individual mason jars	Yes	
Apparatus Schematics	See article	Yes	
Sex	Female	Yes	
Age	Adults	Yes	
Number of Cockroaches (Audience)	10 in each audience box	Yes	
Familiarity of Audience-Audience	Familiar (from same colony)	Yes	
Familiarity of Audience-Participant	Unfamiliar (from different colony)	Yes	
Operational Definition of Finished Trial	Last leg of cockroach fully crossing the goal line	Yes	
Apparatus Materials	Bakelite and plexiglass	Partly	Just plexiglass
Light Output	150 Watts	Partly	Similar estimated lumens output
Apparatus Cleaning	Alcohol	No	Brillianze (Acryllic-specific cleaner)
Number of Cockroaches (Participants)	10 per group	No	102 per group
Static Field	Unknown	Unknown	Below 1kMv (or modeled 8 kMv^{-1})

Power analysis

The original experiment used 10 adult female Oriental cockroaches per group, totaling 40 cockroaches for the intended interaction. However, after calculating the effect size of the original interaction ($\eta^2 = 0.025$) and conducting an a priori power analysis through the program G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) at 90% power, it was evident that the original study was underpowered. Specifically, it revealed that we would require 102 cockroaches per group, totaling 408 cockroaches for the entire interaction, in order to appropriately attempt a replication.

Analysis

In ZHH, the original study design was a 2 (audience present or absent) by 2 (task complexity simple or complex) by 2 (coaction present or absent) between-subjects design. We will conduct the same analyses of variance as the original study excluding the coaction aspect of the study. This will be a 2 (audience present or absent) by 2 (task complexity simple or complex) between-subjects ANOVA. As aforementioned, the conceptual replications up until now have varied widely. In the case of this proposed direct replication, a full replication of results would be for the cockroaches to be slower to finish the simple-runway than the complex-maze when among an audience, yet faster when alone. The design of this analysis allows for a variety of results to occur and be aptly interpreted.

Potential Implications of Replication Outcomes

A replication of ZHH would not be enough to definitively conclude that arousal is the driver of social facilitation in cockroaches *and* humans. Rather, it would demonstrate that arousal is a viable mechanism for social facilitation and is presently the single most parsimonious explanation of the phenomenon. Whether arousal is subsumed as one of multiple potential drivers, or completely replaced by a distinctively different driver, is an important issue which requires future empirical studies in addition to the presently proposed replication of ZHH. Additionally, a targeted metanalysis of the extant animal research could further complement a replication of ZHH by providing insight as to where these potential drivers begin to take effect.

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