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FURTHER ANALYSIS OF SUBTYPES OF AUTOMATICALLY REINFORCED SIB: A REPLICATION AND QUANTITATIVE ANALYSIS OF PUBLISHED DATASETS

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Abstract

Hagopian, Rooker, and Zarcone (2015) evaluated a model for subtyping automatically reinforced self-injurious behavior (SIB) based on its sensitivity to changes in functional analysis conditions and the presence of self-restraint. The current study tested the generality of the model by applying it to all datasets of automatically reinforced SIB published from 1982 to 2015. We identified 49 datasets that included sufficient data to permit subtyping. Similar to the original study, Subtype-1 SIB was generally amenable to treatment using reinforcement alone, whereas Subtype-2 SIB was not. Conclusions could not be drawn about Subtype-3 SIB due to the small number of datasets. Nevertheless, the findings support the generality of the model and suggest that sensitivity of SIB to disruption by alternative reinforcement is an important dimension of automatically reinforced SIB. Findings also suggest that automatically reinforced SIB should no longer be considered a single category and that additional research is needed to better understand and treat Subtype-2 SIB.

Keywords

automatic reinforcement; functional analysis; self-injurious behavior

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's website.

Decades of research have shown that self-injurious behavior (SIB) is socially mediated in most cases, but that it also occurs independent of social variables in 20% to 25% of individuals (Beavers, Iwata, & Lerman, 2013; Kahng, Iwata, & Lewin, 2002). The term automatic reinforcement is used to describe this functional class of SIB because the behavior itself is thought to produce its own reinforcement (Vollmer, 1994). Although there is general consensus regarding the indicators of SIB maintained by automatic reinforcement, our understanding of automatically reinforced SIB is quite limited (LeBlanc, Patel, & Carr, 2000; Vollmer, 1994). Hagopian, Rooker, and Zarcone (2015) proposed and conducted a preliminary evaluation of a model for subtyping automatically reinforced SIB with 39 hospitalized individuals. They based three proposed subtypes on distinct patterns of responding during the functional analysis (FA) and the presence or absence of self-restraint. They categorized automatically reinforced SIB as: (a) Subtype 1, when SIB was highest in the no-interaction (or alone) condition and lowest in the play condition ($n = 16$ or 41.0% of cases); (b) Subtype 2, when SIB was high and variable across all FA conditions ($n = 15$ or 38.4%); or (c) Subtype 3, when SIB was automatically reinforced and there were high levels of self-restraint (a behavior that interferes with the occurrence of SIB; $n = 8$ or 20.5%).

Hagopian et al. (2015) hypothesized that varying levels of differentiation of SIB in the FA conditions, along with the presence (or absence) of self-restraint, could be used to delineate three subtypes of automatically reinforced SIB with unique functional properties. They also hypothesized that these subtypes would show differential responsivity to reinforcement-based interventions and tested this hypothesis using data collected from these participants with automatically reinforced SIB. They also compared the treatment results obtained with these individuals to 13 individuals with SIB maintained by social reinforcement (e.g., attention).

As predicted, Subtype-1 SIB proved more responsive to treatment relative to Subtypes 2 and 3, based on results of competing-stimulus-assessment outcomes, reductions in SIB obtained with first-line treatments (i.e., using reinforcement alone), and the extent to which more restrictive treatment components proved necessary to reduce SIB by 80% relative to baseline. They also observed a strong correlation between the levels of differentiation in the FA and the effectiveness of the first-line treatment involving reinforcement. Finally, they found Subtype-1 SIB and socially maintained SIB to be comparably responsive to treatment using reinforcement alone. Reinforcement alone reduced SIB by at least 80% in 8 of 12 (75.0%) cases with Subtype-1 SIB and in 11 of 13 (84.6%) cases with socially maintained SIB. By contrast, Subtype-2 and -3 SIB showed considerably more resistance to reinforcement-based treatment (reinforcement alone reduced SIB by at least 80% in 0 of 7 cases with Subtype-2 SIB and could not be attempted without restraint with any Subtype 3 cases).

The results of Hagopian et al. (2015) provide considerable empirical support for the proposed subtyping model; however, all of the participants were individuals admitted to an inpatient unit specializing in the treatment of exceptionally severe destructive behavior. As such, it remains unknown whether the results are representative of the larger population of individuals who display automatically reinforced SIB. The purpose of the current study was

to test the generality of the proposed subtyping model, including findings related to differential response to treatment, by using additional participants drawn from a wider variety of settings and described by other researchers. Thus, we replicated the procedures in the original study with every published dataset of automatically reinforced SIB described in the literature between 1982 and 2015 for which there were sufficient FA data to enable us to apply the subtyping criteria. We also tested the generality of the findings with regard to how subtypes differed in their response to treatment (for cases in which treatment data were available).

METHOD

Article Search and Selection Procedures

We identified studies by searching Google Scholar, Pubmed, and Web of Science for any article published after 1982 that contained the following terms “self-injur* AND automatic reinforcement”, “SIB AND automatic reinforcement”, “self-injur* AND sensory”, “SIB AND sensory”, “self-injur* AND nonsocial”, “SIB AND nonsocial”, “self-injur* AND undifferentiated”, “SIB AND undifferentiated”, “self-restrain* AND self-injur*”, and “self-restrain* AND SIB.”

We excluded discussion articles containing previously published data on SIB. We included studies describing all topographies of SIB except hand mouthing, because this behavior is not injurious in many cases. We excluded data sets if the authors did not include an FA in the manuscript, or if the authors stated that SIB was maintained by social reinforcement. We retained any dataset for which the authors concluded that SIB was maintained by “automatic reinforcement,” “nonsocial reinforcement,” or “sensory stimulation.” If the authors described the FA outcome “undifferentiated,” we reviewed the dataset further to determine if it met criteria for inclusion. These criteria required that an FA of SIB containing at least three series of play and alone (or no interaction/ignore) sessions was conducted and each data point was graphically depicted. We also required that the experimenters collected interobserver agreement (IOA) for at least 20% of FA sessions (or across the FA and treatment, if they did not report separate measures of IOA). Among the datasets that met our inclusion/exclusion criteria, we also included treatment data if the experimenters: (a) presented a distinct baseline and treatment phase with at least three data points in each phase; (b) demonstrated experimental control of the treatment using a single-subject experimental design; and (c) collected IOA data during at least 20% of treatment sessions. Thus, we included only original research articles on SIB with sufficient data and experimental control to permit a quantitative analysis.

One study reported more than one FA for an individual (Barry, in Ringdahl, Vollmer, Marcus, & Roane, 1997) and a number of studies reported more than one treatment analysis for a given participant (e.g., Piazza, Fisher, Hanley, Hilker, & Derby, 1996). In such cases, we retained each FA and each treatment analysis that met our inclusion/exclusion criteria. Therefore, we report the results in terms of the number and/or percentage of data sets (or applications) where applicable.

Demographic Information

For the included datasets, we collected available demographic information on gender, age, level of intellectual disability, autism diagnosis, and the topography or topographies of SIB. We classified topographies of SIB using the categories included in Hagopian et al. (2015). Briefly, these categories of SIB included: body-directed (responses that targeted the body [excluding the head], including hitting, banging, or kicking another body part); head-directed (responses that targeted the head, including hitting, banging, or knee to head); mouth-directed (responses that targeted the inside of the mouth or teeth); and skin-directed (responses that targeted the skin, including biting, picking, or scratching at skin on any part of the body). In many of the identified studies, additional topographies of problem behavior (e.g., aggression or disruption) were not reported; therefore, we did not include these categories in the current analysis.

Digitizing Graphs for Data Extraction

For the datasets that met inclusion criteria, we extracted all relevant data points (FA and treatment) using GetData (Federov, 2013) graph digitizer (Version 2.26), a computer program that allows the digital conversion of graphed data points to data values. Investigators have previously used this program to extract data for behavior-analytic publications (Bowman-Perrot, Burke, Zaini, Zhang, & Vannest, 2015) and in other fields such as oncology (Ma et al., 2015; Zhou et al., 2015) and bio-technology (Prieto, Vázquez, & Murado, 2014).

To extract data point values for the current study, we first copied each graph from an electronic version of the manuscript and converted the copied image to a picture file. Next, we uploaded the picture into the GetData program. Following this, we established the *x*- and *y*-axes values based on the values present on the graph, the location of relevant data points (using a point and click method with mouse), and the value of each plotted data point was identified by the program. Once we obtained these values, we reviewed the study procedures to determine the session duration and method of data collection. For datasets depicting rate or percentage of intervals data we rounded each GetData obtained value to the closest possible value given the reported session duration and data collection method. For example, if the article reported that sessions lasted 10 min and responses-per-min (RPM) data were reported, we rounded to the nearest tenth decimal place (e.g., 4.59 was rounded to 4.6 RPM). We used the values obtained by the GetData program without modification for one dataset for which duration data were collected and for five for which session duration was either not reported or reported as a range (e.g., 5 to 10 min).

Functional Analysis and Treatment Data

We analyzed the FA and treatment data in a manner identical to that described by Hagopian et al. (2015). Once the GetData program generated the data values for each graph, we calculated the mean rate (or mean percentage of intervals) of SIB in the alone (or no interaction) and play conditions of the FA. For treatment datasets, we calculated the mean rate (or percentage of intervals) of SIB in baseline and each treatment condition using the last five data points in each condition; we used all data points if there were fewer than five in the phase. We calculated the percentage reduction resulting from the treatment using mean

rate, percentage of intervals, or duration during baseline and the same data in the final implementation of that treatment. In addition, we classified the treatment components into the following categories: reinforcement, reinforcement with protective equipment (e.g., a helmet), reinforcement with blocking (i.e., a therapist physically prevented SIB by interfering with each instance, but otherwise not restricting movement), reinforcement with punishment (e.g., a 30-s baskethold), reinforcement with restraint (i.e., devices that limited movement and/or physically prevented the occurrence of behavior such as arm splints), or reinforcement with multiple components (i.e., more than one of the previously listed treatments).

Identification of an Automatic Function

We used structured criteria to interpret FA results and confirm whether SIB was maintained by automatic reinforcement. Specifically, we classified SIB as maintained by automatic reinforcement if: (a) SIB was differentiated in the alone (or no interaction) condition in comparison to the control condition, or (b) the mean rate of SIB was high across all conditions and greater than 1.5 RPM or 15% of intervals in the alone or no interaction condition. Because Hagopian et al. (2015) identified a relation between subtype and treatment outcome, raters in the current study remained blind to treatment outcomes for all datasets during the FA data review and interpretation process.

Identification of Automatic Subtype

Once we determined that SIB was automatically reinforced, we further scored FAs to identify the subtype of SIB using procedures described by Hagopian et al. (2015). First, scorers drew an upper and lower criterion line (UCL and LCL, respectively) using the play condition. Next, the observers subtracted the number of points in the alone condition that were below the LCL from the number of points above the UCL. They then converted this value to a subtype quotient score by dividing it by the number of alone sessions. We categorized SIB as Subtype 1 if the subtype quotient score was greater than or equal to 0.5. This means that the results of the FA displayed clear differentiation between the alone and play conditions, with lower rates of SIB occurring in the play condition. We categorized SIB as Subtype 2 if: (a) the subtype quotient was less than 0.5, (b) more than 30% of the data points were overlapping between the play and alone conditions, or (c) the mean rate of SIB was more than 50 responses per min (or in 75% or more of intervals in studies where partial-interval data were recorded) in both the play and alone conditions. Thus, to be categorized as Subtype 2, SIB occurred at markedly high levels regardless of the level of stimulation or environmental conditions. SIB was categorized as Subtype 3 if: (a) self-restraint occurred in at least 25% of 10-s intervals (using partial-interval recording) for at least three series of the alone condition of the FA, and (b) SIB was maintained by automatic reinforcement (which, in some cases, was revealed only after self-restraint was blocked).

We encountered patterns of findings in a number of published FA datasets that we did not encounter in the FA datasets included in the original study (Hagopian et al., 2015), which necessitated the development of two additional criteria. The first involved including data from extended alone or no-interaction sessions to calculate the quotient score for datasets in which results obtained during the multielement phase of the analysis led to contradictory

conclusions about subtype. We identified four FA datasets in which SIB was generally low in the play condition, but variable and high in the alone (or no-interaction) condition; thus, SIB was differentiated across these conditions (characteristic of Subtype-1 SIB), yet the quotient score was less than 0.5 (indicating Subtype-2 SIB). Therefore, we used the extended series of alone or no-interaction sessions that were not alternated with play sessions to calculate the subtype differentiation quotient (Bobby, from Camp, Iwata, Hammond, & Bloom, 2009; Michael, from Dozier et al., 2007; Betty, from Garcia & Smith, 1999; Barry's skin directed behavior, from Ringdahl et al., 1997). The second new criterion involved discounting a single aberrant data point that deviated by more than 1 SD from the mean of the play condition for data-sets for which the presence of that aberrant data point resulted in subtype classification that appeared to contradict the overall pattern of results. We applied this rule with two data-sets, one in which the aberrant data point was low (1.6% of 10-s intervals), whereas the others in the play condition ranged from 33% to 98% ($M = 48.3\%$), and one in which the aberrant data point was high (4.5 RPM), whereas the others ranged from 0 to 2.8 ($M = 1.08$).

The formal criteria described above are complex, but they represent an objective method for subtype classification that can be replicated and used for research purposes. However, subtyping can also be determined based on less formal visual inspection that considers the level of differentiation between the play and alone condition of the FA. Blind to subtype classification, the first author conducted visual analysis of each FA graph based on the general principles underlying the formal criteria. Level of agreement with subtype classification between visual analysis and formal quantitative criteria was 100%.

Socially Reinforced SIB Comparison Group

To find a suitable comparison group, we conducted a search of articles to identify a similar number of datasets wherein socially reinforced SIB was assessed and treated. Carr, Severtson, and Lepper (2009) conducted a review of treatment studies using noncontingent reinforcement (NCR) that included 24 articles reporting on 58 datasets with socially reinforced SIB. This study summarized all published cases of the use of NCR, including effective and ineffective applications of this treatment. Of these datasets, 13 FAs (for 12 individuals) targeted only SIB and met the criteria described above for inclusion (e.g., FA contained three series, sufficient IOA). We scored these 13 FAs using the structured criteria for FA interpretation described above using the relevant social condition to confirm they met criteria for a social function. Additionally, treatment data were available for 12 of these datasets.

Interrater Agreement

Two independent raters scored each FA using the structured criteria and subtyping criteria described above for 24.9% of the automatically reinforced SIB datasets and 28.5% of the socially reinforced SIB datasets. These raters agreed on behavioral function and subtype classification for 100% of datasets.

In addition, our raters agreed with the study authors' interpretation of each FA described in each article pertaining to automatic reinforcement for 46 of 48 datasets (95.8%). For one

dataset (Colin, in Magnusson & Gould, 2007) the structured criteria did not correspond to the author's interpretation of automatic reinforcement because SIB occurred at extremely low rates (e.g., the rate of SIB was zero for 40% of the alone conditions); for another (Timon, in Van Camp et al., 2000), the structured criteria did not correspond with the authors' interpretation because SIB only occurred in the presence of a certain toy (see Supporting Information), raising the possibility that the toy occasioned SIB (the authors suggested that the toy and SIB functioned as complementary reinforcers). We identified three FA datasets for which the structured criteria implicated an automatic reinforcement function, but the study authors characterized the FA results as undifferentiated (Gilda, from Garcia & Smith, 1999; Korey, from Vollmer, Marcus, Ringdahl, & Roane, 1995; Andy, from Smith, Iwata, Vollmer, & Pace, 1992).

RESULTS

Search Results and Selection of Datasets

Identification of studies reporting on automatically reinforced SIB—The initial search yielded 261 articles. Of these, we eliminated 120 because either they were not data-based studies or the target behavior of interest was not SIB. We evaluated each of the remaining 141 articles to determine if the authors conducted an FA and concluded that SIB was maintained by “automatic reinforcement,” “nonsocial reinforcement,” “sensory stimulation,” or that the FA was “undifferentiated.” Based on these criteria, we eliminated an additional 95 articles, leaving 46. We used the structured criteria (described in the Method section) to determine if SIB was maintained by automatic reinforcement for each of the 77 datasets described in the 46 articles.

Identification of datasets that allowed for subtype classification—We examined and retained datasets from the remaining 77 only if it was possible to apply the subtyping criteria. In total, 49 datasets reported in 31 studies had sufficient FA data to allow for application of the subtyping criteria. Thus, 28 of the 77 identified FA datasets were excluded (see Excluded Datasets below). The final sample of 49 datasets includes cases in which FA data were obtained from individuals in residential programs (5), vocational programs (3), schools (14), inpatient units (6), and outpatient clinics (13), and includes eight cases in which the setting was not described. Lead authors of articles from which data sets were obtained were affiliated with 15 different institutions, including the Kennedy Krieger Institute. None of the datasets identified in the search were included in the original subtyping study by Hagopian et al. (2015).

Identification of datasets with sufficient treatment data—For 20 individuals with automatically reinforced SIB, we identified 38 treatment applications that met criteria for inclusion (sufficient level of detail for categorization, used experimental designs, and had an adequate number of data points). Of these 38 treatment applications, 20 targeted Subtype-1 SIB and 18 targeted Subtype-2 SIB. In addition, among the 20 individuals who received treatment for automatically reinforced SIB, 17 received a treatment that involved the delivery of reinforcement alone. With these 17 individuals, reinforcement alone was implemented in 30 applications. That is, many of these individuals received multiple, unique

reinforcement treatments; reinforcement alone was attempted 17 times for Subtype-1 SIB, and 13 times for Subtype-2 SIB. One of these 17 individuals had both Subtype-1 and Subtype-2 SIB, and the researcher implemented reinforcement alone separately for each subtype (Barry, in Ringdahl et al., 1997; this unique case is discussed further below). For the remaining three individuals, we excluded their treatment data from our results because the intervention consisted of protective equipment alone or extinction alone (without reinforcement). In these cases, it was not possible to determine if reinforcement alone would have been effective—and therefore the use of these procedures does not provide any indication of how resistant SIB was to disruption by alternative reinforcement.

Subtype Classification

Of the 49 datasets identified with automatically reinforced SIB, 25 met criteria for Subtype 1 (51%), 22 for Subtype 2 (44.9%), and 2 for Subtype 3 (4.1%). Because Barry (from Ringdahl et al., 1997) had both Subtype-1 and -2 SIB, we included both assessment datasets. Subtype quotient scores averaged 0.77, 0.13, and -0.31 for Subtypes 1, 2, and 3, respectively. As reported in the original study, we found Subtype 1 to be the most common subtype, followed by Subtype 2, and then Subtype 3. We found a higher percentage of Subtype-1 SIB cases in the current study relative to Hagopian et al. (2015; 51% vs. 41%, respectively) as well as a slightly lower percentage of Subtype-2 SIB cases (44.9% vs. 38.5%, respectively). Subtype-3 SIB proved to be quite rare among published cases that met criteria for inclusion.

Demographic Variables

Table 1 summarizes demographic data for all cases included in this study. Data are reported separately for each subtype of automatically reinforced SIB, for all cases of automatically reinforced SIB in total, and for the social reinforcement comparison group. Whereas Hagopian et al. (2015) found a male-to-female ratio of 4:1 for Subtype-2 SIB and 2:1 for Subtypes 1 and 3, we found no notable gender differences in the published cases. In addition, Hagopian et al. found more significant intellectual impairments associated with Subtype-3 SIB relative to the other subtypes, but we found those with Subtype-2 SIB to have more significant intellectual impairments—however, the level of functioning was not reported for 18% of those individuals.

Excluded Datasets

The 28 FA datasets that were excluded are described in Supporting Information. For 22 of the excluded datasets, results suggested SIB was maintained by automatic reinforcement, but the amount of data or the manner in which the authors presented the data precluded application of the subtyping criteria. However, we believe that a specific subtype could be plausibly inferred for these datasets. For four of five datasets in which the FA data consisted of fewer than three points per condition, the results showed sufficient consistency such that a subtype could be plausibly inferred (two as Subtype-1 SIB, and two as Subtype-2 SIB, respectively). For 17 of 19 datasets in which the authors summarized the FA data as mean rates of SIB per condition (either in a bar graph or table), differences across conditions were extreme enough that a subtype could be plausibly inferred (14 as Subtype-1 SIB, and 3 as Subtype-2 SIB, respectively). For one case described across two separate studies (an original and a follow-up study; Banda, McAfee, & Hart, 2009, 2012), Subtype-3 SIB seemed

plausible based on the authors' description that self-restraint occurred "almost continuously," though the authors did not present self-restraint data. These FAs could be considered to be plausible datasets of automatically reinforced SIB, and we therefore summarized them in the Supporting Information to document their presence in the literature and also to document why they did not meet criteria for subtyping. If we added these datasets to the more definitive datasets, we would have a total of 71 datasets with automatically reinforced SIB: 41 with Subtype 1 (57.7%), 27 with Subtype 2 (38%), and 3 with Subtype-3 SIB (4.2%). Because these plausible datasets did not meet our formal criteria for subtyping, we did not include them in the analyses summarized below.

Functional Analysis Results

Table 2 summarizes FA outcomes for each dataset, sorted by subtype. Data presented include the primary author of the study, the participant identifier, the mean rate (or percentage of intervals of occurrence) of SIB in the alone or relevant social test condition and play condition of the FA, mean percentage of self-restraint, and the percentage differentiation between the play and test condition for each dataset in each study. Consistent with Hagopian et al. (2015), Subtype-2 SIB showed the highest response rates in the play condition ($M = 5.0$) followed by Subtype 1 ($M = 1.1$), and then socially-reinforced SIB ($M = 0.6$). Because only one Subtype-3 SIB dataset was based on rate data, we did not include that dataset in the following comparisons. A nonparametric ANOVA using the Kruskal-Wallis test revealed a significant difference between groups in the rate of SIB during the play condition ($K = 24.02, p < .0001$). A Dunn's multiple-comparison post-hoc test identified significant differences in the rate of SIB in the play condition between Subtypes-1 and -2 SIB ($p < .0001$), and between Subtype 2 SIB and socially-reinforced SIB ($p < .0001$), but not between Subtype-1 SIB and socially-reinforced SIB. These results replicated those reported in Hagopian et al. (2015). Authors reported the percentage of intervals of occurrence of SIB (instead of rate) for 30.6% of datasets ($n = 16$): seven cases with Subtype-1 SIB, and seven with Subtype-2 SIB, one with Subtype-3 SIB, and one with socially-reinforced SIB. The mean percentage of intervals of SIB in the play condition was higher for Subtype-2 SIB ($M = 35.1\%$) than for Subtype-1 SIB ($M = 11.8\%$). Statistical analyses were not performed given the small sample size (however, subtype differences in the percentage of interval data generally correspond to differences in rate data). Because only one Subtype-3 SIB dataset and one socially reinforced SIB dataset were based on percentage of intervals, those datasets are not presented for comparison.

Figure 1 depicts the percentage of differentiation between the play condition and the relevant test condition for each dataset, as well as the mean for each subtype, for both the current replication study and the original study (i.e., Hagopian et al., 2015). As was reported in the original study, differentiation was generally high for Subtype-1 SIB ($M = 84.4\%$; range, 48.6% to 100%) and for socially-reinforced SIB ($M = 89.5\%$; range, 40% to 100%). We observed lower levels of differentiation with FA data sets involving Subtype-2 SIB ($M = 6.9\%$, range, -65% to 46%) and Subtype-3 SIB ($M = 48.5\%$, range, 14.7% to 82.2%). A nonparametric ANOVA Kruskal-Wallis test revealed a significant difference in the level of differentiation between groups ($K = 42.49, p < .0001$). Consistent with the results reported by Hagopian et al., a Dunn's multiple-comparison post hoc test identified significant

differences between Subtype-1 SIB and Subtype-2 SIB ($p < .0001$), and between Subtype-2 SIB and socially-reinforced SIB ($p < .0001$), but not between Subtype-1 SIB and socially-reinforced SIB. Due to the small group size, we did not conduct statistical analysis with Subtype-3 datasets.

Resistance to Treatment

Behavioral interventions for automatically reinforced SIB typically begin with the use of reinforcement alone, and more intrusive components are added as needed to reduce SIB to clinically acceptable levels. Thus, response to reinforcement and the use of more intensive interventions provide a reasonable (albeit indirect) measure of resistance to treatment. Figure 2 shows the attempted and successful applications of various treatments across subtypes. For 20 individuals with automatically reinforced SIB, researchers reported a total of 38 treatment applications, 30 of which involved reinforcement alone. Reinforcement alone effectively reduced Subtype-1 SIB by 80% or greater in 16 of 17 applications (94.12% of applications); blocking, restraint, and multicomponent treatments were never used. Subtype-2 SIB showed the greatest resistance to treatment, as reinforcement alone produced an 80% or greater reduction in SIB in only 1 of 13 applications (7.7%); more intensive interventions were commonly used, and an 80% or greater reduction was not achieved in 15 of 18 total applications (83.3%). No published treatment datasets were identified for Subtype-3 SIB. Reinforcement alone was effective in reducing socially-reinforced SIB by at least 80% in 16 of 16 applications. For one individual (Barry in Ringdahl et al., 1997) who had both Subtype-1 SIB and Subtype-2 SIB, reinforcement alone was effective for Subtype-1 SIB, but not for Subtype-2 SIB. The findings of the current analysis were comparable to those reported in the original study, which showed that Subtype-2 SIB was highly resistant to treatment, whereas Subtype-1 SIB was responsive to reinforcement at a level comparable to socially-reinforced SIB.

Figure 3 depicts the relation between level of differentiation in the FA and response to first-line treatment (reinforcement alone for automatically reinforced SIB, and reinforcement with extinction for socially-reinforced SIB) among published datasets for both the current replication study and the original study. Researchers implemented reinforcement alone more than once for some participants, in which case we used the initial reinforcement treatment. Two cases merit additional discussion due to how treatment was selected. In one case (Mark, in Piazza et al., 1996), several treatments were compared to validate the results of a competing stimulus assessment. In this case, we selected the treatment that involved the use of high preference stimuli associated with low rates of SIB (as opposed to stimuli that were either low preference or associated with high rates of SIB). In the other case (Rosales, Worsdell, & Trahan, 2010), three variations of reinforcement-only treatments were evaluated simultaneously using a multielement design, thus there was no initial reinforcement treatment. In this case, we used the average of all three treatments.

Correlational analysis of the published data-sets identified a strong relation between level of differentiation in the FA and reduction in SIB during treatment using reinforcement alone ($r = 0.72$, $p < .0001$) similar to what was reported in the original study ($r = 0.61$, $p < .0001$). In addition data for cases with Subtype-1 SIB and socially-reinforced SIB for the current

replication study indicate high differentiation in the FA and generally good reductions to first line treatment (i.e., reinforcement alone), also closely replicating the findings of the original study. We found that reinforcement alone reduced Subtype-1 SIB and socially-reinforced SIB by 80% or greater reduction in 11 of 11 and 13 of 13 cases, respectively. In addition, most of the data points for Subtype-1 SIB and socially-reinforced SIB fell at or close to the regression line, suggesting that the differentiated FA results accurately predicted the reinforcement-only treatment effects. By contrast, reinforcement alone reduced Subtype-2 SIB by 80% or more in just one of seven cases (14.3%). In addition, most of the data points for Subtype-2 fell much further from the regression line, suggesting that the level of differentiation of the FA proved to be much less accurate at predicting reinforcement-only treatment effects for this subgroup. These findings also closely replicated those of the original study.

DISCUSSION

The current replication study examined the generality of the model for subtyping automatically reinforced SIB described by Hagopian et al. (2015). The subtyping model was applied to all datasets of automatically reinforced SIB published from 1982 to 2015 (that included an FA composed of a no-interaction and play condition depicting at least three data points). Although no conclusions can be drawn about Subtype-3 SIB (with self-restraint) from the extant literature due to the small number of datasets that met inclusion criteria, the current findings largely replicated those of Hagopian et al. with respect to Subtype-1 and -2 SIB. By replicating the findings from the original study using a diverse group of participants, treated in a variety of settings (5) by a number of different institutions (15), the key findings obtained with the original sample appear to have good generality.

Although this study drew from the existing body of literature on automatically reinforced SIB, the sample is relatively small. Nevertheless, the current results and those of Hagopian et al. (2015) suggest the following tentative conclusions: (a) automatically reinforced SIB probably should not be considered a single, uniform category; (b) Subtype-1 SIB tends to be amenable to treatment using reinforcement alone; (c) Subtype-2 SIB tends to be more resistant to reinforcement-based treatment (and perhaps other forms of behavioral treatment as well); and (d) the level of differentiation in the FA (and subtype classification) generally predicts how well automatically reinforced SIB is likely to respond to treatment using reinforcement alone.

Datasets in this study tended to cluster together in somewhat of a bimodal distribution in terms of the level of differentiation in the FA, which corresponded to subtype classification. Most datasets had either relatively high differentiation (above 65%) or relatively low differentiation (below 40%). Only 3 of 49 (6.1%) of published datasets showed intermediate levels of differentiation (between 40%–65%) in the FA. Hagopian et al. (2015) found a similar bimodal distribution. Subtype classification also predicted response to first-line treatment (reinforcement alone) in both this study and Hagopian et al. Finally, in both studies, Subtype-1 SIB was more similar to socially-reinforced SIB in terms of response to treatment than it was to Subtype-2 SIB. Thus, the current results closely replicated the

primary findings of Hagopian et al., and together the two studies provide clear empirical support for the subtyping framework with regard to Subtypes 1 and 2.

Although these findings show clinically meaningful differences between automatically reinforced Subtype-1 and -2 SIB, it is important to remember that subtype classification (a categorical variable) is derived largely from the level of differentiation in the FA (which is a continuous variable). As Hagopian et al. (2015) noted, the level of differentiation in the FA can be viewed as an index of the sensitivity of SIB to changing environmental conditions. This notion is supported by the strong correlation between differentiation during the FA and percentage reduction of SIB achieved with first-line interventions (reinforcement) observed in Hagopian et al. and in the current results. That is, these findings show that the sensitivity of SIB to disruption by alternative reinforcement evident in the context of the FA was later evident in the context of treatment—Subtype 1 appeared to be highly sensitive whereas Subtype-2 SIB appeared to be insensitive. Thus, the sensitivity of SIB to disruption by alternative reinforcement appears to be a critical dimension of automatically reinforced SIB.

One important question regarding the observed differences in the sensitivity of SIB to disruption by alternative reinforcement across Subtypes 1 and 2 is whether this is specific to automatically reinforced SIB, or whether it represents a general response tendency of the individual. That is, the sensitivity of SIB to disruption by alternative reinforcement could occur as a function of the individual's general level of functioning. This question can best be answered through a formal empirical analysis (which we are currently in the process of conducting). Interestingly, there was one identified individual in the published literature who exhibited two different subtypes of automatically reinforced SIB, one that met criteria as Subtype-1 and another that met criteria as Subtype-2 (Barry, in Ringdahl et al., 1997). Treatment using reinforcement alone reduced Barry's Subtype-1 SIB by 100%, but was ineffective in reducing his Subtype-2 SIB (in fact, Subtype-2 SIB increased during treatment). Although this is only a single case in which both subtypes of SIB were present within the same individual, it appears that in this case, the sensitivity of SIB to disruption by alternative reinforcement was dimension specific to each subtype of SIB, suggesting it was not secondary to an individual characteristic, such as functioning level. Future research should explore this question further.

With regard to the relative distribution or prevalence of subtypes, we observed some differences between the results of Hagopian et al. (2015) and the current results. Although both studies found Subtype-1 SIB to be the most common subtype, followed by Subtype 2, and then Subtype 3, Subtype-3 SIB was far more prevalent in Hagopian et al. than in the current study (20.5% vs. 4.1%, respectively). The higher prevalence of Subtype-3 SIB might have been due to the setting of the Hagopian et al. study, a specialized treatment facility designed to serve individuals with treatment-resistant problem behavior. This hypothesis seems plausible given that no individual later determined to have Subtype-1 SIB has been admitted to that setting in the last 3 years, but those with Subtype-2 and -3 SIB are commonly admitted. That is, it may be the case that with increased availability of behavioral services in recent years, individuals with Subtype-1 SIB are increasingly being successfully treated as outpatients and not requiring hospitalization.

We also encountered published studies in which self-restraint was reported to occur frequently, but quantitative data on self-restraint were not reported, precluding inclusion in the current study. The limited number of published datasets with Subtype-3 SIB may also be due to the inherent challenges associated with the assessment and treatment of SIB co-occurring with self-restraint. This may limit what analyses can be safely conducted, as well as the clarity of findings (which can also decrease the likelihood of publication). Consequently, the current study provides little information about Subtype-3 SIB beyond what was reported in Hagopian et al. (2015). Even if we combine the current cases of Subtype-3 SIB with those from the first study, there does not appear to be a sufficient amount of information to determine whether this is a distinct subtype. Therefore, in the absence of replicating the findings of the first study with respect to Subtype-3 SIB, its generality beyond the original sample is not established—and points to the need for further study. It is also noteworthy that the level of differentiation in the FA among Subtype-3 SIB datasets from both studies was either high or low (comparable to Subtypes-1 and -2 SIB, respectively). Therefore, additional research is needed to determine if Subtype-3 SIB is a distinct subtype or simply a variant of Subtypes 1 and 2 with self-restraint (see Fisher & Iwata, 1996, for a discussion).

Across both studies, Subtype-1 SIB was effectively treated with reinforcement alone in 19 of 23 cases, whereas Subtype-2 SIB was effectively treated in only 1 of 14 cases. In light of how well subtype classification (and level of differentiation) predicts later response to treatment, we can characterize these variables as *predictive behavioral markers* (which we define here as objective behavioral measures that predict response to treatment) for automatically reinforced SIB. In medicine, *predictive biomarkers* are defined as objective biological measures that predict response to treatment. For example, individuals with cystic fibrosis caused by certain gene mutations respond very well to available medications whereas patients with cystic fibrosis caused by other mutations do not (Becq, 2015). Identification of predictive biomarkers (or predictive behavioral markers) can inform treatment for individual patients and guide research aimed at advancing knowledge about the disease subtypes and the mechanisms by which treatments exert their effects. In the case of automatically reinforced SIB, the observed differences between Subtypes-1 and -2 SIB could suggest differences in the magnitude or quality of reinforcement that SIB produces. Whereas Subtype-1 SIB changes as a function of the level of stimulation in the environment, supporting a peripheral sensory stimulation hypothesis, the insensitivity of Subtype-2 SIB might suggest a stronger biologically reinforcing process. Another question that these findings raise is whether Subtype-2 SIB is an operant. Vollmer (1994) raised the possibility that automatically reinforced SIB may be an elicited response, and in light of how different Subtype-2 SIB is relative to Subtype-1 SIB, it seems that this should be examined in future studies. If so, research must also explore whether Subtype-2 SIB has a unique bio-marker, as this may inform us about relevant biological variables that might help identify the determinants of this behavior and thus lead to novel interventions. Regardless of what avenues are pursued, subtyping automatically reinforced SIB using the current framework should help eliminate heterogeneity in future research studies on SIB, and focus efforts on examining differences between subtypes so that the unique characteristics of each subtype will be more apparent.

With regard to practice, the practitioner working with an individual with automatically reinforced SIB can use the level of differentiation in the FA (and subtype classification) to inform treatment planning and help establish realistic expectations. For example, in cases where the FA is highly undifferentiated and indicative of automatic Subtype-2 SIB, it might be advisable to begin the process of developing plans in the event that less-intrusive interventions prove insufficient. Although the established practice of proceeding from less- to more-restrictive interventions should be followed whenever possible, advanced planning could be helpful for: (a) obtaining additional resources (such as in-home behavior supports), (b) identifying regulations and allowances for the use of more-intrusive interventions (including the use of protective equipment and restraint), and (c) initiating referrals to other programs with more intense services designed to address more severe SIB. Because obtaining these resources can be a lengthy process, an early start can help minimize delays.

The prediction and control of behavior has long been described as a fundamental goal of the science of behavior (Watson, 1913). Skinner elaborated further on the importance of prediction and control and how the ability to both predict and control behavior illustrates a more complete understanding of behavior (Skinner, 1953). Whereas prediction is possible when we can identify the variables that control behavior; control can be achieved only to the extent that we can manipulate those variables. We undertake an FA to predict and control the behavior of an individual organism (Skinner, 1953). In the case of socially-maintained SIB, we can predict the conditions under which SIB would be more or less probable (e.g., Iwata, Dorsey, Slifer, Bauman, & Richman, 1982/1994) and because the relevant antecedents and consequences are socially mediated, we can control these events and thereby effectively treat SIB. Likewise, in the case of automatically reinforced SIB that varies as a function of level of stimulation in the environment (i.e., Subtype-1 SIB), we can predict and control (i.e., treat) SIB. For 19 of 23 cases of Subtype-1 SIB (identified across both studies), prediction and control of SIB was robust—in that differentiation of SIB was relatively high in the FA, and treatment using reinforcement alone reduced SIB to clinically acceptable levels. This suggests that whatever reinforcement Subtype-1 SIB produces, it is probably related to sensory stimulation (because control was achieved through manipulation of the level of stimulation/alternative reinforcement).

For SIB that occurs indiscriminately across FA conditions (i.e., Subtype-2 SIB), prediction and control are quite limited. Prediction is limited in that we cannot identify conditions under which SIB is more or less likely to occur—we only know that it is highly likely to occur in general. When prediction is limited, so is control. For 13 of the 14 cases of Subtype-2 SIB we identified, SIB could not be reduced to clinically acceptable levels with reinforcement alone. Whether this level of resistance to treatment is characteristic of most cases of Subtype-2 SIB requires additional research. Based on this analysis, it appears that automatically reinforced Subtype-2 SIB appears to be a class of behavior for which prediction and control is limited to a degree that is unique among other functional classes of problem behavior.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Percentage differentiation between play and the relevant test condition in the functional analysis for each individual by group for the replication study (top panel) and Hagopian et al., 2015 (bottom panel). Mean percentage for each group is indicated by the horizontal bold lines.

Figure 2.

Number of applications and number of positive outcomes for each type of treatment component by subtype for the replication study (top panel) and Hagopian et al., 2015 (bottom panel). For this analysis, a positive outcome was defined as an 80% reduction from the initial baseline.

Replication Study

Original Study (reprinted from Hagopian et al., 2015)

Figure 3.

Relation between differentiation in the functional analysis and percentage reduction of SIB for each subtype with reinforcement during treatment for replication study (top panel) and Hagopian et al., 2015 (bottom panel). The trend line represents the linear relation between these two variables, which was statistically significant (top panel: Pearson $r = 0.72$, $p < .0001$; bottom panel: Pearson $r = 0.61$, $p < .0001$).

Table 1

Demographic and Behavioral Variables Across Groups

Variable	Total (N = 61)		Subtype 1 (n = 25*)		Subtype 2 (n = 22*)		Subtype 3 (n = 2)		All Automatic (n = 49)		Social	
	n	%	n	%	n	%	n	%	n	%	n	%
Gender												
Female	21	34.4	9	36	7	31.8	1	50	17	34.7	4	33.3
Male	39	65.6	16	64	14	63.6	1	50	31	63.3	8	66.7
Not reported	1	1.6	0	0	1	4.5	0	0	1	2.0	0	0
Age (years)												
3 to 12	22	36.1	7	28	9	40.9	1	50	17	34.7	5	41.7
13 to 17	6	9.8	3	12	3	13.6	0	0	6	12.2	0	0
>18	32	52.5	15	60	10	45.5	0	0	25	51.0	7	58.3
Not reported	1	1.6	0	0	0	0	1	50	1	2.0	0	0
Autism												
Yes	12	19.7	5	20	5	22.7	0	0	10	20.4	2	16.7
Not reported	49	80.3	20	80	17	77.3	2	100	39	79.6	10	83.3
Level of ID												
Mild	2	3.3	1	4	1	4.5	0	0	2	4.1	0	0
Moderate	5	8.2	4	16	0	0	0	0	4	8.2	1	8.3
Severe	10	16.4	5	20	1	4.5	0	0	6	12.2	4	33.3
Profound	27	44.3	7	28	14	63.6	1	50	22	44.9	5	41.7
Unspecified	8	13.1	6	24	2	9.1	0	0	8	16.3	0	0
Not reported	9	14.8	2	8	4	18.2	1	50	7	14.3	2	16.7
SIB topography												
Body-directed	8	13.1	4	16	3	13.6	0	0	7	14.3	1	8.3
Head-directed	43	70.5	14	56	17	77.3	2	100	33	67.3	10	83.3
Mouth-directed	0	0	0	0	0	0	0	0	0	0.0	0	0
Skin-directed	21	34.4	8	32	9	40.9	0	0	17	34.7	4	33.3

* One individual (Barry, from Ringdahl et al., 1997) had one topography of Subtype-1 SIB, and one topography of Subtype-2 SIB

Table 2

Mean Responses per Minute or Percentage of Intervals of SIB and Percentage of Intervals of Self-Restraint During the Functional Analysis for Participants Across Studies

First Author (Year)	Participant	Alone or social test condition	Play condition	% of intervals with self-restraint	% differentiation between alone (or test) and play
Automatic Subtype 1					
Camp (2009)	Anna	0.8	0.2		77.9
Camp (2009)	Bobby	0.4	0.1		68.3
Dozier (2007)	Garvin	3.9	0.4		90.9
Dozier (2007)	Michael	0.7	0.2		75.0
Garcia (1999)	Gilda	4.0	0.1		96.8
Garcia (1999)	Betty	10.5	2.9		72.8
Iwata (1982/1994)	Child 4	81.7 *	16.5 *		79.8
Iwata (1994)	Donnie	84.6 *	16.7 *		80.3
Kennedy (1995)	Geoff	36.2 **	0.0 **		100.0
Kuhn (2009)	Heather	59.3	10.5		82.4
Lindberg (2003)	Robert	3.6	1.3		63.7
Morrison (2011)	Drew	41.7 *	4.44 *		89.3
Patel (2000)	Darion	53.6 *	7.8 *		85.4
Querim (2013)	Pablo	4.1	1.3		69.1
Ringdahl (1997)	Martha	1.4	0.3		81.3
Ringdahl (1997)	Barry ^a	0.7	0.0		100.0
Roane (1999)	Bucky	6.5	0.0		100.0
Rosales (2010)	David	1.2	0.0		100.0
Rosales (2010)	Karen	59.2 *	30.4 *		48.6
Roscoe (1998)	Ellen	1.0	0.0		100.0
Smith (1993)	Marc	7.8	0.2		98.0
Smith (1993)	Laura	8.3	0.3		96.5
St. Peter (2005)	Amy	4.1	1.1		73.4
Stokes (2008)	Tom	33.3 *	5.0 *		85.0
Tang (2008)	Tim	47.5 *	1.7 *		96.5

First Author (Year)	Participant	Alone or social test condition	Play condition	% of intervals with self-restraint	% differentiation between alone (or test) and play
Average (RPM/% Intervals)		6.96/57.37 *	1.1/11.79 *		84.4
Automatic Subtype 2					
Carter (2005)	Gagen	37.6 *	29.8 *		20.9
Healy (2001)	Kevin	35.9 *	49.7 *		-38.4
Le (2002)	Mike	3.2	2.0		35.9
Lerman (1994)	David	3.9	3.4		12.5
Lerman (1994)	Diane	6.3	6.9		-9.5
Lerman (1994)	Stacey	1.6	1.6		-1.3
Lindberg (1999)	Ronald	4.1	4.5		-9.9
Lindberg (1999)	Jim	4.9	6.1		-25.5
Mason (1990)	Kathy	41.4 *	34.6 *		16.4
McKerchar (2001)	Winston	7.0	4.6		35.0
Piazza (1996)	Mel	9.5	15.7		-65.0
Piazza (1996)	Mark	2.6	1.7		35.2
Querim (2013)	Dana	69.7 *	48.3 *		30.6
Querim (2013)	Larry	1.8	1.6		9.6
Querim (2013)	Sal	21.1 *	15.0 *		28.9
Ringdahl (1997)	David	2.3	2.1		11.6
Ringdahl (1997)	Barry ^b	1.1	0.6		46.0
Roscoe (1998)	Ray	12.7	13.7		-7.9
St. Peter (2005)	Greg	2.5	4.0		-62.5
Vollmer (1993)	Rita	10.6	6.7		37.0
Vollmer (1995)	Korey	48.5 *	31.1 *		35.8
Wacker (1996)	Bonnie	44.7 *	37.3 *		16.4
Average (RPM/% Intervals)		4.93/42.7 *	5.00/35.11 *		6.9
Automatic Subtype 3					
Scheithauer (2015)	Wendy	29.2	5.2	65.5	82.2
Smith (1992)	Andy	50.3 *	42.9 *	34.8	14.7
Average		n/a	n/a		48.5

First Author (Year)	Participant	Alone or social test condition	Play condition	% of intervals with self-restraint	% differentiation between alone (or test) and play
Social					
Britton (2000)	Todd	76.1 [*]	7.4 [*]		90.3
Kahng (1997)	Todd	0.9	0.0		100.0
Kahng (1997)	Bob	8.3	1.4		83.5
Kahng (2000)	Julia	2.9	0.3		91.5
Kahng (2000)	Matt	5.1	0.0		99.4
Lalli (1997)	Harry	0.7	0.0		100.0
Lalli (1997)	Tony	1.2	0.1		94.4
Mace (1998)	Kerry ^c	0.6	0.0		100.0
Mace (1998)	Kerry ^d	1.5	0.0		100.0
Vollmer (1993)	Brenda	6.9	2.0		71.9
Vollmer (1993)	Diane	6.1	3.7		40.0
Vollmer (1995)	Kevin	4.0	0.3		93.1
Vollmer (1995)	Mark	1.1	0.0		100.0
Average (RPM)		3.28	0.63		89.5

^aBody-directed SIB;

^bSkin-directed;

^cEscape function;

^dTangible function,

* Percentage of intervals;

** Percentage duration of session